# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Study No. 7*

# *Mainstem Aquatic Habitat Modeling Study*

# *Final Report*

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The following table shows Project river mile designations of riverine features associated with the Boundary Project relicensing documents.

| Feature | Side of River (West Bank / East Bank) | Project River Mile Designation |
|---|---|---|
| **Mouth of Pend Oreille River** | | 0.0 |
| **Waneta Dam** | | 0.5 |
| **Seven Mile Dam** | | 6.0 |
| Salmo R | EB | 13.4 |
| Red Bird Creek | WB | 13.9 |
| Russian Cr | WB | 14.7 |
| Lomond Cr | EB | 16.0 |
| **U.S.-Canada Border** | | 16.0 |
| USGS gaging station 12398600 (@ International Boundary) | WB | 16.1 |
| Stranding and Trapping – Tailrace Region | EB | 16.5 |
| **Boundary Dam** | | 17.0 |
| USGS TDG Gage 12398550 | | 17.0 |
| Boundary Forebay Boat Launch | WB | 17.3 |
| Stranding and Trapping – Forebay Launch Region | WB | 17.3 |
| Stranding and Trapping – Region 1 | Island | 17.6 |
| Island in Forebay Reach | | 17.7 |
| Pewee Creek | WB | 17.9 |
| Mouth of "Z" Canyon | | 18.0 |
| Lime Creek | EB | 19.0 |
| North End of Everett Island | WB | 19.4 |
| Stranding and Trapping – Region 2 | WB | 19.5 |
| Stranding and Trapping – Region 3 | WB | 20.9 |
| Stranding and Trapping – Region 4 | WB | 21.8 |
| Stranding and Trapping – Region 5 | WB | 21.9 |
| Everett Creek | WB | 21.9 |
| Whiskey Gulch | WB | 21.9 |
| Slate Creek | EB | 22.2 |
| Three Mile Creek | EB | 24.3 |
| Beaver Creek | WB | 24.3 |
| Pend Oreille Mine Outfall | EB | 24.8 |
| Stranding and Trapping – Stump Farm Region | EB | 25.2 |
| Stranding and Trapping – Region 6 | WB | 25.4 |
| Flume Creek (Deadman's Eddy) | WB | 25.8 |
| Stranding and Trapping – Flume Creek Region | WB | 25.8 |
| Sullivan Powerhouse (Defunct) | EB | 26.7 |
| Metaline Falls | | 26.8 |
| Sullivan Creek | EB | 26.9 |

| Feature | Side of River (West Bank / East Bank) | Project River Mile Designation |
|---|---|---|
| Stranding and Trapping – Sullivan Creek Region | EB | 26.9 |
| Highway 31 Bridge | | 27.0 |
| Stranding and Trapping – Region 7 | WB | 27.6 |
| Metaline Sewage Treatment Outfall | WB | 27.7 |
| Linton Creek | WB | 28.1 |
| Stranding and Trapping – Region 8 | Center | 28.0 |
| Metaline Boat Ramp | WB | 28.2 |
| Stranding and Trapping – Region 9 | EB | 28.8 |
| Pocahontas Creek | EB | 29.4 |
| Wolf Creek | EB | 30.3 |
| Stranding and Trapping – Region 10 | EB | 30.3 |
| Stranding and Trapping – Region 11 | WB | 30.3 |
| Sweet Creek | WB | 30.9 |
| Stranding and Trapping – Region 12 | WB | 31.0 |
| Stranding and Trapping – Region 13 | WB | 31.3 |
| Stranding and Trapping – Region 14 | EB | 31.5 |
| Sand Creek | EB | 31.7 |
| Stranding and Trapping – Region 15 | WB | 31.8 |
| Stranding and Trapping – Region 16 | EB | 32.1 |
| Lost Creek | WB | 32.2 |
| Stranding and Trapping – Region 17 | EB | 33.1 |
| USGS Gaging Station 12396500 (Auxiliary) | WB | 33.1 |
| Stranding and Trapping – Region 18 | WB | 33.5 |
| USGS Gaging Station 12396500 | WB | 34.3 |
| **Box Canyon Dam** | | 34.5 |

# Study No. 7: Mainstem Aquatic Habitat Modeling Study
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

Study No. 7, Mainstem Aquatic Habitat Modeling, was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007a) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This is the final report describing the field efforts, analyses, and determination of Project effects and represents the completion of the study.

The Mainstem Aquatic Habitat Modeling Study represents the integration of the efforts conducted to assess the changes in aquatic habitat of the Pend Oreille River due to existing Project operations and for operations scenarios. At the center of Study 7 is the mainstem physical habitat model. In addition, several fish and aquatic resource studies have been incorporated into Study 7 that provide, verify, or improve upon biological information critical to applying the mainstem physical habitat model. The substantial effort involved in Study 7 was designed to address Project effects by first assessing the range of conditions created by the interaction of existing Project operations with the physical characteristics and hydrologic conditions present in the study area of the Pend Oreille River. The final report accomplished this by applying the suite of habitat modeling tools to describe mainstem aquatic habitat for historic hourly operation. Historic Project operations were characterized by the "wet," "dry," and "average" years taken from the hydrologic record spanning the period from 1987 through 2005 (R2 Resource Consultants 2008).

The results of the aquatic habitat evaluation for historic operations are presented in this report. This final report does not present the evaluation of operations scenarios. The RSP indicated that operations scenarios would be evaluated in the Final Report; however, this will occur in 2009 as part of the Integrated Resource Analysis (IRA). The results of the IRA effort will be documented in the License Application (LA) to be filed in September 2009.

### 1.1. Background

The Project is operated in a load-following mode, generating power during peak-load hours and curtailing generation during off-peak hours. This operating regime allows SCL to meet continued service area load growth and provide regional system reliability. The Project capacity of the six turbines is about 55,000 cubic feet per second (cfs), which is more than double the average annual flow of the Pend Oreille River (SCL 2007a). The combination of little reservoir storage capacity in relation to inflow and the large turbine capacity means that Project operations can, at times, cause the water surface elevations in the Forebay and Tailrace reaches to fluctuate more than 10 feet in a day (see Figure 1.1-1 for reach locations and Section 3 for Project river

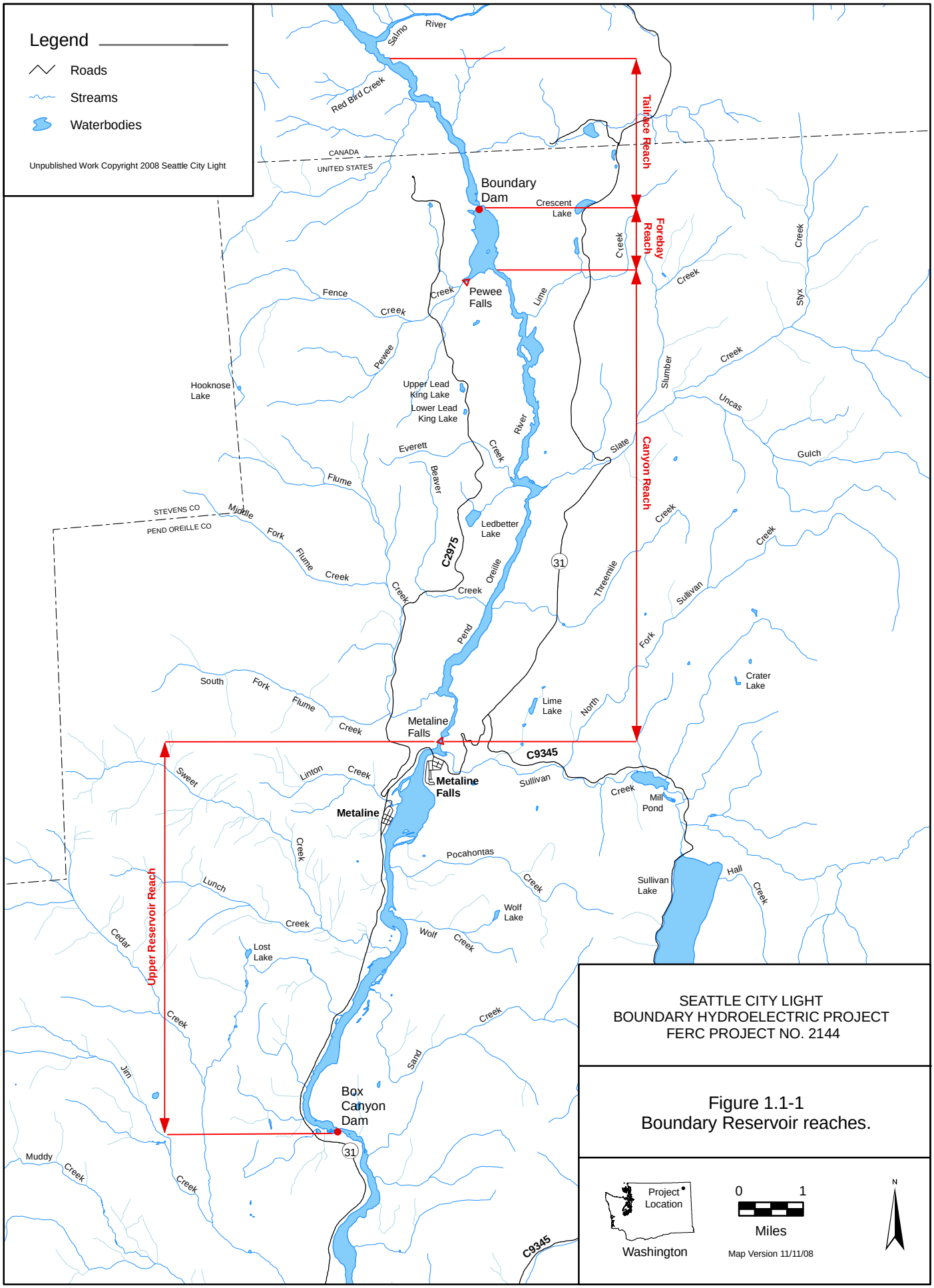
miles [PRM] for each reach). These flow and associated pool surface elevation fluctuations alternately inundate and dewater shallow water areas of the Pend Oreille River, affecting aquatic habitats and biota.

Fluctuations in the water surface elevation of the Boundary Reservoir forebay occur in response to inflow fluctuations at Box Canyon Dam and the Project operations. The resulting water surface elevation fluctuations in the Project forebay extend upstream but attenuate, or dampen, as they travel from the Project forebay upstream through the entire 17.5-mile reservoir to Box Canyon Dam. Variations in channel morphology of the Pend Oreille River upstream of Boundary Dam affect the rate of travel and attenuation of upstream pool surface elevation fluctuations resulting from forebay water surface elevation changes. The most significant of these variations is the constriction and change in bed profile at the site of Metaline Falls (Figure 1.1-1), which slows the passage of water and delays the response time of the Upper Reservoir Reach to changes in downstream forebay elevation fluctuations. When the Project is operating at reservoir water surface elevations lower than the hydraulic control at Metaline Falls, fluctuations in water surface elevations observed at the Boundary forebay are greatly reduced upstream of Metaline Falls (see Section 5.2).

BC Hydro's Seven Mile Dam is located 11 miles downstream of Boundary Dam, and at full pool the Seven Mile Dam backs water up to the tailrace of Boundary Dam. The Seven Mile Project creates forebay water surface fluctuations that can travel upstream to the Boundary Dam tailrace. Consequently, the effects of Project operations on aquatic habitats below Boundary Dam are influenced by Seven Mile Project operations. At low Seven Mile pool levels, riverine habitat is present in the Boundary Dam tailwater, but at high Seven Mile pool levels, the riverine habitat becomes reservoir habitat.

The Seven Mile Project completed upgrades in April 2003 to provide increased generation capacity (Calder et al. 2004). There are also plans by the Columbia Power Corporation (CPC) to add capacity at the Waneta Project downstream of the Seven Mile Project. SCL has begun the process of sharing Project information with BC Hydro and CPC that may be pertinent to their water use plans and operations.

Within Boundary Reservoir, aquatic habitat can be divided into shallow and deep water habitats. The littoral zone, or shallow water habitat, is the bottom area along the shoreline where the level of light penetration is sufficient for photosynthesis. This area usually supports larger and more diverse populations of plants and animals than deep water habitats. Depending upon the substrate type, water velocity, and other characteristics, portions of the littoral zone may have aquatic macrophytes and periphyton that contribute to primary production. Macrophytes also provide unique habitat for fish and certain benthic macroinvertebrate (BMI) species. The deep water zone consists of the open water parts of the reservoir. In general, the deep water zone is less productive than the littoral zone and has a different community of aquatic fauna, although some species, perhaps at different life stages, may be found in both zones.




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 1.1-1
Boundary Reservoir reaches.

Areas of the river channel that are alternately wetted and dewatered by water surface elevation fluctuations are termed the varial zone (Figure 1.1-2). The varial zone typically encompasses some or all of the littoral zone. If the magnitude and frequency of water surface elevation fluctuations is low, the varial zone can be highly productive. However, as the magnitude and frequency of water surface elevation fluctuations increase, the abundance and diversity of periphyton and BMI may be reduced (Fisher and LaVoy 1972; Ward 1992).

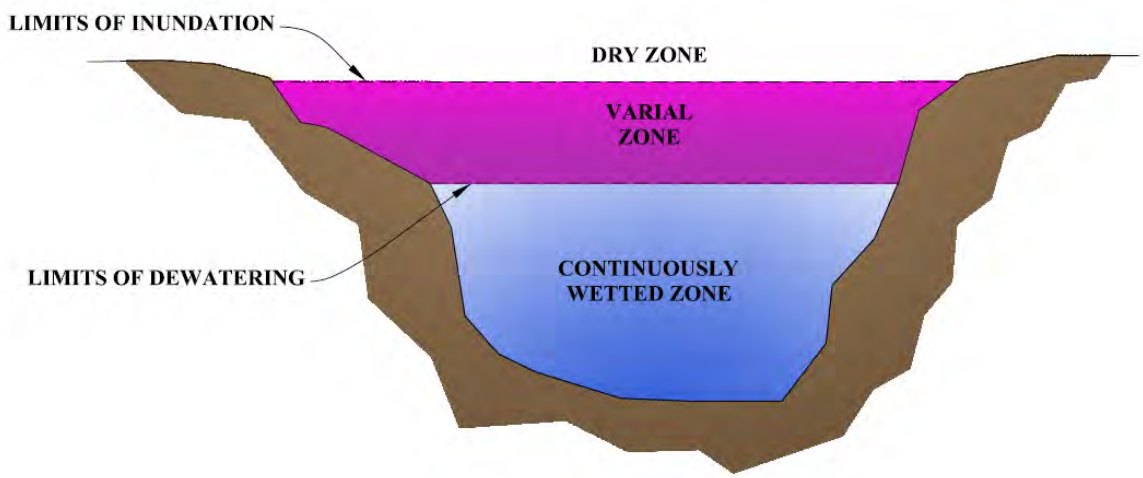



**Figure 1.1-2.** Example cross section of a hypothetical channel margin that depicts extent of varial zone as defined by maximum range in water surface elevation fluctuations.

The mainstem physical habitat model is the core tool that will be used for assessing effects on aquatic habitat of operations scenarios at the Project. A conceptual framework for the mainstem aquatic habitat model is depicted in Figure 1.1-3. Fundamentally, the mainstem physical habitat model is a spatial and temporal representation of physical characteristics considered biologically important to aquatic habitat in Boundary Reservoir and its tailrace. The physical characteristics considered in the model include the following:

- Water depth
- Water surface elevation fluctuations (including magnitude, frequency and rate of change, and associated duration of inundation and dewatering)
- Water velocity
- Substrate type (e.g., boulder, cobble, gravel, sand, fines, etc.)
- Cover for fish (including macrophytes)

The mainstem physical habitat model integrates hydraulic modeling, reservoir bathymetry, and biological information on the distribution, timing, abundance, and suitability of habitat to estimate metrics, such as area and frequency of inundation and dewatering that were used to describe the historic condition in this report. In the IRA leading up to the LA, the metrics will be used to describe operation scenarios and compare them with the baseline condition to determine the effects of operations scenarios.

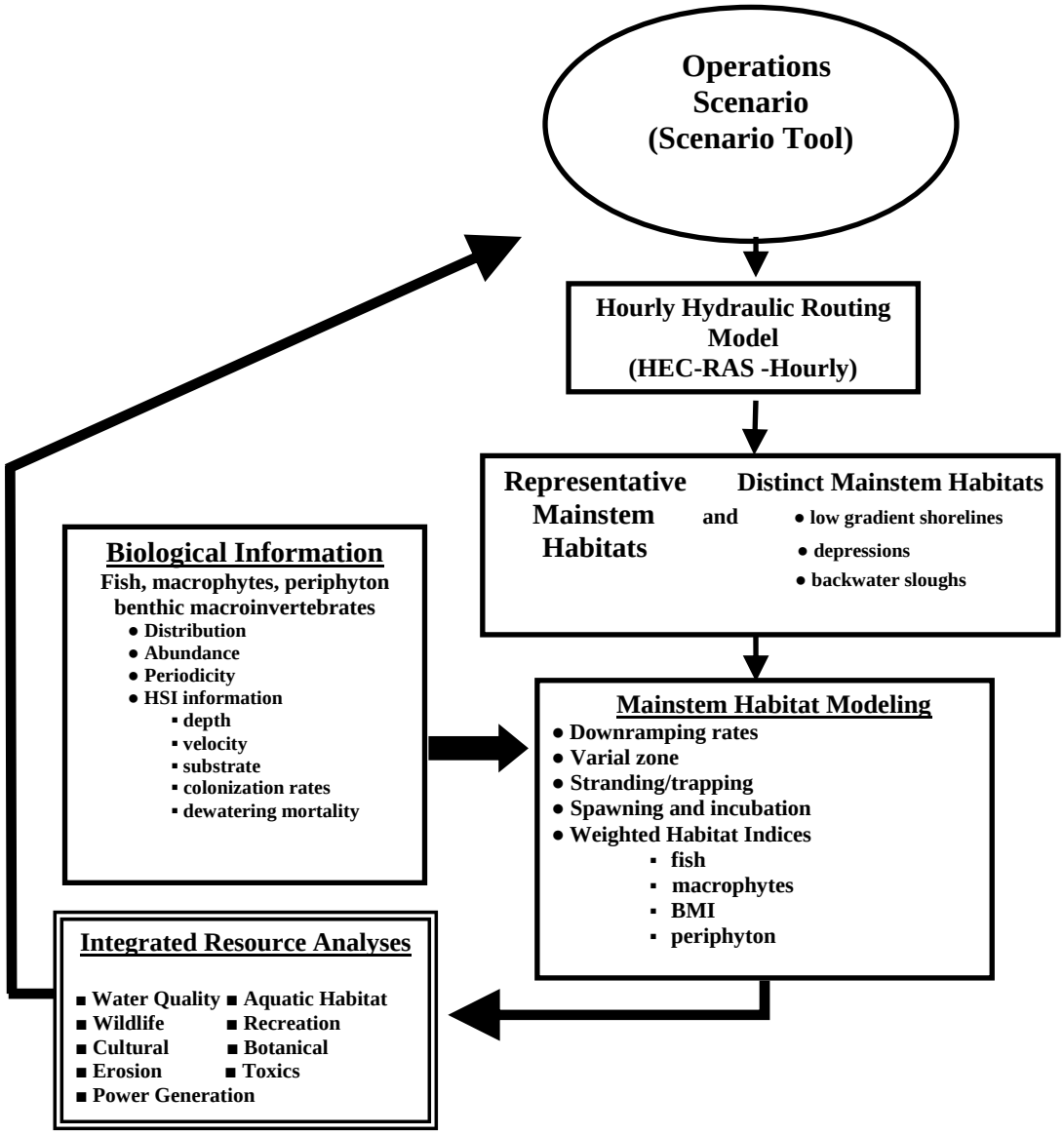



**Figure 1.1-3.** Conceptual workflow for the Mainstem Aquatic Habitat Modeling Study.

The number, location, and placement of transects was coordinated with relicensing participants. The mainstem physical habitat model estimates metrics along transects selected to represent the longitudinal continuum of habitats along the Pend Oreille River. Distinct habitats may include low-gradient shorelines, depressions, backwater sloughs, fish spawning locations, macrophyte beds, or other habitats. These habitat features may support high-value aquatic resources, but because they are found in only a small proportion of the reach, they may not be adequately described by transects selected to describe major morphological channel types. The integration of the high resolution bathymetry into the stranding and trapping, and downramping analyses

described later in this report provide the spatial resolution to address habitat conditions not represented at specific transects. These Geographic Information System (GIS)-based analyses incorporate spatial representation of entire channel and shoreline areas between transects.

## 1.2. Study Components

The Mainstem Aquatic Habitat Modeling Study was divided into nine components or sub-studies, described as follows.

### 1.2.1. Study Component 1—Habitat Descriptors

This study component encompassed the GIS and transect–based information that supported the development and application of the various modeling components of Study 7. This study component provides the geometric representation of the mainstem channel, reservoir, and overbank areas as well as the distribution of various physical characteristics that help define the mainstem aquatic habitat. The primary information sources used for this component are the mapping developed from light detection and ranging (LiDAR) and bathymetry and the mainstem habitat transect surveys. The effort also included mapping of submerged aquatic macrophytes (referred to as macrophytes).

### 1.2.2. Study Component 2—Hydraulic Routing Model

The Hydraulic Routing Model (HRM) was developed from bathymetric data collected in 2006 and 2007 and was used to translate hourly Boundary Dam outflow and forebay water surface elevations for the wet, dry, and average years from the hydrologic record to water surface elevations and mean channel velocity at each of the transects in the mainstem physical habitat model on an hourly basis. For the evaluation of operations scenarios in the IRA leading up to the LA, the HRM will translate hourly forebay water surface elevations and Project outflows from the Scenario Tool (see Section 1.3) to develop the hourly hydraulic information at the habitat transects.

A one-dimensional unsteady flow hydraulic routing software was used to simulate the hydraulic conditions in the reach upstream of Boundary Dam between Box Canyon and Boundary dams and in the reach downstream of Boundary Dam between Boundary Dam and Seven Mile Dam. Application of the unsteady flow hydraulic model was necessitated by Project operations. The process of energy production causes fluctuations in water surface elevation in the forebay of Boundary Reservoir and fluctuations in flow releases to the Boundary tailrace. Slow-moving "waves" originating in the forebay of the Project travel upstream through the Pend Oreille River to as far upstream as Box Canyon Dam, and flow fluctuations originating in the tailrace of the Project travel downstream to as far as just above the confluence with the Salmo River.

### 1.2.3. Study Component 3—Fish Periodicity

Fish periodicity provides the temporal distribution of various fish species and life stages within the study area. The fish periodicity dates help guide the temporal application of fish Habitat

Suitability Index (HSI)[1] curves for habitat modeling, as well as to help assess the potential impacts of fluctuations in water surface elevation on stranding and trapping and on the spawning, incubation, and fry life stages of several fish species.

### 1.2.4. Study Component 4—Stranding and Trapping

Though stranding and trapping are related processes, there are differences that require two separate analyses. Stranding involves the beaching of fish as the water levels recedes and is typically associated with low gradient shoreline areas or cover conditions that result in fish remaining in an area as it is dewatered. Mortality occurs in stranding as fish are left beached on the dewatered shoreline. Trapping is the retention of fish, as the water level recedes, in pools formed by depressions. In trapping, stress and potentially mortality occur to trapped fish from several mechanisms including temperature fluctuations, reduction in dissolved oxygen, predation, and stranding as the water in the pool infiltrates into the substrate.

This study component involved the development and application of models to evaluate the influence of water level fluctuations on the potential for both stranding and trapping. It included field data collection, development of a modeling approach, and application of the model from historic wet, dry, and average hydrologic conditions. The stranding and trapping analyses were conducted to determine indices representing the potential for stranding and trapping of aquatic organisms, primarily fish. The indices are relative expressions of the potential for stranding and trapping to occur under different water surface elevation fluctuation conditions and do not reflect estimates of actual fish mortalities.

### 1.2.5. Study Component 5—Downramping

The downramping analysis included determination of the hourly reductions in water surface elevation at specific locations in the Project area for each of the three hydrologic years. Washington State Instream Flow Guidelines assume that faster rates of water surface elevation reduction are correlated to an increased risk of stranding of aquatic organisms (WDFW and Ecology 2004; Hunter 1992). In these regards, the downramping analysis is closely related to the stranding and trapping analysis and the varial zone analysis (macrophyte, periphyton, and BMI study components).

[1] The abbreviation HSI is used in this document to refer to either Habitat Suitability Index (HSI) models or Habitat Suitability Curves (HSC), depending on the context. HSI models provide a quantitative relationship between numerous environmental variables and habitat suitability. An HSI model describes how well each habitat variable individually and collectively meets the habitat requirements of the target species and lifestage, for the structure of Habitat Evaluation Procedures (USFWS 1980). Alternatively, HSC are designed for use in the Instream Flow Incremental Methodology to quantify changes in habitat for various flow regimes (Bovee et al. 1998). HSC describes the instream suitability of habitat variables related only to stream hydraulics and channel structure. Both HSC and HSI models are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Both models and habitat index curves are hypotheses of species-habitat relationships and are intended to provide indicators of habitat change, not to directly quantify or predict the abundance of target organisms. For the Boundary Project aquatic habitat studies, HSC (i.e., depth, velocity and substrate/cover) and HSI (i.e., light availability, duration of inundation and dewatering) models will be integrated to analyze the effects of alternate operational scenarios.

### 1.2.6. Study Component 6—Macrophyte HSI and Habitat Model

The aquatic macrophytes comprise a diverse assemblage of macroscopic flora that have adapted from terrestrial species to live wholly, or partially, in fresh water (Fox 1996). Macrophytes are classified as emergent, floating-leaved, free-floating, or submersed. Macrophytes can be beneficial to lakes and reservoir systems because they provide cover for fish and substrate for aquatic invertebrates, but the overabundance of macrophytes can become problematic by interfering with recreational activities, affecting water quality and enhancing internal nutrient loading or toxics availability from the sediments, and reducing the mobility of some fish species and sizes. The potential areas for problems with macrophytes in Boundary Reservoir occur in the shallow water areas of the reservoir system, which are conducive to non-native colonization and growth.

This study component was the first of four HSI–based aquatic habitat models (the other three models constituted the remaining study components 7 through 9). The modeling effort determines the weighed useable area (WUA) as the index for representing the habitat conditions for submerged aquatic macrophytes. The WUA is an application of the HSIs for depth, velocity, and substrate as well as curves representing the influence of inundation and dewatering. As is the case with all the WUA models, the macrophyte WUA determination utilizes the results of habitat transect hydraulics. The transect hydraulics are based on the integration of the HRM with the cell depth and velocity determinations from the Physical Habitat Simulation (PHABSIM). The macrophyte habitat model is part of the varial zone analysis.

### 1.2.7. Study Component 7—Periphyton HSI and Habitat Model

Periphyton are benthos in a water body, and live structures or organisms resting on or attached to the bottom such as logs, rocks, or rooted plants. BMI are also organisms that spend most or all of their life in the channel and reservoir substrate. As a result, many elements of the field data collection effort were conducted jointly. Both groups of organisms also respond to inundation and dewatering resulting from fluctuations in water surface elevation caused by Project operations, as well as variation in reservoir inflows. Consequently, each of these biological groups requires HSIs representing the influence of the duration of inundation and dewatering. However, the actual HSIs developed for each group are unique and therefore treated as separate study components in this report.

Periphyton are a complex matrix of algae, bacteria, and other microorganisms. The algae are the primary producers and were the focus of this study component. Primary production is important because it is the base of the food web and refers to the rate of biomass formation of organisms that photosynthesize. Periphytic algae use energy from the sun and nutrients for growth and, in turn, are fed upon by BMI and some fish, birds, and/or mammals.

The periphyton effort was part of the varial zone analysis and was similar to the sixth study component addressing macrophytes. Therefore, both modeling approaches account for the influence of inundation and dewatering in addition to physical habitat conditions associated with depth, velocity, and substrate.

### 1.2.8. Study Component 8—Benthic Macroinvertebrate HSI and Habitat Model

The BMI study component was another part of the varial zone analysis. It was similar to the efforts conducted for macrophytes and periphyton. The objective for developing a BMI model for the Project was to evaluate how differences in depth, velocity, substrate, and the frequency and duration of inundation and dewatering influence BMI biomass.

### 1.2.9. Study Component 9—Fish HSI and Habitat Model

Fish are considered to be an important resource of the region and there is interest among various relicensing participants to ensure habitat conditions are maintained for the benefit of the local fish species. In this effort, fish HSI were developed for each species and each life stage of interest. The HSI curves represent habitat preference for various physical conditions (depth, velocity, and substrate) to estimate quantity of suitable habitat for fish with changes in flow and water surface elevation. The HSI curves were incorporated into the instream physical habitat model to assess how changes in streamflow or reservoir elevation may affect the quantity and quality of habitat for fish. The resulting index, the WUA, was used to establish the existing habitat conditions under historic operations based on application of the fish habitat model to the historic hydrologic conditions represented by the wet, dry, and average years. The effort included an effective spawning and incubation analysis. During the IRA process, similar modeling will be used to evaluate potential effects of different operations scenarios on fish habitat and the other components of the mainstem aquatic habitat addressed in Study 7.

## 1.3. Related Studies

In addition to the efforts contained within Study 7, there are several studies that provide information for the Mainstem Aquatic Habitat Modeling Study. These studies, which may also have objectives beyond support of the Mainstem Aquatic Habitat Model, include:

- *Scenario Tool* (CddHoward Consulting Ltd. 2008). The Scenario Tool (ST) is a Microsoft Excel® spreadsheet used to optimize and simulate Project energy production as a basis for comparing operations scenarios relative to potential effects on resources. Hourly data for Project forebay and tailrace water surface elevations, flow, and energy production metrics will be developed for each operations scenario as input for the HRM.

- *Tributary Delta Habitats in Boundary Reservoir* (Study 8 Final Report [SCL 2009a]). This study involved developing models to describe Project effects on habitats within seven selected tributary deltas. Because tributaries contain a source of water separate from the mainstem river and represent important aquatic habitats, specific tributary delta habitat models were developed. The tributary delta models utilized the results of the HRM to determine water surface elevation fluctuations at the mouths of the tributaries. Study 8 (SCL 2009a) also considered potential changes in delta channel morphology for different operations scenarios over a 50-year period (potential length of the new FERC license for the Project).

- *Mainstem Sediment Transport* (Study 8 Final Report [SCL 2009a]). The study was used to estimate the net change in the volume of sediment deposited in Boundary Reservoir over the potential 50-year term of a new license. The study results also delineated zones of sediment erosion and accumulation in the Boundary Reservoir portion of the Pend Oreille River.

- *Fish Distribution, Timing, and Abundance Study* (Study 9 Final Report [SCL 2009b]). This study provided detailed information on the periodicity, distribution, and abundance of fish in the Project area that was collected during extensive field studies in 2007 and 2008. These field studies found that the fish assemblage of the Boundary Reservoir and Boundary tailrace includes a variety of native and non-native species. Dominant species by number captured in 2007 and 2008 by all gear types included three native sucker and minnow species (largescale sucker *[Catostomus macrocheilus]*, northern pikeminnow *[Ptychocheilus oregonensis]*, and peamouth *[Mylocheilus caurinus]*) and two naturally reared non-native sport fish species (yellow perch *[Perca flavescens]* and smallmouth bass *[Micropterus dolomieu]*). Triploid rainbow trout *(Oncorhynchus mykiss)* annually supplemented for a recreational fishery seasonally accounted for a large proportion of the study catch. These six species accounted for 86 percent of the total study catch in the Boundary Reservoir and Boundary tailrace. The main target species for these studies were native salmonids, including bull trout *(Salvelinus confluentis)*, cutthroat trout *(O. clarki lewisi)*, redband rainbow trout (Boundary Tailrace) *(O. mykiss gairdneri)*, and mountain whitefish *(Prosopium williamsoni)*, which were present in generally very low abundance in the reservoir and tailrace (mainstem). Native salmonids comprised only 1 percent of the more than 26,000 fish included in mainstem study catch. Mountain whitefish accounted for 72 percent of the native salmonid catch in the mainstem, captured mainly in the Upper Reservoir and Tailrace reaches. The majority of the native salmonids captured during the course of the Project studies were encountered in the tributary channels upstream of the mainstem reservoir inundation level. Cutthroat trout dominated the study catch in the tributaries upstream of the mainstem inundation zone, but were rarely observed in the inundated deltas or mainstem habitats.

- *Productivity Assessment* (Study 11 Final Report [SCL 2009c]). This study quantified indices of primary and secondary production in reaches of the Pend Oreille River within the Project area. The Productivity Assessment consisted of evaluating indices of primary (nutrients, phytoplankton, periphyton, and macrophytes) and secondary (zooplankton and BMI) production.

## 1.4. Report Organization

Because each of the nine study components represents a major effort individually, this report has been organized so that the major sections presenting information have subsections dedicated to each of the nine study components. The major sections with materials presented by study component are Section 4 Methods, Section 5 Results, and Section 7 Variances. The subsections presenting information pertaining to the first study component end in 1, those pertaining to the

second study component end in 2, and so on through the ninth study component ending in 9. For example, the Methods for the fourth study component, Stranding and Trapping, are presented in Section 4.4. Section 6, Conclusions, is not organized by study components, but rather by the four study area reaches (see Section 3). This was done to bring the results of all the study components together to provide an integrated discussion of the habitat conditions and associated influences of historic Project operations.

Each study component also has its own appendix; these are numbered from 1 through 9 with the appendix number corresponding to the study component number. Following the same convention as the numbering of subsections within the major sections, the Stranding and Trapping component has material presented in Appendix 4. The appendices are organized as stand-alone reports and present the development of the nine study components and typically include the objectives, methods (field data collection, HSI and factor development, modeling approach), the results of final determination biological response indicators (HSI curves for example), and an example of the model output. Appendices 1, 2, and 3 deviate somewhat from this format as they are presenting basic information that support the habitat modeling efforts (Appendices 1 and 3) or are presenting a model that supports the habitat models (Appendices 2 and 5). The habitat model appendices (Appendices 4 and 6 through 9) do not include discussions of the model results. Detailed discussions of results are provided in Section 5.

The Methods sections for the habitat modeling study components 4, 6, 7, 8, and 9 are organized similarly into three main subsections. The first subsection presents the modeling approach. The second subsection presents the final HSI curves or other descriptor of biological response and the third section provides an example of the model output. Similar material is presented in the appendices, but the presentation in the appendix is more detailed.

Most appendices include attachments that provide information such as tabulation of field data, GIS maps, and detailed model output. Attachments are identified by capital letters (e.g., Attachment A).

# 2 STUDY OBJECTIVES

The goal of the Mainstem Aquatic Habitat Modeling Study and its component study efforts was to provide quantitative indices of the effects of operations scenarios on aquatic habitats. The objectives of the study were as follows:

- Map the current aquatic habitat in Boundary Reservoir and tailrace.
- Select transects to measure and model mainstem Pend Oreille River habitat types.
- Develop a hydraulic routing model that estimates water surface elevations, discharges, and average water velocity along modeled transects on an hourly basis for operations scenarios.
- Develop new, or modify existing, HSIs for selected target species and life stages.
- Develop an integrated mainstem physical habitat model that produces a time series of data for a variety of biological metrics for operations scenarios. These metrics included (but were not necessarily limited to):
    - water surface elevation and flow rates at selected reservoir locations

  - water velocity within transect subdivisions (cells) over a range of flow and reservoir pool levels
  - characterization of varial zone conditions
  - frequency and duration of exposure/inundation of the varial zone at selected reservoir locations
  - habitat area indices developed applying the modeling results to the HSIs
- Conduct a variety of post-processing comparative analyses derived from the output metrics estimated under the mainstem physical habitat model to identify the effects of operations scenarios. These included (but were not necessarily limited to):
  - downramping rates
  - juvenile fish stranding and trapping
  - fish nest viability (effective spawning and incubation)
  - macrophyte distribution and abundance
  - distribution and abundance of periphyton and benthic macroinvertebrates

# 3 STUDY AREA

Two levels of study areas were defined for the Mainstem Aquatic Habitat Modeling effort. There was a detailed study area for which the potential effects of operations scenarios on biological indices will be evaluated. There was also a larger study area required to conduct the HRM effort to accurately model the water surface elevation and flow fluctuations resulting from operations scenarios and upstream hydrologic conditions. The larger study area extends to Seven Mile Dam to account for the influence fluctuations in the Seven Mile forebay elevation may have on hydraulic conditions in the Tailrace Reach.

The detailed study area included all of Boundary Reservoir and portions of the Pend Oreille River mainstem downstream of Boundary Dam that could potentially be affected by operations scenarios and extends to the confluence with Red Bird Creek. The study area was divided into the following four reaches (Figure 3.0-1):

*Boundary Reservoir (Above Boundary Dam)*

- Forebay Reach—Boundary Dam to downstream end of Z Canyon to (PRM 17.0–18.0)
- Canyon Reach—Downstream end of Z Canyon to Metaline Falls to (PRM 18.0–26.8)
- Upper Reservoir Reach— Metaline Falls to Box Canyon Dam (PRM 26.8-34.5)

*Boundary Tailrace (Below Boundary Dam)*

- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

The effects of operations scenarios on aquatic habitats below Boundary Dam are influenced by Seven Mile Project operations. At low Seven Mile Reservoir water surface elevations, riverine habitat is present in the Pend Oreille River downstream to the confluence with Red Bird Creek. At high Seven Mile Reservoir water surface elevations, much of the riverine habitat above the Red Bird Creek confluence becomes reservoir habitat. The Mainstem Aquatic Habitat Modeling

effort included collecting data on up to 3.1 miles of the Pend Oreille River channel exposed for low Seven Mile Reservoir water surface elevations and performing modeling in the Tailrace Reach similar to the three reaches above Boundary Dam.

In addition to the detailed study reach described above, the HRM extended an additional 6.9 miles downstream to Seven Mile Dam at PRM 6.0 (Note: A table of PRM values for major features is provided at the end of the table of contents, following the list of figures). This was necessary to determine the Pend Oreille River water surface elevation, based on Seven Mile Project operations, at the downstream end of the detailed study reach at PRM 13.9. The HRM was used to determine hourly water surface elevations and flow conditions in the Tailrace Reach based on Seven Mile forebay elevations and inflows from the Project.

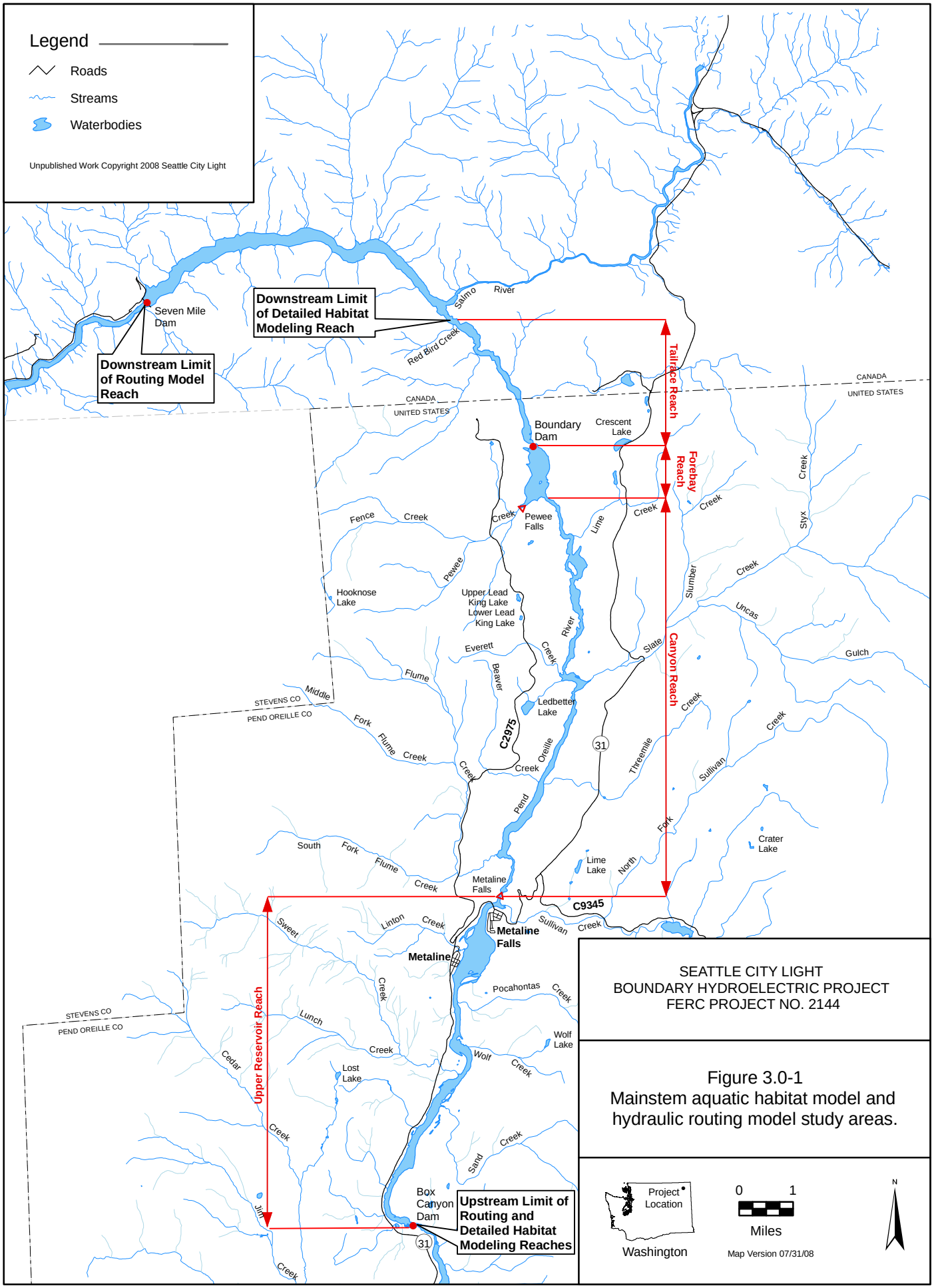



Figure 3.0-1
Mainstem aquatic habitat model and hydraulic routing model study areas.

# 4 METHODS

The methods for the nine primary components of the Mainstem Aquatic Habitat Modeling Study are outlined in this section. In the case of the five sections presenting the methods for developing biological indicates, there is a similar format. The first subsection presents the modeling approach. The next subsection presents the HSI curves and the third and final subsection presents sample model results.

The detailed description for implementation of these methods can be found in the appendices. Development of intermediate products, such as HSI curves, which serve in assessing biological conditions under various hydrologic conditions or operations scenarios, are also found in the appendixes. If more detailed documentation of the study results is needed, the reader should refer to the appendices (Appendix 1 through Appendix 9).

The methods section in the main body of the report and the portion of the associated appendix that presents additional detail are listed below:

- Section 4.1—Transect and GIS–Based Habitat Descriptors (Appendix 1a, Section 4; Appendix 1b, Section 3; and Appendix 1c, Section 4)
- Section 4.2—Hydraulic Routing Model (Appendix 2, Section 4)
- Section 4.3—Fish Periodicity (Appendix 3, Section 4)
- Section 4.4—Stranding and Trapping Development and Modeling Efforts (Appendix 4, Section 4)
- Section 4.5—Downramping Analysis (Appendix 5, Section 4)
- Section 4.6—Macrophyte Habitat Development and Modeling Efforts (Appendix 6, Section 4)
- Section 4.7—Periphyton Habitat Development and Modeling Efforts (Appendix 7, Section 4)
- Section 4.8—BMI Habitat Development and Modeling Efforts (Appendix 8, Section 4)
- Section 4.9—Fish Habitat Development and Modeling Efforts (Appendix 9, Section 4)

## 4.1. Transect- and GIS-Based Habitat Descriptors

This section presents a summary of two important types of information that supported the development and application of the Study 7 mainstem aquatic habitat modeling effort: the transect- and GIS-based habitat descriptors. This information provides the geometric representation of the mainstem channel, reservoir, and overbank areas as well as the distribution of various physical characteristics that help define the mainstem aquatic habitat. The primary information sources used for this component are the mainstem habitat transect surveys and the mapping developed from LiDAR and bathymetry. The effort also included mapping of submerged aquatic macrophytes (referred to as macrophytes).

### 4.1.1. Transect-Based Habitat Descriptors

This study makes extensive use of "mainstem habitat transects" sampled across the Pend Oreille River from Box Canyon Dam to Red Bird Creek in Canada. Transects are representations of physical conditions sampled along a line. Transects provide the geometric representation of the river bed and important physical conditions including substrate and cover. The channel geometry provides the basis for performing hydraulic modeling that allows the determination of flow rates and water surface elevations throughout the Project area. The hydraulic modeling is performed using the HRM described in Section 4.2, Section 5.2, and Appendix 2. The changing water surface elevations determined by the HRM as a result of Project operations and varying inflow provide the basis for analysis of stranding, trapping, and downramping rates. Transects also, when combined with hydraulic modeling, provide detailed description of depth and velocity profiles across the Pend Oreille River. This information, combined with the substrate and cover conditions, are utilized in developing the habitat indices for submerged aquatic macrophytes, periphyton, benthic macroinvertebrates, and fish.

This section presents the methods used to select the habitat transects, perform field data collection, calibrate the mainstem habitat transects, and integrate the habitat transects into the HRM. The steps in this process include transect selection, substrate and aquatic vegetation characterization, velocity and depth measurements, development of cross-sectional profiles, calibration of N-values, and integration of the transect information with the HRM. The section is a summary of the methods associated with development of the mainstem habitat transects. The complete methods are presented in Section 4 of Appendix 1a.

Because the main body of this report has been organized to concentrate on the results of the mainstem habitat modeling effort, the transects are viewed as supporting information and the main body of the report does not concentrate on their development. Therefore, the methods section also includes the summarized presentation of the results. The section does contain a complete description of interaction with relicensing participants and associated agreements on important aspects of the transect development process. Variances from the FERC-approved work plan presented in the RSP (SCL 2007a) are also presented.

#### *4.1.1.1. Transect Selection*

In coordination with relicensing participants, transects in the mainstem Pend Oreille River were selected to describe physical habitat conditions based on channel morphology and major habitat features. Each transect in each reach of the four mainstem reaches was selected to represent a segment of similar habitat. In this manner, each reach was entirely represented by the selected transects.

Field inspection of the preliminary transect placement in the reaches upstream of Boundary Dam occurred prior to final submittal at the April 24, 2007, Fish and Aquatics Workgroup meeting. At this meeting, the number and locations of the transects upstream of the Boundary Dam were approved by the workgroup, with a note that a reduction in the number of Canyon Reach transects was possible due to the general homogeneity of habitat in that reach. Rationale for eliminating five transects in the Canyon Reach was presented and accepted at the June 7, 2007, Fish and Aquatics Workgroup meeting resulting in a final total of 20 transects in the Canyon

Reach. Also at this meeting, the locations of the six U.S. Tailrace Reach transects were approved.

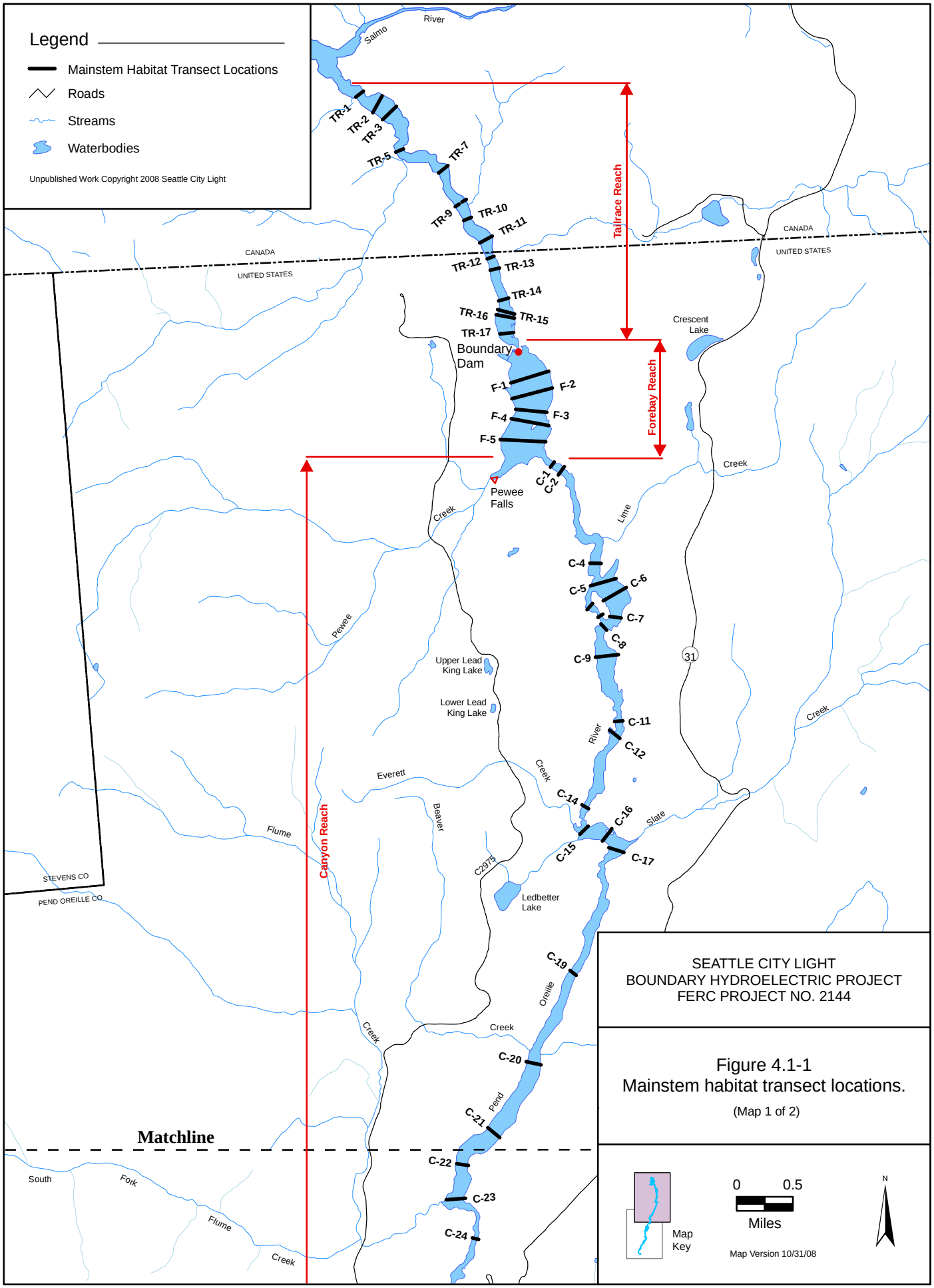
No detailed bathymetry was available for the Canadian Tailrace Reach prior to the transect selection process. To verify that the transect locations accurately represented the available habitat in the absence of detailed bathymetry data, reconnaissance-level mesoscale habitat mapping was completed prior to finalization. The locations of the selected transects were compared to the habitat mapping, resulting in the positioning of the eight transects downstream of the U.S.–Canada border. The number and locations of the Canadian Tailrace transects were approved at the July 24, 2007, Fish and Aquatics Workgroup meeting.

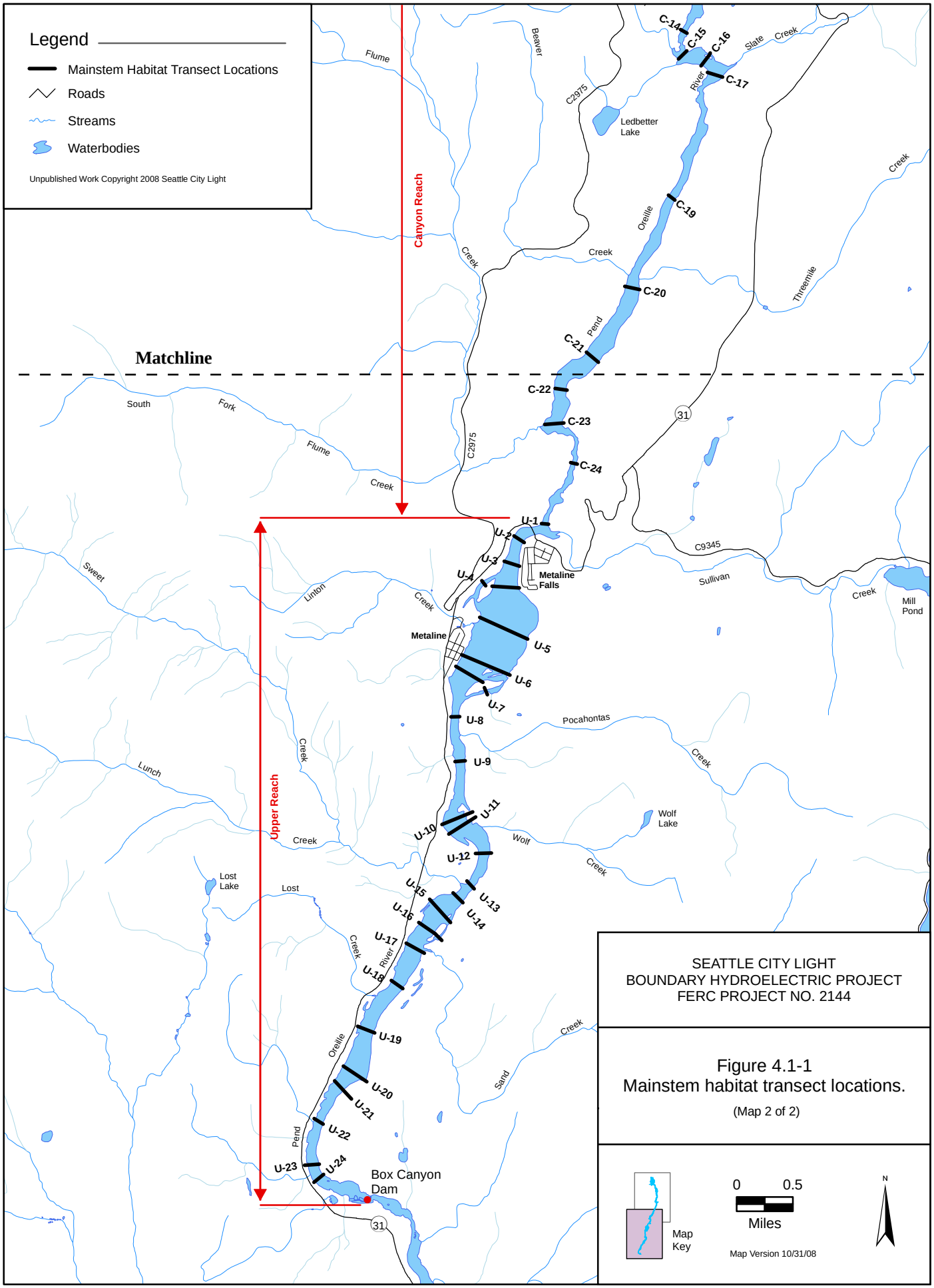
#### *4.1.1.1.1. Locations of Mainstem Habitat Transects*

Through the process just described, proposed transect locations were reviewed and discussed by the Fish and Aquatics Workgroup and some modifications were made to transect number and location prior to reaching consensus in the roundtable meeting environment. The availability of high quality current aerial photographs and the detailed bathymetry and topography allowed the selection and approval of mainstem transects in this environment. A follow-up site visit to confirm/modify habitat transect selections was offered by SCL, but no relicensing participants indicated desire or need, so the trip was not implemented. During subsequent site visits, none of the relicensing participants expressed concerns with the proposed transect locations.

Through the process just described, the location of 63 habitat transects were identified. The location of these transects is presented in Figure 4.1-1. A summary of the number of transects by reaches includes:

- Forebay Reach—5 transects
- Canyon Reach—20 Transects
- Upper Reservoir Reach—24 transects
- Tailrace Reach—14 transects


Legend
Mainstem Habitat Transect Locations
Roads
Streams
Waterbodies
Unpublished Work Copyright 2008 Seattle City Light
Salmo
River
TR-1
TR-2
TR-3
TR-5
TR-7
TR-9
TR-10
TR-11
TR-12
TR-13
TR-14
TR-16
TR-15
TR-17
Tailrace Reach
Forebay Reach
Canyon Reach
CANADA
UNITED STATES
Boundary Dam
Crescent Lake
F-1
F-2
F-4
F-3
F-5
C-1
C-2
Pewee Falls
Creek
Lime
C-4
C-5
C-6
C-7
C-8
C-9
Pewee
Upper Lead King Lake
Lower Lead King Lake
31
C-11
C-12
River
Everett
Creek
C-14
C-16
Slate
Beaver
Flume
C-15
C-17
C2975
STEVENS CO
PEND OREILLE CO
Ledbetter Lake
C-19
Oreille
Creek
C-20
Pend
C-21
Matchline
C-22
C-23
C-24
South
Fork
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 4.1-1
Mainstem habitat transect locations.
(Map 1 of 2)
Map Key
0
0.5
Miles
Map Version 10/31/08
N


Legend
Mainstem Habitat Transect Locations
Roads
Streams
Waterbodies
Unpublished Work Copyright 2008 Seattle City Light
Canyon Reach
Upper Reach
Matchline
C-14
C-15
C-16
C-17
C-19
C-20
C-21
C-22
C-23
C-24
U-1
U-2
U-3
U-4
U-5
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U-11
U-12
U-13
U-14
U-15
U-16
U-17
U-18
U-19
U-20
U-21
U-22
U-23
U-24
Metaline Falls
Metaline
Box Canyon Dam
Ledbetter Lake
Wolf Lake
Lost Lake
Mill Pond
Slate Creek
Beaver Creek
Flume Creek
South Fork Flume Creek
Sweet Creek
Linton Creek
Lunch Creek
Lost Creek
Wolf Creek
Pocahontas Creek
Sullivan Creek
Threemile Creek
Sand Creek
Pend Oreille River
C2975
C9345
31
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 4.1-1
Mainstem habitat transect locations.
(Map 2 of 2)
Map Key
0
0.5
Miles
Map Version 10/31/08
N

#### *4.1.1.1.2. Transect Weighting Factors*

Each transect was selected with the purpose of representing the habitat in the Pend Oreille River for a specific distance immediately upstream and downstream of its location. Based on the information used to perform the transect selection, the distance each transect represents was determined. This distance and the weighting factor to be applied to the distances between transects are provided in Tables 4.1-1 through 4.1-4. These weighting factors are applied in much of the mainstem modeling effort with reach averages determined by transect weighted values using various habitat indices and other indicators or factors that influence useable habitat such as downramping rates.

**Table 4.1-1.** Distances between Forebay Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| --- | 1,245[1] | --- | N/A | --- |
| F-1 | 772 | 265 | 0.343 | 1,510 |
| F-2 | 822 | 285 | 0.347 | 792 |
| F-3 | 516 | 260 | 0.504 | 797 |
| F-4 | 945 | 482 | 0.510 | 738 |
| F-5 | 1,920[2] | 1,060 | 0.552 | 1,523 |

Notes:
1 1,245 feet is distance downstream to Boundary Dam.
2 1,920 feet is upstream habitat distance to Canyon Reach transect C-1.

**Table 4.1-2.** Distances between Canyon Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| --- | 1,920[1] | --- | N/A | --- |
| C-1 | 516 | 249 | 0.483 | 1,109 |
| C-2 | 5045 | 3,031 | 0.601 | 3,298 |
| C-4 | 977 | 635 | 0.650 | 2,649 |
| C-5 | 780 | 183 | 0.235 | 525 |
| C-6 | 1,143 | 584 | 0.511 | 1,181 |
| C-7 | 629 | 457 | 0.727 | 1,016 |
| C-8 | 1,388 | 928 | 0.669 | 1,100 |
| C-9 | 3,132 | 2,100 | 0.670 | 2,560 |
| C-11 | 663 | 494 | 0.745 | 1,526 |
| C-12 | 3,739 | 3,117 | 0.834 | 3,286 |
| C-14 | 1,095 | 596 | 0.544 | 1,218 |
| C-15 | 1,063 | 741 | 0.697 | 1,240 |
| C-16 | 815 | 363 | 0.445 | 685 |
| C-17 | 6,119 | 2,347 | 0.384 | 2,799 |
| C-19 | 4,667 | 1,524 | 0.327 | 5,296 |
| C-20 | 3,707 | 1,948 | 0.525 | 5,091 |
| C-21 | 2,145 | 1,725 | 0.804 | 3,484 |
| C-22 | 1,661 | 1,101 | 0.663 | 1,521 |
| C-23 | 2,500 | 891 | 0.356 | 1,451 |
| C-24 | 1,512[2] | 1,512 | 1.000 | 3,121 |

Notes:

1 1,920 feet is distance from C-1 downstream to Forebay Reach transect F-5 of which 860 feet are associated with habitat for transect C-1.

2 Upstream extent of habitat associated with C-24 is approximately PRM 26.6 (D/S end of Metaline Falls pool).

**Table 4.1-3.** Distances between Upper Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| --- | 607[1] | --- | N/A | --- |
| U-1 | 1,471 | 109 | 0.074 | 716 |
| U-2 | 1,174 | 717 | 0.611 | 2,079 |
| U-3 | 1,207 | 738 | 0.611 | 1,195 |
| U-4 | 1,818 | 902 | 0.496 | 1,371 |
| U-5 | 1,970 | 781 | 0.396 | 1,697 |
| U-6 | 703 | 326 | 0.464 | 1,515 |
| U-7 | 2,172 | 1,170 | 0.539 | 1,547 |
| U-8 | 2,142 | 1,131 | 0.528 | 2,133 |
| U-9 | 2,760 | 1,470 | 0.533 | 2,481 |
| U-10 | 377 | 177 | 0.469 | 1,467 |
| U-11 | 1,865 | 1,082 | 0.580 | 1,282 |
| U-12 | 1,651 | 758 | 0.459 | 1,541 |
| U-13 | 909 | 328 | 0.361 | 1,221 |
| U-14 | 1,049 | 664 | 0.633 | 1,245 |
| U-15 | 1,038 | 398 | 0.383 | 783 |
| U-16 | 1,084 | 542 | 0.500 | 1,182 |
| U-17 | 1,877 | 1,326 | 0.706 | 1,868 |
| U-18 | 2,560 | 932 | 0.364 | 1,483 |
| U-19 | 2,079 | 1,330 | 0.640 | 2,958 |
| U-20 | 911 | 272 | 0.299 | 1,021 |
| U-21 | 1,921 | 780 | 0.406 | 1,419 |
| U-22 | 2,050 | 1,059 | 0.517 | 2,200 |
| U-23 | 670 | 282 | 0.421 | 1,273 |
| U-24 | 2,484[2] | 409 | 1.000 | 2,872 |

Notes:
1 607 feet is the habitat distance downstream of U-1 and the top of Metaline Falls near PRM 26.8.
2 2,484 feet is upstream extent of habitat associated with U-24 to approximately PRM 34.5 (Box Canyon Dam tailrace).

**Table 4.1-4.** Distances between Tailrace Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| --- | 447[1] | --- | n/a | --- |
| TR-1 | 928 | 374 | 0.403 | 821 |
| TR-2 | 729 | 280 | 0.384 | 834 |
| TR-3 | 2,194 | 525 | 0.239 | 974 |
| TR-5 | 2,439 | 1,397 | 0.573 | 3,066 |
| TR-7 | 1,868 | 1,252 | 0.670 | 2,294 |
| TR-9 | 836 | 315 | 0.377 | 931 |
| TR-10 | 1,259 | 591 | 0.469 | 1,112 |
| TR-11 | 843 | 630 | 0.747 | 1,298 |
| TR-12 | 591 | 314 | 0.531 | 527 |
| TR-13 | 1,483 | 650 | 0.438 | 927 |
| TR-14 | 559 | 306 | 0.547 | 1,139 |
| TR-15 | 238 | 86 | 0.361 | 339 |
| TR-16 | 790 | 194 | 0.246 | 346 |
| TR-17 | 409[2] | 409 | 1.000 | 1,005 |

Notes:
1 447 feet is distance from TR-1 downstream to Red Bird Creek.
2 409 feet is upstream habitat distance and does not extend to Boundary Dam, which is another 792 feet.

### *4.1.1.2. Substrate and Aquatic Vegetation Characterization*

Codes and associated descriptors for substrate and cover were developed in consultation with relicensing participants and approved at the July 24, 2007, Fish and Aquatics Workgroup meeting. This effort included a set of additional codes and associated descriptors in the case that aquatic vegetation was identified as the cover type. The aquatic vegetation codes included primary codes for vegetation type and subcodes for density. A primary consideration for both descriptions and coding was compatibility with instream flow study guidelines from the Washington State Department of Fish and Wildlife (WDFW) and Washington Department of Ecology (Ecology) (WDFW and Ecology 2004).

The initial cover and substrate codes collected were condensed during the development of fish HSI and prior to application in the hydraulic model. Fish HSI values were developed for the spawning life stages of whitefish and smallmouth bass using the dominant-only substrate type. Cover HSI were used to model habitat for the rearing life stages of all target fish species by combining the nine original cover codes into six categories:

- 1—no cover
- 2—riparian vegetation (field codes 2, 7, 8, and 9)

- 3—large woody debris (field codes 3, 4, and 5)
- 4—aquatic vegetation (field code 6)
- 5—substrate (using substrate codes 5–9)
- 6—deep water

In the deep water areas of Boundary Reservoir, substrate composition is not expected to play a significant role in determining the habitat suitability for rearing fish, either for feeding, resting, or cover. Given this assumption, and the infeasibility of assessing substrate composition in deep-water areas, the substrate type for fish habitat modeling in deep water was set to a suitability value of 1.0.

The substrate and cover codes were condensed for the single allowable attribute in the PHABSIM based WUA model and the results are tabulated in Table 4.1-5. In the HSI, each single combined code has a discrete suitability value. In the condensed code, the number to the left of the decimal point represents the substrate condition and the number to the right represents the cover condition.

**Table 4.1-5.** Method by which the substrate and cover codes were combined into the single allowable attribute code for PHABSIM.

| Substrate | Cover | Combined | | Substrate | Cover | Combined |
|---|---|---|---|---|---|---|
| 1 | 1 | 1.1 | | 5 | 4 | 5.4 |
| 1 | 2 | 1.2 | | 6 | 1 | 6.1 |
| 1 | 3 | 1.3 | | 6 | 2 | 6.2 |
| 1 | 4 | 1.4 | | 6 | 3 | 6.3 |
| 2 | 1 | 2.1 | | 6 | 4 | 6.4 |
| 2 | 2 | 2.2 | | 7 | 1 | 7.1 |
| 2 | 3 | 2.3 | | 7 | 2 | 7.2 |
| 2 | 4 | 2.4 | | 7 | 3 | 7.3 |
| 3 | 1 | 3.1 | | 7 | 4 | 7.4 |
| 3 | 2 | 3.2 | | 8 | 1 | 8.1 |
| 3 | 3 | 3.3 | | 8 | 2 | 8.2 |
| 3 | 4 | 3.4 | | 8 | 3 | 8.3 |
| 4 | 1 | 4.1 | | 8 | 4 | 8.4 |
| 4 | 2 | 4.2 | | 9 | 1 | 9.1 |
| 4 | 3 | 4.3 | | 9 | 2 | 9.2 |
| 4 | 4 | 4.4 | | 9 | 3 | 9.3 |
| 5 | 1 | 5.1 | | 9 | 4 | 9.4 |
| 5 | 2 | 5.2 | | Deep | Deep | 0.6 |
| 5 | 3 | 5.3 | | | | |

Notes:
Cover codes used in table:
1—no cover
2—riparian vegetation (field codes 2, 7, 8, and 9)
3—large woody debris (field codes 3, 4, and 5)
4—aquatic vegetation (field code 6)
An additional code, 0.6, represents deep water.
PHABSIM – Physical Habitat Simulation

The substrate and habitat conditions were determined during the low pool, low flow transect measurement efforts conducted for each of the reaches. Substrate and aquatic vegetation were mapped and characterized along the mainstem habitat transects to a depth of 50 feet below the low pool water surface. An underwater video camera was used to characterize and map substrate and macrophytes in water too deep to observe from the surface. For the Forebay, Canyon, and Upper Reservoir reaches, the substrate and cover coding for the habitat transects was performed in September 2007. The Tailrace Reach substrate and cover coding was performed during the March 2008 habitat transect measurements. Table 5.2-1 in Appendix 1a provides an example of the combined cover codes developed for Upper Reservoir Reach transect U-8.

#### *4.1.1.3. Velocity and Depth Measurements*

Consultation with relicensing participants resulted in modifications to target river flows, pool water surface elevations, and number of velocity patterns from those identified in the RSP. Velocities, water surface elevations, and transect bottom profiles were measured for a target stable high river flow at full pool elevation (approximately elevation 1,992 feet NAVD 88 [1,988 feet NGVD 29])[2] at all transects upstream of Boundary Dam, and again for a target stable high flow, middle flow, and low flow at low pool elevation (less than approximately 1,984 feet NAVD 88 [1,980 feet NGVD 29]) on transects in the Upper Reservoir Reach above Metaline Falls. Similarly, all transects in the U.S portion of the Tailrace Reach were measured for high flow, high pool (Seven Mile Reservoir) conditions, as well as high, middle, and low flow with low pool conditions. Transects in the Canadian portion of the Tailrace Reach were measured for high pool high flow conditions. The target flows for hydraulic routing model calibration were as follows:

- High flows (i.e., above 40,000 cfs). These typically occur in late May or early June.
- Mid-range flows (i.e., about 20,000 cfs). These typically occur in July.
- Low flows (i.e., below about 10,000 cfs). These typically occur in August.

Velocity and depth measurements for all 63 habitat transects were performed May 2007 and April 2008. Measurements of transects in the reaches upstream of Boundary reservoir were completed by August 2007. The measurements of the habitat transects below Boundary reservoir, the Tailrace Reach, were completed in April 2008. A summary of the dates and flow ranges each set of transect measurements taken in the four reaches is provided in Table 4.1-6.

[2] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

**Table 4.1-6.** Actual flow ranges at time of data collection for water velocity and water surface elevation measurements to be used to model mainstem aquatic habitats in the Pend Oreille River upstream and downstream of the Boundary Dam.

| Reach (Transects) | Actual Flow for Velocity and Water Surface Measurements [1,2] |
|---|---|
| **Forebay (5)**<br>Canyon mouth to Boundary Dam | High pool/high flow: 39,000–43,000 cfs (May 27, 2007) |
| **Canyon (20)**<br>Metaline Falls to Canyon mouth | High pool/high flow: 35,000–43,000 cfs (May 26–28, 2007) |
| **Upper (24)**<br>Box Canyon Dam to Metaline Falls | High pool/high flow: 43,000–53,000 cfs (May 24–26 2007)<br><br>Low pool/high flow: 34,000–39,000 cfs (May 30–31, 2007)<br>Low pool/med. flow: 17,000–22,000 cfs (July 11–12, 2007)<br>Low pool/low flow: 7,500–9,700 cfs (August 22–23, 2007) |
| **Tailrace (14)**<br>Boundary Dam to U.S.-Canada Border **(6)** | High pool/high flow: 43,000–45,000 cfs (April 22, 2008)<br><br>Low pool/high flow: 37,000–39,000 cfs (March 10, 2008)<br>Low pool/med. flow : 21,000–23,000 cfs (March 7, 2008)<br>Low pool/low flow: 11,000–12,000 cfs (March 9, 2008) |
| U.S.-Canada Border to Redbird Creek **(8)** | High pool/high flow: 39,000–47,000 cfs (April 23–24, 2008) |

Notes:
1 Water velocities were not measured at depths greater than 50 feet.
2 In addition to the measurements described in the table, 14 transects in the Canyon and Upper Reservoir reaches that support heavy, late summer macrophyte growth were measured at a high pool and high flow condition (~41,000 cfs) in early May 2007 prior to macrophyte emergence.
cfs – cubic feet per second

#### *4.1.1.3.1. Velocity and Bottom Profile Measurements*

Field data collection and data recording generally followed the guidelines established in the Instream Flow Group field techniques manuals (Trihey and Wegner 1981; Milhous et al. 1984; Bovee 1997). Staff also conducted additional quality control checks that have been used on previous applications of the simulation models.

Velocity acquisition was made with a Teledyne RD Instruments (TRDI) 1200 kilohertz (kHz) Rio Grande acoustic Doppler current profiler (ADCP). A sub-meter accurate Global Positioning System (GPS) with Differential GPS (DGPS) subscription-based corrections (Trimble Pathfinder Pro XRS submeter GPS with OmniSTAR correction) was used to position and track the ADCP concurrent with the velocity measurements. A narrow beam (Airmar 6° 235 kHz digital depth transducer) depth sounder was used for depth soundings concurrent with the ADCP and GPS. For those sections of a transect that could not be readily measured using the ADCP (such as shallow areas (<1 foot), edge cells near the shore, and areas with heavy vegetation growth), staff used mechanical or electromagnetic meters attached to top-set rods. Mechanical velocity meters were vertical-axis, rotating-cup Scientific Instruments Price AA and pygmy-type meters. These meters are accurate where flow is turbulent, shifts in direction occur, and where air is entrained

in the water column. Marsh-McBirney electronic meters were used in areas of dense aquatic vegetation.

#### 4.1.1.3.2. Quality Control

Considerable effort was applied to maintaining strict quality control throughout all aspects of field data collection. To ensure the quality of field data for the Project instream flow study, the following procedures and protocols were used:

- Staff gages were established and continually monitored throughout the course of collecting data at each study site.
- An independent benchmark was established for each set of transects.
- Water surface elevations were measured on both banks on each transect.
- Pin elevations and water surface elevations were calculated during field measurements and compared to previous measurements.
- All calculations were completed in the field (given adequate time and daylight). Calculated discharges were compared between transects at the same flow. If an excessive amount of discharge (greater than 10 percent of the streamflow) was noted for an individual transect cell, additional adjacent stations were established to more precisely define the velocity distribution patterns at that portion of the transect.
- The ADCP compass was calibrated daily to ensure the proper application of magnetic correction.
- The ADCP output was examined in real-time as the unit was deployed and, if necessary, multiple passes were made.
- Each day all mechanical current meters were inspected, pivot pins were replaced if significant wear was noted, pin clearances adjusted, and the meters spin tested.
- Photographs were taken of all transects from downstream, across, and upstream of the calibration flows.

### 4.1.1.4. Development of Cross-Sectional Profiles

Procedures for developing depth and velocity profiles for each habitat transect are presented in this section. The ADCP data required processing after collection to develop the depths and velocities associated with the cell widths assigned to each transect. In the case of the cross sections with depths in excess of 50 feet, the velocity was only measured to 50 feet and required extrapolation to develop velocities in the portion of the section deeper than 50 feet. The procedure to extrapolate the deep water portion of the cross-sectional velocity profiles is also presented.

#### 4.1.1.4.1. Processing of ADCP Transect Data for Depth and Velocity

ADCP transect data were collected and post-processed using TRDI WinRiver software. The American Standard Code for Information Interchange (ASCII) output from WinRiver was input into Thomas R. Payne and Associates (TRPA) utility software to reduce the extensive ADCP data into cell depths and mean column velocities as well as to overlay sequential measurements of the same transect. Initially the high pool, high flow transect data were input into the utility software and the beginning data point set to the field measured distance from the right bank

(looking downstream) headpin. The stationing was selected with a maximum of 300 ADCP measured cells per channel and a minimum cell width of 4 feet. Subsequent ADCP data files (low pool; high, middle, and low flow) were imported and the bottom profiles aligned with the original high pool, high flow profile. Depths were converted to elevations using the water surface elevation surveyed in relation to a temporary benchmark during each ADCP measurement. The true elevations of the temporary benchmarks were determined through real-time kinematic (RTK) GPS surveys. All data within each cell were averaged to output the elevation and mean column velocity. The ADCP elevation and velocity data were then imported into a spreadsheet and all manually measured cells (i.e., edge cells, shallow cells, areas of heavy macrophyte growth) were added.

Attachment A of Appendix 1a provides plots of the resulting velocity distributions for all 63 transects. In cases where multiple sets of measurements were taken, the resulting velocity patterns were provided on a single plot for comparison purposes. For sections where mean column velocities were extrapolated, these velocities were substituted for the measured velocities because, in these cases, the measured velocities did not represent the entire depth.

#### *4.1.1.4.2. Extrapolation of Mean Column Velocities*

For cells with depths greater than 50 feet, it was necessary to develop a method to estimate the mean column velocity. As discussed and agreed to by relicensing participants at the April 24, 2007, Fish and Aquatics Workgroup meeting, ADCP equipment was set to measure velocities to a maximum depth of approximately 50 feet below the water surface. This was sufficient to obtain measurement of the entire transect for all 24 of the Upper Reservoir Reach transects. However, velocities for the full depth were not measured in the five Forebay Reach transects, the 20 Canyon Reach transects and were not measured in four of the 14 Tailrace Reach transects (TR-1, TR-5, TR-7, and TR-9). For the 29 transects (20 Canyon Reach, 5 Forebay Reach, and 4 Tailrace Reach) in which the velocity measurements do not extend to the full transect depth in all columns, a procedure for estimating the mean column velocity for the entire depth of each column over 50 feet deep was developed. Agreement on the procedure was achieved by the Fish and Aquatics Workgroup members through coordination conducted in April and May 2008 with final agreement after the August 7, 2008, meeting in Olympia, Washington.

The procedure was applied to each transect that exceeded 50 feet in depth and velocities were not measured in the portion of the water column below 50 feet. The total flow in a transect was estimated by applying the HRM. A partial transect flow was calculated using the data acquired using an ADCP for portions of the transect less than 50 feet deep. The difference between the HRM estimated total flow and the flow measured by the ADCP was used to calculate the flow for the portion of each column of the transect where it was too deep to measure velocities. The total discharge in each column was determined by adding the measured and unmeasured discharges. The mean velocity in each column was calculated by dividing the total discharge in the column by its depth and width. The details of the procedure are presented in Section 4.4.2 of Appendix 1a.

Graphs showing a comparison of the measured and adjusted column velocities are shown for all transects in Attachment B of Appendix 1a. The figures also include an overlay of the transect bed profile. Two example figures are included in this section to illustrate cases where the

extrapolated mean column velocities were greater than the measured and another example where they were less. The Forebay Reach transect F-1 is presented in Figure 4.1-2 and represents velocity adjustments in the case when application of the mean column velocities from the ADCP measurements result in overestimating the total discharge in the transect. As can be seen in Figure 4.1-2, this requires a downward adjustment in the measured velocities. The application of the mean column velocities measured by the ADCP for the C-4 transect, Figure 4.1-3, results in underestimation of the total discharge in the transect determined from the HRM. In this case, the measured velocities require an upward adjustment.

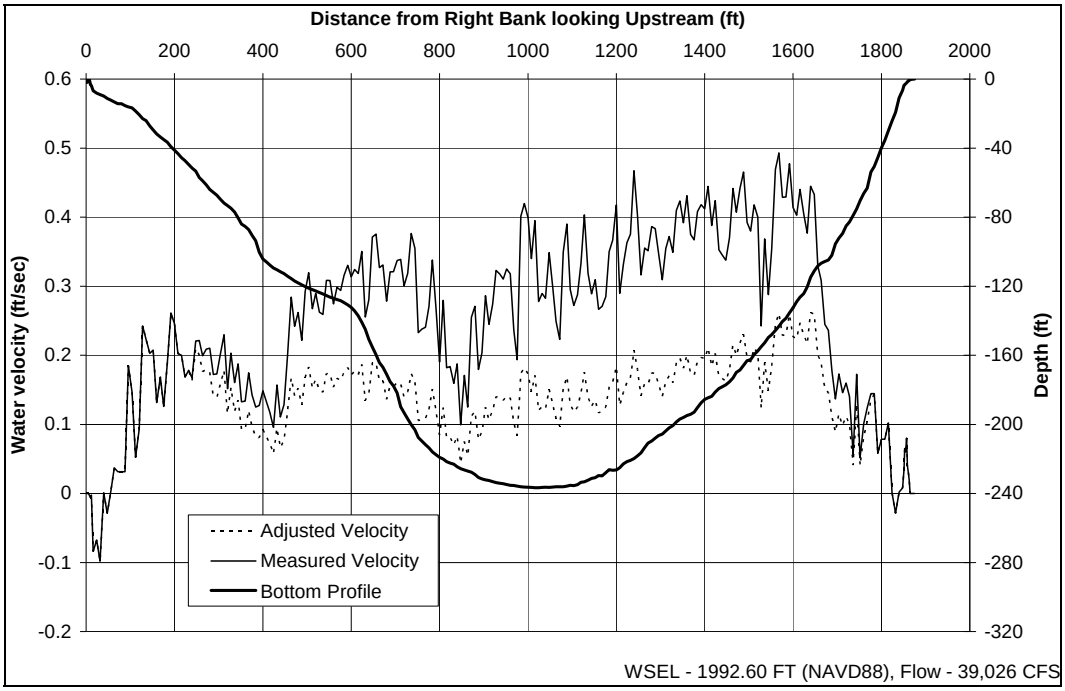



**Figure 4.1-2.** Example of mean column velocity adjustments for habitat transects where ADCP measurement overestimated mean column velocities, Forebay Reach transect F-1.

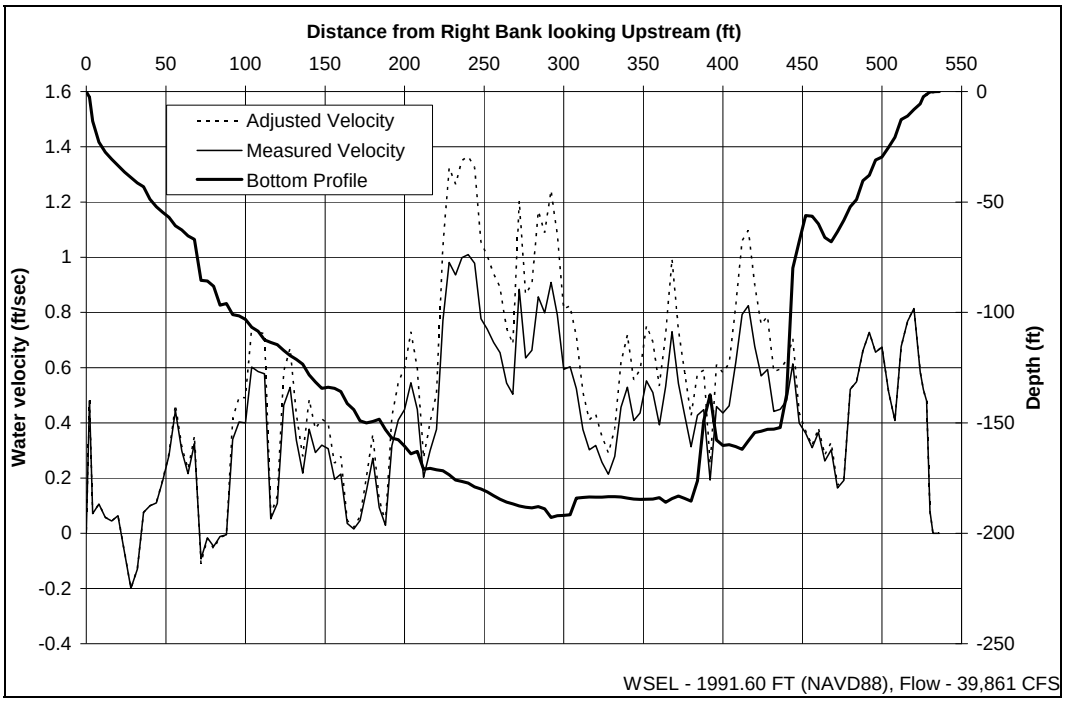



**Figure 4.1-3.** Example of mean column velocity adjustments for habitat transects where ADCP measurement underestimated mean column velocities, Canyon Reach Transect C-4.

### *4.1.1.5. Transect N-Value Calibration*

Manning's N values for each measured vertical at each measured calibration flow were calculated with the River Habitat Simulation Model (RHABSIM) (Payne 1994) software version of U.S. Geological Survey (USGS) hydraulic and habitat program PHABSIM. The required data input for each transect to calculate the N-values were elevation profile, water surface elevation, given discharge, and mean column velocities measured at each vertical. RHABSIM calculates an N-value for each vertical of each transect for each calibration stage/discharge set. For the transects in the Upper Reservoir and Tailrace reaches, four sets of N-values were calculated, one each for the measured stage/discharge calibration sets of: high pool/high flow; low pool/high flow; low pool/medium flow; and low pool/low flow. The calibration N-value for a vertical is assumed to be constant throughout the range of modeled flows, but is adjusted by a velocity adjustment factor (VAF) that compensates for an effective change in N with discharge and stage.

Only the high pool, high flow N-values were used to simulate velocities at greater water surface elevations and flows than measured. For this calibration set, particular attention was given to very large positive and negative N-values (reduce N-value, Type 1 modification), oscillation between positive and negative N-values (change sign of N-value, Type 2 modification)), very small positive and negative N-values (increase N-value, Type 3 modification), and edge effects (adjust N-value for edge effects, Type 4 modification).

Table 4.1-7 lists the calibration modifications techniques applied to each of the 63 cross sections for the various pool and flow conditions. Simulating velocities for higher flow and higher water

surface elevations requires additional calibration of N-values. As can be seen, the vast majority of the modifications were applied to the high pool high flow condition. Attachment C of Appendix 1a provides the calibration notes for each transect. The notes identify the specific transect locations to which the calibration modifications were applied.

**Table 4.1-7.** Types of calibration applied to each transect for each stage/discharge calibration set.

| Transect Number | Number of Points in Transect | Calibration Types Applied to Each Transect and Stage/Discharge Set | | | |
|---|---|---|---|---|---|
| | | High Pool High Flow | Low Pool High Flow | Low Pool Medium Flow | Low Pool Low Flow |
| F-1 | 254 | 0 | N/A | N/A | N/A |
| F-2 | 259 | 0 | N/A | N/A | N/A |
| F-3 | 199 | 0 | N/A | N/A | N/A |
| F-4 | 239 | 0 | N/A | N/A | N/A |
| F-5 | 282 | 0 | N/A | N/A | N/A |
| C-1 | 80 | 0 | N/A | N/A | N/A |
| C-2 | 140 | 0 | N/A | N/A | N/A |
| C-4 | 140 | 0 | N/A | N/A | N/A |
| C-5 | 227 | 0 | N/A | N/A | N/A |
| C-6 | 396 | 0 | N/A | N/A | N/A |
| C-7 | 285 | 0 | N/A | N/A | N/A |
| C-8 | 111 | 4 (1) | N/A | N/A | N/A |
| C-9 | 291 | 0 | N/A | N/A | N/A |
| C-11 | 100 | 0 | N/A | N/A | N/A |
| C-12 | 184 | 0 | N/A | N/A | N/A |
| C-14 | 90 | 0 | N/A | N/A | N/A |
| C-15 | 142 | 0 | N/A | N/A | N/A |
| C-16 | 198 | 0 | N/A | N/A | N/A |
| C-17 | 192 | 0 | N/A | N/A | N/A |
| C-19 | 105 | 0 | N/A | N/A | N/A |
| C-20 | 108 | 0 | N/A | N/A | N/A |
| C-21 | 192 | 0 | N/A | N/A | N/A |
| C-22 | 156 | 0 | N/A | N/A | N/A |
| C-23 | 242 | 0 | N/A | N/A | N/A |
| C-24 | 91 | 4 (2) | N/A | N/A | N/A |
| U-1 | 98 | 4 (1) | 0 | 0 | 0 |
| U-2 | 165 | 4 (2) | 0 | 0 | 0 |
| U-3 | 207 | 2 (1) | 0 | 0 | 0 |
| U-4 | 399 | 4 (2) | 0 | 3 (1) | 0 |
| U-5 | 296 | 4 (6) | 0 | 0 | 4 (1) |
| U-6 | 295 | 4 (2) | 0 | 0 | 4 (6) |
| U-7 | 337 | 4 (4) | 0 | 0 | 0 |
| U-8 | 119 | 2 (1), 4 (1) | 0 | 0 | 0 |
| U-9 | 149 | 2 (1), 4 (1) | 0 | 0 | 0 |

**Table 4.1-7, continued…**

| Transect Number | Number of Points in Transect | Calibration Types Applied to Each Transect and Stage/Discharge Set | | | |
|---|---|---|---|---|---|
| | | High Pool High Flow | Low Pool High Flow | Low Pool Medium Flow | Low Pool Low Flow |
| U-10 | 289 | 4 (2) | 0 | 0 | 0 |
| U-11 | 292 | 4 (2) | 0 | 0 | 0 |
| U-12 | 232 | 0 | 0 | 0 | 0 |
| U-13 | 151 | 4 (2) | 0 | 0 | 0 |
| U-14 | 195 | 4 (8) | 0 | 0 | 0 |
| U-15 | 270 | 0 | 0 | 0 | 0 |
| U-16 | 403 | 4 (2) | 0 | 0 | 0 |
| U-17 | 279 | 4 (2) | 0 | 0 | 3 (1) |
| U-18 | 224 | 4 (3) | 0 | 0 | 0 |
| U-19 | 241 | 4 (22) | 0 | 0 | 0 |
| U-20 | 286 | 2 (1) | 0 | 0 | 0 |
| U-21 | 268 | 4 (3) | 0 | 0 | 0 |
| U-22 | 161 | 4 (6) | 0 | 0 | 0 |
| U-23 | 194 | 4 (2) | 0 | 0 | 0 |
| U-24 | 171 | 4 (2) | 0 | 0 | 0 |
| TR-1 | 162 | 4 (1) | N/A | N/A | N/A |
| TR-2 | 258 | 0 | N/A | N/A | N/A |
| TR-3 | 255 | 4 (1) | N/A | N/A | N/A |
| TR-5 | 119 | 4 (1) | N/A | N/A | N/A |
| TR-7 | 161 | 0 | N/A | N/A | N/A |
| TR-9 | 172 | 4 (3) | N/A | N/A | N/A |
| TR-10 | 119 | 4 (2) | N/A | N/A | N/A |
| TR-11 | 190 | 4 (1) | N/A | N/A | N/A |
| TR-12 | 124 | 4 (1) | 0 | 0 | 0 |
| TR-13 | 151 | 4 (1) | 0 | 0 | 0 |
| TR-14 | 153 | 2 (2), 4 (1) | 0 | 0 | 0 |
| TR-15 | 269 | 4 (1) | 0 | 0 | 0 |
| TR-16 | 256 | 4 (5) | 0 | 0 | 0 |
| TR-17 | 203 | 4 (1) | 0 | 0 | 0 |

Notes:
0 = none, 1 = N-value reduced, 2 = Sign of N-value changed, 3 = N-value increased, 4 = N-value adjusted for edge effect. Values in parentheses "(1)" are number of instances the modification was performed.
N/A – not applicable

### *4.1.1.6. Integration with Hydraulic Routing Model*

The mainstem habitat modeling utilizes the results of the hourly water surface elevations and discharges at each transect location from the HRM to calculate cells depths and velocities. Several steps needed to be taken to integrate the HRM and the habitat transect. The first step was integrating the habitat transect into the cross-sectional geometry of the HRM. The next step

was to check the calibration of the water surface elevations produced by the HRM against the water surface elevations surveyed during the transect measurements. The final step was developing a protocol for applying the multiple sets of N-values developed for the Upper Reservoir Reach and the U.S. portion of the Tailrace Reach.

#### *4.1.1.6.1. Incorporate Habitat Transect in HRM Cross Sections*

Cross-sectional geometry collected during the ADCP transect data collection effort was incorporated into the HRM. The ADCP-collected transect geometry replaced the digital terrain model (DTM)-derived cross-section geometry at the habitat transect locations. Those cross sections in HRM that were not co-located with a habitat transect remained as DTM-derived cross sections. To incorporate the habitat transects into the HRM, for each habitat transect, the left and right end points was geospatially located within ArcGIS using the GPS coordinates determined in the field survey of the end points and overlaid onto the DTM. The portion of the DTM-derived cross section between these two endpoints was removed from the hydraulic routing model and replaced with the ADCP-derived geometry.

#### *4.1.1.6.2. Check HRM Calibration at Habitat Transects*

The HRM underwent extensive calibration and verification using a series of 15-minute water surface elevations recorded at locations throughout the study area. Over 1.5 years of data were used to calibrate and verify the accuracy of the HRM. Details of the HRM calibration and verification process are presented in Appendix 2 and Sections 4.2 and 5.2. To check the performance of the HRM at the habitat transect locations, the surveyed water surface elevations taken during the habitat transect measurements were compared against water surface elevations gentled by the HRM for the time period corresponding to the transect surveys. For the Upper Reach and U.S portion of the study area, four elevations were available for the checking of the HRM-generated water surface elevations. For the Forebay Reach, Canyon Reach, and Canadian portion of the Tailrace Reach, one water surface was available for each transect.

Attachment D of Appendix 1a provides tables that list the measured water surface elevation, HRM modeled water surface elevation and the difference in the two water surface elevations for all 63 habitat transects. This represents a total of 153 measurements with 30 transects having 4 measurements each and 33 transects have 1 measurement each. Statistics on the difference between the measured and modeled water surface elevations were developed. The results were:

- Mean difference: 0.25 foot
- Median difference: 0.21 foot
- Root mean square: 0.31 foot
- Minimum difference: 0.00 foot
- Maximum difference: 0.76 foot

These statistics compare well with results from the calibration of the HRM to the water surface elevations recorded by the pressure transducers and USGS gages used to perform an overall calibration of the HRM over a range of flows. The overall calibration of the HRM produced a root mean square difference of approximately 0.30 foot or less for all locations and maximum difference of approximately 0.75 foot for the Boundary Reservoir model (Upper Reservoir, Canyon, and Forebay reaches) and 1.5 feet for the Tailrace model (Tailrace Reach).

#### *4.1.1.6.3. Velocity Pattern Selection for Aquatic Habitat Modeling*

It was tentatively agreed by the relicensing participants, through the coordination conducted in April and May 2008, that the proposed procedure of using water surface elevation to select the velocity pattern to utilize for a specific flow condition (combination water surface elevation and discharge) was the best procedure to follow when multiple velocity patterns existed. After a presentation of additional information at an August 7, 2008, meeting in Olympia, Washington, with representatives from the State of Washington, it was agreed that in cases where four velocity patterns were measured at a transect the water surface elevation would be used to select the appropriate velocity pattern.

For the 20 Canyon, 5 Forebay, and 8 Canadian Tailrace reach transects, only one set of velocity measurements was performed, high pool/high flow. These transects are located in areas in which conditions are typically more reservoir-like than riverine. The one set of velocity measurements will be utilized for all conditions. In all cases, the measurements were taken at high pool and high flow conditions so that the majority of the time the pattern will be applied to lower water surface elevation and discharge conditions than the one measured for the transect.

For the 24 Upper Reservoir Reach and the 6 U.S portion of the Tailrace Reach transects, four sets of velocity measurements were performed, requiring selection of the appropriate pattern for each flow condition modeled. Using the water surface elevation as the basis of selecting the velocity pattern, the following protocol to use in determining which pattern to apply or a specific condition in the habitat model were agreed upon:

- *High Pool/High Flow*: This velocity pattern is to be used for all modeled water surface elevations greater than the elevation at which the velocity pattern was measured and for all water surface elevations down to the elevation of the low pool high flow pattern
- *Low Pool/High Flow*: This velocity is to be used for all modeled water surface elevations between the elevation at which the low pool high flow and the low pool medium flow measurements were taken.
- *Low Pool/Medium Flow*: This velocity is to be used for all modeled water surface elevations between the elevation at which the low pool medium flow and the low pool low flow measurements were taken.
- *Low Pool/High Flow*: This velocity is to be used for all modeled water surface elevations below the elevation at which the low pool low flow measurement was taken.

Using the agreed-upon procedure of applying velocity patterns based on elevations, the controlling elevations for application of each velocity pattern were determined. Tables 4.1-8 and 4.1-9 provide summaries of the water surface elevations to apply in selecting the velocity pattern for simulating transect hydraulics. These tables apply only to the 24 Upper Reservoir Reach transects and the 6 U.S. portion of the Tailrace Reach transects, the only transects with multiple velocity measurements. The range of water surface elevations at a transect that each of the velocity patterns are applied to during habitat modeling is listed in the tables. The elevation ranges follow the same general selection procedure for all transects. The high pool/high flow condition is used to simulate velocities for all water surface elevations above the water surface

elevation for the measurement and down to the water surface elevation for the low pool/high flow condition. The low pool/high flow condition is used to model velocity patterns from the water surface elevation associated with its measurement down to the water surface elevation associated with the low pool/medium flow measurement. In turn, the low pool/medium flow velocity pattern is used to model down to the water surface elevation for the low pool/low flow measurement. The low pool/low flow pattern is applied to all water surface elevations equal to or less than its corresponding measured water surface elevation. Following this scheme, velocity patterns will be modeled downward, except for water surface elevations exceeding the high pool condition that require modeling upward from the high pool/high flow condition.

**Table 4.1-8.** Upper Reservoir Reach velocity patterns and elevation ranges to apply patterns.

| Transect Number | Velocity Patterns and Elevation Ranges (ft NAVD 88) for Application of Each Pattern | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High Pool/ High Flow | | Low Pool/ High Flow | | Low Pool/ Medium Flow | | Low Pool/ Low Flow | |
| | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) |
| U-1 | N/A | 1,991.75 | 1,991.75 | 1,988.22 | 1,988.22 | 1,984.78 | 1,984.78 | N/A |
| U-2 | N/A | 1,992.22 | 1,992.22 | 1,988.51 | 1,988.51 | 1,985.01 | 1,985.01 | N/A |
| U-3 | N/A | 1,992.12 | 1,992.12 | 1,988.33 | 1,988.33 | 1,984.64 | 1,984.64 | N/A |
| U-4 | N/A | 1,992.20 | 1,992.20 | 1,988.22 | 1,988.22 | 1,984.49 | 1,984.49 | N/A |
| U-5 | N/A | 1,992.69 | 1,992.69 | 1,987.98 | 1,987.98 | 1,984.46 | 1,984.46 | N/A |
| U-6 | N/A | 1,992.64 | 1,992.64 | 1,988.82 | 1,988.82 | 1,984.26 | 1,984.26 | N/A |
| U-7 | N/A | 1,992.46 | 1,992.46 | 1,987.75 | 1,987.75 | 1,984.09 | 1,984.09 | N/A |
| U-8 | N/A | 1,992.34 | 1,992.34 | 1,987.92 | 1,987.92 | 1,983.94 | 1,983.94 | N/A |
| U-9 | N/A | 1,992.38 | 1,992.38 | 1,987.69 | 1,987.69 | 1,983.78 | 1,983.78 | N/A |
| U-10 | N/A | 1,992.86 | 1,992.86 | 1,988.01 | 1,988.01 | 1,983.99 | 1,983.99 | N/A |
| U-11 | N/A | 1,992.83 | 1,992.83 | 1,987.97 | 1,987.97 | 1,983.96 | 1,983.96 | N/A |
| U-12 | N/A | 1,992.78 | 1,992.78 | 1,987.95 | 1,987.95 | 1,983.73 | 1,983.73 | N/A |
| U-13 | N/A | 1,992.88 | 1,992.88 | 1,997.99 | 1,997.99 | 1,983.67 | 1,983.67 | N/A |
| U-14 | N/A | 1,993.12 | 1,993.12 | 1,988.08 | 1,988.08 | 1,983.64 | 1,983.64 | N/A |
| U-15 | N/A | 1,993.15 | 1,993.15 | 1,988.07 | 1,988.07 | 1,983.50 | 1,983.50 | N/A |
| U-16 | N/A | 1,993.05 | 1,993.05 | 1,989.17 | 1,989.17 | 1,984.06 | 1,984.06 | N/A |
| U-17 | N/A | 1,992.99 | 1,992.99 | 1,989.03 | 1,989.03 | 1,984.24 | 1,984.24 | N/A |
| U-18 | N/A | 1,993.05 | 1,993.05 | 1,988.75 | 1,988.75 | 1,984.30 | 1,984.30 | N/A |
| U-19 | N/A | 1,993.39 | 1,993.39 | 1,988.58 | 1,988.58 | 1,984.22 | 1,984.22 | N/A |
| U-20 | N/A | 1,993.51 | 1,993.51 | 1,988.61 | 1,988.61 | 1,984.33 | 1,984.33 | N/A |
| U-21 | N/A | 1,993.68 | 1,993.68 | 1,988.55 | 1,988.55 | 1,984.45 | 1,984.45 | N/A |
| U-22 | N/A | 1,993.91 | 1,993.91 | 1,988.80 | 1,988.80 | 1,984.63 | 1,984.63 | N/A |
| U-23 | N/A | 1,994.75 | 1,994.75 | 1,989.56 | 1,989.56 | 1,985.22 | 1,985.22 | N/A |
| U-24 | N/A | 1,995.03 | 1,995.03 | 1,989.94 | 1,989.94 | 1,985.75 | 1,985.75 | N/A |

Note:
N/A – not applicable

**Table 4.1-9.** Tailrace Reach velocity patterns and elevation ranges to apply patterns.

| Transect Number | Velocity Patterns and Elevation Ranges (ft NAVD 88) for Application of Each Pattern | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High Pool/ High Flow | | Low Pool/ High Flow | | Low Pool/ Medium Flow | | Low Pool/ Low Flow | |
| | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) |
| T-12 | N/A | 1,731.12 | 1,731.12 | 1,727.97 | 1,727.97 | 1,726.74 | 1,726.74 | N/A |
| T-13 | N/A | 1,731.83 | 1,731.83 | 1,728.51 | 1,728.51 | 1,726.99 | 1,726.99 | N/A |
| T-14 | N/A | 1,733.61 | 1,733.61 | 1,729.80 | 1,729.80 | 1,727.50 | 1,727.50 | N/A |
| T-15 | N/A | 1,733.91 | 1,733.91 | 1,730.05 | 1,730.05 | 1,727.67 | 1,727.67 | N/A |
| T-16 | N/A | 1,734.79 | 1,734.79 | 1,730.54 | 1,730.54 | 1,727.86 | 1,727.86 | N/A |
| T-17 | N/A | 1,734.95 | 1,734.95 | 1,731.41 | 1,731.41 | 1,728.27 | 1,728.27 | N/A |

Note:
N/A – not applicable

## 4.1.2. GIS-based Habitat Descriptors

### *4.1.2.1. Macrophyte Mapping*

The primary purpose of the aquatic vegetation mapping was to identify and record the distribution and characteristics of aquatic vegetation within Boundary Reservoir. The description of the methods is divided into the work performed in 2007 and the work performed in 2008. The work to be performed in 2008 was conducted to provide information that was found to be necessary to support application of the stranding and trapping modeling effort. The macrophytes maps produced from the 2007 and 2008 mapping efforts are presented in Appendix 1b. An example is shown in Figure 4.1-4.

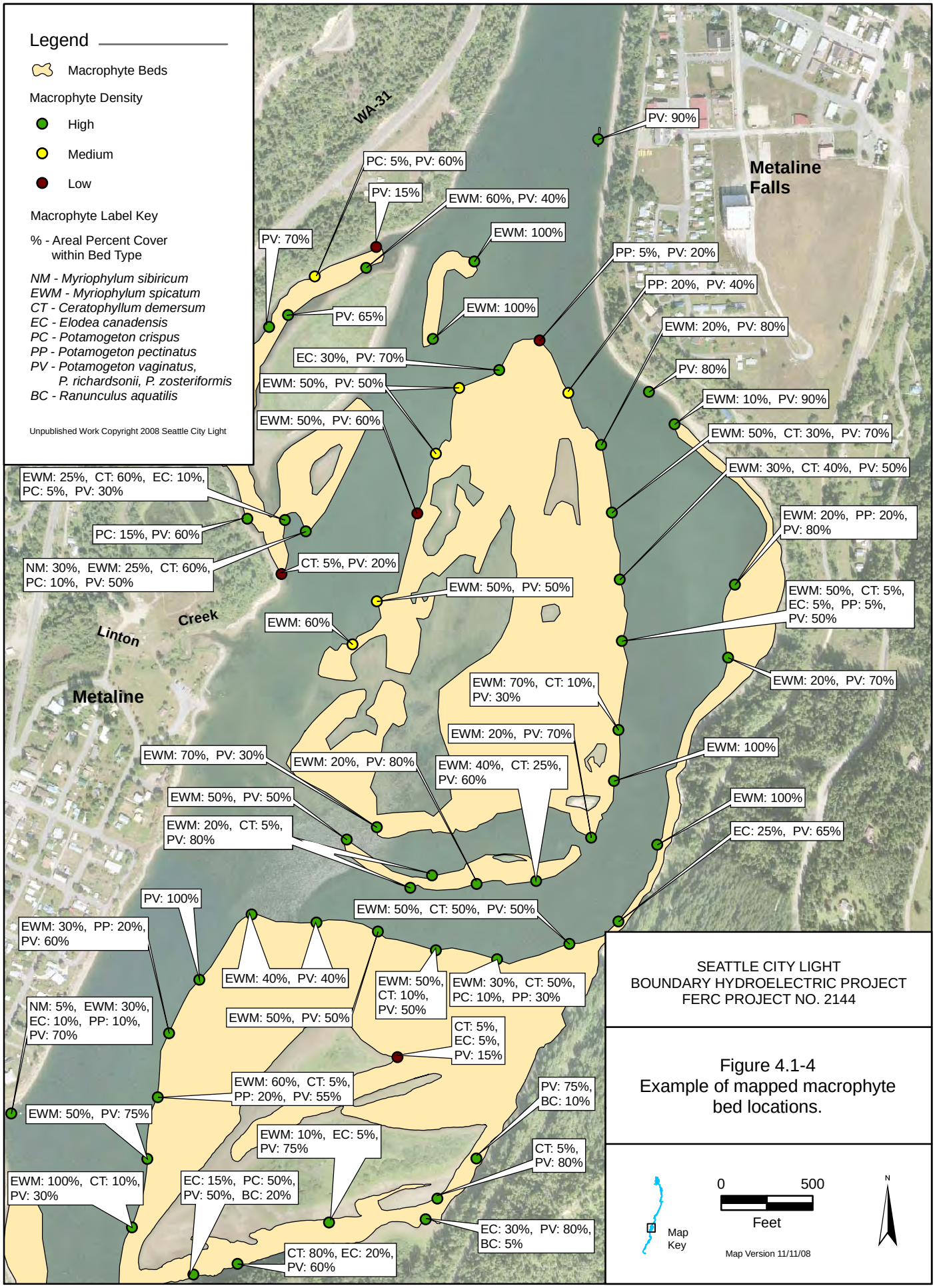



Figure 4.1-4
Example of mapped macrophyte bed locations.

#### 4.1.2.1.1. 2007 Mapping

Measurement of macrophyte abundance and macrophyte mapping surveys were conducted in August 2007 during peak macrophyte growth. The entire shoreline from Box Canyon tailrace to Boundary Dam was surveyed for the presence of macrophytes. A GPS point was taken every 1,000 meters or when macrophytes were encountered. When macrophytes were present, GPS points were taken at the boundaries of these beds and every 300 feet along the outside of the beds. A sufficient number of points were recorded to clearly define the limits of each bed. At each GPS point within the beds, species present and the respective percent cover were recorded. If dewatered and dry macrophytes were encountered the species identification and the respective percent cover were estimated.

#### 4.1.2.1.2. 2008 Mapping

Further mapping of existing macrophyte beds in depressions, on low gradient bars, side channels, and other habitats with potential for stranding and trapping was performed in 2008. The updated macrophyte data from 2008 was used to support the study of potential for stranding and trapping of fish (Sections 4.4 and 5.4). Additionally, the final bathymetry was not available at the time of the 2007 mapping effort. The final bathymetry was reviewed in the 2008 efforts to determine if there were any features likely to contain macrophytes that were not identifiable in the earlier versions of the mapping. These features included the potential fish stranding and trapping areas identified from the GIS-based analysis. These areas were visited during scheduled reservoir drawdown and macrophytes present in these areas were mapped and identified. The mapping was performed utilizing a mapping-grade GPS set to track the locations at one second intervals as the perimeter of the macrophyte beds are being traced (by walking the perimeter with GPS in hand). GPS points were also taken along the perimeter of the bed and at certain locations within the bed to record the macrophyte species present and the respective percent cover. In addition, the mapping effort was coordinated with the stranding and trapping study component (Sections 4.4 and 5.4) so that any additional small localized macrophyte beds found during the stranding and trapping field studies could be identified and mapped.

### 4.1.2.2. Stranding and Trapping Maps and Physical Characteristics

GIS analysis was used to identify the stranding areas and trapping pools and the physical characteristics associated with them. The steps in this process included:

- GIS based identification of stranding and trapping pools
- Field verification of GIS based information
- Adjustments to trapping pools based on field verification
- Development of physical characteristic parameters associated with the stranding areas and trapping pools.

Detailed discussion of each step is provided in Appendix 1c.

Detailed mapping of potential stranding and trapping regions was developed from the bathymetry of the Boundary Reservoir and tailrace using ArcGIS (version 9.2). Use of the GIS system allowed for the incorporation of both physical and biological conditions on a geographic basis to determine of the characteristics used for the stranding and trapping modeling effort

discussed Section 4.4. An example of the stranding and trapping maps developed for the study area is presented in Figure 4.1-5. The complete set of stranding and trapping maps are located in Appendix 1c, Attachment A.

## 4.2. Hydraulic Routing Model

This section documents the development and final calibration of the HRM used in support of analyzing effects of existing Project operations and operations scenarios on aquatic and terrestrial habitats. The HRM is an analytical tool used to support a multitude of study plan analyses; however, the primary use of the HRM was to support Study 7.

The methods described in the following subsections were presented at the July 24, 2007, Fish and Aquatics Workgroup Meeting and at the October 17, 2007, relicensing participants meeting. The methods were agreed upon by the relicensing participants. At the July 24 meeting, the presentation included the data requirements for the HRM, the proposed calibration method, the cross section locations, and the relationship of the HRM to the other studies such as Study 2 (Analysis of Peak Flood Flow Conditions Above Metaline Falls), Study 7, and Study 8. At the October 17 meeting, the presentation primarily included a status report on the model calibration and preliminary results of the model calibration.

Three subsequent presentations were made to relicensing participants as the HRM was being developed and calibrated. The March 26, 2008, meeting defined the need for the HRM within the relicensing process, identified the sources of information for development of the HRM and presented the coordinated framework for the working relationship of the HRM and the ST in analyzing effects of existing Project operations and operations scenarios. On May 22, 2008, a meeting was held that included demonstrations of how the HRM and ST would be used together for resource evaluations and a presentation of the preliminary calibration and verification results of the HRM. The final relicensing meeting involving the HRM was held on August 14, 2008. This meeting included a demonstration of the HRM and ST for a hypothetical operation alternative and presentation of the final calibration and verification of the HRM. Prior to the meeting, a draft report of the HRM calibration and verification was submitted to the relicensing participants for review and comment. No comments were received from the relicensing participants.

The domain of the HRM extends from Box Canyon Dam at the upstream end of the model to Seven Mile Dam at the downstream end of the model, thereby including nearly 28 miles of the Pend Oreille River. The HRM will be used to determine the hydraulic characteristics, resulting from changing hydrologic and operation conditions, throughout the reach upstream of Boundary Dam between Box Canyon and Boundary Dam and throughout the reach downstream of Boundary Dam between Boundary and Seven Mile dams.

The HEC-RAS one-dimensional unsteady flow hydraulic routing software (USACE-HEC 2008) was used develop the HRM. Due to the presence of Boundary Dam, it was necessary to actually develop and calibrate two separate hydraulic routing models. The HEC-RAS software is not an operations software and hence does not have the capability of simulating dam operations or spillway hydraulics. One HRM was developed for the reach upstream of Boundary Dam (Boundary Reservoir HRM) and was used to analyze the changing flow rates and water surface

elevations in the Boundary reservoir resulting from Project operations. A second, separate HRM for the reach downstream of Boundary Dam (Boundary Tailrace HRM) was used to analyze the changing flow rates and water surface elevations downstream of Boundary Dam resulting from Project operations.

The ST (Cdd Howard 2008) is designed specifically to optimize power operations of the Boundary Project. For the analysis of effects of existing Project operations and operations scenarios on aquatic and terrestrial habitats, the Boundary Reservoir HRM and the Boundary Tailrace HRM were supported by both the ST (Cdd Howard 2008) and the Peak Flow Model developed for Study 2, Analysis of Peak Flood Flow Conditions Above Metaline Falls (SCL 2009d). The ST provided the simulation of Project operations necessary to link the two HRMs. The ST provided forebay elevations for the Boundary Reservoir HRM and upstream inflows to the Boundary Tailrace HRM.

The Peak Flow Model was used to determine the hydraulic characteristics within the Boundary Reservoir for mainstem hydrologic conditions that exceed 80,000 cfs. As described in the following subsections, the Boundary Reservoir HRM was calibrated and verified for flows up to approximately 55,000 cfs and can reliably be applied to flows as high as 80,000 cfs. For study analyses (such as the stranding and trapping) that required analysis of hydraulic conditions for flow rates in excess of 80,000 cfs, the Peak Flow Model was used together with the Boundary Reservoir HRM. For study analyses that only required analysis of hydraulic conditions associated with flow rates less than 80,000 cfs, the Boundary Reservoir HRM was used exclusively. The Boundary Tailrace HRM was used for the entire range of mainstem flows.

Section 4.2.1 briefly describes the methods used to construct the two HRMs. Section 4.2.2 presents a brief discussion of the approach used for model calibration and the results of the calibration. The evaluation of the need for a separate seasonal model is described in Section 4.2.3. Finally, the relationship of the HRM to the other models in the study is presented in Section 4.2.4. A more detailed presentation of these topics is documented in Appendix 2.

### 4.2.1. Hydraulic Routing Model Construction

Version 4.0 of the U.S. Army Corps of Engineers (USACE) HEC-RAS model, along with Version 4.1.1 of the USACE HEC-GeoRAS software, was chosen as the modeling software for use in the study. The HEC-RAS executable code and documentation are public domain software that was developed by the Hydrologic Engineering Center (HEC) for the USACE (USACE-HEC 2008). HEC-RAS is designed to perform one-dimensional hydraulic calculations for a dendritic network of natural and constructed channels. HEC-GeoRAS is an ArcGIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into HEC-RAS and generation of GIS data from HEC-RAS output.

The basic information necessary for the development of the Boundary Reservoir HRM and the Boundary Tailrace HRM were topographic data and boundary condition data. The topographic data were used to develop the series of cross sections (oriented perpendicular to the flow) that represent the geometry of the river and reservoir. The boundary condition data were used to define the hydraulic conditions at the open boundaries of each of the two hydraulic models. The specific data and information that were used to construct the models included the following:

- Current bathymetric data of the reservoir between Box Canyon Dam and Boundary Dam and of the Pend Oreille River between Boundary Dam and Seven Mile Dam.
- Recent light detection and ranging (LiDAR)-based data of the upper banks of the Boundary Reservoir and the Pend Oreille River between Box Canyon Dam and Seven Mile Dam.
- Field-surveyed cross section geometry at each habitat location.
- Continuously recorded water surface elevation data (at 15-minute time intervals) obtained from pressure transducers deployed at seven locations between Box Canyon Dam and Seven Mile Dam in September 2006. Table 4.2-1 summarizes the coordinate location of each pressure transducer installation as well as the abbreviated naming convention assigned to each pressure transducer installation. Table 4.2-1 is organized in an upstream to downstream order. The location of each installation is shown in Figure 4.2-1.
- Continuously recorded water surface elevation data and flow data (at 15-minute time intervals) obtained from USGS gaging stations. Data are available at only one USGS gaging station (USGS gage 12396500) in the Project area, as summarized in Table 4.2-2 and Figure 4.2-1. This station includes a primary recording station and an auxiliary recording station, so there are actually two sets of water surface elevations associated with USGS gage 12396500.
- Continuously recorded Boundary Dam outflow data (15-minute time intervals) available from the SCL System Control Center (SCC).
- Continuously recorded water surface elevation data (at 15-minute time intervals) in the Seven Mile Dam forebay, also obtained from the SCL SCC.
- Synthesized flow records for all streams tributary to the Pend Oreille River between Box Canyon Dam and Boundary Dam and for Salmo River downstream Boundary dam (R2 Resource Consultants 2008).

**Table 4.2-1.** Pressure transducer installation locations and abbreviated naming convention.

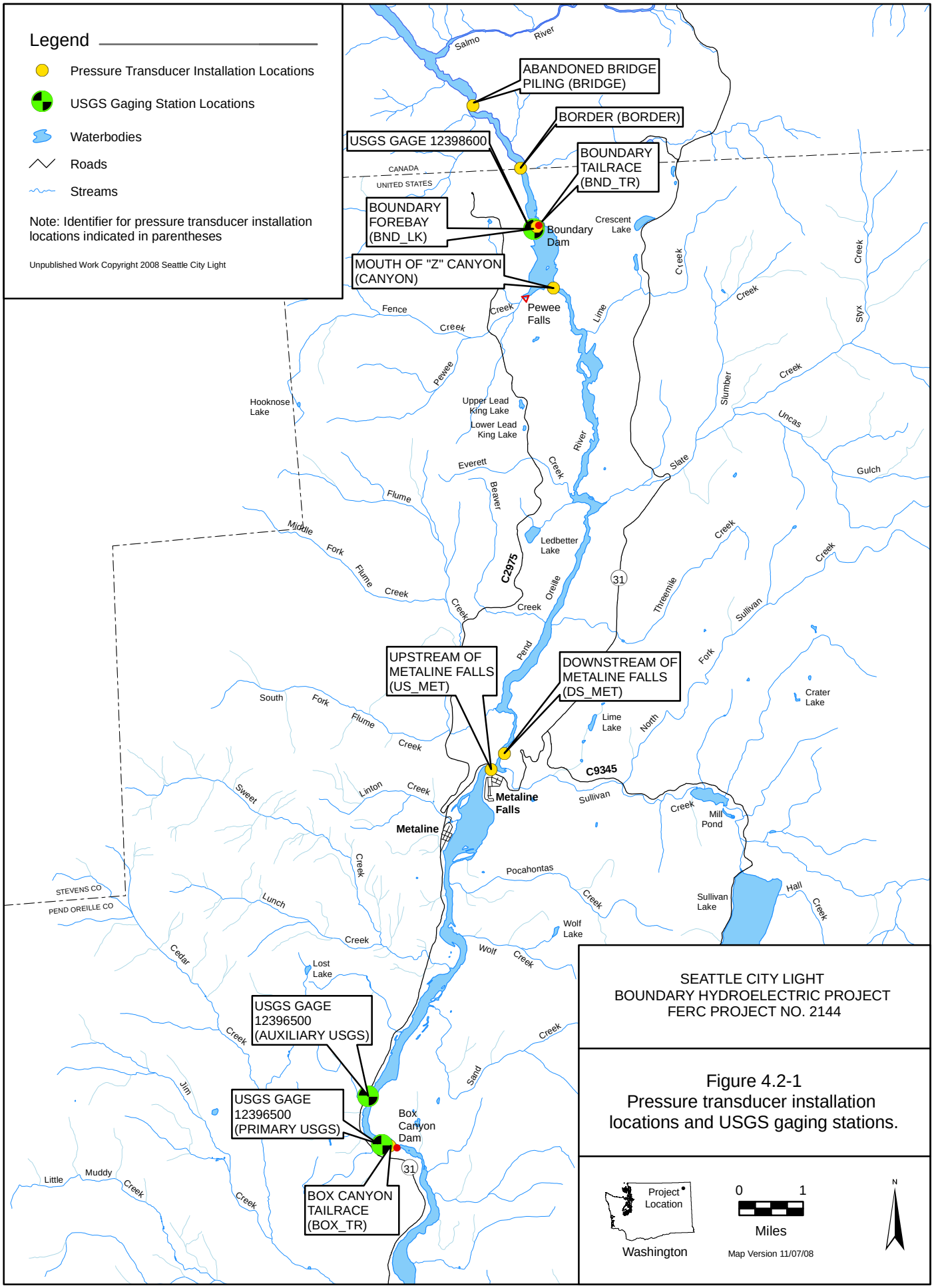
| Pressure Transducer Installation Name | Description of Pressure Transducer Installation Location | Northing[1] (ft) | Easting[1] (ft) |
|---|---|---|---|
| BOX_TR | Box Canyon tailrace. | 743809.42 | 2476985.28 |
| US_MET | Upstream of Metaline Falls. Transducer mounted on one of the piers of the Highway 31 bridge. | 698985.74 | 2473103.68 |
| DS_MET | Downstream of Metaline Falls. Transducer mounted on old powerhouse on east bank. | 700302.83 | 2474187.03 |
| CANYON | Mouth of Z Canyon. Transducer mounted on canyon wall on east bank. | 738667.89 | 2478253.01 |
| BND_LK | Boundary Dam forebay. | 743748.62 | 2476857.27 |
| BND_TR | Boundary Dam tailrace. | 743809.42 | 2476985.28 |
| BORDER | Pend Oreille River at international border. | 748590.61 | 2475525.29 |
| BRIDGE | Pend Oreille River at abandoned bridge piling | 753733.24 | 2471582.29 |

Note:
1 Northing and easting coordinates are relative to the Washington State Plane North Zone (4601) coordinate system and the NAD 1983 horizontal datum.

**Table 4.2-2.** USGS gaging stations in Project area.

| Station Number | Station Name | Latitude | Longitude |
|---|---|---|---|
| 12398600[1] | Pend Oreille River at International Boundary | 48° 59’ 56” | 117° 21’ 09” |
| 12396500[2] | Pend Oreille River Below Box Canyon, Near Ione, WA | 48° 46’ 52” | 117° 24’ 55” |

Notes:
1 USGS gage 12398600 is a total dissolved gas monitoring station and does not provide direct measurement of flow rate.
2 USGS gage 12396500 comprises a primary station and an auxiliary station, so there are actually two sets of water surface elevations associated with this gage.




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 4.2-1
Pressure transducer installation locations and USGS gaging stations.

### 4.2.2. Hydraulic Routing Model Calibration

The Boundary Reservoir HRM was calibrated to water surface elevation data that were post-processed from data obtained at the five pressure transducer installations upstream of Boundary Dam. Water surface elevation data reported at the USGS gage station 12396500 were also used in the calibration. The period of record used for the model calibration was the 19-month period between September 2006 and March 2008, inclusive. All data were available in 15-minute resolution and were converted to Pacific Standard Time (PST). All water surface elevation data were either provided or converted to NAVD 88 vertical datum.

The Boundary Tailrace HRM was calibrated to water surface elevation data that were post-processed from data measured at three pressure transducer installations downstream of Boundary Dam. The period of record used for the model calibration was the 23-month period between September 2006 and mid-July 2008, inclusive. All data were available in 15-minute resolution and converted to PST. All water surface elevation data were either provided or converted to NAVD 88 vertical datum.

The same basic procedure was used to calibrate both the Boundary Reservoir HRM and the Boundary Tailrace HRM. Calibration was conducted in three phases as summarized below:

- Phase One—Model Calibration
- Phase Two—Model Verification
- Phase Three—Broad-Scale Model Verification

Phase One included identification of the primary model parameters to be used as variables during calibration, initial selection of the magnitudes of these parameters, selection of the specific time periods to be used in the calibration, and determination of an acceptable error range for the calibration. In this phase, the model was calibrated to the water surface elevation data within each of the specific time periods.

Phase Two included selection of the specific time periods to be used to verify the calibration, and determination of an acceptable error range for the verification. In this phase, the calibration of the models was verified by comparing the model-predicted water surface elevations with the measured data within each of the specific time periods. This phase also included refinement of the calibration parameters in case the verification results were outside of the acceptable error range.

Phase Three included an execution of the verified model for the entire 19-month data collection period for the Boundary Reservoir HRM and for the entire 23-month data collection for the Boundary Tailrace HRM. The model-predicted water surface elevations were compared to the measured data at each of the calibration locations and the resulting comparisons were statistically summarized to quantify the overall success of the calibration procedure.

#### 4.2.2.1. Boundary Reservoir HRM Calibration—Phase One

The primary model parameters that were identified as variables for the calibration process included the following:

- Main channel hydraulic resistance (Manning's roughness) coefficient
- Overbank Manning's roughness coefficient
- Expansion and contraction coefficients
- Ineffective flow boundary definitions

Both the Manning's roughness coefficients and the expansion and contraction coefficients are spatially variable, empirical parameters, the values of which are based upon local substrate conditions, channel and overbank vegetation, cross section geometry, and other localized conditions that affect the hydraulics of the system. The ineffective flow boundary definitions are not parameters but are locally defined portions of specific cross sections that do not "effectively" convey discharge. Ineffective flow areas are portions of the cross section where the downstream velocity is near zero. Eddy areas upstream and downstream of natural constrictions or constructed constrictions such as bridges can create ineffective flow areas in a cross section.

A sufficient portion of the 19-month record was identified so that the calibration was representative of the wide range of Boundary forebay conditions and Box Canyon outflow conditions observed during this time period. A matrix comprising six specific portions of the 19-month record was developed using unique combinations of the following forebay conditions and Box Canyon outflow conditions:

- *High pool conditions*—conditions during which the Boundary forebay elevation was generally greater than the 1,985-foot NAVD 88 (1,981-foot NGVD 29) elevation, thereby drowning out the hydraulic control at Metaline Falls.
- *Low pool conditions*—conditions during which the Boundary forebay elevation was less than the 1,980-foot NAVD 88 (1,976 foot NGVD 29) elevation, thereby exposing the hydraulic control at Metaline Falls.
- *High flow conditions*—conditions during which outflow from Box Canyon Dam was greater than 40,000 cfs as recorded at USGS gage 12396500.
- *Moderate flow conditions*—conditions during which outflow from Box Canyon Dam was approximately 20,000 cfs.
- *Low flow conditions*—conditions during which outflow from Box Canyon Dam was less than 10,000 cfs.

Table 4.2-3 presents the matrix and summarizes the identified time periods used for the calibration of the upstream hydraulic model. This table also summarizes the naming convention used to identify each of the calibration time periods. The first half of the naming convention defines the Boundary forebay condition (Hi = high pool and Lo = low pool). The second half of the naming convention defines the Box Canyon outflow condition (Hi = high flow, Mod = moderate flow and Lo = low flow).

**Table 4.2-3.** Calibration periods for Boundary Reservoir HRM.

| Pool Condition | Flow Condition | Identifier | Time Period | Number of Days |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/19/06 | 17 |
| High | Moderate | Hi_Mod | 1/7/07 – 1/31/07 | 24 |
| High | High | Hi_Hi | 3/26/07 – 4/4/07 | 9 |
| Low | Low | Lo_Lo | 9/3/07 – 9/16/07 | 13 |
| Low | Moderate | Lo_Mod | 10/3/06 – 10/20/06 | 17 |
| Low | High | Lo_Hi | 5/11/07 – 5/23/07 | 12 |

Note:
All simulations start and end at noon on the specified days of the calibration time period.

During the iterative calibration process, the model-predicted water surface elevation hydrographs were compared in Microsoft Excel® to the observed water surface elevation hydrographs at each of the six calibration locations for each of the six calibration periods. For each comparison, a determination of the maximum absolute error was computed, thus providing quantitative feedback as to specific points in time, within a given calibration period, when the most significant deviation from observed conditions occurred. To provide a quantitative measure of the deviation from observed conditions at each calibration location for each calibration period, the root mean square error (RMSE) was computed.

The magnitudes of each calibration parameter were iteratively varied, within physically acceptable ranges, until the model was calibrated for all six calibration periods within a predefined acceptable error range. The pre-defined error range for absolute error was specified at a nominal value of 0.75 foot. The predefined error range for RMSE for a single calibration location within a single calibration period was specified as 0.50 foot.

Table 4.2-4 is a concise, tabular summary of the results of the Boundary Reservoir HRM calibration. This particular table is just one of several types of tables in Appendix 2 that summarize the calibration results. Table 4.2-4 is a cumulative frequency distribution that was developed by comparing the model predicted water surface elevations predicted by the calibrated model to the measured data (at 15-minute time increments) at each calibration location for all six of the calibration periods. Because the calibration periods included a total of 92 days of observed conditions (see Table 4.2-3), nearly 8,800 time ordinate comparisons were made at each calibration location. Table 4.2-4 shows that, for more than 99 percent of the time during the calibration periods, the model-predicted water surface elevations were within 0.6 foot of the observed water surface elevations at all of the calibration locations. Furthermore, this table also shows that the model-predicted water surface elevations were within 0.4 foot of the observed water surface elevations more than 86 percent of the time at all calibration locations. As detailed in Appendix 2, an initial goal of a maximum absolute differential of 0.75 foot was established at the onset of the model calibration process. Table 4.2-4 clearly shows that this goal was attained at all of the calibration locations.

**Table 4.2-4.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all calibration periods—Boundary Reservoir HRM.

| Cumulative Range | Calibration Location | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| < 0.2 feet | 60.93 % | 53.30 % | 52.64 % | 67.47 % | 88.41 % | 99.76 % |
| < 0.4 feet | 93.12 % | 94.40 % | 86.65 % | 94.66 % | 99.44 % | 99.99 % |
| < 0.6 feet | 99.99 % | 100.00 % | 99.90 % | 99.99 % | 100.00 % | 100.00 % |
| < 0.75 feet | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % |

Notes:
1 There were a total of 92 calendar days represented in the calibration periods.
2 Model output and observed data were compared at 15-minute time intervals.
BOX TR – Box Canyon tailrace
DS MET – Downstream of Metaline Falls
USGS – U.S. Geological Survey
US MET – Upstream of Metaline Falls

### *4.2.2.2. Boundary Reservoir HRM Calibration—Phases Two and Three*

Verification of the model calibration was conducted using a separate set of time periods from the 19-month record than were used for calibration. Using an approach similar to that used to define the original calibration time periods; five hydrologic conditions were defined as the verification periods. Table 4.2-5 summarizes the time periods used for the model verification. The time period identified as Var_Var in Table 4.2-5 is representative of a wide range of pool and flow conditions and covers both a Hi_Mod and a Lo_Mod condition.

**Table 4.2-5.** Verification periods for Boundary Reservoir HRM.

| Pool Condition | Flow Condition | Identifier | Time Period[1] | Number of Days |
|---|---|---|---|---|
| High | High | Hi_Hi[2] | 5/22/07 – 5/29/07 | 7 |
| Variable | Variable | Var_Var | 2/1/07 – 2/28/07 | 27 |
| Low | Low | Lo_Lo[2] | 8/18/07 – 8/26/07 | 8 |
| Low | Moderate | Lo_Mod[2] | 7/6/07 – 7/13/07 | 7 |
| Low | High | Lo_Hi[2] | 5/28/07 – 6/2/07 | 5 |

Notes:
1 All simulations start and end at noon on the specified days of the verification time period.
2 The Hi_Hi, Lo_Lo, Lo_Mod, and Lo_Hi periods correspond with time periods when TRPA conducted acoustic Doppler current profiler (ADCP) velocity measurements.

The calibrated hydraulic model was executed for each of the five verification periods. Model-predicted water surface elevations were compared to the observed water surface elevations at each of the six calibration locations for each verification period. Absolute maximum difference and RMSE were computed. Because the results of this comparison were within the predefined error range defined originally for the calibration step, it was determined that the calibration was successful.

Table 4.2-6 is a concise, tabular summary of the results of the Boundary Reservoir HRM verification. This table is identical to that which was previously used to present the calibration results. Because the verification periods included a total of 54 days of observed conditions (see Table 4.2-5), approximately 5,100 time ordinate comparisons were made at each calibration location. As compared to the calibration results presented previously in Table 4.2-4, the accuracy of the model-predicted water surface elevations for the verification periods is roughly equivalent to or even exceeds in some locations the accuracy of the model-predicted water surface elevations for the calibration periods. This clearly indicates that a successful calibration of the Boundary Reservoir HRM was attained.

**Table 4.2-6.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all verification periods – Boundary Reservoir HRM.

| Cumulative Range | Calibration Location | | | | | |
|---|---|---|---|---|---|---|
| | **BOX_TR** | **Primary USGS** | **Auxiliary USGS** | **US_MET** | **DS_MET** | **CANYON** |
| < 0.2 feet | 58.71 % | 60.60 % | 49.84 % | 63.37 % | 93.92 % | 99.98 % |
| < 0.4 feet | 90.21 % | 94.13 % | 91.34 % | 92.36 % | 99.74 % | 100.00 % |
| < 0.6 feet | 99.98 % | 99.98 % | 99.98 % | 99.96 % | 100.00 % | 100.00 % |
| < 0.75 feet | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % |

Notes:
1 There were a total of 54 calendar days represented in the verification periods.
2 Model output and observed data were compared at 15-minute time intervals.
BOX TR – Box Canyon tailrace
DS MET – Downstream of Metaline Falls
USGS – U.S. Geological Survey
US MET – Upstream of Metaline Falls

The final step in the calibration process (Phase Three) was to execute the calibrated model for the entire 19-month time period. The model results were then organized by month and the maximum difference and RMSE were then computed by month at each calibration location. Refer to Appendix 2 for the tabular summary statistics of the Boundary Reservoir HRM broad verification.

#### *4.2.2.3. Boundary Tailrace HRM Calibration—Phase One*

Calibration and verification of the Boundary Tailrace HRM followed an identical procedure as was outlined in the previous sections for the calibration and verification of the Boundary Reservoir HRM.

The primary model parameters that were identified as variables for the calibration process included the following:

- Main channel hydraulic resistance (Manning's roughness) coefficient
- Overbank Manning's roughness coefficient
- Expansion and contraction coefficients

- Definition of ineffective flow areas

For the calibration of the Boundary Tailrace HRM, a sufficient portion of the 23-month record was identified so that the calibration procedure incorporated the entire range of Seven Mile forebay conditions and Boundary Dam outflow conditions observed during the 23-month record. A matrix was developed using two pool conditions (high and low) and three flow conditions (high, moderate, and low), and the 23-month record was reviewed to define specific portions of the record representing each possible combination. The definitions for the two pool and three flow conditions were consistent with those used in defining the target pool and flow conditions for water surface and velocity measurements at the habitat transects and are summarized as follows:

- *High pool conditions*—conditions during which the Seven Mile Dam forebay elevation was generally greater than the 1,728-foot NAVD 88 (1,724-foot NGVD 29) elevation, thereby drowning out the hydraulic controls in the Tailrace Reach
- *Low pool conditions*—conditions during which the Seven Mile Dam forebay elevation was less than the 1,726-foot NAVD 88 (1,722 foot NGVD 29) elevation, thereby exposing the hydraulic controls in the tailrace reach. Preference was given to finding conditions when Seven Mile Dam forebay elevations were less than 1,713-foot NAVD 88 (1,709 foot NGVD 29) when the hydraulic controls in the tailrace are fully exposed.
- *High flow conditions*—conditions during which outflow from Boundary Dam was greater than 40,000 cfs.
- *Moderate flow conditions*—conditions during which outflow from Boundary Dam was approximately 20,000 cfs.
- *Low flow conditions*—conditions during which outflow from Boundary Dam was less than 10,000 cfs.

Table 4.2-7 presents the matrix and summarizes the time periods identified from the 23-month record that included the combination of pool and flow conditions. Given the daily variability in flow rate and forebay elevations, the time periods summarized in Table 4.2-4 were not exclusively composed of the particular combination of pool and flow condition; however, a sufficient portion of each time period was. The naming convention in Table 4.2-7 is identical to that defined previously for the Boundary Reservoir HRM calibration procedure.

**Table 4.2-7.** Calibration periods for Boundary Tailrace HRM.

| Pool Condition | Flow Condition | Identifier | Time Period [1] | Number of Days in Time Period |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/30/06 | 28 |
| High | Moderate | Hi_Mod | 12/21/06 – 1/12/07 | 22 |
| High | High | Hi_Hi | 5/3/07 – 5/31/07 | 28 |
| High | High | Hi_Hi2 | 4/17/08 – 5/17/08 | 30 |
| Low | Low | Lo_Lo | 8/7/07 – 8/28/07 | 21 |
| Low | Moderate | Lo_Mod | 7/11/07 – 7/29/07 | 18 |
| Low | Moderate | Lo_Mod2 | 3/24/08 – 4/17/08 | 24 |
| Low | High | Lo_Hi | 3/31/07 – 4/19/07 | 19 |
| Var | Var | Var_Var | 2/26/08 – 3/24/08 | 27 |

Note:
1 All simulations start and end at noon on the specified days of the verification time period.

The same iterative calibration procedure used for calibration of the Boundary Reservoir HRM was used for the calibration of the Boundary Tailrace HRM. However, in the early stages of the Phase One calibration effort, it became apparent that there were going to be challenges associated with calibrating the Boundary Tailrace HRM within the calibration criteria established for the Boundary Reservoir HRM. The challenges were primarily associated with matching the precise timing of the stage hydrographs at the transducer locations, which resulted in producing maximum differences in excess of the 0.75-foot calibration criteria. The primary cause was that the Boundary Dam outflow data provided by SCL were average hourly flow data, which often obscured the actual short-term variability in discharge from the Project. (This issue is discussed in more detail in Appendix 2.) For this reason, the calibration criteria were redefined for the Boundary Tailrace HRM as follows:

- Maximum absolute difference between the observed water surface elevation hydrograph and the model predicted water surface elevation hydrograph of *less than 1.50 feet* for each calibration location within each calibration period
- RMSE between observed and model predicted less than 0.50 feet for each calibration location within each calibration period

Table 4.2-8 is a concise, tabular summary of the results of the Boundary Tailrace HRM calibration. This particular table is just one of several types of tables in Appendix 2 that summarize the calibration results and is identical in format to the tables previously used to present the result of the Boundary Reservoir HRM calibration. Because the calibration periods included a total of 217 days of observed conditions (see Table 4.2-7), approximately 20,800 time ordinate comparisons were made at each calibration location.

**Table 4.2-8.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all calibration periods—Boundary Tailrace HRM.

| Cumulative Range | Calibration Location | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| < 0.2 feet | 43.40 % | 56.97 % | 73.76 % |
| < 0.4 feet | 77.63 % | 84.11 % | 97.43 % |
| < 0.6 feet | 94.44 % | 92.31 % | 99.79 % |
| < 0.8 feet | 98.45 % | 96.13 % | 100.00 % |
| < 1.0 feet | 99.52 % | 98.54 % | 100.00 % |
| < 1.2 feet | 99.85 % | 99.69 % | 100.00 % |
| < 1.4 feet | 99.99 % | 99.95 % | 100.00 % |
| < 1.5 feet | 100.00 % | 99.99 % | 100.00 % |

Notes:
There were a total of 217 calendar days represented in the calibration periods.
Model output and observed data were compared at 15-minute intervals
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

### *4.2.2.4. Boundary Tailrace HRM Calibration—Phases Two and Three*

Verification of the model calibration was conducted using a separate set of time periods from the 23-month record than were used for calibration. Using an approach similar to that used to define the original calibration time periods; eight hydrologic conditions were defined as the verification periods. Table 4.2-9 summarizes the time periods used for the model verification. A total of 136 days of the record were included in the model verification. The time periods identified as Hi_Hi2 and Var_Var in Table 4.2-9 are the same time periods used in the calibration. However, these two time periods include the dates when water surface elevations were surveyed at the habitat transects; it was this additional data that were used in the verification.

**Table 4.2-9.** Verification periods for Boundary Tailrace HRM.

| Pool Condition | Flow Condition | Identifier | Time Period [1] | Number of Days in Time Period |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/30/06 | 28 |
| High | Moderate | Hi_Mod | 12/21/06 – 1/12/07 | 22 |
| High | High | Hi_Hi | 5/3/07 – 5/31/07 | 28 |
| High | High | Hi_Hi2 | 4/17/08 – 5/17/08 | n/a[2] |
| Low | Low | Lo_Lo | 8/7/07 – 8/28/07 | 21 |
| Low | Moderate | Lo_Mod | 7/11/07 – 7/29/07 | 18 |
| Low | High | Lo_Hi | 3/31/07 – 4/19/07 | 19 |
| Var | Var | Var_Var | 2/26/08 – 3/24/08 | n/a[2] |

Notes:
1 All simulations start and end at noon on the specified days of the verification time period.
2 The Hi_Hi2 and Var_Var periods are the original calibration periods and include the specific dates when water surface elevations were surveyed at the habitat transect locations. It is these additional observed data that were used in the verification. Neither period is officially considered a verification period.

The calibrated hydraulic model was executed for each of the six verification periods. Model-predicted water surface elevations were compared to the observed water surface elevations at each of the three calibration locations for each verification period. Absolute maximum difference and RMSE were computed. Because the results of this comparison were within the predefined error range defined originally for the calibration step, it was determined that the calibration was successful.

Table 4.2-10 is a concise, tabular summary of the results of the Boundary Tailrace HRM verification. This table is identical to that which was previously used to present the calibration results. Because the verification periods included a total of 136 days of observed conditions (see Table 4.2-9), approximately 13,100 time ordinate comparisons were made at each calibration location. Compared to the calibration results presented previously in Table 4.2-8, the accuracy of the model-predicted water surface elevations for the verification periods is roughly equivalent to, or even exceeds in some locations, the accuracy of the model-predicted water surface elevations for the calibration periods. This clearly indicates that a successful calibration of the Boundary Tailrace HRM was attained.

The final step in the calibration process (Phase Three) was to execute the calibrated model for the entire 23-month time period. The model results were then organized by month and the maximum difference and RMSE were then computed by month at each calibration location. Refer to Appendix 2 for the tabular summary statistics of the Boundary Tailrace HRM broad verification.

**Table 4.2-10.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all verification periods – Boundary Tailrace HRM.

| Cumulative Range | Calibration Location | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| < 0.2 feet | 45.08 % | 67.87 % | N/A |
| < 0.4 feet | 79.75 % | 87.57 % | N/A |
| < 0.6 feet | 93.71 % | 93.33 % | N/A |
| < 0.8 feet | 97.68 % | 96.60 % | N/A |
| < 1.0 feet | 99.24 % | 98.86 % | N/A |
| < 1.2 feet | 99.78 % | 99.68 % | N/A |
| < 1.4 feet | 99.97 % | 99.94 % | N/A |
| < 1.5 feet | 100.00 % | 100.00 % | N/A |

Notes:
There were a total of 136 calendar days represented in the verification periods.
Model output and observed data were compared at 15-minute intervals
N/A indicates that none of the verification periods included time periods when the BRIDGE pressure transducer was collecting data
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

### 4.2.3. Evaluate Need for Separate Seasonal Models

It was recognized that that presence of high-density macrophyte beds in the Upper Reservoir Reach may contribute to the need to develop a separate seasonal Boundary Reservoir HRM. During the period of most robust growth of macrophytes, June through September, the density of the growth could potentially reduce the active conveyance capacity of the channel such that a separate set of calibration parameters would be necessary to replicate observed water surface elevations during this summer period. The methodology that was used to evaluate this need is summarized in Appendix 2.

Successful calibration and verification of the Boundary Reservoir HRM was attained for the 19-month data collection period without the need for using seasonal correction factors to account for the presumed increase in hydraulic resistance due to the presence of macrophytes. This led to the initial conclusion that the growth patterns of macrophytes in the Pend Oreille River have less influence on the hydraulic resistance in the Pend Oreille River than initially theorized.

To verify this initial conclusion, the results of the calibrated Boundary Reservoir HRM were reviewed to determine if the model was consistently underpredicting water surface elevations during the seasonal periods of peak macrophyte growth. This would be expected if the calibrated hydraulic roughness parameters were not accurately accounting for the increased hydraulic resistance contributed by the macrophyte growth. As detailed in Appendix 2, the review was conclusive in finding that there was no consistent trend in the model results that would indicate that the model, as currently calibrated, was underpredicting water surface elevations during periods of macrophyte growth. Therefore, it was concluded that there was no need to develop a

separate set of calibration parameters or a separate hydraulic model to account for the effect of macrophyte growth on the hydraulics of the system.

### 4.2.4. Model Documentation and Executable Model

The calibrated hydraulic routing model will be used integrally with several other models (during the IRA process and preparation of the LA) in the evaluation of operations scenarios. Figure 4.2-2 is a conceptual schematic illustration of the relationship between the models that will be used in support of the study.

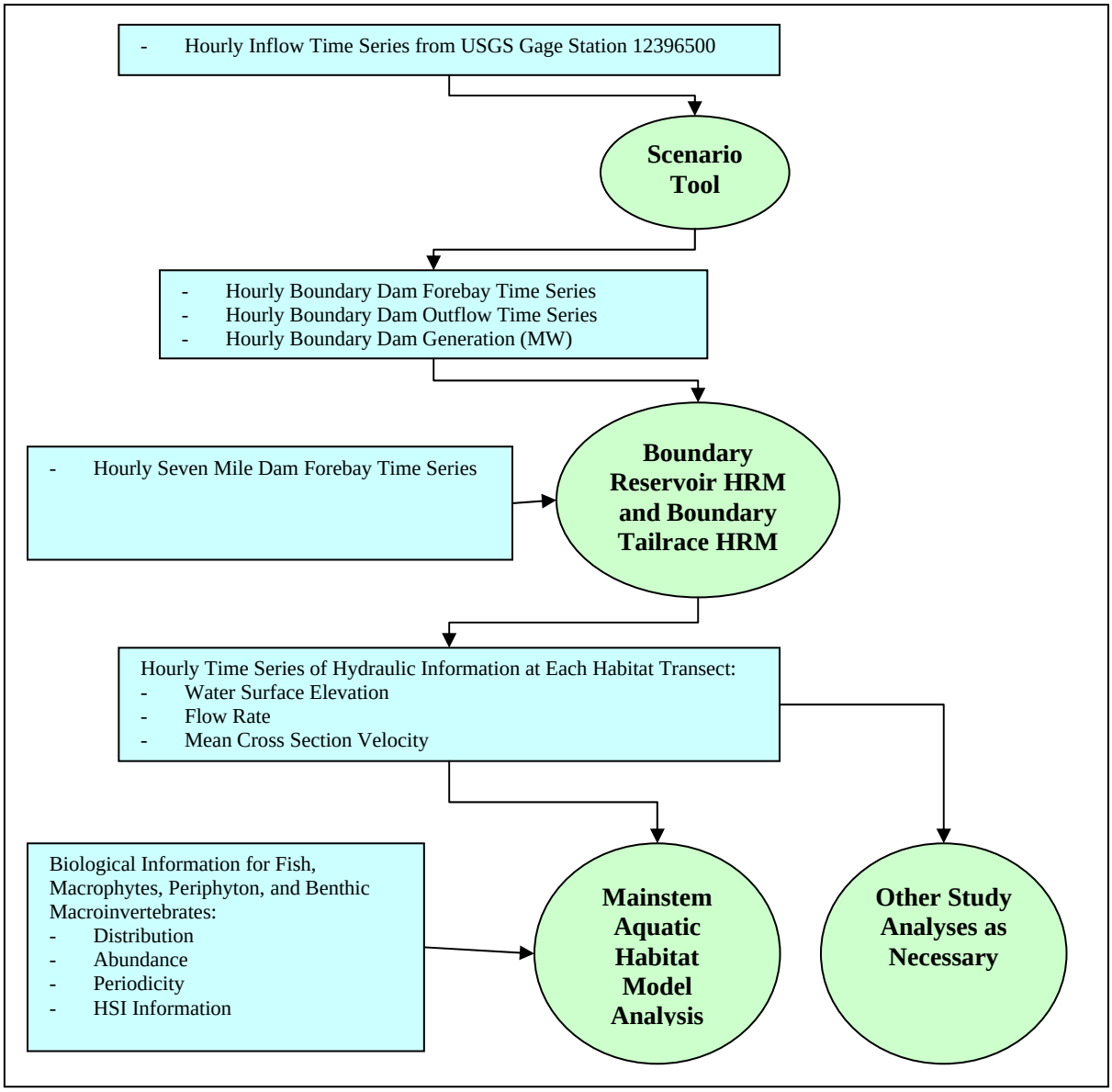



**Figure 4.2-2.** Conceptual model framework for Study 7.

The ST is an Excel®-based hydroelectric operations tool tailored to the requirements of relicensing for the Project (CddHoward 2008). It will be used to simulate optimization of Boundary Project, under specific operational constraints, using three hydrologic periods corresponding to an average year, a wet year, and a dry year. The calendar year 2002 will be used to represent an average hydrologic year, and the calendar years 1997 and 2001 will be used to represent the wet and dry hydrologic years, respectively. Hydrologic data used to drive the ST consist of an hourly inflow hydrograph (as recorded at the USGS gage 12396500) for each year. For each operations scenario, output from the ST will consist of an hourly time series of Boundary outflow and Boundary forebay elevation.

The Mainstem Aquatic Habitat Model is the core model that will be used for assessing changes in aquatic habitat for operations scenarios. Hourly HRM output at each of the habitat transects will be used as input to the mainstem aquatic habitat model.

As illustrated in Figure 4.2-2, output from the hydraulic routing models will also be used as necessary in supporting other study efforts in assessing changes in aquatic and terrestrial habitat for operations scenarios. For example, downramping information determined by the hydraulic routing models was used to support Study 1, Erosion Study Final Report (SCL 2009e). Long-term water surface elevation hydrographs, using the 19-year hydrologic record, were generated by the HRM and provided to Study 8 (SCL 2009a) to assist in determining whether Project operations have affected tributary delta morphology. Output from the hydraulic routing model, in the form of water surface elevation hydrographs, was used in Study 15, Waterfowl/Waterbird Study Final Report (SCL 2009f), to assess changes in terrestrial habitat conditions resulting from operations scenarios.

### 4.2.5. Summary

Successful calibration of the Boundary Reservoir HRM was attained using specific portions of the 19-month record (September 2006 through May 2008). Six distinct periods of the 19-month record, encompassing a total of 92 days, were identified and used for the calibration. The six periods were representative of the entire range of Boundary forebay elevations and USGS flow rates recorded during the 19-month period. The calibration of the model was successfully verified, using five additional periods of the 19-month record, encompassing a total of 54 days and using water surface elevations surveyed at each of the habitat transect locations. The calibrated model was then executed for the entire 19-month period as a broad verification of the model calibration.

The 19-month time period to which the Boundary Reservoir HRM was calibrated included a wide range of flows and Boundary forebay conditions, and therefore the model is considered a reliable tool in evaluating hydraulic conditions in the reservoir. The range of conditions to which the model was calibrated is summarized as follows:

- Flow rates (as measured at the USGS gage 12396500) that ranged between 2,400 cfs and 55,400 cfs
- Boundary forebay elevations that ranged between 1,964.62 and 1,995.08 feet NAVD 88 (1,960.59 and 1,991.05 feet NGVD 29).

Successful calibration of the Boundary Tailrace HRM was attained using specific portions of the 23-month record (September 2006 through mid-July 2008). Nine distinct periods of the 23-month record, encompassing a total of 217 days, were identified and used for the calibration. The nine periods were representative of the entire range of Boundary Dam discharge rates and Seven Mile Dam forebay elevations recorded during the 23-month period. The calibration of the model was successfully verified, using six additional periods of the 23-month record, encompassing a total of 136 days and using water surface elevations surveyed at each of the habitat transect locations. The calibrated model was then executed for the entire 23-month period as a broad verification of the model calibration.

The 23-month time period to which the Boundary Tailrace HRM was calibrated included a wide range of flows and Seven Mile Dam forebay conditions, and therefore the model is considered a reliable tool for evaluating hydraulic conditions in the Tailrace Reach between Boundary Dam and Red Bird Creek. The range of conditions to which the model was calibrated are summarized as follows:

- Synthesized 15-minute instantaneous Boundary Dam discharge rates that ranged between 0 cfs and 108,900 cfs
- Seven Mile Dam forebay elevations that ranged between 1,702.43 and 1,736.16 feet NAVD 88 (1,698.40 and 1,732.13 feet NGVD 29).

## 4.3. Fish Periodicity

Fish periodicity information is an important component for several aspects of the mainstem aquatic habitat model. Fish periodicity is necessary to help assess the potential effects of fluctuations in reservoir water surface elevations, by identifying the time periods when fish nests, eggs, or fry are susceptible to stranding or trapping. Identifying periodicity dates is necessary for estimating the effects of different instream flow scenarios on the quantity and quality of habitat, by determining the specific time periods for applying fish species and life-stage specific HSI curves. Fish periodicity dates were determined by using a combination of literature-based periodicity information, by analyzing site-specific capture and stranding data in the Project area from the Study 9 Final Report(SCL 2009b), and by discussion of periodicity information with relicensing participants in two periodicity workshops (July 17 and August 27, 2008).

### 4.3.1. Developing Fish Periodicity Tables

Interim periodicity tables were developed for species of interest, including the target species[3], to describe the temporal periods when each species and life stage of interest was expected to occur in the Project area (Table 4.3-1). Additional periodicity dates were also developed for other fish species (suckers, yellow perch, largemouth bass, and sunfishes) to represent the time periods when spawning and fry life stages may be vulnerable to stranding and trapping during operations scenarios. These periodicities were determined by visual reference to literature-based estimates

[3] The term "target species" specifically refers to native salmonids including bull trout, cutthroat trout, redband/rainbow trout, and mountain whitefish. The target species as well as other species for which HSI curves were developed are species of interest. To simplify discussions, all species for which HSI curves were developed and WUA and ESI/PSI analysis were performed are collectively referred to as species of interest except when native salmonids are solely being discussed.

with validation of dates, where possible, with actual site-specific capture of fish during Study 9 electrofishing surveys or fish stranding surveys (SCL 2009b). Periodicity dates from literature sources were plotted together along a common timeline, and then site-specific fish captures were added to the timeline (mostly for fry as few spawning observations were made). Interim periodicities for each species and life stage were then visually estimated by giving greater weight to data from geographically similar locations, with less weight to data from distant sources or from general literature reviews, which tend to produce very broad periodicities. These interim periodicities were then compared to site-specific capture data from the Project area (as of August 2008 sampling) and the dates were adjusted accordingly. These interim periodicity dates were discussed with relicensing participants during two meetings (July 17 and August 27, 2008), and consensus on final dates was reached for all species. Final periodicity dates and detailed methodologies used to derive them can be found in Appendix 3.

**Table 4.3-1**. List of species and life-stages included in the periodicity analysis.

| Species | Spawning | Incubation | Fry Rearing [5] |
|---|---|---|---|
| Mountain Whitefish | Y | Y | Y |
| Bull Trout | Y | Y | N |
| Cutthroat Trout | Y | Y | Y |
| Redband Trout | Y | Y | Y |
| Smallmouth Bass[1] | Y | Y | Y |
| Sunfish spp.[2] | Y | Y | Y |
| Cyprinid Forage spp.[3] | Y | Y | Y |
| Yellow Perch | Y | Y | Y |
| Largescale Suckers[4] | Y | Y | Y |

Notes:
1 Also intended to represent largemouth bass
2 Mostly black crappie and pumpkinseed
3 Mostly northern pikeminnow and peamouth
4 Few longnose suckers also present
5 Fry <55 mm, juvenile, and adults present year-round

### 4.3.2. Example Fish Periodicity Data and Final Table

Figure 4.3-1 gives an example of a periodicity figure (for smallmouth bass) with a supporting data table (Table 4.3-2) used to develop spawning, incubation, and fry rearing periodicities. Table 4.3-3 summarizes the final periodicity dates for each species and life stage. Periodicity dates were developed to represent the full range of occurrence and the period of peak occurrence for the spawning, incubation, and fry (up to 55 mm in length) for each species. It was assumed that adult life stages and juvenile life stages (fish >55 mm but not yet adult) were present in the Project area year-round. Those dates included within the full range of periodicity, but not within the period of peak occurrence were identified as the shoulder, or off-peak periods.

These comparative peak and shoulder periods were used in the stranding and trapping analysis to estimate the relative proportion of each species/life stage that would be impacted by fluctuations in water surface elevations under different operations scenarios. This was done by calculating

the number of days of each shoulder and peak period, and dividing that number into an estimate of the percentage of the population that was represented by either the peak or the shoulder period. This division produced an estimated percentage of the total population (e.g., percent of spawning adults, nests, or fry) that could be affected on a daily basis. For example, lacking sufficient site-specific information on spawning timing or density in the Project area, we assumed that the peak periods for spawning and incubation represented 70 percent of the population, whereas the remaining 30 percent was represented by the shoulder periods. Using salmonid fry data from Project tributary surveys and non-salmonid fry data from mainstem electrofishing, stranding, and trapping surveys, frequency plots were constructed according to date to estimate the proportion of observed fry in their respective peak and shoulder periods. These estimated period durations, proportions of peak and shoulder periods, and percentage of affected populations are listed in Table 4.3-3.

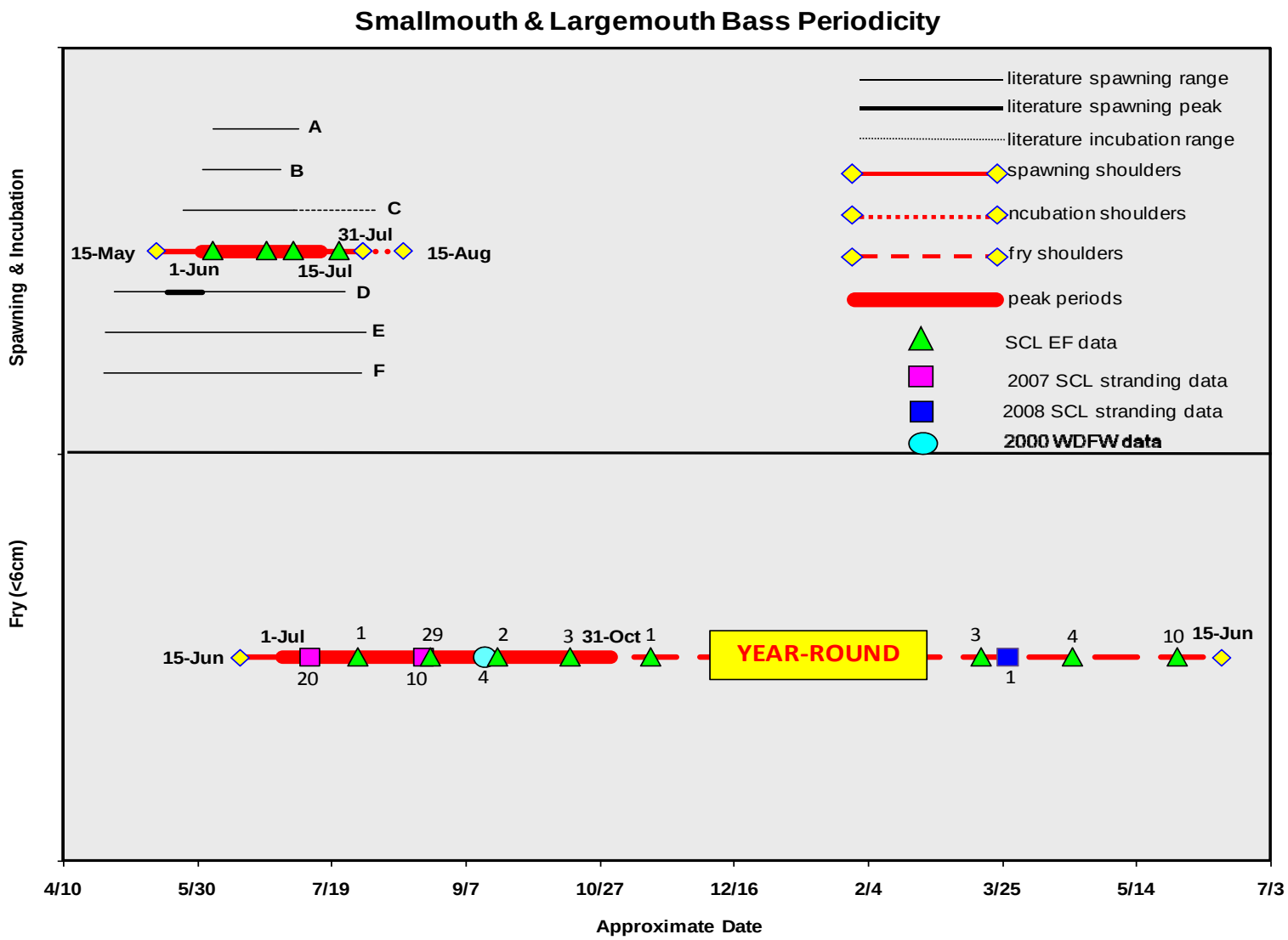



**Figure 4.3-1.** Example periodicity figure showing literature-based periodicity dates (letters refer to datasets listed in Table 4.3-1), Study 9 site-specific observations from the Project area (EF=electrofishing), and the final periodicity dates for bass spawning, incubation, and fry rearing.

**Table 4.3-2.** Supporting data table giving literature-based periodicity information for smallmouth bass.

| | Periodicity Dataset | Life Stage | | Range | Peak | Source | Notes |
|---|---|---|---|---|---|---|---|
| **A** | Saskatchewan Lake | spawning | start | 5-Jun | | Rawson 1945 | |
| **A** | Saskatchewan Lake | spawning | end | 7-Jul | | Rawson 1945 | |
| **B** | Boundary Anglers PC's | spawning | start | 1-Jun | | SCL 2007 | based on SCL angler interviews |
| **B** | Boundary Anglers PC's | spawning | end | 30-Jun | | SCL 2007 | |
| **C** | FW Fish of Canada | spawning | start | 25-May | | Scott & Crossman 1998 | spawning at 55-68$^{o}$ F (mostly at 61-65$^{o}$ F) |
| **C** | FW Fish of Canada | spawning | end | 5-Jul | | Scott & Crossman 1998 | |
| **C** | FW Fish of Canada | incubation | end | 5-Aug | | Scott & Crossman 1998 | dispersal ~3 wks after spawning |
| **D** | Snake R, Hells Canyon | spawning | start | 29-Apr | 19-May | Richter 2003 | 9-30 days from nest construction to swim-up |
| **D** | Snake R, Hells Canyon | spawning | end | 24-Jul | 1-Jun | Richter 2003 | |
| **E** | Columbia R | spawning | start | 26-Apr | | Henderson & Foster 1957 | spawning initiated at 55-60$^{o}$ F |
| **E** | Columbia R | spawning | end | 1-Aug | | Henderson & Foster 1957 | |
| **F** | Hanford Reach, Columbia R | spawning | start | 25-Apr | | Montgomery et al. 1980 | |
| **F** | Hanford Reach, Columbia R | spawning | end | 30-Jul | | Montgomery et al. 1980 | |

Note:
Letters in first column refer to datasets shown in Figure 4.3-1.

**Table 4.3-3.** Final periodicity dates for all species, including the duration, relative proportion, and daily percentage of affected population in peak and shoulder periods.

| Activity | Unit | Whitefish | Bull Trout | Cutthroat Trout | Redband Trout | Bass | Sunfish | Cyprinids | Yellow Perch | Suckers |
|---|---|---|---|---|---|---|---|---|---|---|
| Spawning range | start | 10/15 | 9/15 | 3/15 | 3/1 | 5/15 | 5/15 | 5/1 | 3/15 | 4/10 |
| | stop | 2/28 | 12/31 | 6/15 | 6/30 | 7/31 | 8/31 | 8/5 | 5/31 | 7/15 |
| Spawning peak | start | 11/1 | 10/1 | 4/1 | 4/1 | 6/1 | 6/15 | 6/1 | 4/5 | 4/30 |
| | stop | 1/15 | 11/30 | 5/31 | 5/31 | 7/15 | 7/31 | 7/15 | 5/15 | 6/24 |
| Incubation range | start | 10/15 | 9/15 | 3/15 | 3/1 | 5/15 | 5/15 | 5/1 | 3/15 | 4/10 |
| | stop | 4/30 | 3/25 | 7/31 | 8/15 | 8/15 | 9/3 | 8/15 | 6/10 | 7/31 |
| Incubation peak | start | 11/1 | 10/1 | 4/1 | 4/1 | 6/1 | 6/15 | 6/1 | 4/5 | 4/30 |
| | stop | 3/17 | 2/22 | 7/16 | 7/16 | 7/30 | 8/3 | 7/25 | 5/25 | 7/10 |
| Fry range | start | 4/1 | 3/15 | 6/1 | 6/15 | all | all | all | 3/25 | all |
| | stop | 9/15 | 7/15 | 4/30 | 4/30 | year | year | year | 10/31 | year |
| Fry peak | start | 5/15 | 4/15 | 8/1 | 9/1 | 7/1 | 7/1 | 6/5 | 4/15 | 6/11 |
| | stop | 7/10 | 6/15 | 10/31 | 12/31 | 10/31 | 9/30 | 9/30 | 9/30 | 10/31 |
| Spawning shoulder | # days | 61 | 47 | 32 | 61 | 33 | 62 | 52 | 37 | 41 |
| Spawning peak | # days | 75 | 60 | 60 | 60 | 44 | 46 | 44 | 40 | 55 |
| Incubation shoulder | # days | 61 | 47 | 32 | 61 | 33 | 62 | 52 | 37 | 41 |
| Incubation peak | # days | 136 | 144 | 106 | 106 | 59 | 49 | 54 | 50 | 71 |
| Fry shoulder | # days | 110 | 61 | 242 | 198 | 242 | 274 | 248 | 52 | 223 |
| Fry peak | # days | 57 | 62 | 92 | 122 | 123 | 91 | 117 | 169 | 142 |
| Spwn / Incub shoulder: | % of pop | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Spwn / Incub peak: | % of pop | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Fry shoulder: | % of pop | 0.1 | n/a | 0.2 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.3 |
| Fry peak: | % of pop | 0.9 | n/a | 0.8 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 0.7 |
| Spawning shoulder | %/day | 0.5% | 0.6% | 0.9% | 0.5% | 0.9% | 0.5% | 0.6% | 0.8% | 0.7% |
| Spawning peak | %/day | 0.9% | 1.2% | 1.1% | 1.1% | 1.6% | 1.5% | 1.6% | 1.7% | 1.3% |
| Incubation shoulder | %/day | 0.5% | 0.6% | 0.9% | 0.5% | 0.9% | 0.5% | 0.6% | 0.8% | 0.7% |
| Incubation peak | %/day | 0.5% | 0.5% | 0.7% | 0.7% | 1.2% | 1.4% | 1.3% | 1.4% | 1.0% |
| Fry shoulder | %/day | 0.1% | n/a | 0.1% | 0.2% | 0.1% | 0.1% | 0.0% | 0.2% | 0.1% |
| Fry peak | %/day | 1.6% | n/a | 0.9% | 0.6% | 0.7% | 0.9% | 0.8% | 0.5% | 0.5% |

## 4.4. Stranding and Trapping Development and Modeling Efforts

The stranding and trapping analyses were conducted to determine indices representing the potential for stranding and trapping of aquatic organisms, primarily fish. This section reviews the modeling approach, discusses development of the parameters used in the model, and provides examples of the model output. The stranding and trapping analyses are presented in detail in Appendix 4. The discussion of the results is provided in Section 5.4.

Though stranding and trapping are related processes, there are differences that require two separate analyses for the effects. Both analyses develop indices that represent the potential negative influence on fish as water levels recede because of either Project operations or reduction of inflow to the Project, resulting in the fish being isolated from access to the mainstem. Stranding involves the beaching of fish as the water levels recede and is typically associated with low gradient shoreline areas or cover conditions that attract fish to areas where dewatering occurs. Mortality occurs when stranded fish are beached on dewatered shoreline. Trapping, however, is the retention of fish, as the water levels recede, in pools formed by side-channel depressions. When fish are trapped, stress and the potential for mortality increases based on several factors including temperature fluctuations, reduction in dissolved oxygen, predation, and stranding as the water in the pool infiltrates the substrate.

### 4.4.1. Modeling Approach

The approach to the trapping and stranding analyses is similar to other analyses involving the evaluation of the effects of water surface elevation fluctuations in the varial zone. These other analyses include the evaluation of indices for macrophytes, periphyton, and BMI (Sections 4.6, 4.7, and 4.8). As with the other indices, the stranding and trapping indices utilize results of the Scenario Tool and the HRM to determine the water surface elevation on an hourly basis and to evaluate pool conditions throughout the mainstem habitat modeling study area. However, the other varial zone analyses track the hourly habitat conditions and estimate usable habitat area through a combination of index values and pool conditions that is based on the sum of the hourly values. The stranding and trapping analyses determine indices based on each water level fluctuation cycle. The stranding and trapping index reflects the influence of pool conditions on biological groups in the reservoir on an hourly basis or over a period of several days.

The stranding and trapping analyses track the period of dewatering (stranding) or the period of disconnection (trapping). Fish are assumed to return to potential stranding and trapping areas shortly after the water surface elevation rises to once again inundate/connect the side-channel areas. Stranding and trapping indices are not treated as values that are summed on an hourly basis. Stranding and trapping are viewed as a series of events or cycles, and part of the index expression includes this frequency of events. Therefore, the results are computed at the end of a cycle based on the duration of the cycle, and then results are summed over the series of cycles. A cycle starts when a stranding area becomes dewatered or a trapping area becomes disconnected from the mainstem; it ends when a stranding area becomes inundated or a trapping area becomes reconnected to the mainstem. Each cycle is represented by a single index value computed at the end of the cycle rather than a summation of hourly values calculated over the cycle. A cycle may be as short as an hour or may last many days. The distinction between discrete hourly values for macrophytes, periphyton, and BMI versus a single value per cycle for

stranding and trapping is made because in the former case the hourly indices represent the relative state of the biological group (e.g., fish species or life stage) on an hourly basis whereas the stranding and trapping indices represent the overall potential for stranding and trapping at the completion of a water level fluctuation cycle.

For both the stranding and trapping analyses, ramping rates were not directly incorporated as a factor in the calculation of the indices. Strong relationships between ramping rate and incidence of trapping are not consistently demonstrated in previous studies (Hunter 1992; Higgins and Bradford 1996; R.W. Beck and Associates 1989). Ramping rates were determined for historic wet, dry, and average years as part of the downramping analysis including the exceedance of specific hourly rates ranging from 2 inches per hour to over 12 inches per hour (Appendix 5 and Sections 4.5 and 5.5). The results of both indices can be reviewed along with the reported ramping rates associated with a specific hydrologic condition or operations scenario.

The indices for stranding and trapping are based on equations that relate physical characteristics of the stranding and trapping sites to the potential for stranding and trapping to occur. The information for the physical site characteristics was derived from the bathymetry and mapping through the application of GIS. The index equations have physical factors related to site area, depth, and cover conditions. The observations and data collected during the stranding and trapping field surveys assisted in developing the ratings for several of these factors.

#### *4.4.1.1. Stranding*

The equation for determining the stranding index was presented several times at Fish and Aquatic Workgroup meetings including October17, 2007; February 28, 2008; and July 7, 2008. Final approval on the approach was reached after October 1, 2008, workgroup meeting. The stranding equation is simpler than the trapping equation. The primary differences are the lack of the duration of trapping and the contributing basin area factors (see Section 4.4.1.2 for the trapping equation). A duration of stranding factor is not needed because it is assumed that the 1 hour time interval for modeling is sufficient to cause mortality to the vast majority of fish that become stranded. The resulting equation for stranding is:

$$SI = A_S * C_S$$

Where:

$SI$ = stranding index
$A_S$ = stranding area in square feet
$C_S$ = cover factor for stranding

Figure 4.4-1 provides a conceptual sketch of a trapping area, both in plan and section view, which will help in defining several of the above factors.

##### *4.4.1.1.1. Stranding Index*

The stranding index (SI) is calculated once for each stranding event. It was assumed that the 1-hour time interval of the modeling is sufficient to cause mortality for the vast majority of fish stranded for this length of time. It was also assumed that once the stranding area is again inundated, it reaches its full potential for stranding; that is the fish population is replenished.

The SI is calculated for each 1-foot elevation band. Elevation bands are assigned to the nearest habitat transect in the HRM for the purpose of calculating an area and for defining the hourly water surface elevation used to determine whether the stranding area is inundated or dewatered. The factors on the right side of the equation are defined for each 1-foot elevation band within the range of Project operations. There are a set of elevation bands assigned within each region for the purpose of calculating the SI.

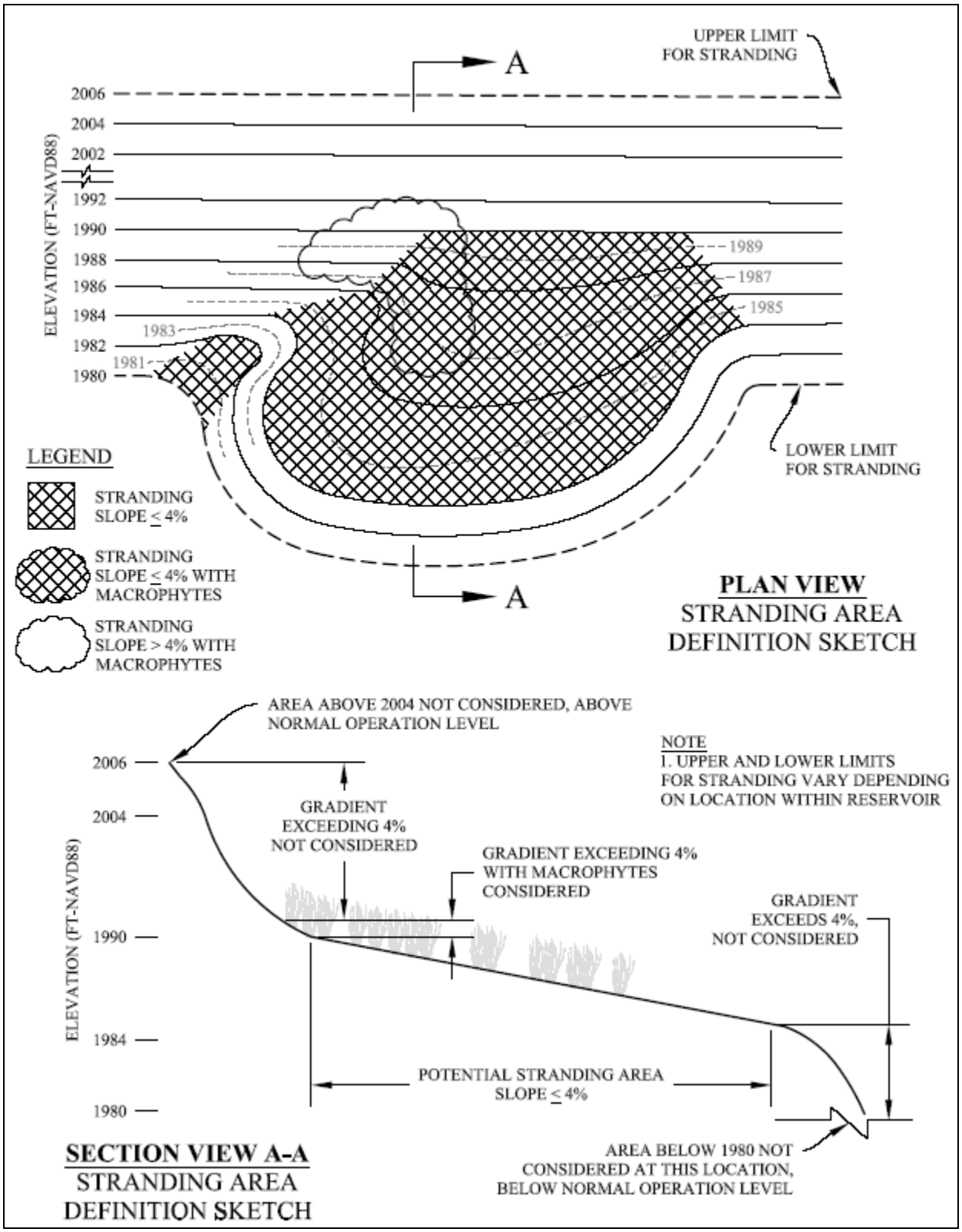



**Figure 4.4-1.** Conceptual sketch of stranding area, plan and section views.

#### 4.4.1.1.2. Area of Stranding

Stranding areas ($A_S$) are defined as areas with a slope of 4 percent or less, excluding depression areas that have already been included in the trapping area analysis. Stranding areas are also defined as areas where cover poses a potential for stranding regardless of slope; these are areas, based on the stranding surveys, where macrophyte beds have been mapped.

Specific stranding zones are defined at 1-foot elevation intervals to allow for tracking of dewatering of stranding areas as the water surface elevation rises and falls. Stranding zones are assigned to each mainstem habitat transect and correspond to the length of the mainstem assigned during the transect weighting (see Section 4.1.1). The unit for stranding areas is square feet. Only potential sites of contiguous areas of 1,000 square feet or greater were considered in the stranding analysis. Several elevation bands may make up the 1,000-foot minimum as long as they are connected to each other. Just as the trapping area was applied directly as a factor in the TI calculation, it was assumed that the potential presence of fish in a stranding elevation band is directly proportional to the area of the elevation band.

#### 4.4.1.1.3. Cover Factor

The stranding cover factor ($C_S$) represents the influence of aquatic macrophytes on the potential for stranding. Cover factors are developed for low gradients slopes of 4 percent or less and for slopes greater than 4 percent. The primary influence on the cover factor is the presence of macrophytes.

### 4.4.1.2. Trapping

The equation for determining the trapping index was presented several times at Fish and Aquatic Workgroup meetings including October17, 2007; February 28, 2008; and July 7, 2008. Final approval on the approach was reached after October 1, 2008, workgroup meeting.

The equation for computing the trapping index has been formulated as:

$$TI = A_T * T_T(D) * C_T$$

Where:

| | | |
|---|---|---|
| TI | = | trapping index |
| $A_T$ | = | trapping area (square feet) |
| $T_T(D)$ | = | duration of trapping factor |
| $C_T$ | = | cover factor representing the influence of macrophytes and other cover |

The factors $A_T$ and $C_T$ represent the risk that fish will be trapped in the pool. The larger these factors, the higher the potential for trapping fish in the pool. $T_T(D)$ represents the potential for mortality of fish trapped in a pool once it becomes isolated from the mainstem; it is the ratio of fish mortalities to total fish trapped. As originally proposed, the trapping index equation had one additional parameter, the contributing basin factor, $B_T$. This factor was eliminated after results of the analysis of the data collected for the current study did not indicate clear relationship between this factor and the risk of trapping. This is discussed further in Section 4.4.2.

The trapping factors are not species-specific. The results of the trapping index calculations require review of fish periodicity to determine whether species of interest and associated life stages susceptible to trapping are present during a particular period.

Figure 4.4-2 provides a conceptual sketch of a trapping area, both in plan and section view to help in defining several of the aforementioned factors. The remainder of the section provides a description of each of the factors and provisional values.

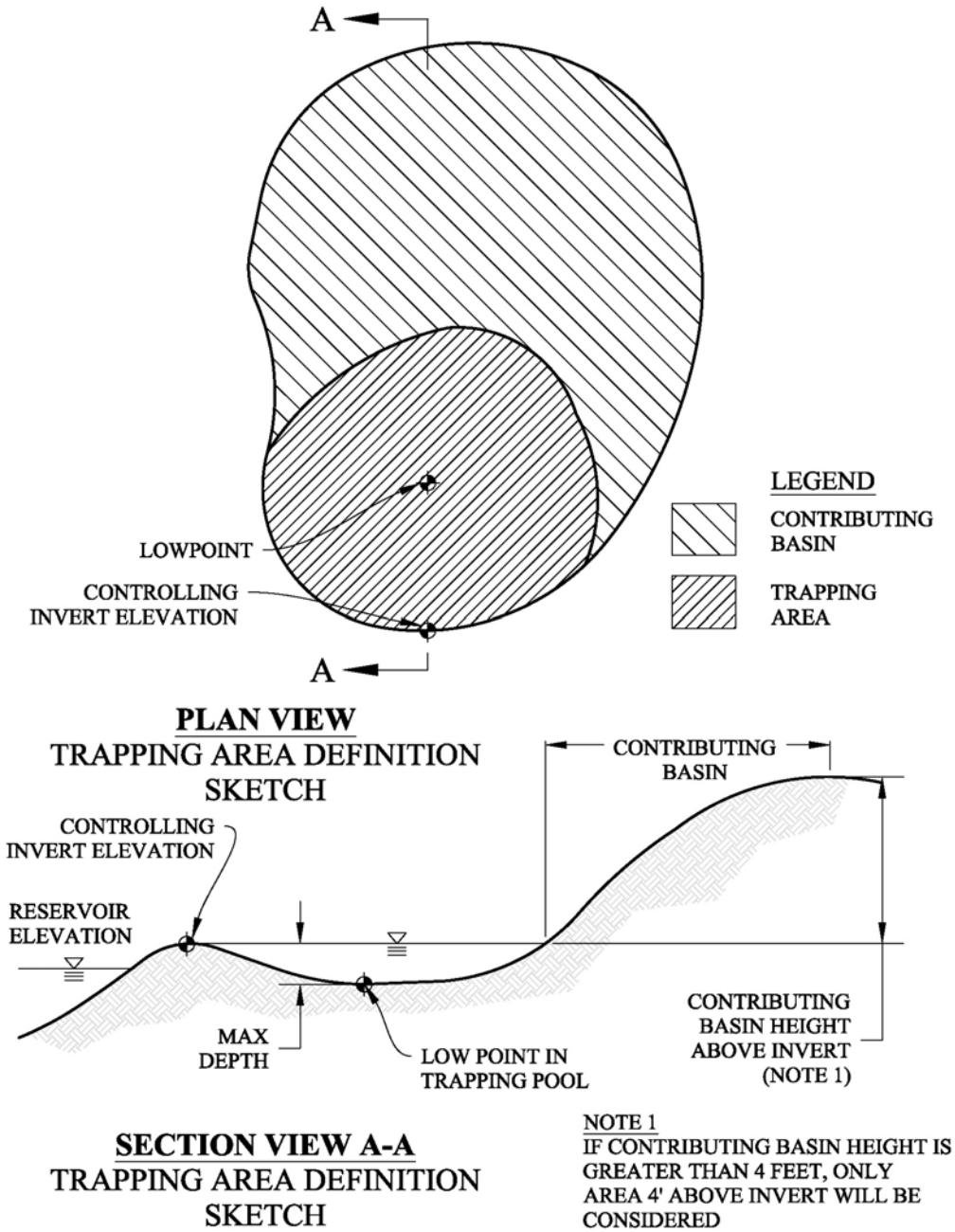



**Figure 4.4-2.** Conceptual sketch of trapping area, plan and section views.

#### 4.4.1.2.1. Trapping Index

The trapping index (TI) is calculated once per trapping event and contains factors that describe the likelihood that fish will be trapped in the pool when the pool becomes disconnected from the mainstem flow, and the potential for fish mortality that is dependent on the duration of the trapping event. The TI is calculated for each individual trapping depression. Consequently, the factors on the right side of the equation are defined for individual trapping pools. Each pool has an effective elevation assigned to its outlet, which allows for determination of trapping duration based on application of the hourly elevations available from the HRM and the mainstem habitat transect closest to controlling water surface for the trapping pool outlet.

It is only necessary to calculate the index at the end of the event, not at intermediate points. It is assumed that once the trapping area is reconnected, it reaches its full potential for trapping within the 1 hour that elapses before the next time interval. This assumption represents a 100 percent recolonization within 1 hour.

#### 4.4.1.2.2. Trapping Area

The trapping area factor ($A_T$) is the actual area of the depression or pool in square feet. GIS tools have been used to identify each depression and determine its area and several other parameters. In using the area of the depression directly as a factor, it is assumed that the potential presence of fish in a trapping area is directly proportional to the area of the depression. This is the area of the depression or pool that is below the "effective outlet elevation." The effective outlet elevation is used to account for the influence of a mat of macrophytes causing the outlet to be effectively disconnected from the mainstem at an elevation above the actual outlet invert. A value of 0.5 foot was added to the outlet invert elevation if macrophytes were present. Additionally, a marginal depth of 0.1 foot for clear outlets was added to the outlet elevation to account for minimum depth at which fish will still utilize the outlet. Depressions with areas of less than 100 square feet were not considered in the trapping analysis.

#### 4.4.1.2.3. Duration of Trapping Factor

The duration of trapping factor ($T_T[D]$) is incorporated to account for the temporal aspect of the potential for fish mortality as the duration that a pool is isolated increases. A variety of conditions can contribute to the mortality rate as the duration the outlet has been dewatered increases including temperature change (heating in summer or cooling/freezing in winter), lowering of dissolved oxygen, predation, and dewatering of the pool by seepage. The depth of the pool can influence how quickly these mechanisms result in trapped fish mortality. Therefore, the provisional assumption was to have three separate depth-based curves to define the factor. Each curve represents the increase in mortality as the duration of isolation increases for a range of maximum pool depths.

#### 4.4.1.2.4. Cover Factor

The cover factor ($C_T$) represents the influence of cover on the potential for trapping of fish in disconnected depressions. A variety of cover conditions had been initially considered and discussed for application in determining this factor including macrophytes, large woody debris (LWD), and coarse substrate. The provisional cover factor only considered the presence of macrophytes as a contributing condition. LWD was excluded because its occurrence is relatively

rare compared to macrophytes and was considered a secondary influence. Substrate was not considered in the provisional cover factor because there is limited cobble in gently sloping areas associated with trapping pools. However, Region 10 is primarily cobble and coarse gravel containing several significant pools that appear to have been created by past gravel mining activities. Region 10 was included in the trapping surveys to investigate this aspect of trapping.

#### *4.4.1.3. Hydraulic Model Integration*

The HRM is a key element of the stranding and trapping analyses. It is used to determine water surface elevations on an hourly time step along the entire study area. The hourly water surface elevations provide the basis for identifying when a stranding or trapping site becomes dewatered or disconnected from the mainstem channel as well as the duration. The HRM was run for the historic wet, dry, and average years and will be run for each operations scenario. The HRM provides a series of hourly water surface elevations associated with each hydrologic condition or scenario at each habitat transect.

The hourly water surface elevations from the hydraulic routing model are used slightly differently depending on whether the information is being used for the calculation of the SI or the TI. This is due to the differences in spatial representation of the stranding areas versus the trapping areas and in the definition of the elevation used to represent the hydraulic connection with the mainstem. Separate descriptions of the use of the hydraulic routing model results are provided for stranding and trapping.

##### *4.4.1.3.1. Stranding*

The low gradient stranding areas were identified from the bathymetry using GIS and divided into zones of 1-foot elevation increments. For each hourly time increment, the hourly elevation from the HRM for the representative habitat transect is compared against the midpoint elevations for each stranding zone to determine which stranding zones become dewatered during the current time increment. When the HRM indicates an elevation zone becomes dewatered, a stranding cycle begins and the SI is computed for the elevation zone for that hour. The computed SI is added to the sum of the stranding indices from all previous stranding cycles for the elevation zone. For this procedure, the SI is cumulative over the entire modeling period, with each stranding event contributing once to the total.

A new cycle is not initiated until the stranding elevation zone once again becomes inundated and is subsequently dewatered. The SI is only increased during the initial hour of a stranding cycle because the assumption was made that 1 hour is sufficient to cause mortality to the vast majority of fish stranded.

##### *4.4.1.3.2. Trapping*

The trapping pools were identified from the bathymetry using GIS tools. The effective outlet elevation was set at either 0.5 or 0.1 foot above the outlet invert of the trapping pool based on the presence or absence of macrophytes, respectively. Each trapping pool was assigned a habitat transect from the HRM to determine the hourly water surface elevations adjacent to the trapping area. Trapping areas within a region were assigned to the habitat transect that best represents the water surface elevations in that region.

For each hourly time increment, the hourly elevation from the HRM for the representative habitat transect is compared against the effective outlet elevation for each trapping pool to determine whether a trapping pool is connected or disconnected from the mainstem. When a trapping area becomes disconnected during an hourly interval, a trapping event has been initiated and the trapping model starts tracking the duration of the event. For each hourly interval the trapping pool remains dewatered (that is, the water surface elevation in the mainstem remains below the effective outlet elevation), an hour is added to the duration of trapping. Once the water surface elevation in the mainstem rises above the effective outlet elevation of the trapping pool, the trapping event is over and the duration is not increased by an hour. At the end of the trapping event, the total duration of the event and the maximum pool depth are used to derive the duration of trapping factor. The TI for the trapping event is calculated by multiplying the duration of trapping factor by the other associated trapping factors. This TI value is added to the previously summed TI value for the given trapping area.

### 4.4.2. Final Values for Stranding and Trapping Factors

This section presents the final values for the stranding factors and the final trapping factors. A more detailed presentation of the development of the final factor values is presented in Section 6 of Appendix 4. The development of the final factors involved analyzing the 2008 stranding area and trapping pool data to adjust the provisional factor values. The methods for conducting the stranding and trapping data collection in both 2007 and 2008 are presented in Section 4 of Appendix 4. The results of the stranding and trapping surveys are presented in Section 5 of Appendix 4. These factor values were applied to the modeling approach detailed in Section 4.4.1 to produce the stranding and trapping modeling results that are presented in detail in Section 5.4. Representative examples of the both stranding and trapping model output are presented in Section 4.4.3.

The development of the final factor values included interaction with the relicensing participants. The analysis of the stranding area data and potential adjustments to the provisional factors were presented to the relicensing participants during a WebEx teleconference on August 28, 2008. A follow-up memo with final recommendations for stranding factors was developed after the August 28, 2008, WebEx teleconference and discussed during a second WebEx teleconference held on September 11, 2008. During the second WebEx teleconference, the relicensing participants agreed to the recommended factors presented.

A similar process was conducted to reach agreement with the relicensing participants on the trapping factors. A WebEx teleconference was held on October 1, 2008, in which a memo detailing the development of the final factors and the actual recommendations for the final factors was presented to the relicensing professionals. The relicensing participants tentatively agreed to the factors as recommended and provided their final agreement in an October 10, 2008, phone call to Al Solonsky of SCL.

#### *4.4.2.1. Final Stranding Factor Values*

There are two factors in the stranding equation: the stranding area factor ($A_s$) and the stranding cover factor ($C_s$).

#### 4.4.2.1.1. Stranding Area Factor

By comparing the densities of stranded fish between various stranding area conditions, the relative potential for stranding for each condition was determined. In this process, it was a basic assumption that the potential to strand fish is directly proportional to the surface area of the pool when it becomes isolated from the mainstem flow. Therefore, the stranding area factor remained unchanged from the provisional recommendation of being set equal to the area of the stranding location in square feet.

#### 4.4.2.1.2. Final Stranding Cover Factor

The final cover factor values for all conditions including a high density stranding area in Region 17 are presented in Table 4.4-1. Factors values are provided for low gradient areas with different levels of macrophyte cover and slopes greater than 4 percent with moderate/high macrophyte cover. The originally proposed provisional values are also provided in the table for comparison.

**Table 4.4-1.** Provisional and final values for the cover factor ($C_S$) in the stranding analysis.

| **Provisional Cover Factor** | |
|---|---|
| **Cover Description** | **$C_S$ Factor** |
| ≤ 4% Gradient without macrophytes | 1.0 |
| ≤ 4% Gradient with macrophytes | 3.0 |
| > 4% Gradient without macrophytes | 0.0 |
| > 4% Gradient with macrophytes | 2.0 |
| **Final Cover Factor** | |
| **Cover Description** | **$C_S$ Factor** |
| ≤ 4% Gradient without macrophytes | 1.0 |
| ≤ 4% Gradient with macrophytes | 15 |
| > 4% Gradient without macrophytes | 0 |
| > 4% Gradient with macrophytes | 5 |
| Region 17 high density stranding area | 30 |

Because macrophyte cover level varies seasonally, it was necessary to incorporate macrophyte periodicity into the cover factor values. Table 4.4-2 presents the final stranding cover factor values based on seasonal changes in the level of macrophyte biomass. The low macrophyte and moderate to high macrophyte cover conditions were interpreted to represent the level of macrophyte biomass in different seasons, not the mapped stem density of the macrophytes. Therefore, all areas mapped as containing macrophytes, including both low density and high density based on the number of macrophyte stems, were considered to contain macrophytes during the summer period of high macrophyte growth. The low macrophyte cover condition factors was applied to all areas mapped as containing macrophytes during the period of early growth and late fall senescence. The high density of fry observed beached in the area of Region 17 was modeled by using a stranding weighting factor of 30 for this specific area for the entire year. Macrophyte periodicity was incorporated by identifying the period of high macrophyte

presence to be July 15 though October 31 and the period of low macrophyte presence to be April 15 to July 15 and November 1 though December 15.

**Table 4.4-2.** Summary of final stranding cover factor seasonal values for combinations of channel bed gradient and presence of macrophytes.

| **High Season of Macrophyte Growth (July 16 through October 31)** | | |
|---|---|---|
| | **No macrophytes** | **Macrophytes** |
| Less than 4% gradient | 1 | 15 |
| Greater than 4 % gradient | 0 | 5 |
| **Low Season of Macrophyte Growth (December 16 through April 15 and November 1 through December 15)** | | |
| | **No macrophytes** | **Macrophytes** |
| Less than 4% gradient | 1 | 2 |
| Greater than 4 % gradient | 0 | 0 |
| **Macrophyte Winter Resting Period (December 16 through April 15)** | | |
| | **No macrophytes** | **Macrophytes** |
| Less than 4% gradient | 1 | 1 |
| Greater than 4 % gradient | 0 | 0 |
| **Region 17 High Density Area (January 1 through December 31)** | | |
| Less than 4% gradient (Area ~ 1%) | 30 (cover is “no macrophytes” for entire area) | |

### *4.4.2.2. Final Trapping Factor Values*

There are three factors in the trapping index equation: the trapping area factor $A_T$, the trapping cover factor $C_T$, and duration of trapping factor $T_T(D)$. In addition, a contributing basin factor $B_T$ was originally proposed, but was not included in the final trapping equation because the data collected for this study did not indicate a clear relationship between the risk of fish being trapped and the contributing basin area.

#### *4.4.2.2.1. Final Area Factor*

By dividing the number of trapped fish by the pool area, a comparison of the potential trapping risk between pools of varying sizes can be made. It is a basic assumption of the trapping index procedure that the potential to trap fish is directly proportional to the surface area of the trapping pool when it becomes isolated from the mainstem flow.

#### *4.4.2.2.2. Cover Factor*

Based on the 2008 trapping survey data, cover factors were developed to be consistent with the trends exhibited by the data. Similar to stranding, macrophyte periodicity was included in the development of the factor values. Table 4.4-3 lists the final factor values developed for the various cover conditions and also provides the provisional factor values for comparison. Because the trapping data collected did not indicate that low macrophyte cover increased the risk of trapping, the shoulder season (April 16 through July 15 and November 1 through December 15) were grouped with the period of no macrophyte presence (December 16 through April 15).

The results in the trapping cover factor values for areas with mapped macrophytes were set to 1.0, corresponding to Fines and Gravel with Low-No Macrophytes, for the period of November 1 through July 15. For the period of high macrophyte presence, the cover factor value was set to 8. Trapping was found to be influenced by the presence of cover substrate. This conclusion was drawn from data collected in the shallow depressions in Region 10. Applying macrophyte periodicity, the resulting final cover factor values are presented in Table 4.4-4.

**Table 4.4-3.** Provisional and final values for the cover factor ($C_T$) in the trapping analysis.

| **Provisional Cover Factor** | |
|---|---|
| **Cover Description** | **$C_T$ Factor** |
| No macrophytes | 1.0 |
| < = 25 % (sparse submerged macrophytes) | 1.5 |
| > 25 % (abundant submerged macrophytes) | 3.0 |
| **Final Cover Factor** | |
| **Cover Description** | **$C_T$ Factor** |
| Fines and gravel with low-no submerged macrophytes | 1.0 |
| Fines with high-moderate submerged macrophytes | 8.0 |
| Cobbles | 6.0 |

**Table 4.4-4.** Final cover factor ($C_T$) values considering submerged macrophyte periodicity.

| **High Season of Macrophyte Biomass (July 16 though October 31)** | |
|---|---|
| **Condition** | **Cover Factor $C_T$** |
| Fines and Gravel (without mapped macrophytes) | 1 |
| Fines (with mapped macrophytes) | 8 |
| Cobbles | 6 |
| **Seasons of Low Macrophyte Biomass and Winter Resting (November 1 through July 15)** | |
| **Condition** | **Cover Factor $C_T$** |
| Fines and Gravel (without mapped macrophytes) | 1 |
| Fines (with mapped macrophytes) | 1 |
| Cobbles | 6 |

#### *4.4.2.2.3. Contributing Basin Factor*

The data collected for development of the trapping index do not show an apparent relationship between the risk of trapping fish in a pool and the contributing basin area ratio. Based on these results a reliable contributing basin ratio could not be developed. Therefore, the contributing basin area ratio was eliminated from the trapping index equation for the current study.

#### 4.4.2.3. Duration of Trapping Factor Values for Summer Conditions

Evaluation of original data collected from pools throughout the Project during July and August 2008 were used to generate relationships between estimated duration of disconnection of a pool from the mainstem reservoir and the mortality of fish (percent of total numbers).

#### 4.4.2.4. Summary of Final Duration of Trapping Factor Values.

Table 4.4-5 lists both the provisional and final values for the duration of trapping factor $T_T(D)$. The final factor values retain the three depth intervals from the provisional factor, but 100 percent mortality was not achieved as rapidly in the recommended values. An initial mortality value of 0.1 was set in the final factors to account for predation not being directly measured in the field efforts and non-lethal stress that may occur when fish are trapped. In developing the final factors, the potential for pools freezing solid in the winter was investigated but determined to require a longer duration than already proposed for 100 percent mortality. Because freezing is not an issue and in the absence of sufficient data available from winter, spring, and fall trapping surveys, the duration of trapping factor values presented in Table 4.4-5 are proposed for the entire year.

**Table 4.4-5.** Provisional (summer period) and final duration of trapping factor $T_T(D)$ values (all seasons).

| **Provisional Values** | | | | | |
|---|---|---|---|---|---|
| **Depth < 1 foot** | | **Depth 1 to 2 feet** | | **Depth > 2 feet** | |
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 6 | 0.25 | 9 | 0.25 | 12 | 0.25 |
| 12 | 0.50 | 18 | 0.50 | 24 | 0.50 |
| 18 | 0.75 | 27 | 0.75 | 36 | 0.75 |
| 24 | 1.0 | 36 | 1.0 | 48 | 1.0 |
| **Final Values** | | | | | |
| **Depth < 1 foot** | | **Depth 1 to 2 feet** | | **Depth > 2 feet** | |
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 1 | 0.10 | 1 | 0.10 | 1 | 0.10 |
| 15 | 0.20 | 32 | 0.20 | 67 | 0.20 |
| 19 | 0.25 | 37 | 0.25 | 71 | 0.25 |
| 31 | 0.50 | 48 | 0.50 | 78 | 0.50 |
| 42 | 0.75 | 57 | 0.75 | 83 | 0.75 |
| 51 | 1.0 | 63 | 1.0 | 86 | 1.0 |

### 4.4.3. Model Application and Example Output

The detailed discussion of the results is presented in Section 5.4. This section of the report provides the example figures of the output from the stranding model and the trapping model

along with examples of summary tables generated by the post-processing. The results presented in this section and the rest of the report address the existing Project conditions to establish a baseline as a reference for comparison when the effects of operations scenarios are later developed. The potential term of a new license is 50 years, but Project influences on certain resources were evaluated only during three representative years. These years were selected as representative of wet, dry, and average conditions based on average annual flows (R2 Resource Consultants 2008). The wet year is based on 1997, the dry year on 2001, and the average year on 2002.

#### *4.4.3.1. Stranding Model Results*

This section presents the results from the stranding modeling effort. SI values were calculated for each of the regions on an hourly basis for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. A summary of the annual total SI value for each of the representative years is presented in Table 4.4-6. The stranding modeling results are presented graphically in the figures in Attachment D of Appendix 4.

**Table 4.4-6.** Summary of annual total stranding index (SI) value and average daily weighted channel width of exposed stranding area that occurred during the wet (1997), dry (2001), and average year (2002).

| Reach | Reach Length (ft) | Potential Strand-ing Risk Area ($ft^2$) | Average Channel Width of Potential Strand-ing Risk Area (ft) | Wet Year (1997) | | Dry Year (2001) | | Average Year (2002) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Strand-ing Area (ft) |
| Forebay | 5,360 | 281,200 | 52 | 1,250 | 6.4 | 940 | 4.8 | 400 | 2.0 |
| Canyon | 44,156 | 538,200 | 12 | 7,075 | 4.4 | 3,668 | 2.3 | 2,700 | 1.7 |
| Upper Reservoir | 38,549 | 11,896,900 | 309 | 88,943 | 63.2 | 168,200 | 119.5 | 128,112 | 91.1 |
| Total Boundary Reservoir | 88,065 | 12,716,300 | 144 | 97,267 | 31 | 172,808 | 55 | 131,212 | 42 |
| Tailrace | 15,613 | 285,300 | 18 | 2,473 | 4.3 | 2,490 | 4.4 | 2,600 | 4.6 |
| **Total Project** | **103,678** | **13,001,600** | **125** | **99,740** | **26** | **175,297** | **46** | **133,813** | **35** |

An example of the monthly total SI values for the Upper Reservoir Reach is presented in Figure 4.4-3. Daily total SI values for Region 10 and Region 11 are shown in Figure 4.4-4 and Figure 4.4-5, respectively. Region 10 represents an area predominantly of cobble substrate without the presence of macrophytes. Region 11 represents an area predominantly of fines substrate with the

presence of macrophytes. As illustrated in these example figures, the x-axis for each plot covers the calendar year from January 1 through December 31. The left y-axis is for the SI.

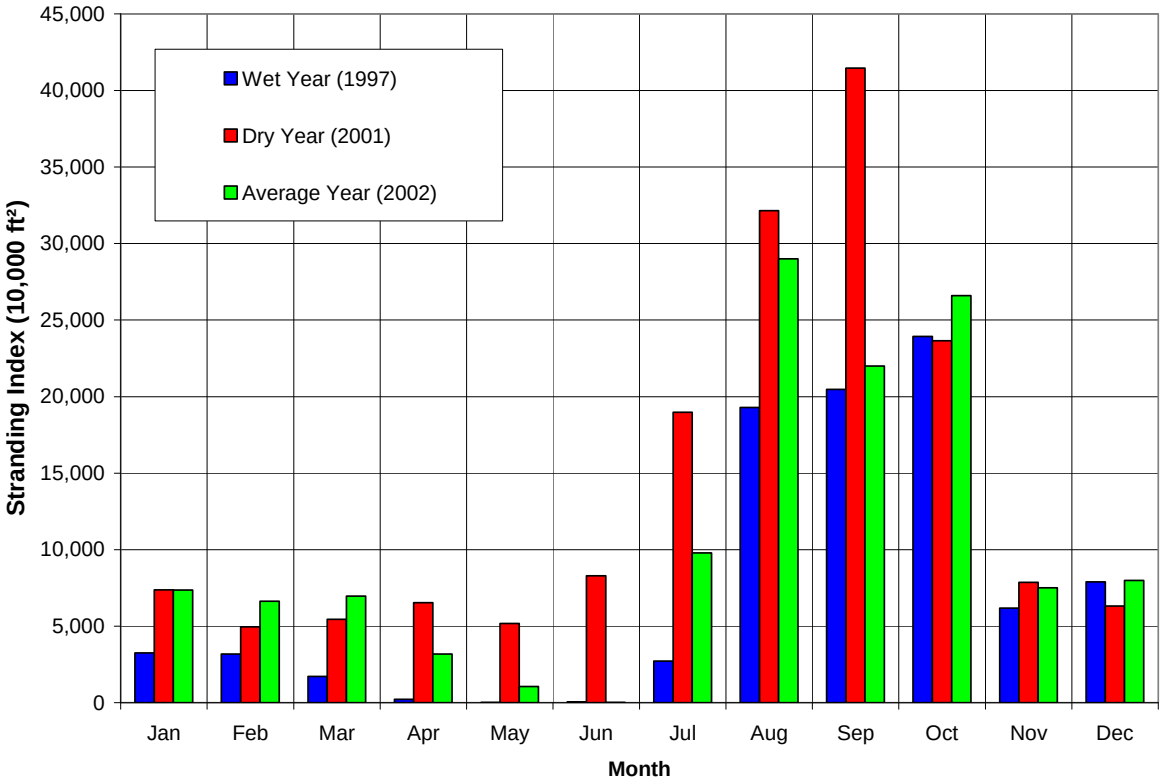



**Figure 4.4-3.** Example of monthly total stranding index value for the Upper Reservoir Reach that occurred during the wet (1997), dry (2001), and average year (2002).

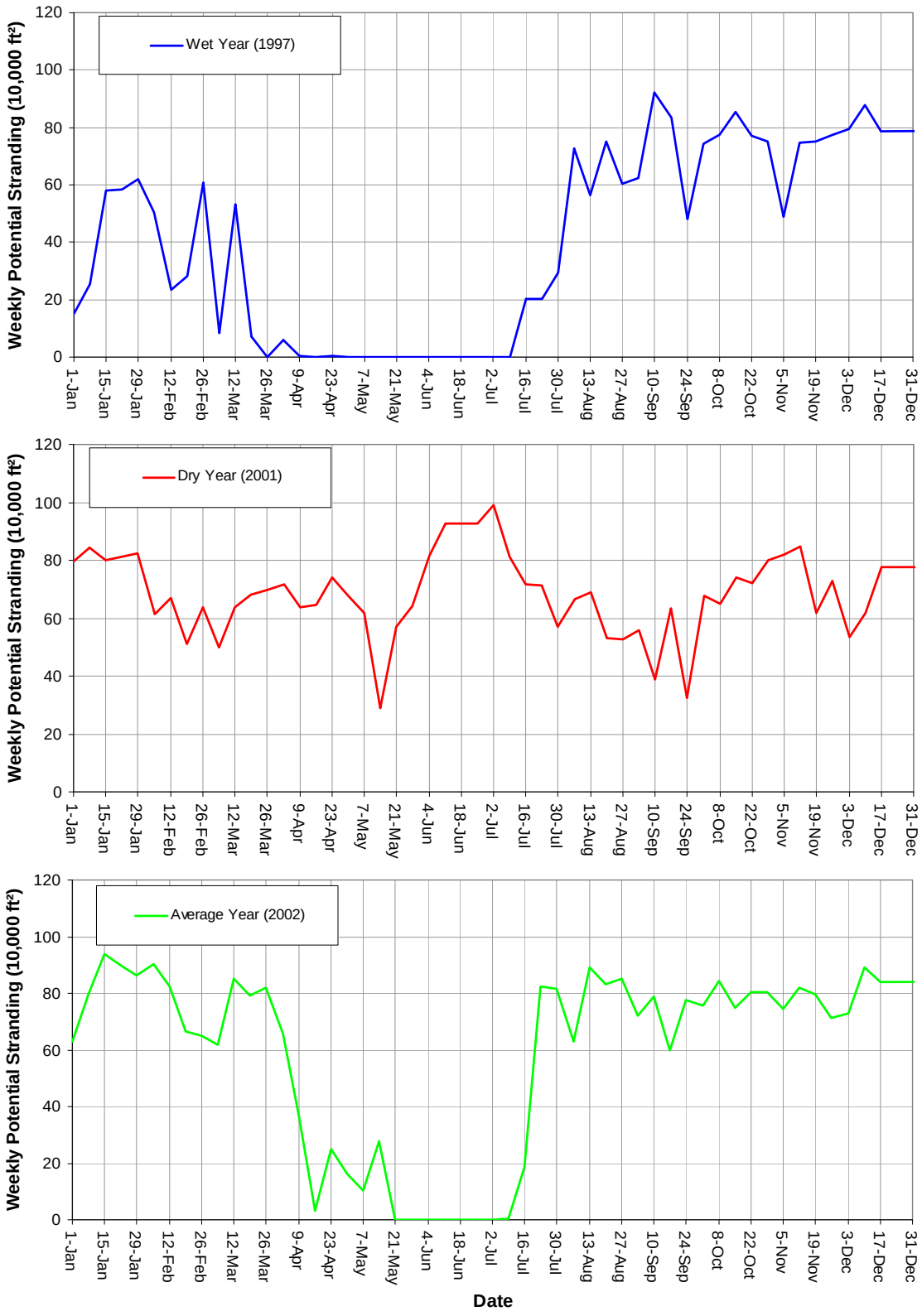



**Figure 4.4-4.** Example of the comparison of Region 10 daily total stranding index value that occurred during the wet (1997), dry (2001), and average year (2002).

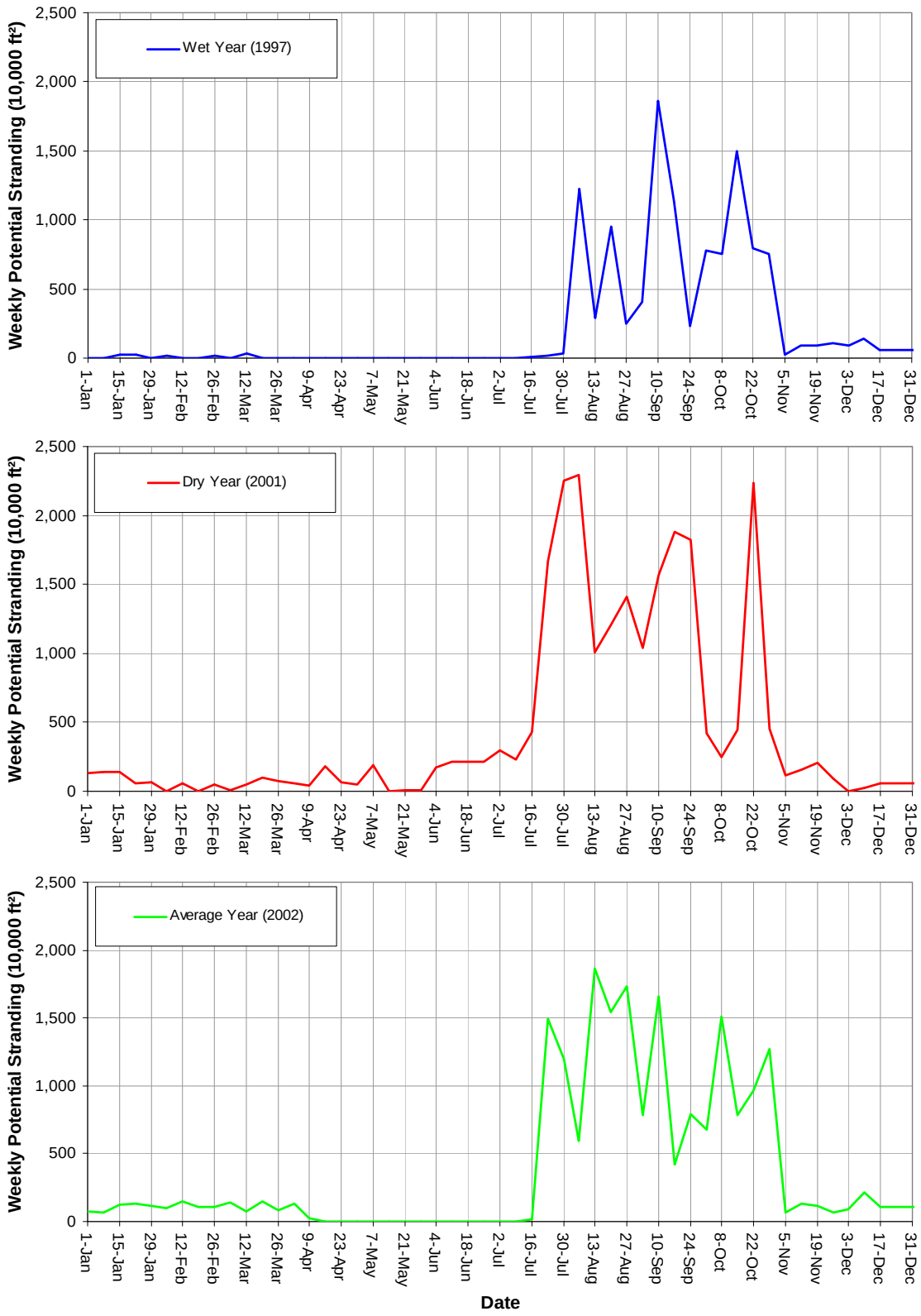



**Figure 4.4-5.** Example of the comparison of Region 11 daily total stranding index value that occurred during the wet (1997), dry (2001), and average year (2002).

### 4.4.3.2. Trapping Model Results

This section presents the results from the trapping modeling effort. TI values were calculated for each of the regions on an hourly basis for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. A summary of the annual total trapping index value for each of the representative years is presented in Table 4.4-7. The trapping modeling results are presented graphically in the figures in Attachment E of Appendix 4.

**Table 4.4-7.** Summary of annual total trapping index (TI) value that occurred during the wet (1997), dry (2001), and average year (2002).

| Reach | Total Area of Trapping Pool ($ft^2$) | Annual Total Trapping Index (10,000 $ft^2$) | | |
|---|---|---|---|---|
| | | Wet Year (1997) | Dry Year (2001) | Average Year (2002) |
| Forebay | 11,300 | 1.1 | 2.4 | 1.0 |
| Canyon | 99,800 | 163 | 160 | 93 |
| Upper Reservoir | 2,487,200 | 1,616 | 3,916 | 2,478 |
| Total Boundary Reservoir | 2,598,300 | 1,780 | 4,079 | 2,572 |
| Tailrace | 20,300 | 139 | 213 | 163 |
| **Annual Total** | **2,618,600** | **1,920** | **4,292** | **2,735** |

An example of the monthly total trapping index values for the Upper Reservoir Reach is presented in Figure 4.4-6. Daily total trapping index values for Region 10 and Region 11 are shown in Figure 4.4-7 and Figure 4.4-8, respectively. Region 10 represents an area predominantly of cobble substrate without the presence of macrophytes. Region 11 represents an area predominantly of fines substrate with the presence of macrophytes.

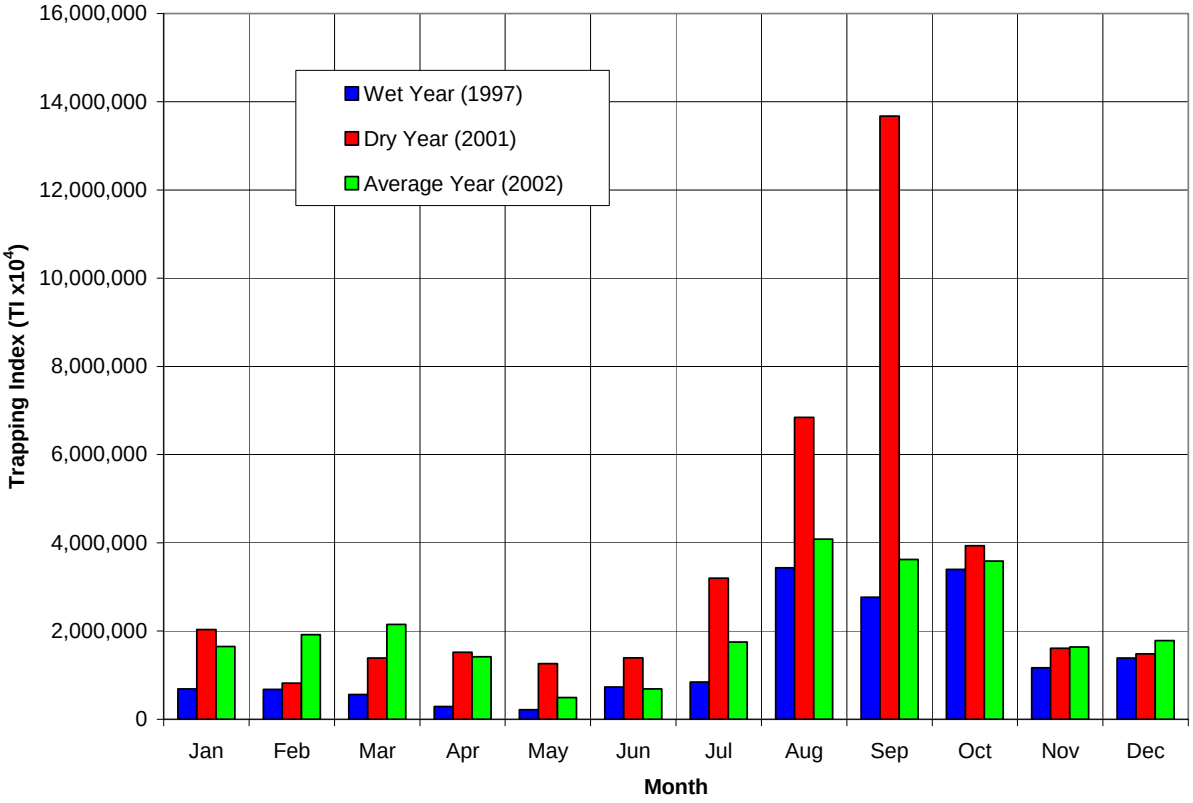



**Figure 4.4-6.** Example of monthly total trapping index (TI) value for the Upper Reservoir Reach that occurred during the wet (1997), dry (2001), and average year (2002).

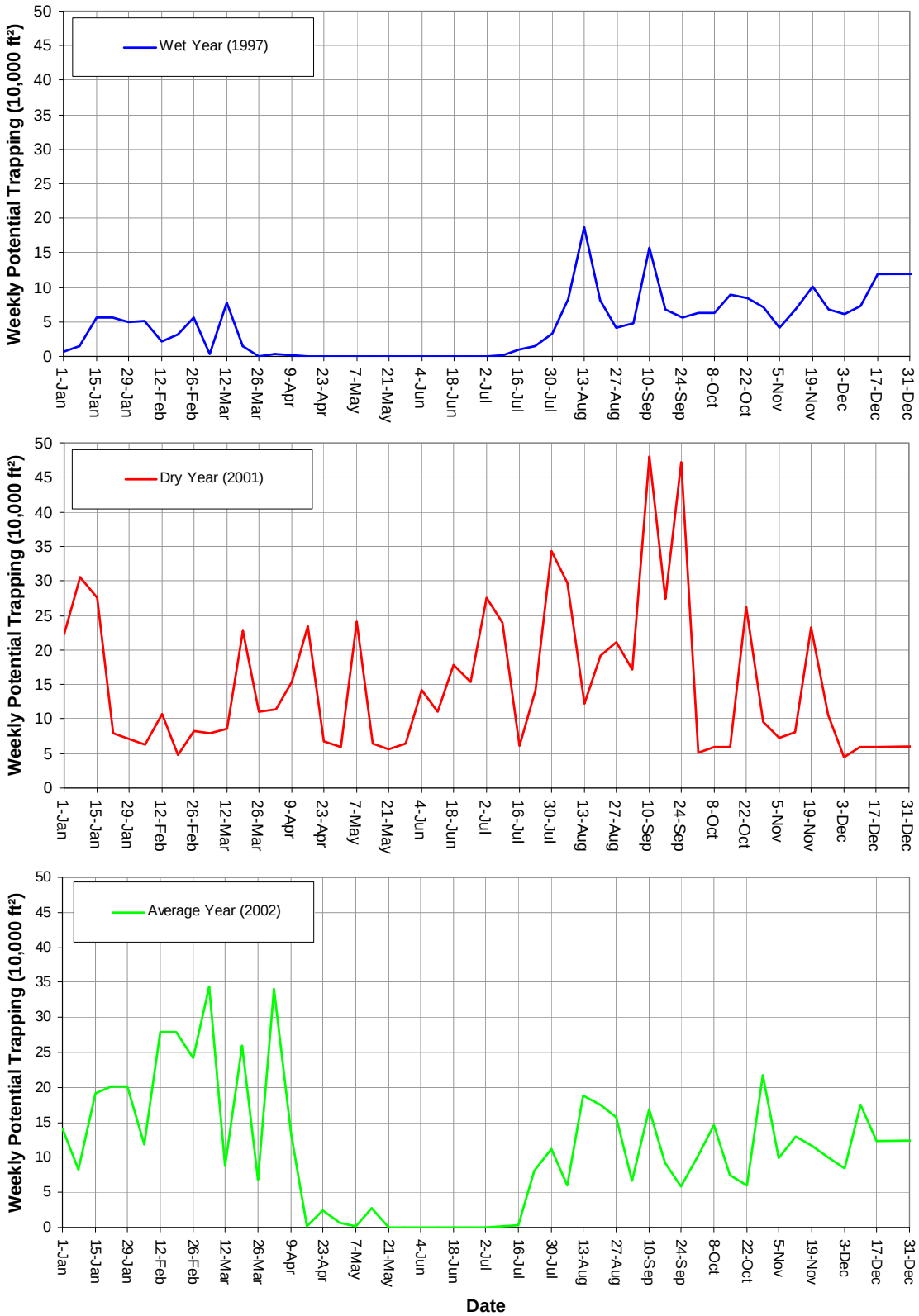



**Figure 4.4-7.** Example of the comparison of Region 10 daily total trapping index (TI) value that occurred during the wet (1997), dry (2001), and average year (2002).

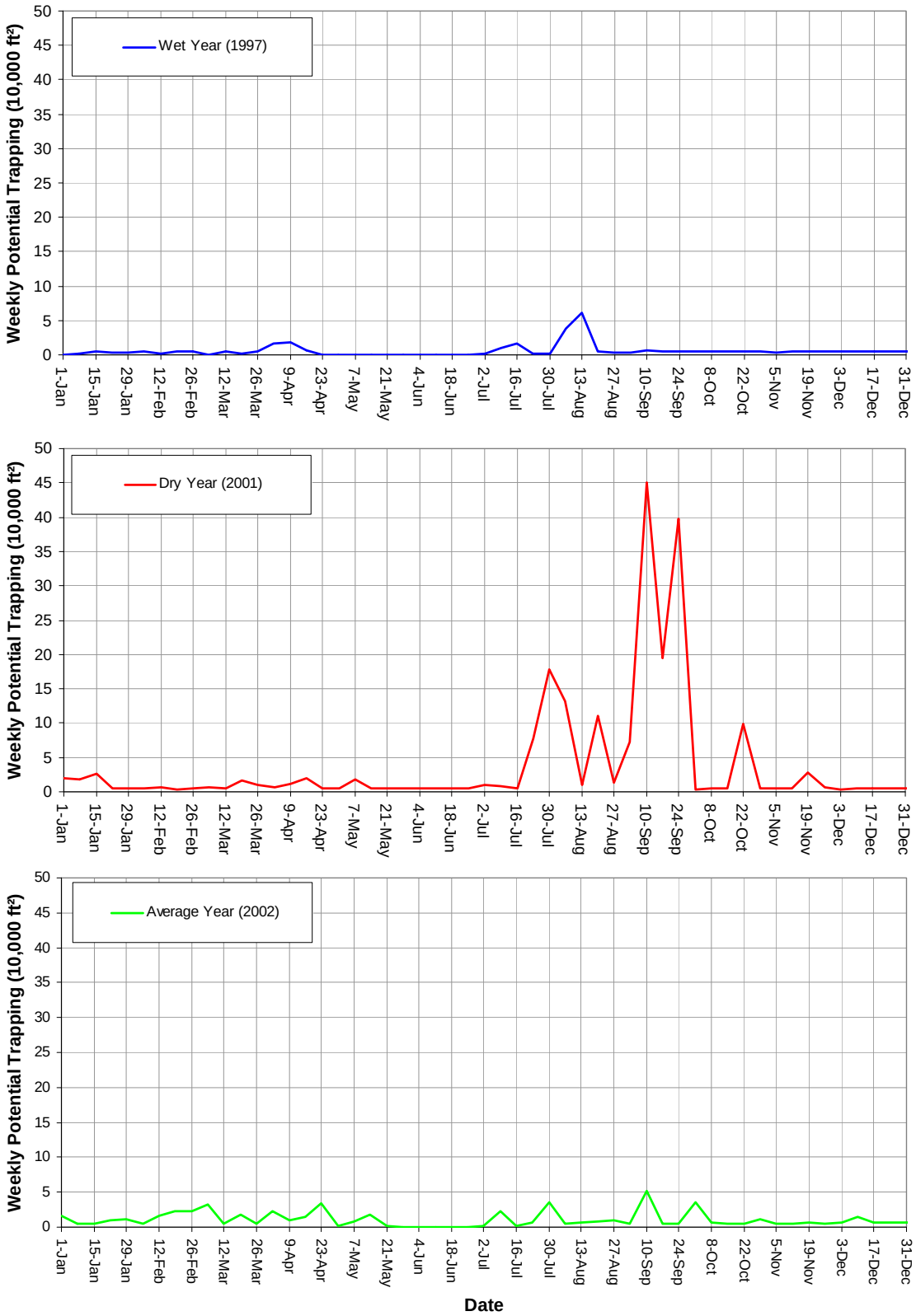



**Figure 4.4-8.** Example of the comparison of Region 11 daily total trapping index (TI) value that occurred during the wet (1997), dry (2001), and average year (2002).

## 4.5. Downramping Analysis

The downramping analysis is a comparative analysis conducted to quantify the effects of Project operations and of operations scenarios on aquatic organisms. The analysis included determination of the hourly reductions in water surface elevation at specific locations in the Project area for each of the three hydrologic years. Washington State Instream Flow Guidelines assume that faster rates of water surface elevation reduction are correlated to an increased risk of stranding of aquatic organisms (WDFW and Ecology 2004; Hunter 1992). In this regard, the downramping analysis was closely related to the stranding and trapping analysis (see Appendix 4) and the varial zone analysis (see Appendices 6, 7, and 8). All three of these efforts were directed toward evaluating the potential effect of mainstem water surface elevation fluctuations on aquatic habitat. For the stranding and trapping and varial zone analyses, the potential effect was evaluated by determining the change in wetted area associated with fluctuations in the water surface elevation. For the downramping analysis, the parameter of interest was the rate of the water surface elevation reduction over time and the frequency at which specific rates of downramping are exceeded.

The goal of the downramping analysis was to quantify historical downramping rates for the mainstem Pend Oreille River throughout the Project area. The objectives of the study were to:

1. Determine hourly downramping rates at each of the habitat transect locations throughout each of the three hydrologic years (1997, 2001, and 2002).
2. Develop transect-weighted, reach-averaged downramping rate exceedance curves for each of the four reaches in the study area for each of the three hydrologic years.
3. Provide information to allow for the evaluation of the effects of existing Project operations and operations scenarios on aquatic organisms.

This section summarizes the methodologies used to address the goal of the analysis. Section 4.5.1 describes the methods used to quantify the hourly downramping rates at each of the habitat transects in the Boundary Reservoir and Boundary tailrace using output from the Boundary Reservoir HRM and the Boundary Tailrace HRM, respectively.

Section 4.5.2 summarizes the methodologies used to determine the transect-weighted, reach-averaged downramping rate exceedance curves.

A more detailed discussion of the downramping analysis can be found in Appendix 5.

### 4.5.1. Determination of Hourly Downramping Rates

Hourly water surface elevation time series at each habitat transect were generated by the Boundary Reservoir HRM and the Boundary Tailrace HRM for each representative hydrologic years—1997 (wet year), 2001 (dry year), and 2002 (average year). For each habitat transect, a post-processing routine was used to first identify those specific hourly time periods in each year when the water surface elevation was decreasing (i.e., downramping). For those time periods, the hourly reduction in water surface elevation was then computed and expressed in units of inches per hour. To maintain consistency with the mainstem aquatic habitat modeling analysis, downramping rates were only determined when the Pend Oreille River flow rate (as measured at

the USGS gage 12396500) was greater than 80,000 cfs. This was an appropriate threshold flow rate for the downramping analysis because, for flow rates greater than about 55,000 cfs, the Project typically curtails the load-following mode of operation. Extending the analysis to 80,000 cfs more than encompasses the range of flows in which Project-related downramping occurs. An additional reason why this threshold flow rate is appropriate is because on the receding limb of the annual hydrograph, downramping rates in the Boundary Reservoir are typically dominated by the natural recession of the flow rate, not Project operations.

### 4.5.2. Determination of Downramping Rate Exceedance Curves

A frequency analysis was then conducted on the hourly downramping rates at each habitat transect location. The frequency analysis determined the number of hours when the downramping rate was within the bounds of each of the following five numeric categories:

- Greater than 0 but less than 2 inches per hour
- Greater than 2 but less than 4 inches per hour
- Greater than 4 but less than 8 inches per hour
- Greater than 8 but less than 12 inches per hour
- Greater than 12 inches per hour

The number of hours of downramping within each of these categories was calculated by month and by annual total for each of the three representative hydrologic years. Finally, the number of hours of downramping within each category was calculated as a transect-weighted, reach-averaged total for the four mainstem Pend Oreille reaches (Upper Reservoir, Canyon, Forebay, and Tailrace). Again, the results were calculated by month and by annual total for each of the years. The transect weighting factors that were used in computing the transect-weighted, reach-averaged totals are presented in Appendix 1a. The final step was then to report the transect-weighted, reach-averaged hourly rates in the form of cumulative exceedance curves.

## 4.6. Macrophyte Habitat Development and Modeling Efforts

This section reviews the final macrophyte HSI curves developed for use in the Mainstem Aquatic Habitat Model to determine the suitability of macrophyte habitat present under different operational scenarios. The modeling approach and final HSI curves were developed in conjunction with and agreement from relicensing participants. Detailed methods and results of the macrophyte HSI development are found in Appendix 6.

### 4.6.1. Modeling Approach

Macrophytes, along with periphyton and BMI, comprise the key biota of interest in the varial zone analysis. The general approach to habitat modeling in the varial zone was presented to the relicensing participants and agreed upon at the July 24, 2007, Fish and Aquatics Workgroup meeting in Spokane, Washington. The varial zone analysis involves application of habitat models to evaluate indices that provide relative quantification of habitat suitability between operations scenarios in the portion of the reservoir influenced by water surface fluctuations. The results of evaluating the indices allow comparison between operations scenarios for the Project on habitat suitability within the varial zone.

This section presents the modeling approach utilized in developing the indices to evaluate habitat suitability within the varial zone associated with operations scenarios. The approach is being presented in the macrophyte section (Section 4.6), but is the same for periphyton (Section 4.7) and BMI (Section 4.8) and is often referred to as the "varial zone" model. The primary differences in the analysis between macrophytes, periphyton, and BMI are in the different suitability curves used for the three biotic groups. Another difference between the modeling for the three biotic groups is in the use of upper and lower bounds on determination of WUA values. To prevent temporary inclusion of elevation ranges in the WUA values during water surface elevation fluctuations at which macrophytes will not be established, upper and lower elevation limits for the WUA calculations were set for macrophytes. For periphyton, only a lower limit was set. For BMI, neither an upper nor lower limit was set.

Macrophyte bounding limits for the calculation of WUA were based on the combination of the HRM and information from the depth HSI curve. The bounding limits were based on typical water surface elevations that occurred during the March and April period of the average hydrologic year (2002). The March through April timeframe corresponds to the critical period for establishment of macrophyte beds. To represent typical conditions during the critical period, the water surface elevation profile from the HRM for a median forebay elevation of 1,988 feet NAVD 88 (1,984 feet NGVD 29) and a median inflow into Boundary Reservoir of 18,800 cfs was used to define the upper bounding limits. Above the elevations defined by this profile, the model-calculated WUA was set to zero. In the Tailrace Reach, a median Seven Mile forebay elevation of 1,726 feet NAVD 88 (1,722 feet NGVD29) and a median outflow from Boundary Dam of 24,200 cfs was used to define the upper bounding limit. Similarly, a lower bounding limit for macrophytes of 33 feet below the average hydrologic year median flow, median forebay elevation water surface profile was set based on the maximum suitable depth from the HSI curve. Below these elevations the model-calculated WUA was set to zero. For analysis of operations scenarios, the bounding limits can be adjusted based on changes from the historic condition for the median flow and median forebay water surface elevations for the operations scenario being evaluated.

#### *4.6.1.1. General Description*

The varial zone is defined as the areas of the channel alternately inundated and dewatered by water surface elevation fluctuations. Figure 4.6-1 illustrates the concept of the varial zone. The varial zone analysis approach is based on developing indices for the biota of interest that reflect the relative habitat suitability incorporating the influence of the varial zone being alternately inundated (wetted) and dewatered (dried). Therefore, the upper limit of the varial zone is considered the maximum elevation for colonization for the biota of interest and represents the highest water surface elevation at a given transect during Project operations. The lower limit of the analysis was taken to extend below the lowest elevation experienced during Project operations because the influence of the water surface elevation fluctuation may extend below the limit of dewatering into the euphotic zone. To account for the potential influence below the limit of dewatering, the varial zone analysis was extended 50 feet below the existing low operating pool water surface elevation. Figure 4.6-2 illustrates the elevation limits of the varial zone analysis within a transect.

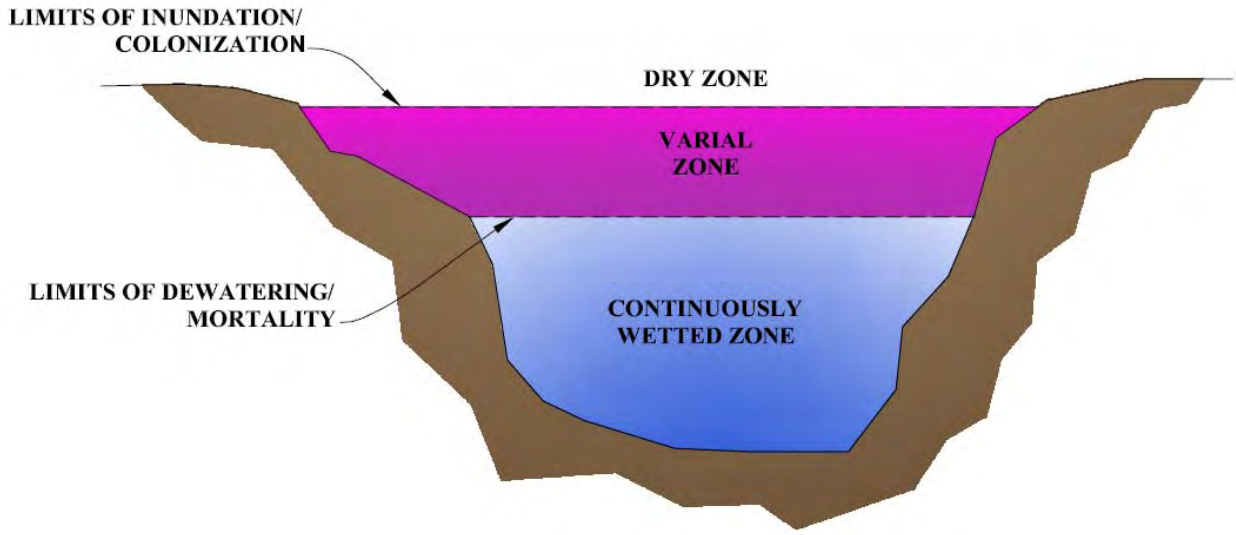



**Figure 4.6-1.** Conceptual sketch of varial zone definition.

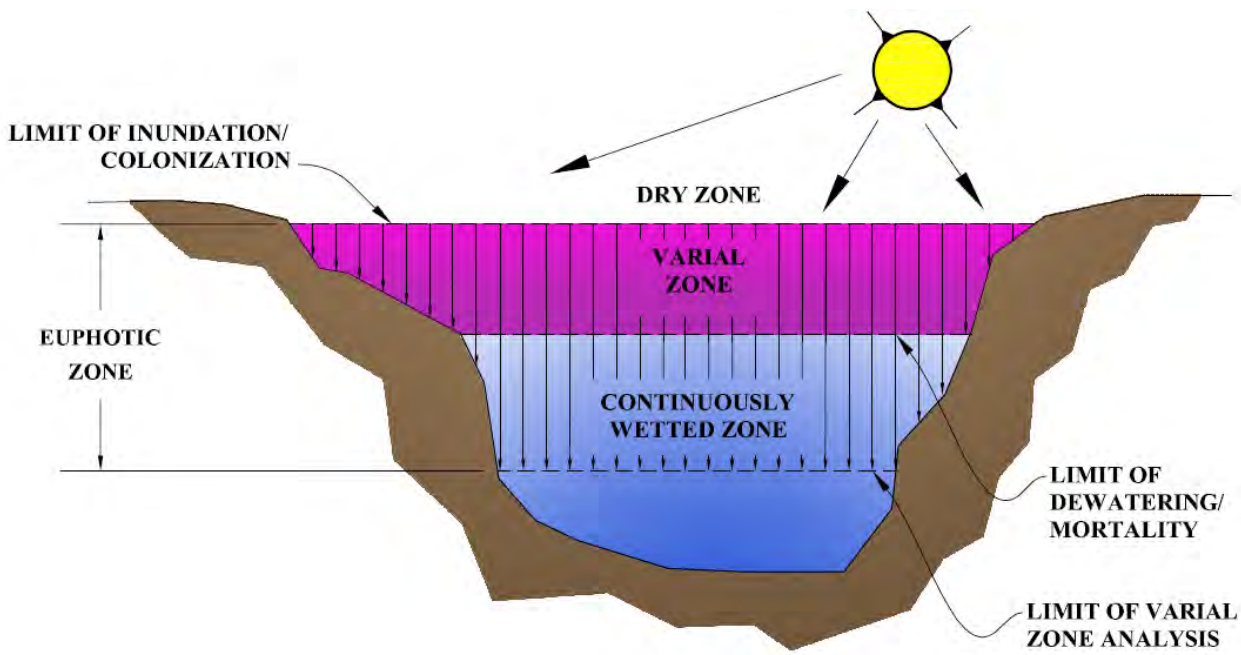



**Figure 4.6-2.** Conceptual sketch of varial zone analysis limits based on depth of euphotic zone.

### *4.6.1.2. Integration with Hydraulic Routing Model*

The water surface elevation fluctuations within the varial zone depend on three factors: Project operations, location within the Project, and upstream inflows (outflow from Box Canyon Dam). Figures 4.6-3 and 4.6-4 present historic reservoir elevations for selected periods in the Boundary

forebay that provide examples of these influences. In Figure 4.6-3, the pool water surface elevations are kept relatively high, above 1,987 feet NAVD 88 (1,983 feet NGVD 29) through about September 20, 2006, when they are lowered as far as 1,980 feet NAVD 88 (1,976 feet NGVD 29) until returning to about 1,987 feet NAVD 88 (1,983 feet NGVD 29) by September 24, 2006. For the periods when the forebay water surface elevation is kept near or above 1987, the Box Canyon USGS gage elevation fluctuations follow those in the forebay within about 1 foot or less. This illustrates not only how existing Project operations cause the water to fluctuate, but also how the magnitude of the fluctuations can change at different locations in the reservoir. The September 2006 illustration (Figure 4.6-3) was for a relatively low-flow period, whereas the information for the May and June period in 2003 (Figure 4.6-4) is for a higher flow period. The contrast between these two figures illustrates the influence of upstream inflow. In the low-flow condition (September 2006), the magnitude of fluctuations was nearly equal in the forebay and below Box Canyon until the forebay was dropped to an elevation of approximately 1,984 feet NAVD 88 (1,980 feet NGVD 29) and lower. At high flows (May 2003) the fluctuations in the forebay resulting from Project operations are greatly reduced upstream at the USGS gage below Box Canyon Dam. The flows rose above approximately 50,000 cfs and fluctuations due to load following ceased as the capacity of the powerhouse was exceeded on May 28, 2003. At this point, forebay elevations are primarily controlled by the spillway gates and the Box Canyon elevations become increasingly governed by the outflow from Box Canyon.

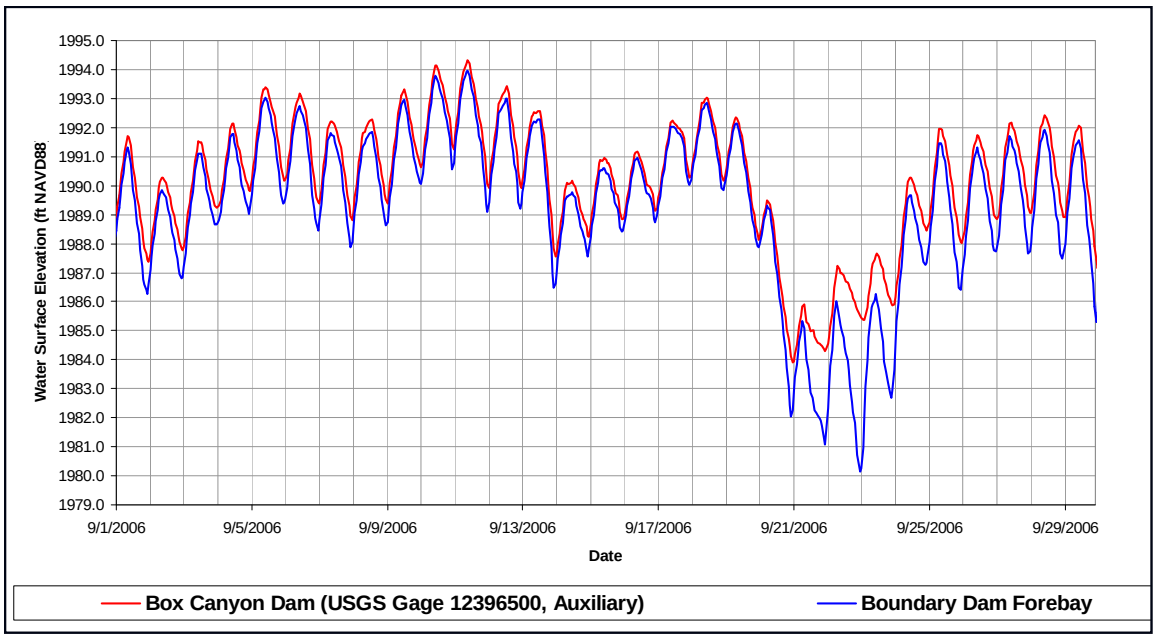



**Figure 4.6-3.** Example water surface elevation fluctuations below Box Canyon Dam and Boundary forebay, September 2006.

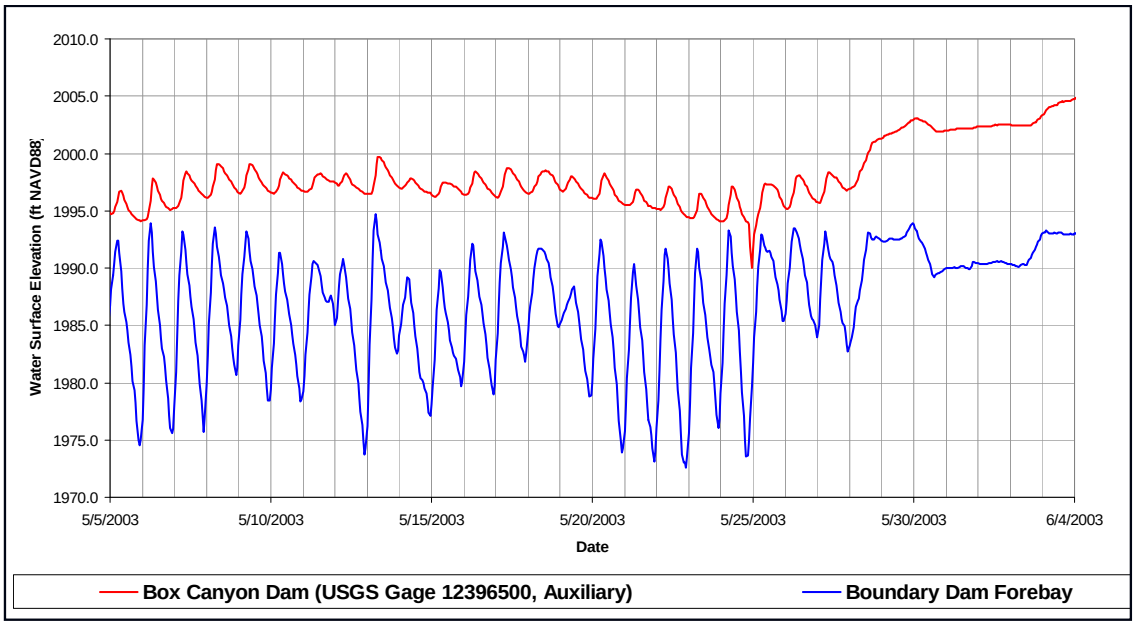



**Figure 4.6-4.** Example water surface elevation fluctuations below Box Canyon Dam and Boundary forebay, early May though early June 2003.

Because of the complex interaction between Project operations, location, and upstream inflows in determining the water surface elevation fluctuations, the varial zone analysis is linked to the HRM and was performed at the habitat transect locations. By using the hourly water surface elevations and discharges at the habitat transect to conduct the varial zone analysis, the temporal and spatial complexity of the varial zone conditions can be analyzed.

#### *4.6.1.3. Formulation of Composite Suitability Index*

To reflect the influence of fluctuating water surface elevations on the biota of interest, the varial zone analysis incorporates the concepts of inundations and dewatering and the corresponding colonization and mortality/emigration. To accomplish this, the varial zone analysis was based on evaluation of a Composite Suitability Index (CSI). The CSI incorporates the standard HSC developed for each biota, which is then multiplied by an HSI that is a function of the history of alternating inundation and dewatering periods. This subsection describes the formulation of the CSI approach. Specific methods for development of the HSC and HSI for macrophytes, periphyton, and BMI are presented in Sections 4.6.2, 4.7.2, and 4.8.2 and Appendices 6, 7, and 8, respectively.

The CSI is defined as:

$$CSI_i = HSC_i * HSI_i$$

Where:

$CSI_i$ = composite suitability index of cell i
HSCi = composite habitat suitability of cell i
$HSI_i$ = habitat suitability index for inundation and dewatering of cell i

To represent the HSC, the most common method of calculating weighted usable area values in PHABSIM studies was adopted and is a multiplicative aggregation given by:

$$HSC_i = D_i * Vo_i * S_i$$

Where:

HSCi = composite habitat suitability of cell i
$D_i$ = suitability associated with depth in cell i
$Vo_i$ = suitability associated with velocity in cell i
$S_i$ = suitability associated with substrate in cell i

Using a multiplicative aggregation, if any of the variables results in a score of zero, the composite value will become zero and the habitat would be rated as unsuitable for use for that time step. This composite HSC approach will be used for all three biota of interest. However, the value of a cell for use by the biota of interest is also affected by the length of time that the cell has been inundated. Cells that have been inundated for several weeks or more typically support a higher biomass than cells that are newly inundated. Cells that have been dewatered for even a period of hours may have a lower biomass than cells that have not been dewatered. Frequent cycles of dewatering and inundation will affect productivity of the biota of interest in a cell regardless of its suitability as defined by depth, velocity, and substrate.

In order to evaluate the effects of pool elevation fluctuations on productivity for the biota of interest, the inundation history of the cell will be tracked using hourly time steps. As the duration of continuous inundation increases, the biomass is assumed to increase up to a maximum suitability of 1.0. The rate of biomass increase is determined from a Duration of Inundation (DI) HSI. While biomass in a cell increases as the duration of continuous inundation increases, dewatering of the cell will reduce biomass through emigration or mortality. The rate of biomass decrease in response to dewatering is determined from a Duration of Dewatering (DD) HSI that decays from a maximum suitability of 1.0 to a suitability of zero. Figures 4.6-5 and 4.6-6 provide conceptual examples of the DI and DD HSI curves.

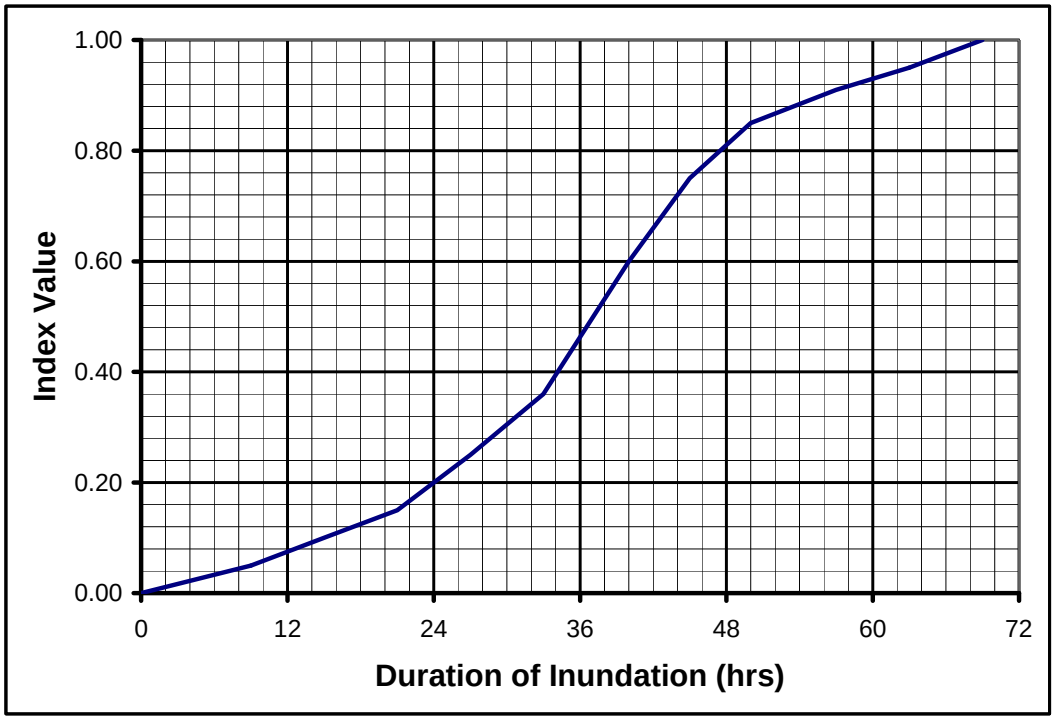



**Figure 4.6-5.** Conceptual example of DI HSI curve for calculation CSI in the varial zone analysis.

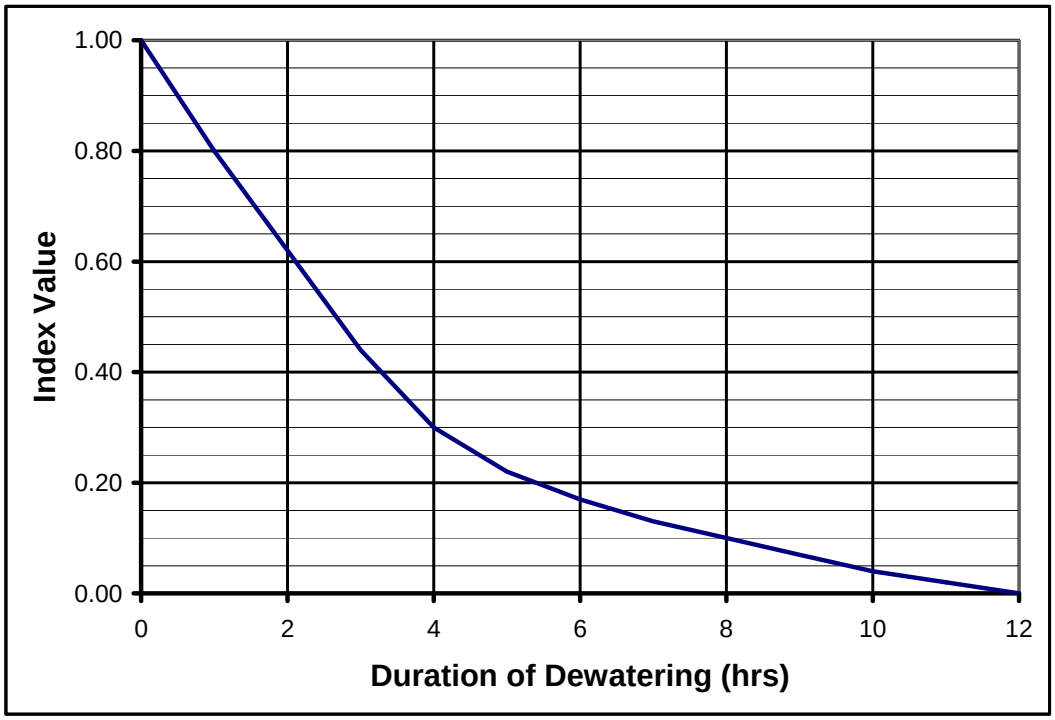



**Figure 4.6-6.** Conceptual example of DD HSI curve for calculation CSI in the varial zone analysis.

#### 4.6.1.4. CSI Calculation Procedure

The pattern of prior inundation and dewatering will determine the relative status of a cell at a given time step as indicated by an HSI value between 1.0 and zero. An integrated HSI value of less than 1.0 will indicate that the prior history of inundation and dewatering has reduced production in that cell at the specific time step. The key to maintaining the prior history of inundation and dewatering is switching between the DI and DD curves for determination of the HSI at the time increment at which the particular transect cell being evaluated has its cell depth change from a positive value to zero (dewatered). Similarly, the tracking of the HSI value switches from the DD curve to the DI curve at the time increment when the depth in the cell becomes greater than zero (inundated).

An example of the computation procedure for application of the HSC and HSI to develop the CSI in the varial zone is provided below. The example utilizes the conceptual DI and DD curves presented in Figures 4.6-7 and 4.6-8. Table 4.6-1 provides a summary of the steps in the process. The procedure concentrates on the actual calculation of the CSI within a cell, but includes the additional steps to repeat the effort necessary to develop the area weighted CSI for the transect, reach, and Project area. To avoid complicating the explanation, the HSC values for the cell are assumed to be 0.80 for time increments with positive depths and 0.0 for periods with zero depths. The example starts at a condition at which the composite HSI value for inundation and dewatering is at a value of 0.75. Table 4.6-2 provides the overview of calculation results for the cell as the example progresses from a period of inundation, to a period of dewatering, and back to a period of inundation.

**Table 4.6-1.** Steps in calculation of the CSI for an individual cell within a habitat transect.

| Step | Action |
|---|---|
| 1 | Determine depth, velocity and substrate for the cell at the time interval (hourly) |
| 2 | Look up suitability: $D_i$ , $Vo_i$ and $S_i$ for the time interval |
| 3 | Calculate: $HSC_i = D_i * Vo_i * S_i$ |
| 4 | If cell depth > 0 for cell i, go to step 5a / If depth for cell i = 0, proceed to step 5b |
| 5a | Depth > 0, look up $HSI_i$ from DI curve based on composite history, proceed to step 6 |
| 5b | Depth = 0, look up $HSI_i$ from DD curve based on composite history, proceed to step 6 |
| 6 | Calculate: $CSI_i = HSC_i * HSI_i$ |
| 7 | Multiply $CSI_i$ by wetted cell width to weight by width |
| 8 | Go to next cell and repeat steps 1 through 7 until all cells within the varial zone have been calculated |
| 9 | Sum all width weighted CSI values for the transect to produce the $CSI_T$ for the time interval |
| 10 | Multiply width weighted sum of CSI values by weighted distance between upstream and downstream transects to produce the weighted useable area for the transect, $WUA_T$ for the hourly time interval |
| 11 | Repeat steps 1 through 10 for the next hour and add to total for the transect |
| 12 | Repeat steps 1 through 11 for the next transect |
| 13 | Sum all transects in a reach (Upper, Canyon, Forebay and Tailrace) to produce the weighted useable area for the reach, $WUA_R$ |
| 14 | Sum $WUA_R$ for all four reaches to produce the weighted useable area for the study area, WUA<br>Note: Calculation of the WUA for each of the three biota of interest, macrophytes, periphyton and BMI, can proceed concurrently using the same procedure by applying their specific HSC and HSI curves. |

**Table 4.6-2.** Example of CSI determination for an individual cell in a transect with periods of inundation and dewatering.

| Time Step | Equivalent Historic Duration (Hour) | Depth (ft) | HSC | HSI Inundation | HSI Dewater | CSI (HSC•HSI) |
|---|---|---|---|---|---|---|
| 25 | 45 | 5 | 0.80 | 0.75 | NA | *0.60* |
| 26 | 46 | 5 | 0.80 | 0.77 | NA | *0.62* |
| 27 | 47 | 4 | 0.80 | 0.79 | NA | *0.63* |
| 28 | 48 | 3 | 0.80 | 0.81 | NA | *0.65* |
| 29 | 49 | 2 | 0.80 | 0.83 | NA | *0.66* |
| 30 | 50 | 1 | 0.80 | 0.85 | NA | *0.68* |
| 31 | 0.8 | 0 | 0.00 | NA | 0.85 | *0.00* |
| 32 | 1.8 | 0 | 0.00 | NA | 0.67 | *0.00* |
| 33 | 2.8 | 0 | 0.00 | NA | 0.50 | *0.00* |
| 34 | 3.8 | 0 | 0.00 | NA | 0.36 | *0.00* |
| 35 | 33 | 1 | 0.80 | 0.36 | NA | *0.29* |
| 36 | 34 | 2 | 0.80 | 0.39 | NA | *0.31* |

<u>Step 1—Depth, velocity, and substrate</u>
The first step in the application of the varial zone analysis to a cell within a transect is to look up the calculated depth, velocity, and substrate from post-processed hydraulic routing model results for the first cell of interest for the current time increment. For the example, the initial depth is 5 feet. Values for velocity and substrate are not being used in this example, rather an HSC value of 0.80 is assumed for positive depths.

For the general modeling procedure for macrophytes, an upper bounding elevation was established at which the $HSC_i$ value is set to 0.00 for water surface elevations above this elevation. The bounding elevation represents an upper limit on the elevation at which macrophytes will be established. This prevents inclusion of areas temporarily inundated during flood flows from unrealistically increasing the WUA. For the historic conditions modeled in this report, this bounding elevation was set at an elevation of 1,988 feet NAVD 88 (1,984 feet NGVD 29) for the Forebay and Canyon reaches and an elevation of 1,990 to 1,992 feet NAVD 88 (1,986 to 1,988 feet NGVD 29) for the Upper Reservoir Reach. In the Tailrace Reach, the upper bounding limit was set at an elevation of 1,725 to 1,732 feet NAVD 88 (1,721 to 1,728 feet NGVD 29). These bounding elevations were set based on the HRM results and compared well with field observations made during surveys of all plant colonies throughout the Reservoir in 2007 and 2008. This bounding elevation only applies to macrophytes and not periphyton and BMI.

Lower bounding elevations were set to prevent the inclusion of areas permanently inundated below the minimum elevation at which macrophytes can establish. The lower limit was set using the depth at which the HSI depth curve goes to 0.0, 33 feet. This depth was based on limitations for vascular plants posed by hydrostatic pressure. $HSC_i$ values were set to 0.00 for depths below the lower bounding elevation. For the historic conditions modeled in this report, this boundary elevation was set at an elevation of 1,955 feet NAVD 88 (1,951 feet NGVD 29) in the Forebay and Canyon reaches and in the Upper Reservoir Reach an elevation of 1,957 to 1,959 feet NAVD 88 (1,953 to 1,955 feet NGVD 29). In the Tailrace Reach, a lower bounding limit of 1,693 to 1,700 feet NAVD 88 (1,689 to 1,696 feet NGVD 29). For analysis of operations scenarios, the bounding limits can be adjusted based on changes from the historic condition for the median flow and median forebay water surface elevations for the operations scenario being evaluated.

Step 2—Look up suitability for depth, velocity, and substrate

For the biota of interest, the suitability ($D_i$, $Vo_i$, and $S_i$) from the associated depth, velocity, and substrate curves is looked up utilizing the values from Step 1. Individual curves will be provided for macrophytes, periphyton, and BMI.

Step 3—Calculate HSC Value

Utilizing the values of $D_i$, $Vo_i$, and $S_i$ from Step 2, the composite habitat suitability of cell (i) is calculated as:

$$HSC_i = D_i * Vo_i * S_i$$

In the actual varial zone analysis, a separate HSC value would be determined for macrophytes, periphyton, and BMI. For illustrative purposes, an assumed value of 0.80 has been utilized for all positive depths and a value of 0.0 for depths of 0. These are entered into Table 4.6 -2.

Step 4—Check inundation/dewatering state of the cell

For the current time increment, it is determined whether the cell is currently dewatered or inundated. If the cell is inundated, then the calculations proceed to Step 5a, which involves determination of the HSI based on the DI curve. If the cell is dewatered, then the calculation proceeds to step 5b, which involves determination of the HSI based on the DD curve. In the example shown in Table 4.6-2, the example is entered in the 25th time increment for an inundated state. It continues through time step 30 as inundated, though the depth decreases from 5 feet to 1 foot. The state switches to dewatered during time step 31 and remains at zero depth through time step 34. For the final two time steps, 35 and 36, the cell in the example returns to an inundated state at a depth of 1 foot at time step 35 and 2 feet at time step 36.

For the general modeling procedure for macrophytes, periphyton and BMI, prior to the start of the modeling period, an initial warm-up period was necessary to establish the starting condition of the inundation/dewatering factor. A two-week period was specified giving sufficient time to develop a state of quasi-equilibrium for the duration of inundation/ dewatering factor at the onset of the simulation period. Inflows and corresponding water surface elevations from the two weeks prior to the end of the simulation was used as the basis of the warm-up period.

Step 5a—Look up HSI value for inundated state of cell

The example problem is entered on the 25th time step at a depth of 5 feet and a $HSI_i$ value of 0.75. The equivalent historic duration of inundation corresponding to 0.75 is 45 hours. For each subsequent hour that the cell is inundated, an hour is added to the period of inundation and the corresponding value is obtained from the HSI curve. As the depth decreases, but remains greater than zero for the next five hourly time steps, the $HSI_i$ value continues to grow for every hour of inundation up to a value of 0.85 at the 30th time step. This progression of values is indicated by the arrows on the DI HSI curve shown in Figure 4.6-7. After a period of dewatering for time steps 31 through 34 (see Step 5b), the state of the cell returns to inundated. However, during the period of dewatering, the $HSI_i$ value decreased each hour to reenter the DI HSI curve at a value of 0.36, which corresponds to an equivalent historic duration of inundation of 33 hours. For the 36th time step, one hour is added to this value and the $HSI_i$ value for the 36th time step is based on looking up the DI HSI value for 34 hours, which is 0.39. The progression of the $HSI_i$ values is shown on Figure 4.6-7 and the resulting $HSI_i$ values are tracked in Table 4.6-2. For periods when the DI HSI curve is used, the $HSI_i$ values are shown in the HSI inundation column and for periods when the DD HSI curve is used, the $HSI_i$ values are shown in the HSI dewater column.

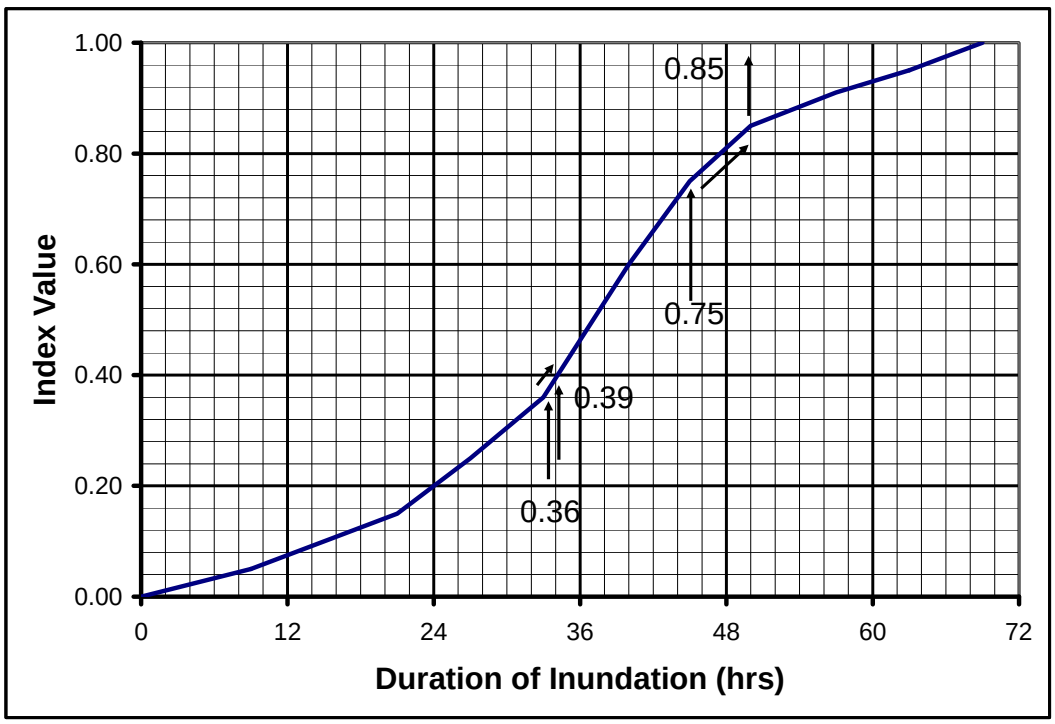



**Figure 4.6-7.** Illustration of use of DI HSI curve for determination of HSI during the periods of inundation in the CSI example calculation.

Step 5b—Look up HSI value for dewatered state of cell

At the 31st time step, the cell in the example becomes dewatered (depth = 0). At the previous time step, the value from the DI HSI curve was 0.85. For the 31st time increment, the $HSI_i$ value of 0.85 is adopted and the DD HSI curve is entered at this value. The equivalent historic duration of dewatering corresponding to 0.85 on the DI HSI curve is 0.8 hour. For each

subsequent hour that the cell is dewatered, an hour is added to the period of dewatering and the corresponding value is obtained form the DD HSI curve. As the cell remains dewatered, for the next three hourly time steps, the $HSI_i$ value continues to decrease for each additional hour of dewatering down to a value of 0.36, at the 34th time step. At the final dewatered time step, the DI HSI value corresponds to an equivalent historic duration of dewatering of 3.8 hours. This progression of values is indicated by the arrows on the DD HSI curve shown in Figure 4.6-8.

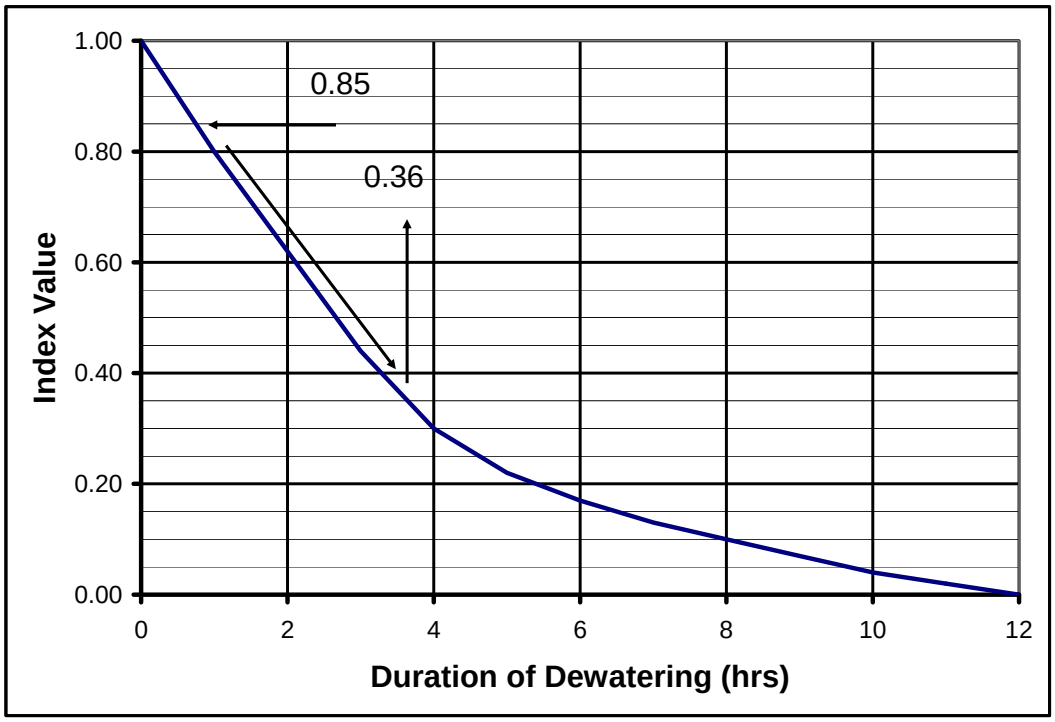



**Figure 4.6-8.** Illustration of use of DD HSI curve for determination of HSI during the period of dewatering in the CSI example calculation.

Step 6—Calculate CSI

The composite suitability index, $CSI_i$, for the cell is calculated each time increment by multiplying the $HSI_i$ by the $HSC_i$:

$$CSI_i = HSC_i * HSI_i$$

Step 7—Weight CSI for cell by wetted width

The $CSI_i$ value for the cell is multiplied by the cell width of cell i, $W_i$.

Steps 8 through 14—Iteration steps to obtain weighted CSI transect, reach, and study area

After calculating the width weighted CSI for the cell, the calculation proceeds to the next cell (Step 8) in the transect and steps 1 through 7 are repeated for the new cell. Steps 1 through 8 are repeated until the product of the cell width and $CSI_i$ has been calculated for all the cells in the transect. Step 9 consists of summing all of the width weighted CSI values for the transect. This value is the transect CSI or $CSI_T$. The weighting factors were presented in Section 4.1.1 and

represent the proportion of the distance between transects assigned to the each transect. The transect CSI is multiplied by weighted distances to the next upstream transect and the weighted distance to the next downstream transect (Step 10). This produces a weighted useable area for the transect, $WUA_T$, for the hourly time interval. Steps 1 through 10 are repeated for the next hour in the time period of interest and this repetition continues until all hourly intervals have been calculated for the time period of interest and the results summed producing the $WUA_T$ for the period of interest (Step 11). The time period of interest could be a year representing a specific hydrologic condition such as wet, dry, and average; a series of years in the hydrologic record; or a particular period within a single year. Step 12 is to go to the next transect and repeat Steps 1 through 11 producing the $WUA_T$ for all transects. Steps 13 and 14 are to sum the individual $WUA_T$ first by reach (Upper, Canyon, Forebay, and Tailrace) to develop the weighted useable area of the reach ($WUA_R$), and to sum the reach values to produce the overall weighted useable area for the study area (WUA).

The steps presented above can be performed for each of the three biota of interest for the varial zone: macrophytes, periphyton, and BMI. Because each set of calculations uses the same set of information, except for the specific HSI and HSC curves, the calculations can be performed together.

#### *4.6.1.5. Detailed Description of the Macrophyte Model*

The Project macrophyte model combines a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.6-3). The model is designed to integrate the HSC and HSI values to develop a CSI for each cell within a mainstem habitat transect using hourly time steps.

**Table 4.6-3.** Project macrophyte model.

| **Macrophyte Composite Suitability Index** | $CSI_{Macrophyte} = HSC_i * HSI_i$ |
|---|---|
| Macrophyte HSC | $HSC_i = D_i * Vo_i * S_i$ |
| Macrophyte HSI | $HSI_i = f (DI_i, DD_i)$ |
| Macrophyte Variables | $D_i$ = Depth of Light<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

The methods used to determine provisional values for each of the five variables are described in the next paragraphs, and the results from literature review are described below in further detail (see Appendices 6, 7, and 8 for further details).

### 4.6.2. Biological Response (HSI)

The macrophyte HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data, 3) calibration of the literature-based HSI curves using field data and 4) finalization of the macrophyte HSI for Boundary Reservoir. Field data generation included macrophyte abundance data with depth and cross sectional data with depth, velocity, and substrate measurements.

A literature review was conducted to gather existing information and data on macrophyte habitat preferences in terms of depth, substrate, velocity, and duration of inundation and dewatering. During the literature review no appropriate suitability curves were found, so other literature information was used to develop provisional suitability values. Field surveys were then conducted to assess aquatic plant distribution and abundance data along with depth, velocity, and substrate gradients extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions. Once all macrophyte data were collected, field data along with results from the hydraulic model were used to further refine and calibrate the macrophyte HSI curves. Observed macrophyte response curves were developed and compared to provisional literature-based curves. Adjustments to the provisional macrophyte HSI curves were made based on the macrophyte coverage map, the cross section and routing model data, existing conditions within Boundary Reservoir, and the biological growth requirements of aquatic macrophytes. A roundtable discussion with relicensing participants and regional experts assisted with the development of final HSI curves. For more detailed information on the methods used to develop the final suitability curves for macrophytes see Appendix 6.

Habitat suitability values and HSI curves for macrophytes in Boundary Reservoir are summarized below.

#### *4.6.2.1. Depth*

A histogram for depth was developed using site-specific data collected during field studies. These data were then used to create an observed HSI curve that varied from the provisional literature-based curve. The factors considered for the refinement of the depth HSI curve were ice, winter/late spring pool levels, water clarity, hydrostatic pressure, and survival of plants during their resting stage and as seeds and fragments. Considering both the observed and literature-based curves, a proposed final curve was presented to the roundtable. Relicensing participants agreed to adopt the proposed depth curve with one change: expanding the range of optimum stability (HSI value of 1.0) from 3.5–12.0 feet to 2.0–12.0 feet. The final macrophyte HSI values for depth of light are shown in Figure 4.6-9.

The final depth of light HSI curve for macrophytes was revised in January 2009 (presented to relicensing participants at the January 28, 2009, Fish and Aquatics Workgroup meeting). These revisions to the HSI curve were necessary to separate the effect of depth of light from the duration of dewatering scores used to estimate weighted useable area for macrophytes on hourly time intervals and from each transect with the Mainstem Aquatic Habitat Model. Final revisions to the depth of light HSI curve included assigning a suitability value of 0 when depth of light is 0 feet (Figure 4.6-10). This HSI score differs from the final curve that was co-developed with

relicensing participants where a suitability value of 0.5 was assigned when depth was 0 feet (Figure 4.6-9). Both depth of light and duration of dewatering contribute HSI scores that describe availability of aquatic habitat. This relationship between the two variables used in generating suitability scores through the Mainstem Aquatic Habitat Model needed to be separated so that effects of each variable were independent of the other. The revised final macrophyte suitability values for depth are presented in Table 4.6-4, and the revised final HSI curve is presented in Figure 4.6-10.

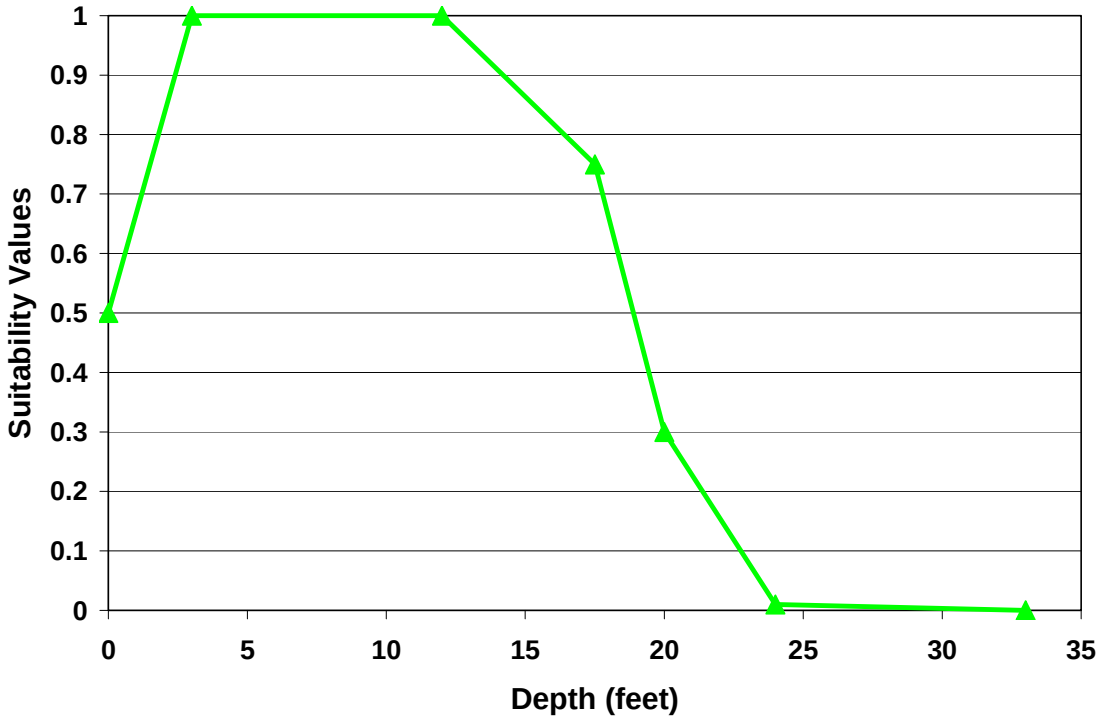



**Figure 4.6-9.** Final macrophyte HSI curve for depth.

**Table 4.6-4.** Depth of light revised final suitability values for macrophytes.

| Depth of Light | Final Suitability Values |
|---|---|
| 0 (maximum) | 0.0 |
| 0.1 | 0.5 |
| 3 feet | 1.0 |
| 12 feet | 1.0 |
| 17.5 feet | 0.75 |
| 20 feet | 0.3 |
| 24 feet | 0.01 |
| 33 feet | 0 |

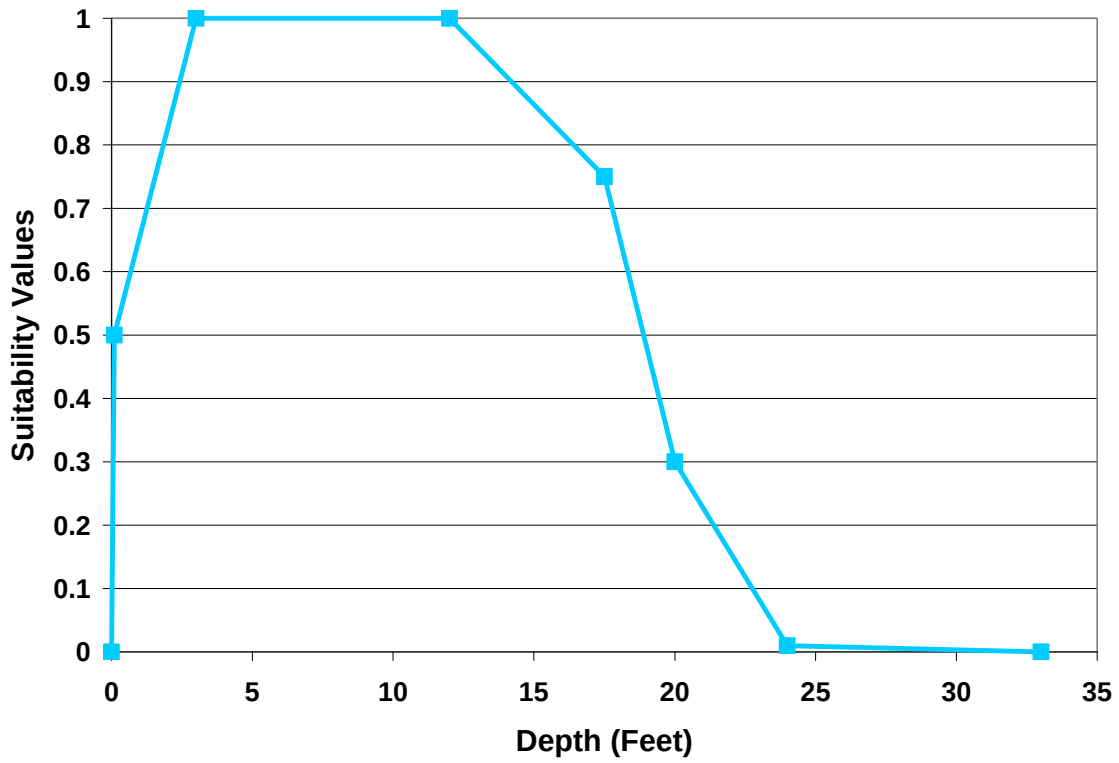



**Figure 4.6-10.** Revised final macrophyte HSI curve for depth (revised curve approved by relicensing participants at January 28, 2009, meeting).

### *4.6.2.2. Velocity*

A histogram for velocity was developed using site-specific data collected during field studies. These data were then used to create an observed HSI curve that varied from the provisional literature-based curve. The factors affecting refinement of the velocity HSI curve were substrate stability and seed and fragment rooting and anchoring. At velocities exceeding 2.5 feet/second, substrate instability limits the establishment and persistence of macrophytes. Considering both the observed and literature-based curves, a proposed final curve was presented to the roundtable, and the relicensing participants agreed to adopt it. The final macrophyte HSI values for velocity are presented in Table 4.6-5 and the final HSI curve is presented in Figure 4.6-11.

**Table 4.6-5.** Velocity final suitability values for macrophytes.

| Velocity | Final Suitability Values |
|---|---|
| 0 | 0.8 |
| 0.164 ft/s | 1.0 |
| 0.3 ft/s | 0.75 |
| 0.6 ft/s | 0.3 |
| 1.6 ft/s | 0.1 |
| 3.5 ft/s | 0.0 |

Note:
ft/s – feet per second

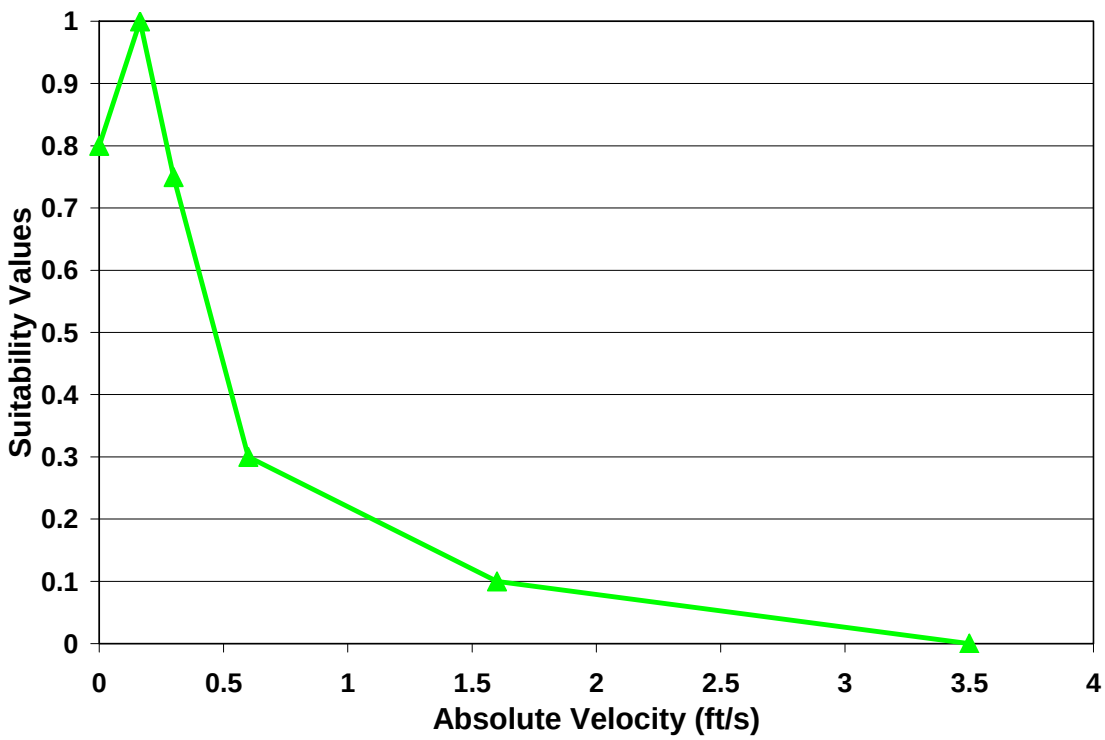



**Figure 4.6-11.** Final macrophyte HSI curve for velocity.

### *4.6.2.3. Substrate*

The literature-based HSI for substrate was revised from the provisional scores to reflect the percentage of macrophyte beds located on each substrate type. Almost three-quarters of the macrophyte beds surveyed were located in fine substrate (e.g., intermediate organic and fine texture substrates). Therefore, the final macrophyte HSI for substrate was revised from the provisional curve to reflect the distribution of macrophyte beds in the final HSI values. The final HSI values are presented in Table 4.6-6, and the final HSI curve is presented in Figure 4.6-12.

**Table 4.6-6.** Substrate types and final suitability values for macrophytes.

| Substrate Type | Final Suitability Values |
|---|---|
| Intermediate organic and fine texture substrates | 1.0 |
| Sandy, gravel, cobble | 0.28 |
| Bedrock | 0 |

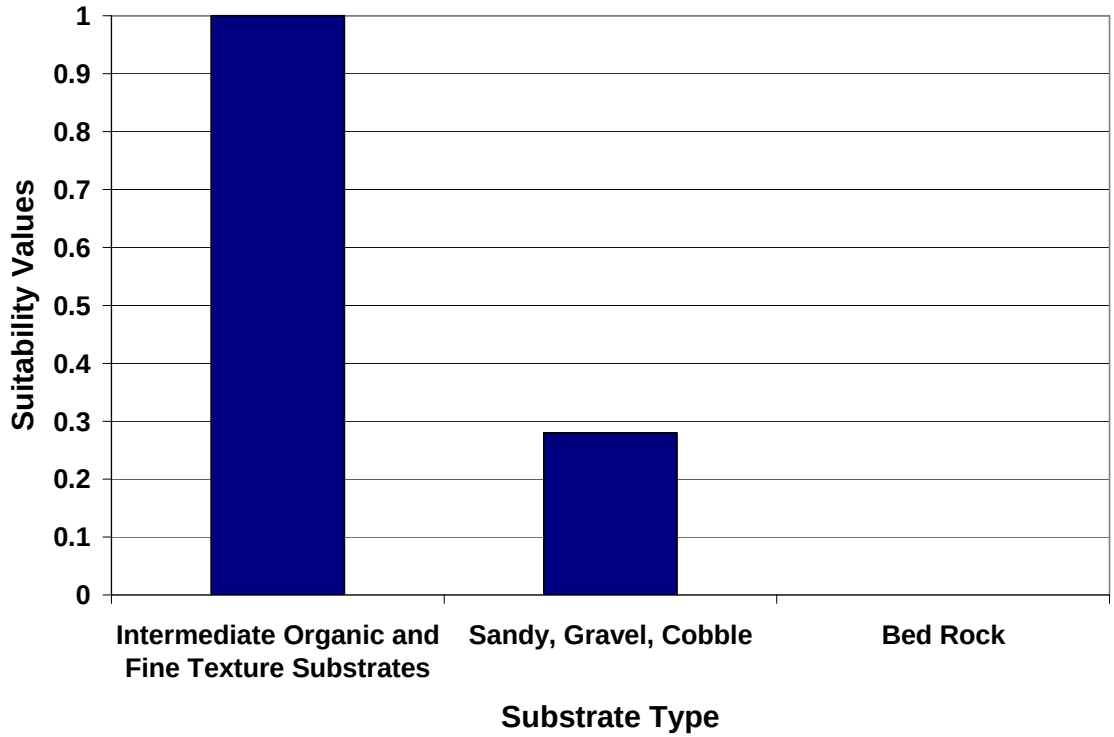



**Figure 4.6-12.** Final macrophyte HSI for substrate.

### *4.6.2.4. Duration of Dewatering*

Based on the roundtable discussion it was determined that separate curves would be needed for the HSI for duration of dewatering (one for the establishment of new beds, one for growth of established beds). Note that because the newly established beds are more sensitive to dewatering, only the established beds were used in the habitat model for describing current conditions under normal, dry, and wet precipitation years. The relicensing participants agreed to adopt the proposed-final duration of dewatering curves. The final HSI values are presented in Table 4.6-7, and the final HSI curves are presented in Figure 4.6-13.

**Table 4.6-7.** Duration of dewatering final suitability values for macrophytes.

| New Beds | | Growth and Established Beds | |
|---|---|---|---|
| **Hours** | **Final Suitability Values** | **Hours** | **Final Suitability Values** |
| 0 | 1 | 0 | 1 |
| 6 | 0.4 | 6 | 0.8 |
| 12 | 0.3 | 12 | 0.7 |
| 24 | 0.2 | 24 | 0.6 |
| 72 | 0 | 72 | 0.5 |
| | | 720 | 0 |

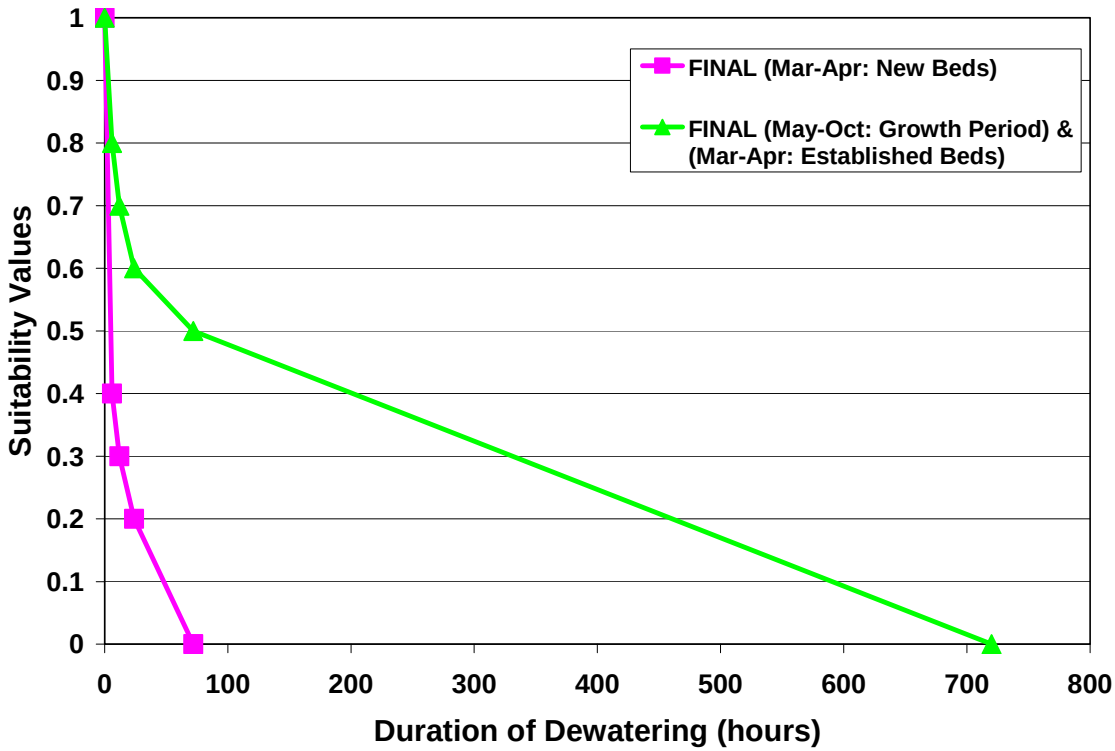



**Figure 4.6-13.** Final macrophyte HSI curves for duration of dewatering.

### *4.6.2.5. Duration of Inundation*

The growth rates of non-native macrophytes are up to twice those of native species, and as a result non-native species outcompete native species in most instances. The relicensing participants proposed to base duration of inundation curves on the response of non-native species. The literature-based HSI curve did not differ from that observed in the field; therefore, the provisional HSI curve was accepted as the final. The final HSI values for duration of

inundation for non-native macrophytes are presented in Table 4.6-8, and the final HSI curve is presented in Figure 4.6-14.

**Table 4.6-8.** Duration of inundation final suitability values for macrophytes.

| Hours | Final Suitability Values |
|---|---|
| 0 | 0 |
| 144 | 0.15 |
| 288 | 0.5 |
| 432 | 0.85 |
| 576 | 1.0 |

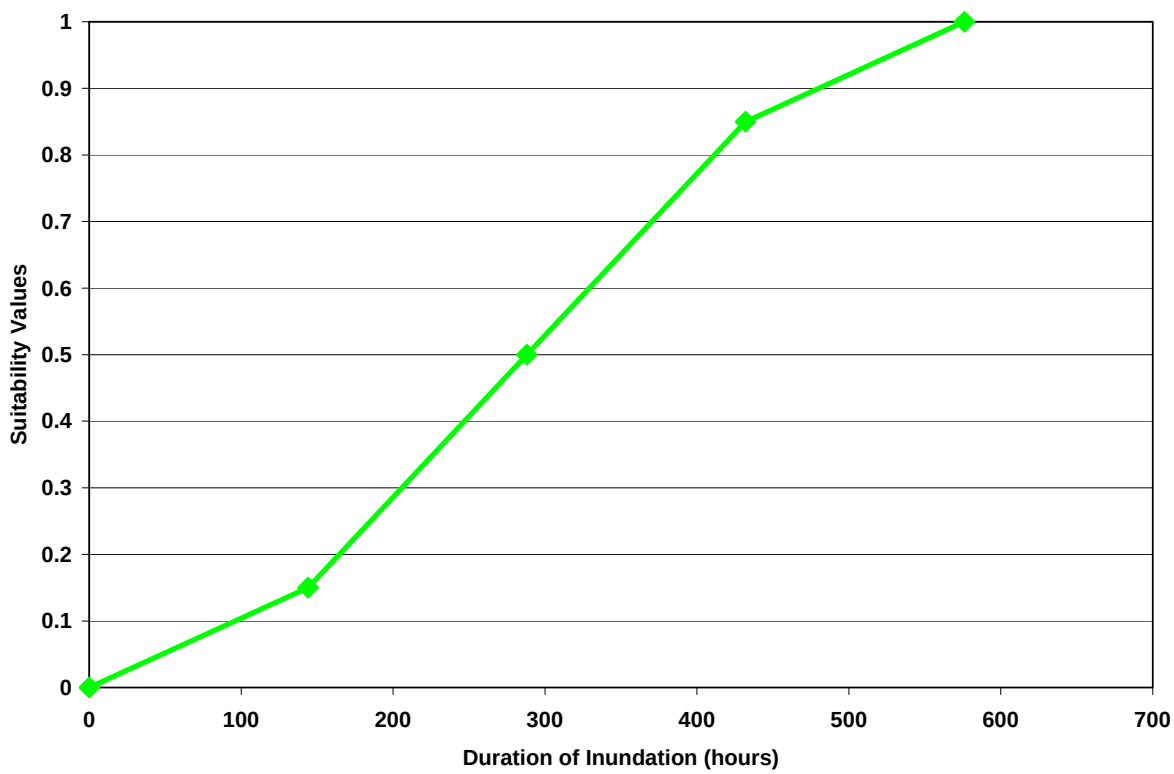



**Figure 4.6-14.** Final macrophyte HSI curve for duration of inundation.

### 4.6.3. Application of Macrophyte Model

The final habitat suitability curves for macrophytes were used in conjunction with the mainstem habitat model to determine the WUA in Boundary Reservoir for macrophytes. The mainstem habitat model was run for three hydrologic years—a wet year (1997), a dry year (2001), and an average year (2002)—and produced results on an hourly time step. The macrophyte WUA was

summarized by month from the hourly time-step graphs prepared for each hydrologic year. The WUA estimates were based on the final HSI curves describing established macrophyte beds, excluding curves describing development of new macrophyte beds. HSI values from established macrophyte beds were used exclusively (instead of values for new macrophyte beds) because mature macrophyte beds reflect current reservoir conditions and the influence on existing macrophyte distribution patterns and densities within Boundary Reservoir. HSI values for new macrophyte beds will be used in the model for scenarios that have the potential to promote expansion with new macrophyte beds. The HSI values for new macrophyte beds will be applied only for the months of March and April. A detailed discussion of macrophyte WUA can be found in Section 5.6 and also in Appendix 6. An example of the WUA in Boundary Reservoir for macrophytes in the Upper Reservoir Reach for a dry year is presented in Figure 4.6-15. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for macrophytes on the y-axis. Additional information and modeling results are presented in Section 5.6.

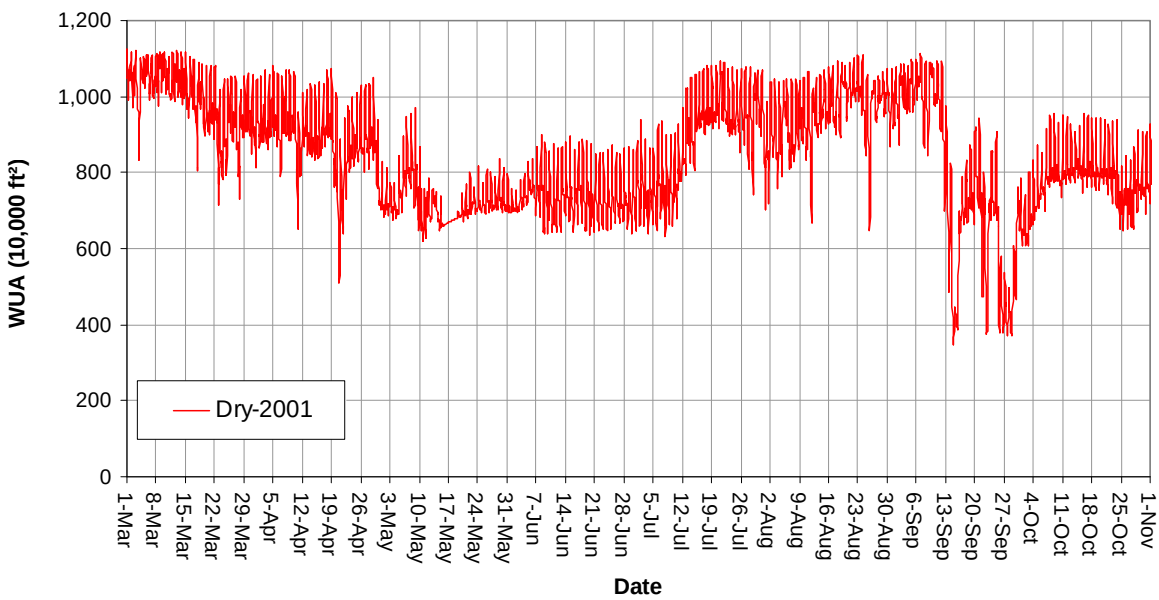



**Figure 4.6-15**. Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir, determined by the mainstem habitat model, for a dry water year (2001).

The macrophyte WUA estimates used the duration of dewatering HSI curve for "established" macrophyte beds and not the "new bed" HSI curve. The description of macrophyte beds and potential for colonization throughout the reservoir is based on current conditions. Established beds reflect current operations and do not reflect establishment of any new beds. Changes from current operations scenarios will use the "new bed" HSI curve in conjunction with the "existing bed" HSI curve if additional habitat becomes available during the March-April time period when establishment of additional beds is expected to occur in the reservoir.

## 4.7. Periphyton Habitat Development and Modeling Efforts

This section reviews the final periphyton HSI curves developed for use in the Mainstem Aquatic Habitat Model to determine the suitability of macrophyte habitat present under different operational scenarios. The modeling approach and final HSI curves were developed in conjunction with and agreement from relicensing participants. Detailed methods and results of the macrophyte HSI development are found in Appendix 7.

### 4.7.1. Modeling Approach

The Project periphyton model combined a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.7-1). The model is multiplicative, because if any of the variables result in a score of zero, the HSI is zero and habitat is not suitable for periphyton growth. Further detail and a general discussion of the varial zone modeling approach are provided in Section 4.6.1 of this report. Section 4.6.1.3 provides a discussion of the formulation of the CSI. The previously presented material is for macrophytes. One difference between the procedure for macrophytes and periphyton is the periphyton modeling only incorporates a lower limit.

The lower bounding limit for periphyton WUA was based on the combination of the HRM and information from the depth HSI curve. The bounding limit was set 54 feet below the typical water surface elevations that occurred during the March and April period of the average hydrologic year (2002). To represent typical conditions during this period, 54 feet was subtracted from the water surface elevation profile from the HRM for a median forebay elevation of 1,988 feet NAVD 88 (1,984 feet NGVD 29) and a median inflow into Boundary Reservoir of 18,800 cfs was used to define the upper bounding limits. Below the elevations defined by this profile, the model-calculated WUA was set to zero. In the Tailrace Reach, 54 feet was subtracted from the water surface profile corresponding to a median Seven Mile forebay elevation of 1,726 feet NAVD 88 (1,722 feet NGVD29) and a median outflow from Boundary Dam of 24,200 cfs to define the lower elevation limit for periphyton.

**Table 4.7-1.** Project periphyton model.

| **Periphyton Composite Suitability Index** | $CSI_i = HSC_i * HSI_i$ |
|---|---|
| Periphyton HSC | $HSC_i = D_i * Vo_i * S_i$ |
| Periphyton HSI | $HSI_i = f (DI_i, DD_i)$ |
| Periphyton Variables | $D_i$ = Depth<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

### 4.7.2. Biological Response (HSI)

The periphyton HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data, 3) calibration of the literature-based HSI curves using field data, and 4) finalization of the periphyton HSI for Boundary Reservoir. Field data generation included periphyton data with depth and cross-sectional data with depth, velocity, and substrate measurements. Site-specific periphyton monitoring consisted of three different components, artificial substrate sampling on hard substrate surfaces, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

A literature review was conducted to gather existing information and data on periphyton habitat preferences in terms of depth, substrate, velocity, and duration of inundation and dewatering. During the literature review no appropriate suitability curves were found, so other literature information was used to develop provisional suitability values. Once all periphyton monitoring data were collected, field data along with results from the hydraulic model were used to further refine and calibrate the periphyton HSI curves. Observed periphyton response curves were developed and compared to provisional literature-based curves. Final periphyton response curves were developed from the provisional and observed curves and included input from a panel of relicensing participants and regional experts. For more detailed information on the methods used to develop the final suitability curves for periphyton, see Appendix 7.

Habitat suitability values for periphyton in Boundary Reservoir are summarized in Tables 4.7-2 through 4.7-6. The final periphyton HSI curves are shown below in Figures 4.7-1 through 4.7-6.

The final depth HSI curve for periphyton was revised in January 2009 (presented to relicensing participants at the January 28, 2009, Fish and Aquatics Workgroup meeting). These revisions to the HSI curve were necessary to separate the effect of depth from the duration of dewatering scores that estimate the weighted useable area for periphyton on hourly time intervals and from each transect with the Mainstem Aquatic Habitat Model. Final revisions to the depth HSI curve included assigning a suitability value of 0 when depth is 0 feet (Figure 4.7-2). This HSI score differs from the final depth curve that was co-developed with relicensing participants in which a suitability value of 0.25 was assigned when depth was 0 feet (Figure 4.7-1). Both depth and duration of dewatering contribute HSI scores that describe availability of aquatic habitat. This relationship between the two variables used in generating suitability scores through the Mainstem Aquatic Habitat Model needed to be separated so that effects of each variable were independent of the other. The revised final periphyton suitability values for depth are presented in Table 4.7-2, and the revised final HSI curve is presented in Figure 4.7-2.

**Table 4.7-2.** Final revised depth suitability values for periphyton in Boundary Reservoir.

| Depth (feet) | Final Suitability Values |
|---|---|
| 0 | 0.0 |
| 0.1 | 0.25 |
| 5 | 0.75 |
| 6 | 1.0 |
| 11 | 1.0 |
| 21 | 0.75 |
| 32 | 0.6 |
| 38 | 0.4 |
| 54 | 0 |

**Table 4.7-3.** Final velocity suitability values for periphyton in Boundary Reservoir.

| Velocity (feet/second) | Final Suitability Values |
|---|---|
| 0 | 0.9 |
| 0.82 | 1.0 |
| 1.64 | 1.0 |
| 2.46 | 0.5 |
| 3.28 | 0 |

**Table 4.7-4.** Final substrate suitability values for periphyton in Boundary Reservoir.

| Substrate | Final Suitability Values |
|---|---|
| Hard Substrate | 1.0 |
| Silt or Organic Substrate | 0 |

**Table 4.7-5.** Final duration of dewatering suitability values for periphyton in Boundary Reservoir.

| Duration of Dewatering (hours) | Final Suitability Values |
|---|---|
| 0 | 1.0 |
| 9 | 0.8 |
| 17 | 0.1 |
| 24 | 0 |

**Table 4.7-6.** Final duration of inundation suitability values for periphyton in Boundary Reservoir.

| Duration of Inundation (hours) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 96 | 0.3 |
| 432 | 0.7 |
| 720 | 0.85 |
| 1,344 | 1.0 |

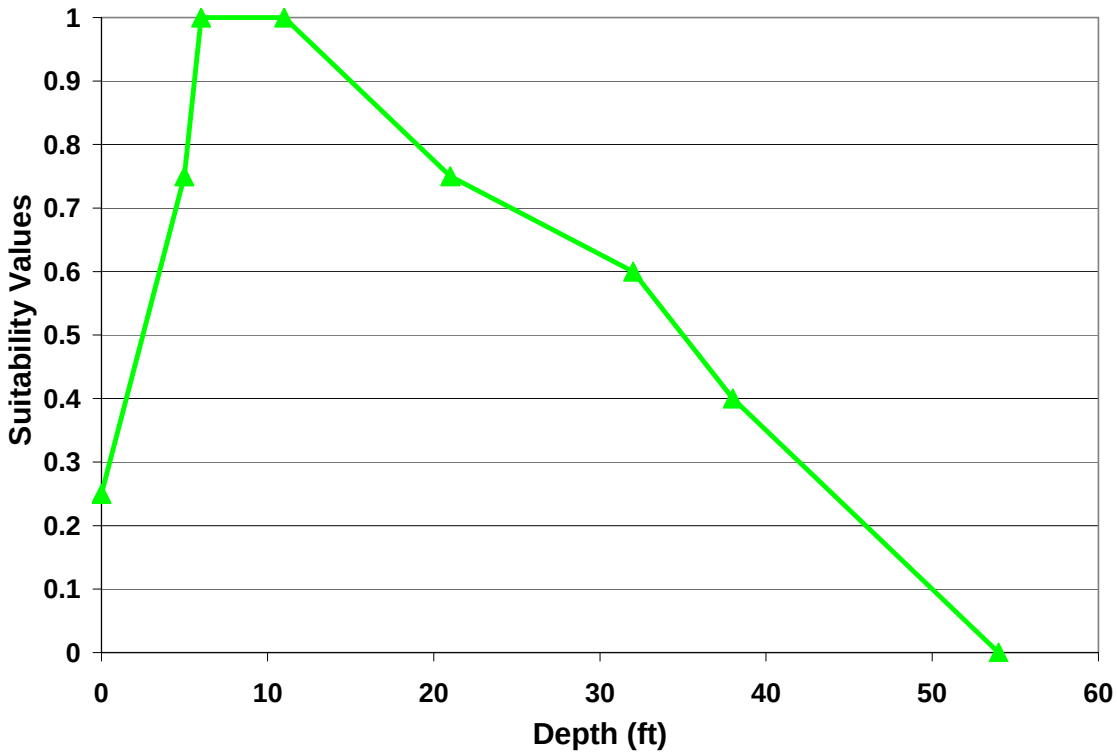



**Figure 4.7-1.** Final depth HSI curve for periphyton in Boundary Reservoir.

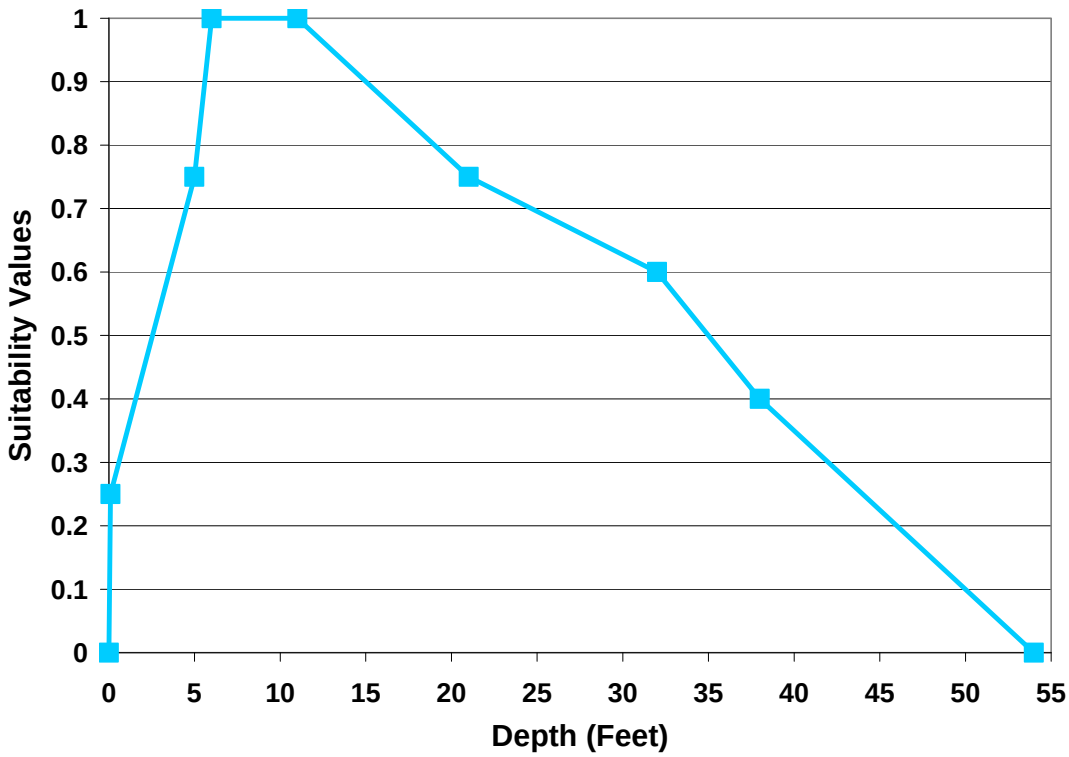



**Figure 4.7-2.** Revised final depth HSI curve for periphyton in Boundary Reservoir (revision approved by relicensing participants at January 28, 2009, meeting).

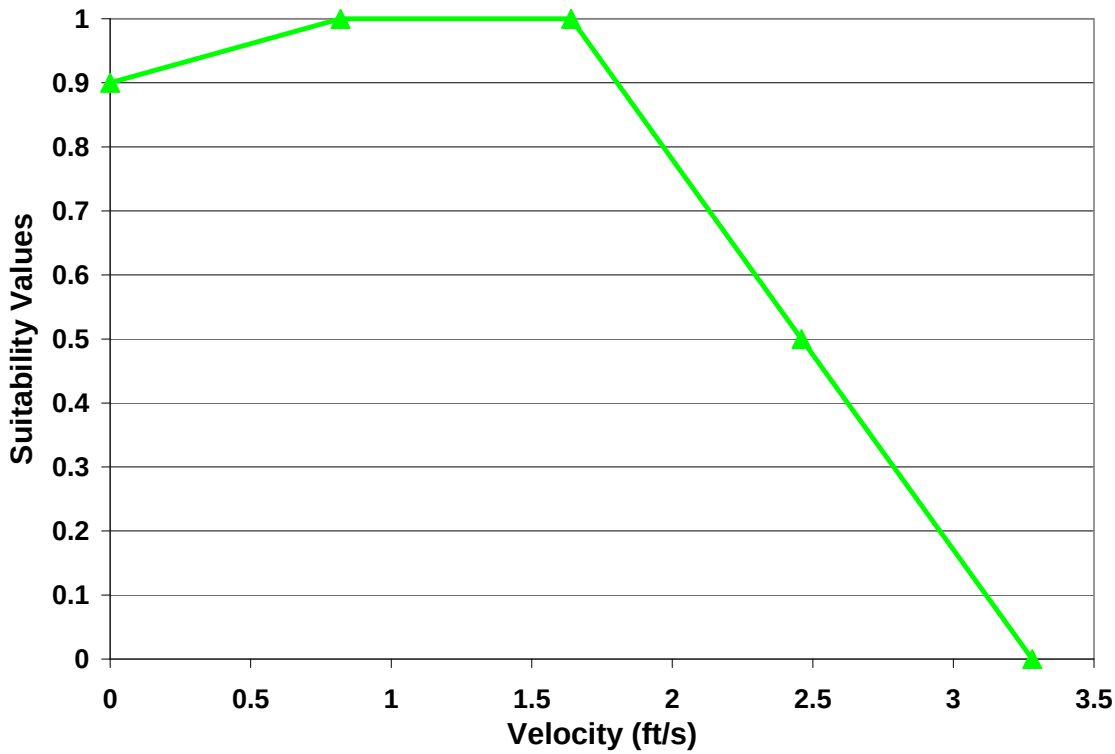



**Figure 4.7-3.** Final velocity HSI curve for periphyton in Boundary Reservoir.

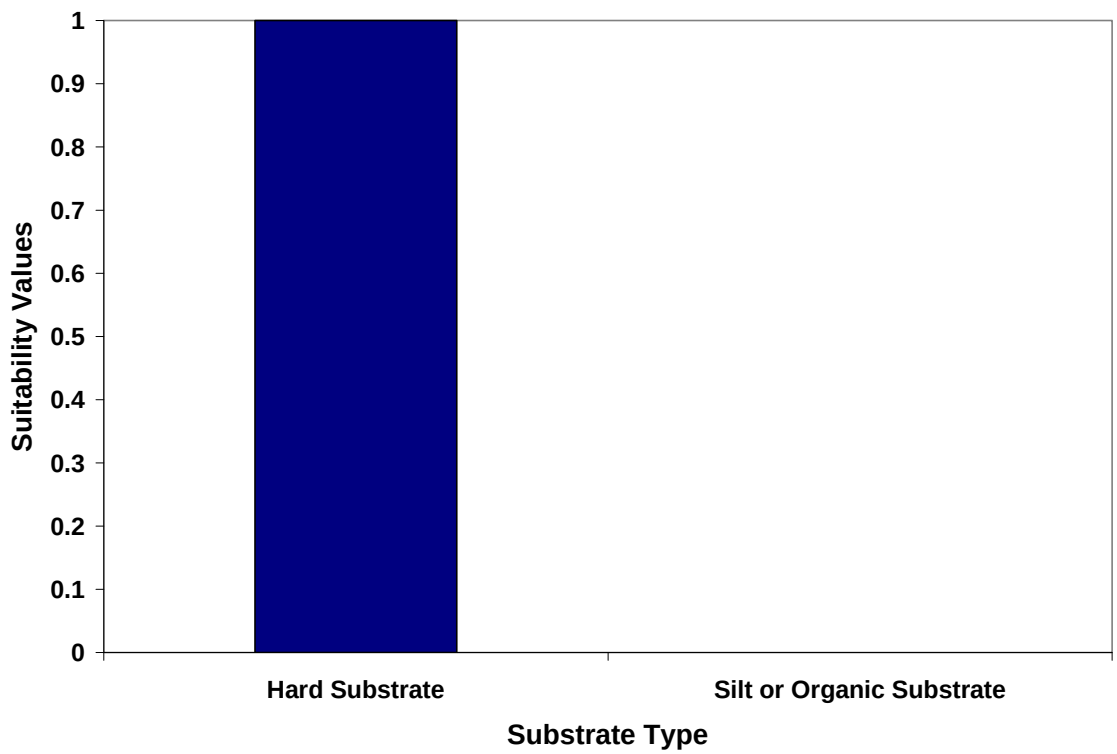



**Figure 4.7-4.** Final substrate HSI curve for periphyton in Boundary Reservoir.

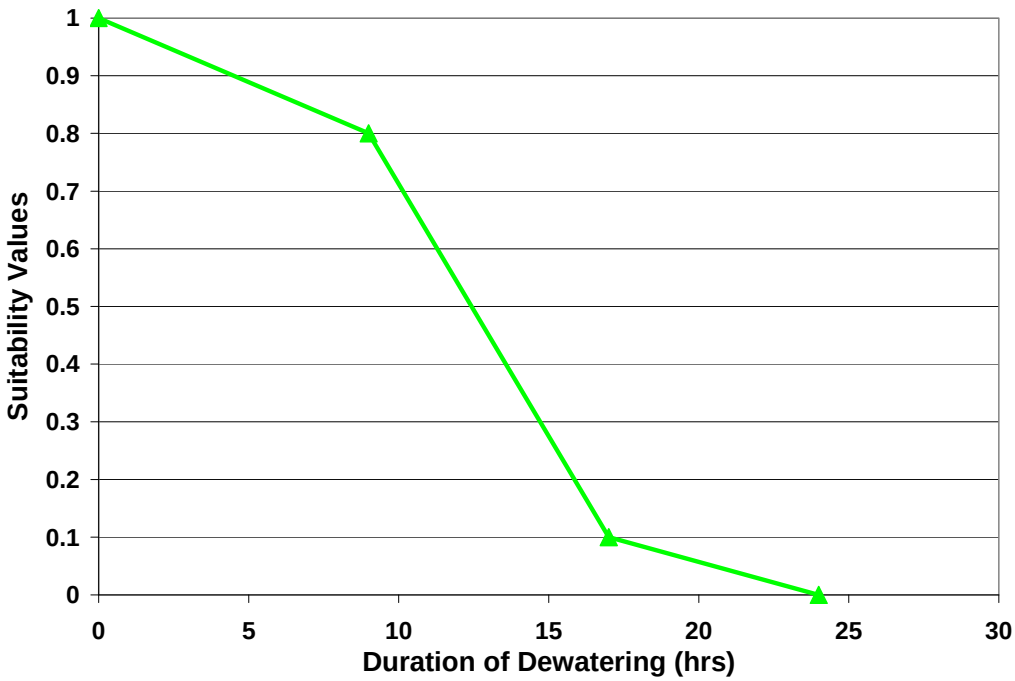



**Figure 4.7-5.** Final duration of dewatering HSI curve for periphyton in Boundary Reservoir.

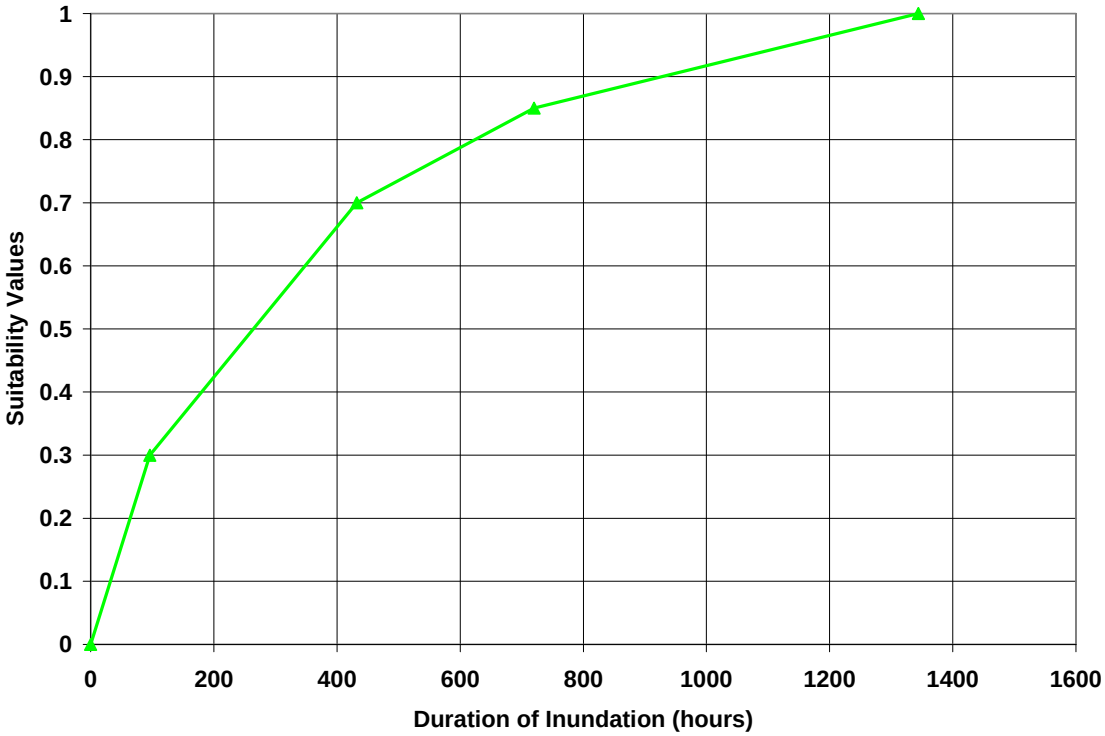



**Figure 4.7-6.** Final duration of inundation HSI curve for periphyton in Boundary Reservoir.

### 4.7.3. Application of Periphyton Model

The final habitat suitability curves for periphyton were used in conjunction with the mainstem habitat model to determine the WUA in Boundary Reservoir for periphyton. The mainstem habitat model was run for three hydrologic years—a wet year (1997), a dry year (2001), and an average year (2002)—and produced results on an hourly time step. Periphyton WUA was summarized by month from the hourly time-step graphs prepared for each hydrologic year. The WUA estimates were based on the final HSI curves used to describe response to fluctuating water surface elevations in each reach and during three hydrologic years (e.g., wet, dry, and average). WUA estimates are a representation of the potential periphyton habitat in Boundary Reservoir and do not directly relate to periphyton production or standing crop. An example of the WUA in Boundary Reservoir for periphyton in the Upper Reservoir Reach for a dry year is presented in Figure 4.7-7. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for periphyton on the y-axis. Additional information and modeling results are presented in Section 5.7. A more detailed discussion on periphyton production, factors influencing periphyton production, and how WUA may used to estimate impacts on periphyton production can be found in the Study 11 Final Report (SCL 2009c).

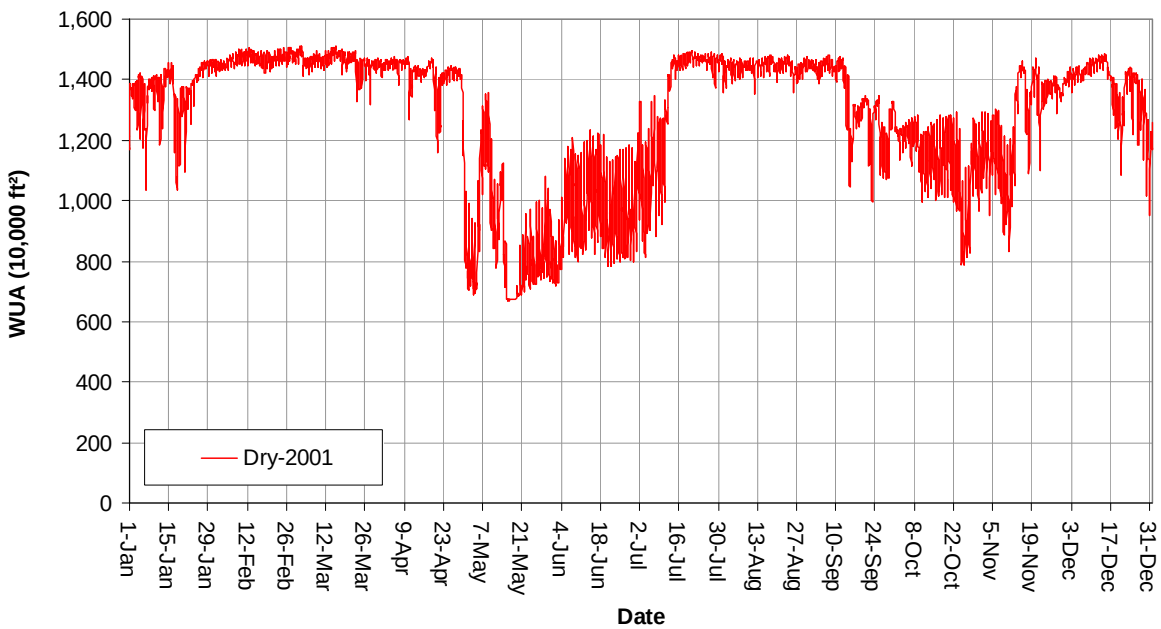



**Figure 4.7-7**. Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir, determined by the mainstem habitat model, for a dry water year (2001).

## 4.8. BMI Habitat Development and Modeling Efforts

This section reviews the final macrophyte HSI curves developed for use in the Mainstem Aquatic Habitat Model to determine the suitability of macrophyte habitat present under different operational scenarios. The modeling approach and final HSI curves were developed in

conjunction with and agreement from relicensing participants. Detailed methods and results of the macrophyte HSI development are found in Appendix 8.

### 4.8.1. Modeling Approach

The Project BMI model combined a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.8-1). The model was designed to integrate the HSC and HSI values to develop a composite suitability index for each cell within a mainstem habitat transect using hourly time steps. Further detail and a general discussion of the varial zone modeling approach are provided in Section 4.6.1 of this report. Section 4.6.1.3 provides a discussion of the formulation of the CSI. For the determination of WUA values for BMI, neither an upper nor a lower limit on the elevations was set. This is in contrast to macrophytes, for which both and upper and lower limit were set, and periphyton, for which a lower limit was set.

**Table 4.8-1.** Project BMI model.

| **BMI Composite Suitability Index** | $CSI_{BMI} = HSC_i * HSI_i$ |
|---|---|
| Benthic Macroinvertebrate HSC | $HSC_i = Di * Vo_i * S_i$ |
| Benthic Macroinvertebrate HSI | $HSI_i = f(DI_i, DD_i)$ |
| BMI Variables | $D_i$ = Depth<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

### 4.8.2. Biological Response (HSI)

The BMI HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data (hard and soft substrates), 3) calibration of the literature-based HSI curves using field data, and 4) finalization of the BMI HSI for Boundary Reservoir. Field data generation included BMI data with depth and cross-sectional data with depth, velocity, and substrate measurements. Site-specific BMI monitoring consisted of four different components, artificial substrate sampling on hard substrate surfaces, sampling of BMI communities in soft substrate, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

A literature review was conducted to gather existing information and data on BMI habitat preferences in terms of depth, substrate, velocity, and duration of inundation and dewatering. Based on an extensive literature review, numerous suitability curves for individual species, genus, insect order, and functional groups of BMI were found. These studies documented BMI habitat suitability for lotic environments, but did not apply directly to conditions in the Boundary Reservoir. Existing work on BMI suitability curves focused on a few, select benthic macroinvertebrate taxa. Using the literature information found, provisional suitability curves for BMI in Boundary Reservoir were developed. Once all BMI monitoring data were collected,

field data along with results from the hydraulic model were used to further refine and calibrate the BMI HSI curves. Observed BMI response curves were developed and compared to provisional literature-based curves. Final BMI response curves were developed from the provisional and observed curves and included input from a panel of relicensing participants and regional experts. For more detailed information on the methods used to develop the final suitability curves for BMI see Appendix 8.

Final habitat suitability values for BMI in Boundary Reservoir are summarized in Tables 4.8-2 through 4.8-6. The final BMI HSI curves are shown below in Figures 4.8-1 through 4.8-5.

**Table 4.8-2.** Final depth suitability values for BMI in Boundary Reservoir.

| Depth (feet) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 0.3 | 0.2 |
| 0.5 | 0.4 |
| 3 | 0.7 |
| 10 | 1.0 |
| 22 | 1.0 |
| 40 | 0.9 |
| 60 | 0.1 |
| 275 | 0.1 |

**Table 4.8-3.** Final velocity suitability values for BMI in Boundary Reservoir.

| Velocity (feet/second) | Final Suitability Values |
|---|---|
| 0 | 0.6 |
| 0.12 | 0.8 |
| 1.4 | 1.0 |
| 2.6 | 1.0 |
| 3.8 | 0.6 |
| 5.0 | 0.3 |
| 8.0 | 0.1 |
| 10 | 0 |

**Table 4.8-4.** Final substrate suitability values for BMI in Boundary Reservoir.

| Substrate | Final Suitability Values |
|---|---|
| Soft Substrates (Sand, Silt, or Organic Material) | 0.75 |
| Macrophytes | 0.6 |
| Gravel, Cobble, and Boulder | 1.0 |
| Bedrock | 0.2 |

**Table 4.8-5.** Final duration of dewatering suitability values for BMI in Boundary Reservoir.

| Duration of Dewatering (hrs) | Final Suitability Values |
|---|---|
| 0 | 1.0 |
| 9 | 0.8 |
| 18 | 0.1 |
| 24 | 0 |

**Table 4.8-6.** Final duration of inundation suitability values for BMI in Boundary Reservoir.

| Duration of Inundation (hours) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 192 | 0.2 |
| 600 | 0.6 |
| 1,344 | 1.0 |

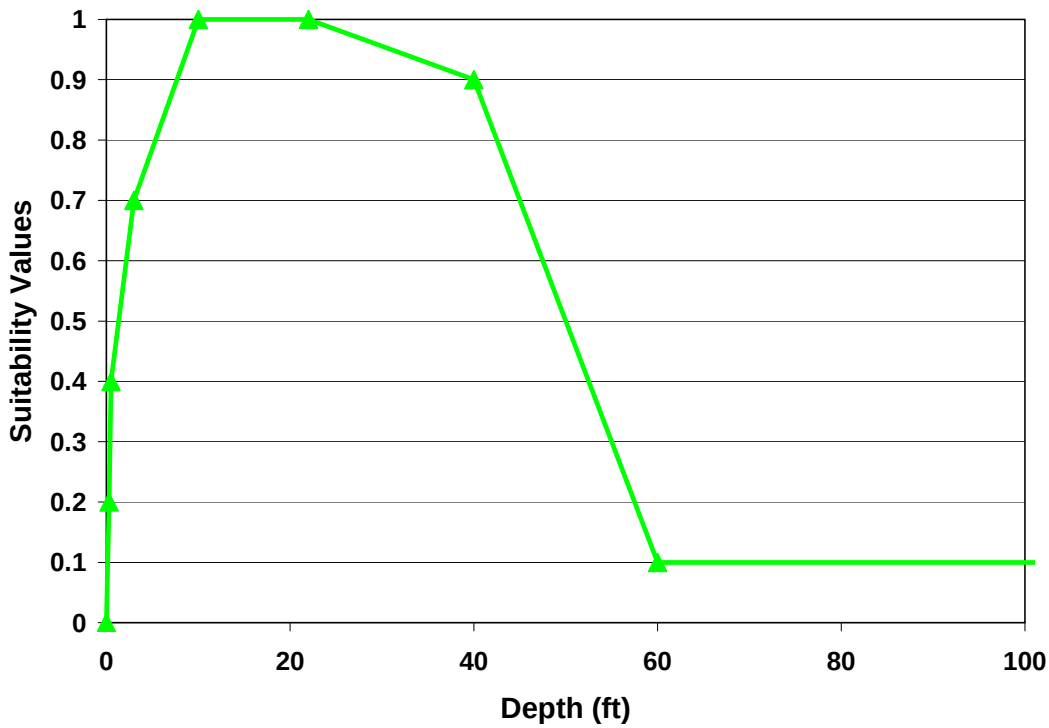



**Figure 4.8-1.** Final depth suitability curve for BMI in Boundary Reservoir.

**Figure 4.8-2.** Final velocity suitability curve for BMI in Boundary Reservoir.

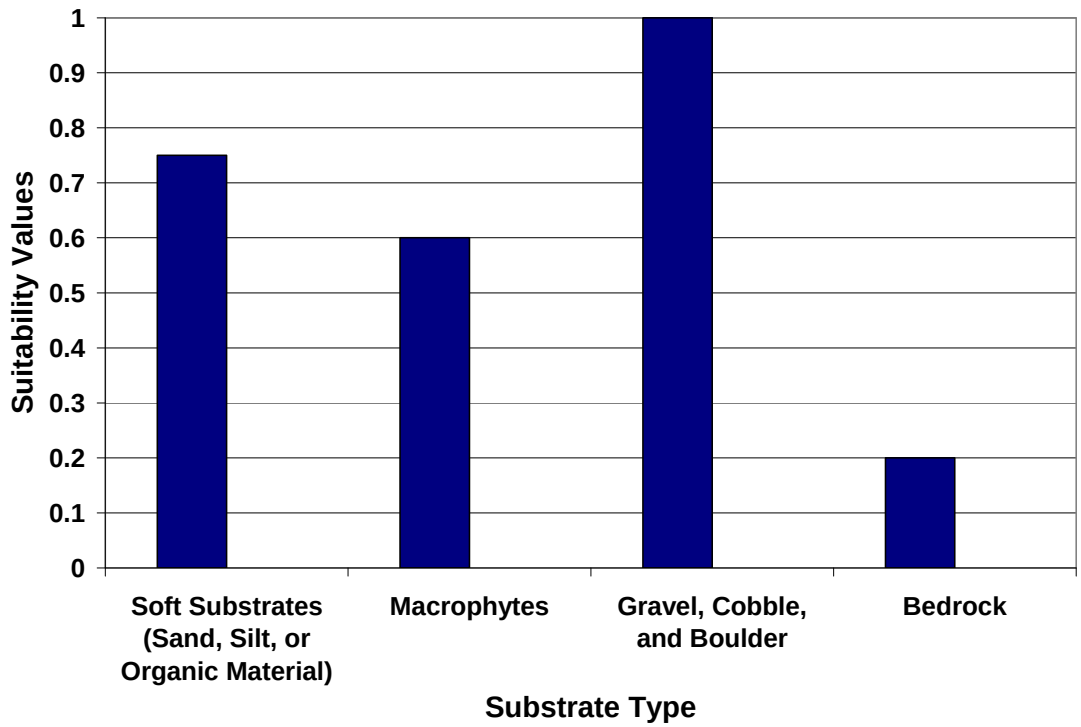



**Figure 4.8-3.** Final substrate suitability curve for BMI in Boundary Reservoir.

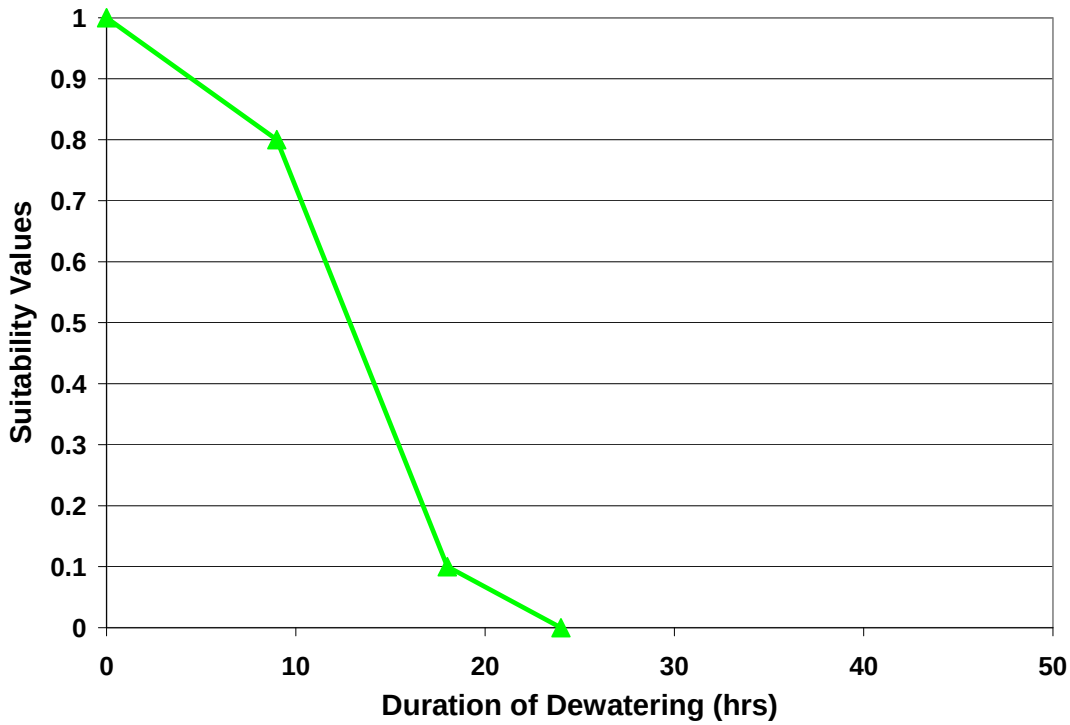



**Figure 4.8-4.** Final duration of dewatering suitability curve for BMI in Boundary Reservoir.

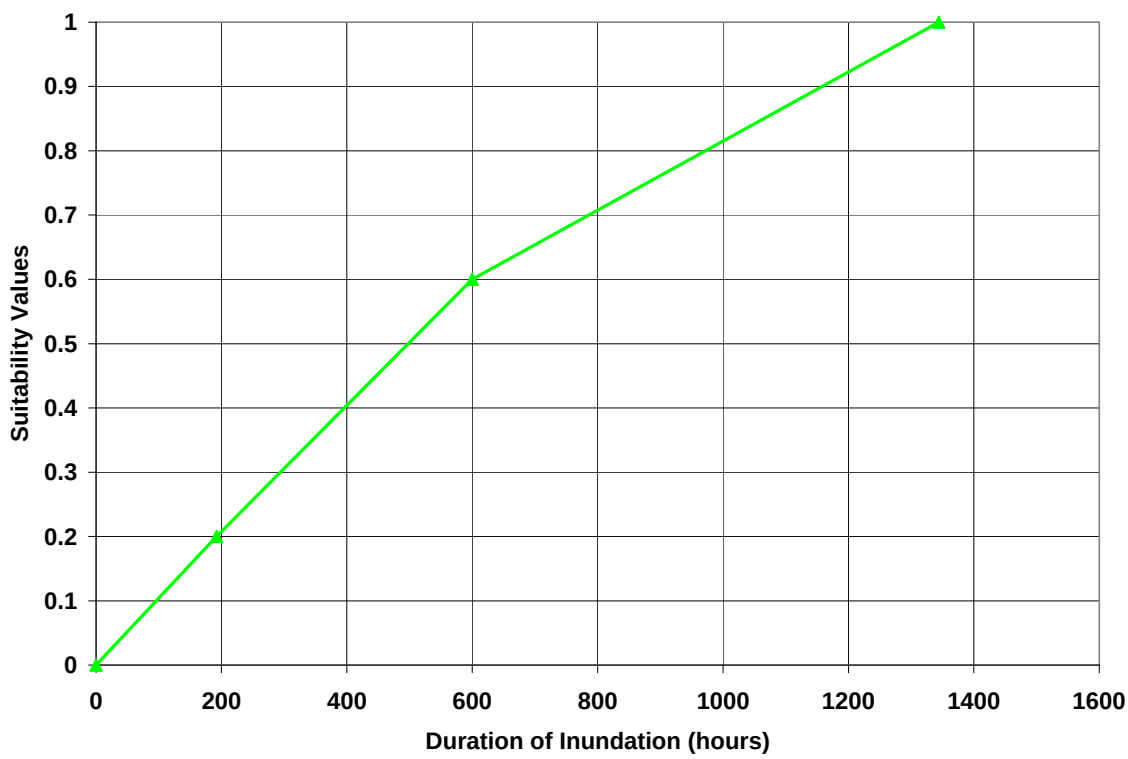



**Figure 4.8-5**. Final duration of inundation curve for BMI in Boundary Reservoir.

### 4.8.3. Application of BMI Model

The final habitat suitability curves for BMI were used in conjunction with the mainstem habitat model to determine the WUA in Boundary Reservoir for BMI. The mainstem habitat model was run for three hydrologic years—an average year (2002), a dry year (2001), and a wet year (1997)—and produced results on an hourly time step. The WUA for BMI was summarized by month from the hourly time-step graphs prepared for each hydrologic year. The WUA estimates incorporated the final HSI curves used to describe response to fluctuating water surface elevations in each reach and during three hydrologic years (e.g., wet, dry, and average). WUA estimates are a representation of the potential BMI habitat in Boundary Reservoir and do not directly relate to BMI production. An example of the WUA in Boundary Reservoir for BMI in the Upper Reservoir Reach for a dry year is presented in Figure 4.8-6. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for BMI on the y-axis. Additional information and modeling results are presented in Section 5.8. A more detailed discussion on BMI production, factors influencing BMI production, and how WUA may used to estimate impacts on BMI production can be found in the Study 11 Final Report (SCL 2009c).

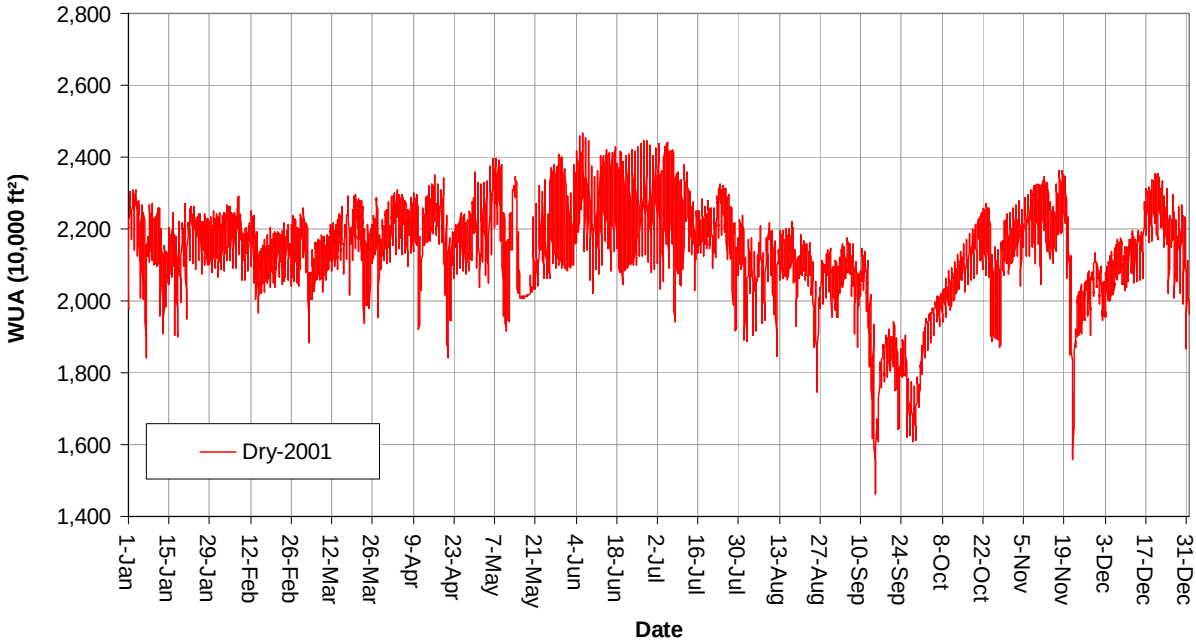



**Figure 4.8-6.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir, determined by the mainstem habitat model, for a dry water year (2001).

## 4.9. Fish Habitat Development and Modeling Efforts

Fish HSI variables were used in the instream flow modeling of Boundary Reservoir and tailrace by incorporating a small set of physical parameters that are commonly associated with habitat quality for fish. Fish HSI were developed for each species and each life stage that were selected

to represent the fish community in the Project area (Table 4.9-1). The HSI variables were incorporated into the mainstem physical habitat model to assess how changes in streamflow or reservoir elevation may affect the quantity and quality of habitat for fish. This information was used to evaluate the effects of operations scenarios on fish habitat. Any effects on fish habitat are expected to influence individual fish species populations.

**Table 4.9-1.** List of species and life stages included in the HSI analysis.

| Species | Spawning | Fry [1] | Juvenile [1] | Adult [1] |
|---|---|---|---|---|
| Mountain Whitefish | Y | Y | Y | Y |
| Bull Trout | N | N | Y | Y |
| Cutthroat Trout | N | Y | Y | Y |
| Redband Trout[2] | N | Y | Y | Y |
| Smallmouth Bass | Y | Y | Y | Y |
| Cyprinid Forage spp. [3] | N | Y | N | N |

Notes:
1 Size-class definitions: Fry <55 mm, Juvenile 55-150 mm, Adult >150 mm.
2 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.
3 Mostly northern pikeminnow and peamouth, only fry/juv/adults <100 mm.

HSI curves represent an assumed functional relationship between an independent variable, such as depth, velocity, and substrate, and the response of a fish species life stage to a gradient of the independent variable (suitability), which is expressed over a scale of 0.0 (poor habitat) to 1.0 (best habitat) (Bovee 1982) (Figure 2.5-1 in the RSP [SCL 2007a]). In traditional instream flow studies, HSI fish curves for depth, velocity, substrate, and/or cover are combined in a multiplicative fashion to rate the suitability of discrete areas of a stream for use by a species and life stage of interest. HSI curves translate hydraulic and channel characteristics into measures of overall habitat suitability in the form of WUA. Depending on the extent of data available, HSI curves were developed from the literature, or from physical and hydraulic measurements made in the field in areas used by the species and life stages of interest (Bovee 1986). HSI curves for the Project were based on information contained in available literature and validated with site-specific data where available. Further detail and a general discussion of the varial zone modeling approach are provided in Section 4.6.1. An overview of the fish habitat modeling approaches is presented in Section 4.9.1. The development of the provisional and final HSI curves is described in Section 4.9.2. The application of the fish habitat models, both the calculations of WUA for fry, juvenile, and adult life stages and the calculations of potential and effective spawning widths is provided in Section 4.9.3.

### 4.9.1. Modeling Approach

The modeling approach to quantify the quality and quantity of fish habitat in the Boundary Reservoir and Boundary Tailrace included two separate but related components. WUA was calculated for fry, juvenile, and adult life stages, whereas potential and effective spawning index widths were calculated for spawning adults and for egg incubation. The modeling approach for

WUA is presented in Section 4.9.1.1; the approach for modeling potential and effective spawning widths is provided in Section 4.9.1.2.

#### *4.9.1.1. Weighted Usable Area (WUA)*

WUA is a habitat index in relation to flow conditions that provides an estimate of both the quantity and quality of available species-specific habitat. WUA is used in this report to develop the description of aquatic habitat for baseline conditions using the wet, dry, and average years from the historic record. WUA will be used in the LA to compare the effects of several operations scenarios on aquatic habitat.

The primary input in the computation of the WUA is obtained from PHABSIM models of depth, velocity, and substrate/cover over a range of flows, linked with HSI developed specifically for a particular life stage of a particular fish species. The WUA is the product of the respective suitability of physical conditions at sample points, weighted by the surface area represented by each point. A more descriptive name for the WUA term is Physical Habitat Index (PHI or $\Phi$), because it is a dimensionless value that does not represent true area (Payne 2007). However, the original conceptualization of WUA is retained in this section for consistency with the literature.

The procedures used to determine WUA for macrophytes, periphyton, and BMI were described in detail in Section 4.6.1 for macrophytes. The procedure for the fish species is similar and in some ways less involved because the fish procedure does not incorporate the cyclic influences of inundation and dewatering. However, the WUA calculations for fish incorporate multiple species and life stages, whereas the WUA calculations for the other three biota are applied to a single set of HSI curves for each biota.

The analysis of habitat conditions for a particular hydrologic condition begins with the execution of the HRM to generate hourly time series of water surface elevations and flow rates. This model output is used to call hydraulic routines extracted from the computer code for PHABSIM. The PHABSIM routines use the calibrated transect information (Appendix 1a) to calculate cell depths and velocities. The fish habitat model then calculates the WUA of the transect, referred to as $WUA_T$. The $WUA_T$ index values represent width and length-weighted habitat index values specific to the transect and hydraulic conditions and are computed for each transect and hourly interval by the two equations below:

$$WUA_i = D_i * Vo_i * S_i$$

Where:

$WUA_i$ = composite habitat suitability of cell i
$D_i$ = HSI suitability associated with depth in cell i
$Vo_i$ = HSI suitability associated with velocity in cell i
$S_i$ = HSI suitability associated with substrate in cell i

The $WUA_T$ value is obtained by multiplying each of the $WUA_i$ values by the width of the cell ($W_i$) and the representative length of the transect and summing all of the values as indicated in the following equation:

$$WUA_T = \sum WUA_i * W_i * L_i$$

Where:

$WUA_i$ = composite habitat suitability of cell i
$W_i$ = width of cell i (feet)
$L_i$ = length of cell i (feet)
$WUA_T$ = width weighted aggregate habitat suitability for the transect (square feet)

The cell-specific suitability values ($D_i$, $Vo_i$, and $S_i$) are obtained from the HSI curves for the particular life stage and fish species. The individual HSI curves are presented in Appendix 9.

This sequence is repeated for each transect and for each hour by executing the PHABSIM routines with the water surface elevations and discharges generated by the HRM. This process is repeated for all hours in the simulation, resulting in $WUA_T$ values for each hourly time interval for all transects. The time period of interest could be a year representing a specific hydrologic condition such as wet, dry, or average; a series of years in the hydrologic record; or a particular season for all years. The final step is to sum the individual $WUA_T$ values first by reach (Upper Reservoir, Canyon, Forebay, and Tailrace) to develop the WUA of the reach ($WUA_R$), and to sum the reach values to produce the overall WUA for the entire reservoir or tailrace study area ($WUA_O$).

This sequence of calculations is executed for each life stage of each fish species being evaluated. This is accomplished by substituting the appropriate set of HSI curves of the life stage and species of interest.

WUA calculations did not consider flows exceeding 80,000 cfs. Once flows exceeded this volume, the calculated WUA for a given fish species and life stage species was not included in the either plotted results or numerical values of the WUA. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs ensured the incorporation of all flows potentially influenced by Project operations. When flows exceed 55,000 cfs, pool level fluctuations are typically dominated by inflow hydrology not Project operations as shown by the HRM.

#### *4.9.1.2. Potential and Effective Spawning Widths*

The approach for calculating potential and effective spawning widths is similar to the approach for calculating WUA—the primary differences are the absence of a reach length component for the widths and the different life stage of interest. Whereas the WUA was calculated for fry, juvenile, and adult life stages, potential and effective spawning index widths were calculated only for spawning adults and for egg incubation. Habitat transects were selected for modeling and the calculated widths represent the potential and effective spawning distances along the transects. The potential spawning index (PSI) is a width that represents the distance along a

transect at a specific point in time with suitable depth and substrate conditions for spawning. The effective spawning index (ESI) is a width that considers inundation over the incubation period to identify only the portion of the PSI width that can effectively support egg incubation. Both PSI and ESI widths were developed to provide indicators of the spawning and incubation habitat for conditions using the representative wet, dry, and average years from the historic record. PSI and ESI widths will be used in the LA to compare the influence of operations scenarios on aquatic habitat.

PSI and ESI widths were calculated for two fish species of interest as shown in Table 4.9-1. Mountain whitefish are native salmonids and one of the target species. Smallmouth bass, a non-native sport fish, are a species of interest. The spawning seasons (shoulder and peak) and durations of incubation for these species are detailed in Appendix 3, Fish Periodicity Final Report. As fewer fish spawn during the shoulder seasons compared to the peak season, seasonal weightings were applied to calculations of annual potential and effective widths using values presented in Appendix 3. The PSI and ESI widths were calculated only at habitat transects where active spawning was observed or along habitat transects within the spawning regions identified as a part of Study 9, Fish Distribution, Timing, and Abundance (SCL 2009c) where the potential for spawning was greatest based on the presence of suitable velocity and substrate. Based on the HSI curve for velocity of spawning smallmouth bass (Appendix 9), only portions of selected transects where velocity was suitable during the high flow conditions of the spawning season were modeled. These areas were checked against the observed spawning nest locations, and adjustments were made, if required, to include locations of observed nests. Similarly, surface substrate coding input to the model was adjusted, if necessary, for consistency with the substrate present in the observed nests. Because smallmouth bass excavate spawning nests, the surface substrate may be less than optimal for spawning if excavation can reveal more suitable size material (as was frequently noted at observed nests). Macrophytes were typically observed where fines dominated the substrate; because no nests were observed within macrophyte beds and fines are unsuitable for spawning, these areas were not included in modeling of potential and effective spawning areas. Figure 4.1-1 illustrates the locations of the habitat transects selected for modeling. Table 4.9-2 summarizes the spawning and incubation characteristics modeled for mountain whitefish and smallmouth bass. The periodicity of mountain whitefish spawning was the subject of focused biological monitoring efforts during the fall and winter 2008, but the results of those efforts were not available at the time this report was prepared. As a result, the mountain whitefish periodicity presented in Table 4.9-2 represents the best data available at the time the modeling was conducted.

**Table 4.9-2.** Mountain whitefish and smallmouth bass spawning and incubation characteristics.

| Spawning and Incubation Characteristics | Mountain Whitefish | Smallmouth Bass |
|---|---|---|
| Shoulder Spawning Seasons | 10/15 – 10/31; 1/16 – 2/28 | 5/15 – 5/31; 7/16 – 7/31 |
| Peak Spawning Season | 11/1 – 1/15 | 6/1 – 7/15 |
| Shoulder Season Weighting | 0.3 | 0.3 |
| Peak Season Weighting | 0.7 | 0.7 |
| Incubation Duration (days) | 61 | 15 |
| Modeled Habitat Transects | U-05, U-10, U-11, U-23, U-24, TR-15, TR-16 | C-06[1], C-07[1], U-05, U-06, U-07, U-10, U-16, U-17, U-21 |

Note:
1 Only the portion of these channels on the west side of Everett Island was modeled.

The primary input in the computation of the PSI and ESI widths was obtained from PHABSIM models of depth and substrate/cover over a range of flows, linked with HSI developed specifically for the spawning life stage of the two fish species of interest. The PSI and ESI widths are the product of the respective suitability of physical conditions at cells along habitat transects, weighted by the width represented by each cell. The calculations followed the same approach as the WUA, except that widths were calculated instead of areas.

The analysis of PSI and ESI widths for a particular hydrologic condition began with the execution of the HRM to generate hourly time series of water surface elevations and flow rates. These model outputs were used to call hydraulic routines extracted from the computer code for PHABSIM. The PHABSIM routines used the calibrated transect information (Appendix 1a) to calculate cell depths and velocities. The spawning model then calculated the PSI width of the transect using the depth and substrate at each cell across the transect. Velocity was not used in the calculations; however, the presence of suitable velocity for spawning was used as part of the criteria for selecting transects for modeling of spawning. The calculation of PSI width is shown in the following two equations:

$$PSI_i = D_i * S_i$$

Where:

$PSI_i$ = composite potential spawning index of cell i
$D_i$ = HSI suitability associated with depth in cell i
$S_i$ = HSI suitability associated with substrate in cell i

$$PSI = \sum PSI_i * W_i$$

Where:

PSI = cell-width-weighted aggregate potential spawning index (feet)
$PSI_i$ = composite potential spawning index of cell i
$W_i$ = width of cell i (feet)

The cell-specific suitability values ($D_i$ and $S_i$) were obtained from the HSI curves for the particular life stage and fish species. The individual HSI curves for mountain whitefish are presented in Section 6.1 of Appendix 9; the curves for smallmouth bass are provided in Section 6.5 of Appendix 9.

The calculation sequence was repeated for each transect and for each hour by executing the PHABSIM routines with the water surface elevations and discharges generated by the HRM. This process was repeated for all hours in the spawning period, resulting in PSI and ESI widths for each hourly time interval for selected transects. While the widths were calculated only within the spawning season, the calculations of ESI width require analyses of water surface elevation over the incubation period even after the spawning season has ended.

Calculated hourly PSI values indicate the potential extent of spawning based on habitat suitability during the specified hour. If conditions are suitable for spawning, a subsequent evaluation of inundation conditions over the incubation period was conducted to identify the portion of the potential spawning habitat that could result in successful incubation of eggs. The portion of the potential spawning habitat that remains inundated over the incubation period is considered to be successful or effective. The ESI index considers the minimum water surface elevation over the incubation period to determine whether eggs spawned in a specific hour remain inundated for the entire incubation period. The duration of the incubation period is added to each hour that spawning is modeled and the minimum water surface elevation determined for the time interval from the hour at which spawning occurred to the end of the incubation period. The spawning model was developed such that spawning and associated egg incubation were considered effective only for the portions of the PSI width that remain continuously inundated over the incubation period. Dewatered portions of the PSI width were not considered to be effective habitat for egg incubation.

The hourly calculations were weighted within each day in the spawning season to calculate daily PSI and ESI widths. Each of the 24 hours in a day was assigned a factor between 0 and 1 so that the 24 hourly weighting factors summed to one. The hourly weighting factors were applied to account for peak and off-peak spawning hours. The hourly PSI and ESI widths were multiplied by the hourly factors so that the 24 resulting values could be summed to produce a weighted daily width. No evidence was available for smallmouth bass to indicate there are preferred spawning hours within a day, so all hours were weighted equally with a factor of 0.0417 (1/24). Based on monitoring of mountain whitefish spawning by R. L. & L. Environmental Services (2001) in the Columbia and Kootenay rivers, hourly spawning preferences demonstrated diel spawning periodicity focused around the crepuscular periods. In particular, spawning intensity was highest near dusk, with a lesser peak near dawn. The observations noted by R. L. & L. Environmental Services (2001) were made in mid January. Due to differences between the hours of dawn and dusk over the spawning period, the occurrence of the peak hours was shifted based on sunrise and sunset data for the midpoint of each month in the spawning season. The hours of peak spawning intensity were averaged between the Columbia and Kootenay rivers for application to the study area. This approach yielded five hours at dusk and two hours at dawn of peak spawning intensity. Professional judgment was used to weight peak hours twice as much as off-peak hours. Thus, the peak hour weighting factor for mountain whitefish was calculated as 0.0645 and the off-peak factor was calculated as 0.0323.

Annual PSI and ESI widths were calculated over the spawning season using seasonal weighting factors applied to the daily widths calculated from the hourly values. As fewer fish spawn during the shoulder seasons compared to the peak season, the shoulder seasons were not weighted as much as the peak season (see Table 4.9-2). The seasonal weighting factors sum to one. The daily widths within each season were averaged, and then multiplied by the seasonal weighting factors. The resulting components were then summed to produce weighted annual PSI and ESI widths.

On an annual basis, the ratio of ESI width to PSI width was calculated as an indicator of the influence of Project operations on spawning and incubation habitat. If reservoir water surface elevations remained higher than the elevation of the spawning areas, the effective width would equal the potential width and the ratio would be one. Conversely, if water surface elevation fluctuations were so great as to dewater all suitable spawning habitat at a transect, the effective width would be zero and the ratio of effective to potential spawning widths would be zero. When the ratio of effective spawning width to potential spawning width at a transect is close to one, the influence of water surface elevation fluctuations on this aquatic habitat is minor; a more substantial influence is indicated by a ratio closer to zero.

A single indicator was calculated for each of the PSI and ESI widths by study reach to facilitate comparisons of the influence of Project operations between operations scenarios. The indicator is a spawning width for all modeled transects within a study reach weighted by the contribution of the PSI width at each transect to the total PSI width of all modeled transects within a reach. The ESI width for a study reach was calculated as shown in the following equation (for simplicity, the calculation of $PSI_R$ is not shown, but the calculation is similar to the equation below):

$$ESI_R = \frac{\sum_{t=1}^{n} PSI_t * ESI_t}{\sum_{t=1}^{n} PSI_t}$$

Where:

| | | |
|---|---|---|
| $ESI_R$ | = | transect-weighted, reach-averaged effective spawning width (feet) |
| $PSI_t$ | = | potential spawning width at transect t (feet) |
| $ESI_t$ | = | effective spawning width at transect t (feet) |
| n | = | total number of modeled transects within a study reach |

This approach condenses the modeled output across multiple transects within a reach into a single numeric indicator. Larger values of $ESI_R$ indicate greater availability of potential spawning habitat that remains inundated throughout the incubation period. A similar calculation was carried out to generate a single reach-based value of PSI.

### 4.9.2. Biological Response (HSI)

The principal HSI variables describe the relative suitability of water depth, mean column water velocity, and bottom substrate or cover type, for each fish species and life stage of interest, over the summer (April 1 to October 31) and winter (November 1 to March 31) periods. Final fish HSI curves were initially developed using a combination of literature-based information and site-specific data collection from Study 9 (SCL 2009b), and then reviewed and finalized by consensus from a panel of HSI experts over the course of two meetings (April 23 and August 27, 2008). This section will simply summarize the detailed information provided in Appendix 9 relating to the development of fish HSI curves.

#### *4.9.2.1. Literature-Based Provisional HSI Curves*

Draft provisional HSI curves were initially developed for spawning, fry, juvenile, and adult life stages for the four target species (bull trout, cutthroat trout, rainbow/redband trout, and mountain whitefish) and smallmouth bass, a species of interest (Table 4.9-1). It should be noted, however, that some of these species/life stages are not known to occur in Boundary Reservoir. Following consensus with relicensing participants, it was decided to drop the spawning life stages for bull trout, cutthroat trout, and redband trout, and the fry life stage for bull trout, from the habitat modeling. Additionally, habitat for redband trout was only assessed in the Boundary tailrace, but not within the reservoir. In addition to the species of interest listed above, HSI were also developed to represent forage fish species that are utilized by larger game fish. The original forage species in the RSP was redside shiner. Following meetings with relicensing participants, the forage species of interest was changed to be a species guild defined as cyprinid species (mostly northern pikeminnow and peamouth) less than 10 cm in length. This change is discussed in Section 7.

The provisional HSI curves were developed by first assembling available HSI data from scientific publications; unpublished “gray” literature; and from state, federal, or consultant curve libraries. Based on the literature search, over 60 HSI datasets were located, yet HSI data remained rare for several species, including bull trout, cutthroat trout, and native northwestern cyprinids. Also, the vast majority of available HSI curves was developed during the warmer months and was not deemed suitable for representing habitat suitability at low water temperatures. Consequently, the winter HSI curves were largely based on professional judgment. For juvenile and adult redband/rainbow trout, the number of available HSI datasets were excessive for legible plotting and interpretation; therefore, the available datasets for those species/life stages were screened to identify a manageable and more representative selection based on several criteria, including curve type, data sample size, and stream habitat characteristics (e.g., larger rivers).

All available or selected literature-based HSI curves were plotted on a common axis and visually compared to identify overall suitability trends, particularly in relation to the ranges in depth and velocity where suitability is maximum, and those ranges where suitability goes to zero. For some species and life stages, site-specific HSI data were available from electrofishing and/or biotelemetry studies in the study area, and those data were also plotted with the literature-based HSI curves to better assess probable suitability for species of interest in the Project area. Provisional HSI curves intended to represent the Project area were then plotted on the common

figure to facilitate discussion and consensus of final curves by the HSI workgroup. Because literature-based substrate and cover HSI could not easily be plotted on a common axis (due to differences in coding systems used by various researchers), consensus on HSI values for the Project substrate and cover codes was reached following group discussion.

#### *4.9.2.2. Site-Specific Habitat Utilization Data*

Site-specific HSI data were collected for species of interest in the Project area from March 2007 to February 2008 using biotelemetry and boat electrofishing methodologies. It was expected that biotelemetry would provide the least biased HSI information for adult fish, because efficient electrofishing is restricted to shallow, nearshore locations. However, both methodologies possess limitations that must be recognized when developing HSI curves. For example, neither methodology allows a precise identification of focal positions of the captured or monitored fish. Consequently, HSI data (e.g., depths, velocities, etc.) associated with each observation are approximate. Details regarding the collection of HSI data using biotelemetry and the electrofishing methodologies can be found in the Study 9 Final Report (SCL 2009b).

A summary of the number of electrofishing cells sampled by boat electrofishing and the number of fish tagged with radio or CART tags, along with the number of individual fish captures associated with those samples, is given in Table 4.9-3. This table illustrates the rarity of the target species (i.e., the salmonids) and the necessity to rely on literature-based HSI for these species and life-stages.

**Table 4.9-3.** Summary of site-specific HSI data from cell electrofishing and biotelemetry in the Project area, March 2007 through February 2008.

| Sampling Method | Sample Period | No. of Cells[1] Sampled | Bull Trout | Cut-throat Trout | Redband Trout (wild) | White-fish | <6 cm | SM Bass 6-15cm | >15 cm | Forage< 10cm |
|---|---|---|---|---|---|---|---|---|---|---|
| Boat Electro-fishing | Mar-07 | 11 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| | Apr-07 | 103 | 0 | 0 | 1 | 0 | 0 | 2 | 3 | 4 |
| | May-07 | 87 | 0 | 0 | 1 | 1 | 0 | 5 | 13 | 4 |
| | Jun-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Jul-07 | 60 | 0 | 0 | 0 | 0 | 1 | 5 | 5 | 0 |
| | Aug-07 | 97 | 0 | 0 | 0 | 0 | 9 | 24 | 15 | 14 |
| | Sep-07 | 96 | 0 | 0 | 0 | 0 | 3 | 19 | 4 | 7 |
| | Oct-07 | 32 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 |
| | Nov-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Dec-07 | 35 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 2 |
| | Jan-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Feb-08 | 73 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 8 |
| | # Cells[2,3] | 594 | 0 | 1 | 4 | 5 | 13 | 59 | 43 | 44 |
| | # Fish[4] | - | 0 | 1 | 4 | 7 | 14 | 96 | 51 | 130 |
| Bio-telemetry | # Tagged | - | 0 | 5 | 0 | 13 | 0 | 0 | 19 | 0 |
| | # HSI[5] Obs | - | 0 | 18 | 0 | 19 | 0 | 0 | 49 | 0 |

Notes:
1 Number of HSI cells sampled by electrofishing.
2 Number of cells with species present (in species columns).
3 Only EF cells <10 ft (n=384) were used to develop summer (Apr-Oct) HSC for smallmouth bass and cyprinids.
4 Total number of fish in all EF cells.
5 Number of biotelemetry HSI observations includes multiple observations for several tagged fish.

The site-specific HSI data collected by boat electrofishing or biotelemetry studies were combined with the literature-based HSI curves for developing the final HSI curves. Where sufficient site-specific data were collected in the Project area, new site-specific HSI curves were proposed for use. A generally accepted "rule of thumb" is that 150 to 200 site-specific observations of habitat use by a species of interest and life stage are recommended to construct new and robust HSI curves (Bovee 1986), although lower sample sizes are frequently used to develop HSI when collected using a rigorous sampling design and the frequency distributions do not show undesirable characteristics (e.g., multiple modes, extreme outliers, etc.). Consequently, new HSI curves were created for those species that met those criteria (smallmouth bass and forage cyprinids, see Section 4.9.2.4). None of the target species, native salmonids, met the criteria. Even for those species with abundant site-specific data, subjective decisions regarding habitat suitability were required by the workgroup participants due to the known limitations of site-specific data collection methodologies, such as the shallow water bias of electrofishing, and the imprecision of assessing focal point locations inherent to both electrofishing and biotelemetry. For species and life stages that did not meet the sample size or distribution criteria,

the existing site-specific data were used to select or modify an existing HSI curve from among the literature-based curves as described in Appendix 9, or else to modify the provisional HSI curve through consensus among the relicensing participants.

#### *4.9.2.3. Relicensing Participant Panel*

A panel of biologists knowledgeable on the species of interest, local fish populations, and habitat modeling methodologies were convened in the spring (April 23) and summer (August 27) of 2008 to review the provisional HSI information and to finalize the input data for the physical habitat model. Provisional HSI curves for each species and life stage were presented to the panel with the underlying literature-based and the site-specific data, and consensus was reached on HSI curves for all species and life stages.

#### *4.9.2.4. Development of Final HSI Curves*

The combination of literature-based HSI, site-specific habitat utilization data, and professional judgment from the HSI workgroup meetings was used to develop the final HSI curves presented in Appendix 9. The sample sizes for all species of interest and life stages were below the minimum suggested goal of 150 fish observations (Bovee 1986); however, site-specific HSI curves were developed to represent the warm-water season (April 1to October 31) for smallmouth bass and cyprinid forage fish as an option for consideration, given the large number of cells sampled for HSI data (Table 4.3-5). Sample sizes for all salmonid species were insufficient to attempt development of site-specific HSI curves; consequently, final HSI curves for those species and life stages were developed by consensus of the HSI workgroup by reference to existing literature-based HSI curves as adjusted by the available site-specific observations from electrofishing and biotelemetry results (see Appendix 9 for details on HSI curve development).

New site-specific HSI curves were developed for fry, juvenile, and adult smallmouth bass and for cyprinid forage fish using the capture data from the 384 of the 594 HSC cells that were sampled by the boat electrofishing efforts during the warm-water period (only cells <10 feet deep were utilized). The presence of each species/life stage that was captured in each electrofishing cell was plotted (as a value of “1” for present) against the depth or velocity of that cell. Likewise, the depth or velocity of each cell that did not contain that species/life stage was also plotted (with a value of “0” for absent). Then the distribution of 1’s and 0’s was fit with a logistic regression model, typically using a second- or third-degree polynomial. The predicted counts were normalized to 1.0 for the maximum value, and then plotted on the HSI figures with the literature-based HSI curves. Logistic regression is a method particularly suited for presence/absence data where many samples do not contain the species of interest, and those that do contain fish generally contain few individuals. The distribution of captures from the cell electrofishing data followed this pattern, with most cells containing zero captures and few cells containing a more than two individuals of the species of interest.

This density-based method of HSI creation accounts in-part for habitat availability effects because all sampled cells are included in the analysis, both those cells that contained the species of interest and those that did not contain fish. This is in contrast to HSI curves constructed solely from habitat utilization data, where only those locations where fish are observed are used to

construct the HSI curve. Because the electrofishing cell methodology was only efficient to depths less than approximately 10 feet, the site-specific HSI curves could only be applied to shallower depths, and professional judgment was required for those species that were known to occur in deeper water. Other existing HSI curves and biotelemetry data (for adult bass) were used to account for the limitations of the electrofishing cell data. This suite of HSI curves and site-specific data was evaluated by the HSI workgroup, and the site-specific curve was either accepted as proposed; modified by consensus (with reference to other curves or biotelemetry data) then accepted; or else used to create a new, consensus-based HSI curve.

Figure 4.9-1 provides an example of existing HSI curves from literature sources for adult smallmouth bass, along with site-specific HSI data from the Project area, and the final Boundary HSI curve based on that data. All of the literature-based HSI curves, the site-specific HSI observations from Study 9 surveys (SCL 2009b), and the final HSI curve values for all species and life stages can be found in Appendix 9.

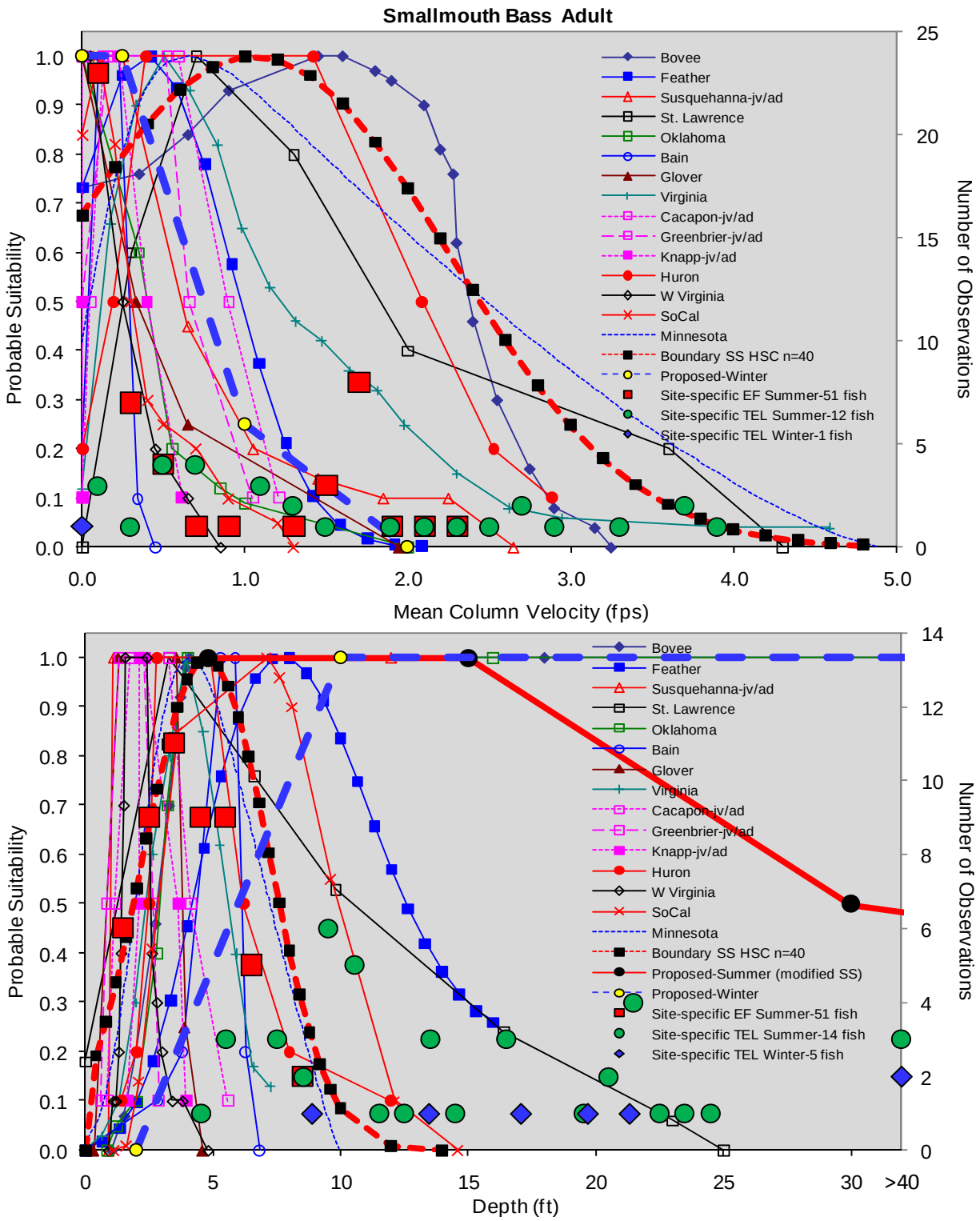



**Figure 4.9-1**. Example of HSI curve-sets for adult smallmouth bass, showing available literature-based HSI values (left axis), site-specific electrofishing (EF) and biotelemetry (TEL) observation frequencies from the Boundary Project area (right axis), and the final Boundary curves.

### 4.9.3. Application of Fish Models

The final HSCs for fish species were used in conjunction with the physical habitat model to determine the WUA and the PSI and ESI widths in Boundary Reservoir for selected species and life stages. An example of the WUA in Boundary Reservoir for adult smallmouth bass is presented in Figure 4.9-2. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for the specified fish species and specified life stage on the y-axis.

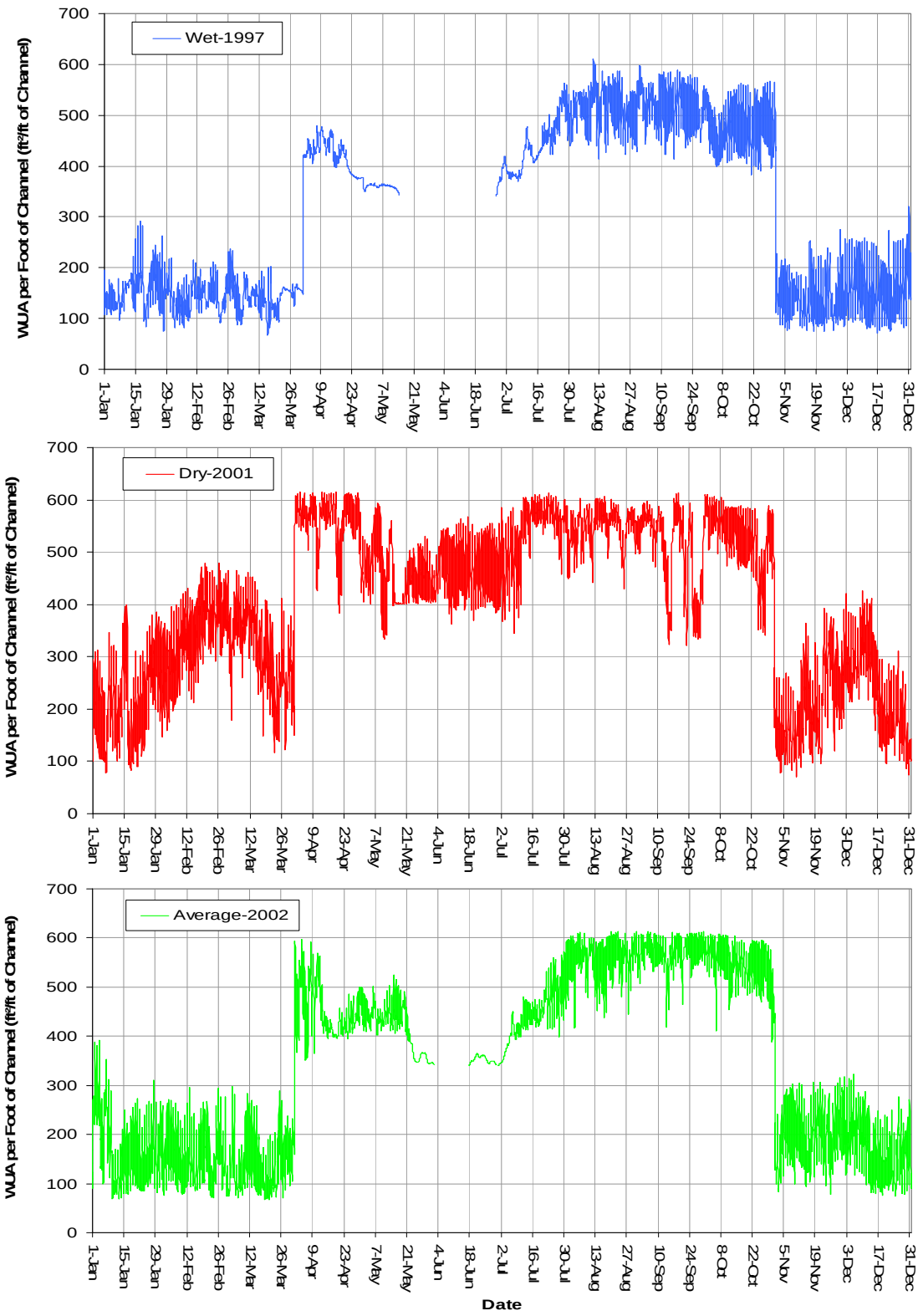



**Figure 4.9-2.** Example of hourly WUA for adult smallmouth bass in the Upper Reservoir Reach by the representative years using winter HSI (November 1 through March 31 and summer HSI during April 1 through October 31).

An example of the PSI and ESI widths calculated for smallmouth bass at habitat transect U-17 in the Upper Reservoir Reach is presented in Figure 4.9-3. The figure presents the spawning period plotted on the x-axis, elevation on the primary (left) y-axis, and spawning widths on the secondary (right) y-axis. Conditions represented by the historic wet year are plotted on top, historic dry year conditions are shown in the middle plot, and the historic average year conditions are shown on the bottom plot. Additional information and modeling results are presented in Section 5.9.

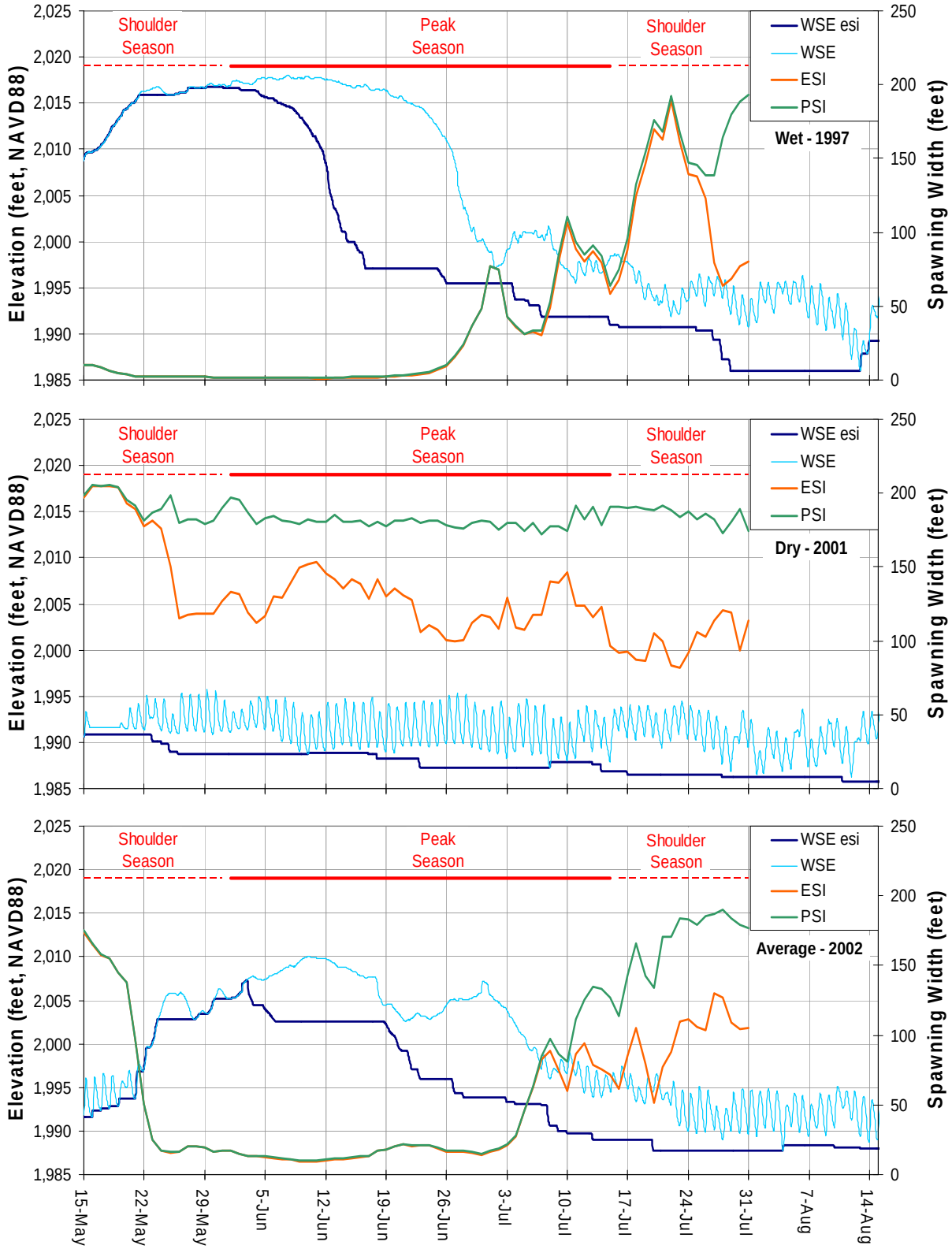



**Figure 4.9-3.** Example of daily PSI and ESI widths for smallmouth bass at habitat transect U-17 during representative wet (1997), dry (2001), and average (2002) years.

# 5 RESULTS

This section provides the results for the nine study components. Additional details on results are presented in the appendices associated with each study component. This section has been organized to concentrate on the presentation of the primary results of the analysis and modeling efforts. The outcome of intermediate steps and field work supporting the primary analysis and modeling efforts are presented in the associated appendices. In some case, such as HSI curves, intermediate results are also summarized in the Methods section for the study component. The results section has been organized in this manner to allow the reader to concentrate on the most important aspects of each effort. If more detailed documentation of the study results is needed, the reader should refer to the appendices (Appendix 1 through Appendix 9). In many cases, the appendices include attachments that provide graphs and tables that were generated by the various habitat models or created from post-processing the output from these models.

The results section in the main body of the report and the portion of the associated appendix that presents additional detail are listed below:

- Section 5.1—Transect-Based and Habitat Descriptors (Appendix 1a, Section 5)
- Section 5.2—Hydraulic Routing Model (Appendix 2, Section 5)
- Section 5.3—Fish Periodicity (Appendix 3, Section 5)
- Section 5.4—Stranding and Trapping Development and Modeling Efforts (Appendix 4, Section 5)
- Section 5.5—Downramping Analysis (Appendix 5, Section 5)
- Section 5.6—Macrophyte Habitat Development and Modeling Efforts (Appendix 6, Section 5)
- Section 5.7—Periphyton Habitat Development and Modeling Efforts (Appendix 7, Section 5)
- Section 5.8—BMI Habitat Development and Modeling Efforts (Appendix 8, Section 5)
- Section 5.9—Fish Habitat Development and Modeling Efforts (Appendix 9, Section 5)

The results presented in this section address historic Project effects using various indices of aquatic habitats. Historic Project effects on aquatic resources were evaluated during three representative years. These years were selected as representative of wet, dry, and average conditions based on average annual flows (R2 Resource Consultants 2008). The wet year is based on 1997, the dry year on 2001, and the average year on 2002. The flow hydrographs for the wet, dry, and average years are plotted in Figures 5.0-1 through 5.0-3, respectively. A comparison of the flow hydrographs across these 3 years is shown in Figure 5.0-4.

An integration of the study results presented in this section into a determination of historic Project effects is developed in Section 6. Development of the baseline condition along with other operation scenarios will be conducted during the IRA process. The baseline condition will be developed using the Scenario Tool and is currently formulated to represent an optimized model of Project operations under existing Project constraints including the voluntary minimum summertime forebay water surface elevation restriction. The historic condition presented in this

report is based on the actual operations that occurred during the representative wet (1997), dry (2001) and average (2002) years. The IRA process has been discussed with relicensing participants throughout the relicensing proceeding and was a main topic of the December 3, 2008, relicensing workshop. Additional meetings were held in January and February 2009, and coordination with relicensing participants will continue through spring and early summer 2009. The results of the IRA effort will be documented in the LA to be filed in September 2009.

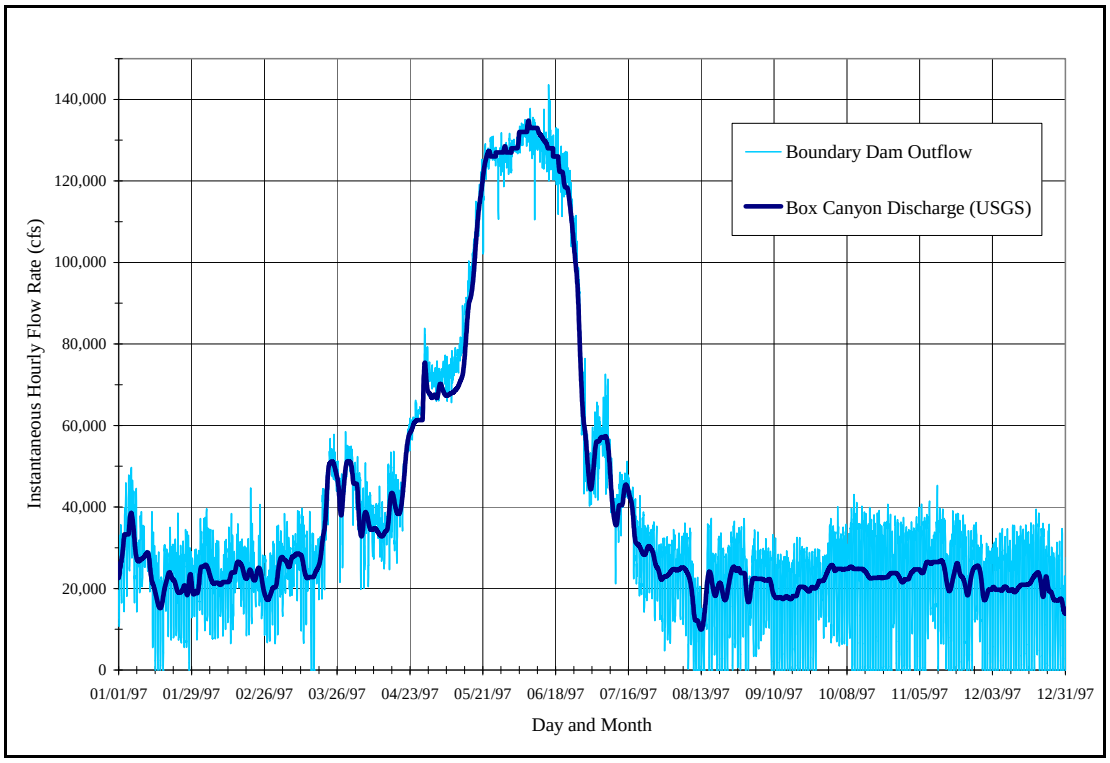



**Figure 5.0-1.** Wet (1997) year hydrographs of flow entering and being discharged from Boundary Reservoir.

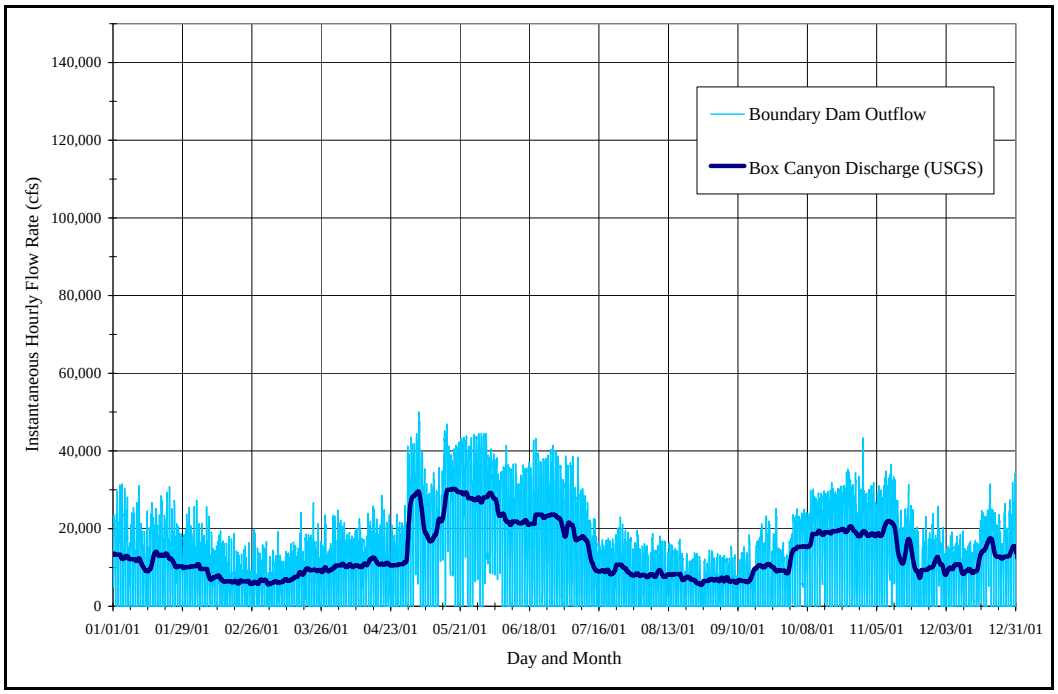



**Figure 5.0-2.** Dry (2001) year hydrographs of flow entering and being discharged from Boundary Reservoir.

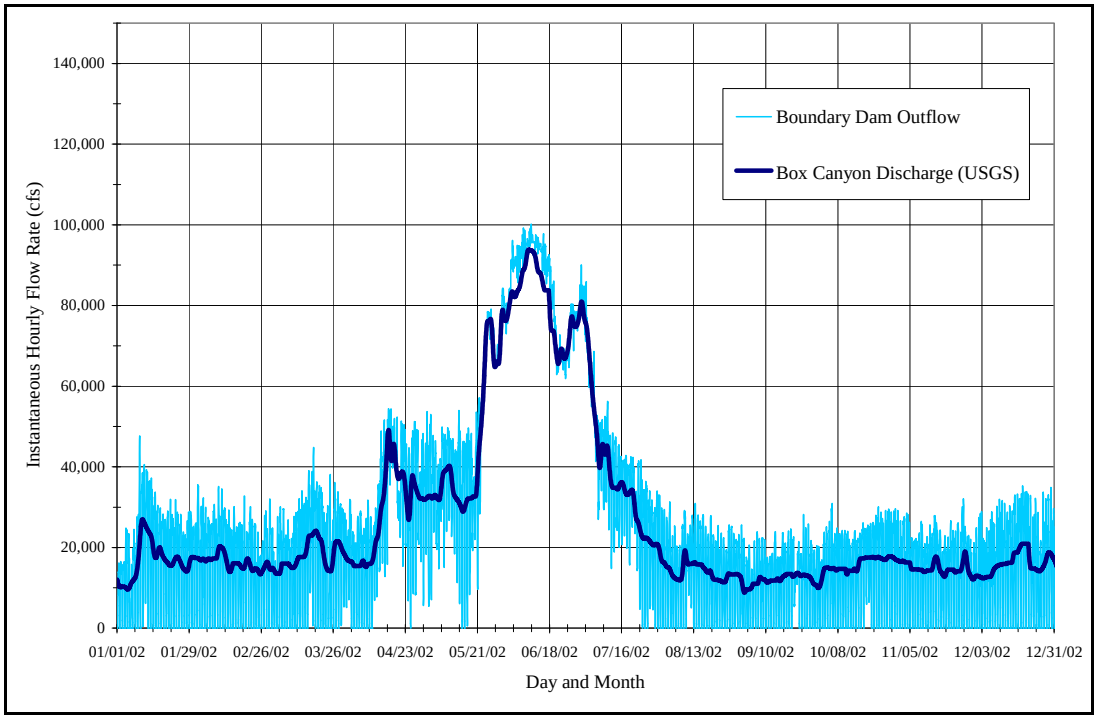



**Figure 5.0-3.** Average (2002) year hydrographs of flow entering and being discharged from Boundary Reservoir.

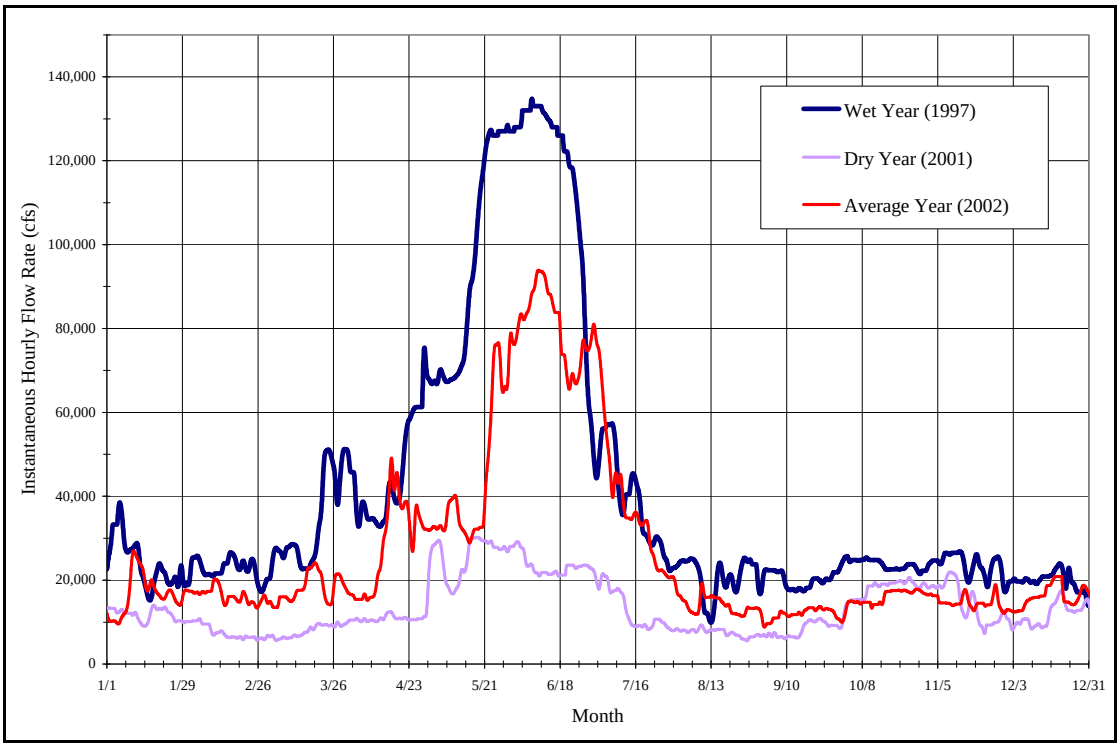



**Figure 5.0-4.** Comparison of wet (1997), dry (2001), and average (2002) year flows entering Boundary Reservoir from Box Canyon Dam.

## 5.1. Transect and GIS–Based Habitat Descriptors

This section presents two types of information that provide much of the physical characterization of the mainstem study area required to perform the Study 7 modeling efforts. This information includes the transect-based data that describe the geometry of the channel bed, hydraulic conditions, and habitat characteristics on a profile taken across the mainstem channel. The other element is the GIS mapping, which provides a two-dimensional plan view of various conditions as well as a three-dimensional surface that provides a detailed model of the bathymetry and topography. The GIS application was used to create a layer depicting the results of the macrophyte mapping surveys and to develop the physical characteristics of the stranding areas and trapping pools. The DTM from the bathymetry and topography was also used to create cross sections for the HRM, which is described in Appendix 2.

Transect locations were identified using methods described in Section 4.1.1; these locations were used as a basis to integrate several layers of physical information. Additional information added to characterization of segments throughout the reservoir included macrophyte bed location and extent, as well as conditions under which stranding and trapping of fish species could occur along the reservoir.

### 5.1.1. Transect-Based Habitat Descriptors

The results section in this report is being used to present results of the modeling and other habitat analysis efforts. The mainstem habitat transects are supporting information. Development of the

mainstem habitat transects was summarized in Section 4.1.1 and complete details are provided in Appendix 1a.

Sixty-three habitat transects were identified using methods described in Section 4.1. The location of transects is provided in Figure 3.0-1; the number of transects in each reach of the Boundary Reservoir is summarized below:

- Forebay Reach—5 transects
- Canyon Reach—20 transects
- Upper Reservoir Reach—24 transects
- Tailrace Reach—14 transects

As discussed in the Section 4.1, each transect was selected with the purpose of representing the habitat in the Pend Oreille River for a specific distance immediately upstream and downstream of its location. Based on the information used in the selection process, representation of distance upstream and downstream of transect location was determined. This distance and the weighting factor applied between transects are provided in Tables 5.1-1 through 5.1-4 of Appendix 1a. Criteria for selection of appropriate velocity patterns for habitat modeling are provided in Tables 5.6-1 and 5.6-2 of Appendix 1a. Velocity patterns, extrapolation of deep water velocity patterns, and N-value calibration notes are provided in Attachments A, B, and C of Appendix 1a.

### 5.1.2. GIS-Based Habitat Descriptors

Several characteristics of habitats along the reservoir margin were identified with geospatial coordinates to develop GIS coverages. These types of habitat presented a risk for stranding and trapping of fish species and associated life stages. Based on analysis of GIS coverages, the trapping pools and physical conditions (such as macrophytes) that would increase the trapping risk of fish species were located. The following sections (Sections 5.1.2.1 and 5.1.2.2) describe preliminary results from this analysis.

#### *5.1.2.1. Macrophyte Mapping*

As part of Study 7 aquatic habitat mapping, field surveys of aquatic plant distribution and abundance data were conducted. These studies were conducted along depth, velocity, and substrate gradients extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions. This portion of the study was designed to map the current aquatic macrophyte coverage within Boundary Reservoir and record location and composition of the macrophyte beds on GIS coverages.

The existing distribution and abundance of macrophytes in the Forebay, Canyon, Upper Reservoir, and Tailrace reaches were assessed during field surveys conducted in August 2007 and August 2008. The macrophyte distribution, abundance, and species present in the various reaches as determined during the macrophyte mapping effort are presented in Appendix 1b.

Macrophyte beds within the reservoir covered 20.7 acres in the Canyon and Forebay reaches and 202.5 acres in the Upper Reservoir Reach upstream of Metaline Falls. Aquatic macrophyte beds, mainly in the Upper Reservoir Reach within low-gradient stranding areas and trapping pools,

covered 25.3 acres. Eurasian watermilfoil (*Potamogeton* species) and coontail (*Ceratophyllum demersum)* were the dominant plant species found in Boundary Reservoir (see Appendix 1b). Curly pondweed appears to be invading areas of established Eurasian watermilfoil beds displacing both Eurasian watermilfoil and coontail in these more established beds. The relative number of macrophyte beds found in the various reaches are further summarized in Appendix 1b (Table A.1b-1).

#### *5.1.2.2. Stranding and Trapping Maps/GIS Factors*

Maps depicting the stranding areas and trapping pools within the study area were developed using GIS. Physical characteristics derived either directly from GIS coverages or GIS-based parameters were the basis for development of site factors used in the stranding and trapping analyses. Characteristics such as area, outlet elevations, and the presences of macrophytes were compiled into a geospatial database. This database provided several inputs used in the stranding and trapping models (see Appendix 1c).

Detailed mapping of potential stranding and trapping regions was developed from the bathymetry of the Boundary Reservoir and tailrace using ArcGIS (version 9.2). The resulting maps served two primary purposes. The first purpose was to aid field efforts in locating and characterizing areas where fish may become stranded or trapped during reduction in water surface elevations. The second purpose was to provide an accurate basis for characterizing the stranding and trapping regions to conduct the modeling effort described in Appendix 4 and Section 4.4 and Sections 5.4.

Based on results from the GIS mapping effort, a summary of the potential stranding area by 1-foot elevation bands for the four reaches (Forebay, Canyon, Upper Reservoir, and Tailrace) are presented below in Figure 5.1-1 and Figure 5.1-2. Potential stranding area within the Forebay Reach can occur from 1,954 to 1,989 feet NAVD 88 (1,950 to 1,985 feet NGVD 29) however the maximum stranding potential for a given 1-foot elevation band occurs when water surface elevations pass through an elevation of 1,977 feet NAVD 88 (1,973 feet NGVD 29). Within the Canyon Reach, the majority of potential stranding occurs between an elevation range of 1,974 to 1,989 feet NAVD 88 (1,970 to 1,985 feet NGVD 29). The potential stranding area within the Upper Reservoir Reach primarily occurs between an elevation range of 1,972 to 1,996 feet NAVD 88 (1,968 to 1,992 feet NGVD 29) with the maximum potential stranding for a single 1-foot elevation band occurring at an elevation of 1,986 feet NAVD 88 (1,982 feet NGVD 29).

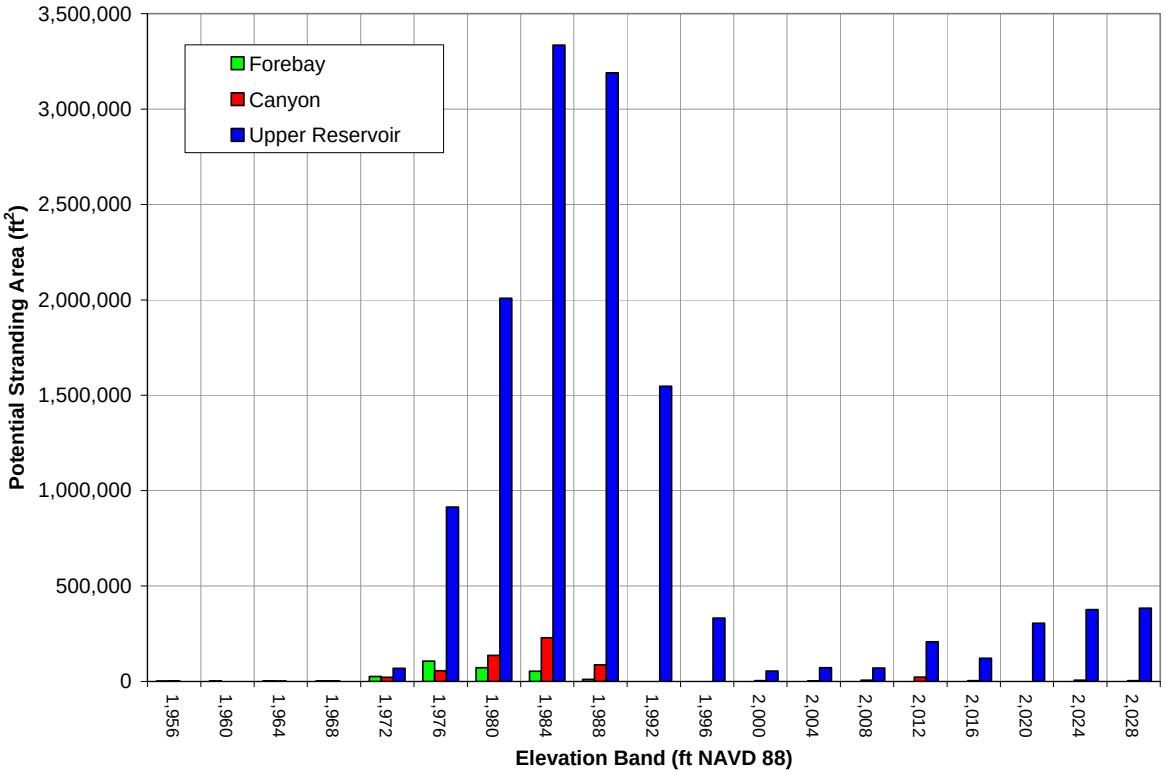



**Figure 5.1-1.** Potential stranding area for a given 1-foot elevation band within the Forebay, Canyon, and Upper Reservoir reaches.

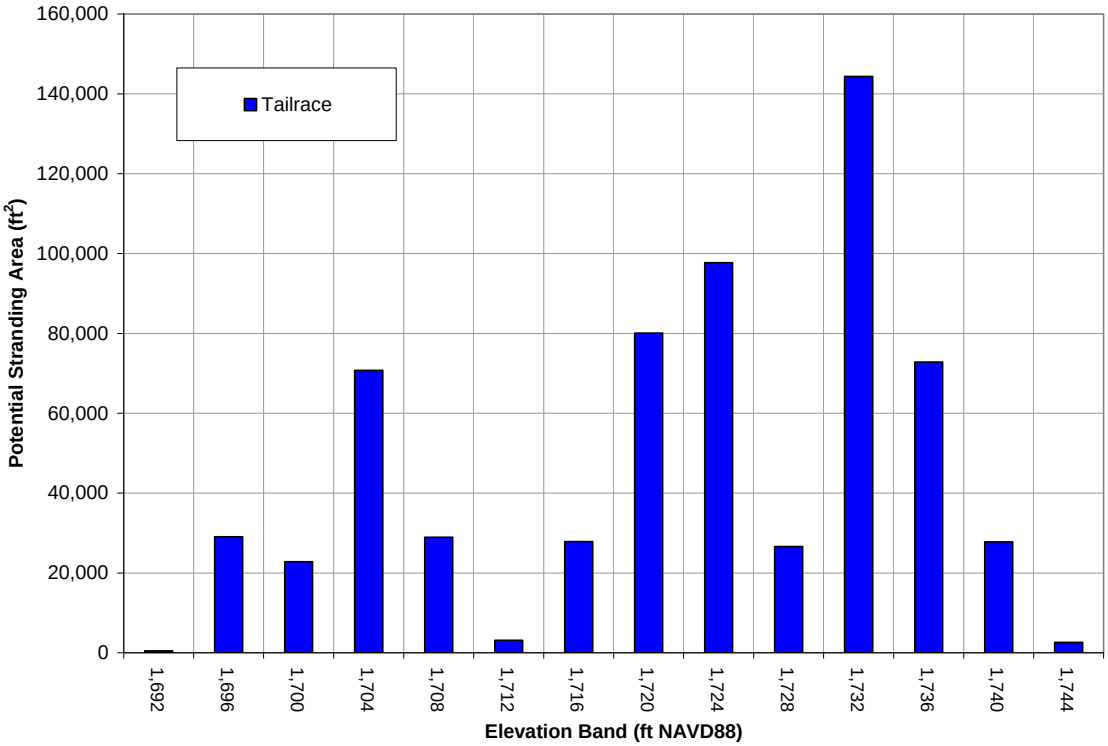


**Figure 5.1-2.** Potential stranding area for a given 1-foot elevation band within the Tailrace Reach.

Figures 5.1-3 and 5.1-4 present the potential trapping pool area versus the controlling trapping pool outlet elevation for the four reaches. Review of the trapping pool area within the Boundary reservoir shows that in the case of the Forebay Reach, the majority of the potential trapping area is located between an elevation of 1,975 feet NAVD 88 (1,971 feet NGVD 29) and 1,979 feet NAVD 88 (1,975 feet NGVD 29). In the case of the Canyon Reach, the potential trapping pool area is concentrated between an elevation of 1,979 feet NAVD 88 (1,975 feet NGVD 29) and 1,984 feet NAVD 88 (1,980 feet NGVD 29). The Upper Reservoir Reach has the largest potential trapping pool area available and the greatest degree of variability across the elevation bands. The potential trapping pool area within the Upper Reservoir Reach is primarily concentrated between 1,979 to 1,994 feet NAVD 88 (1,975 to 1,990 feet NGVD 29) and between the elevation ranges of 2,004 to 2,011 feet NAVD 88 (2,000 to 2,007 feet NGVD 29). Potential trapping pool area in the Tailrace Reach varies across the range of elevations analyzed however the greatest potential trapping pool area resides at an elevation of 1,729 feet NAVD 88 (1,725 feet NGVD 29).

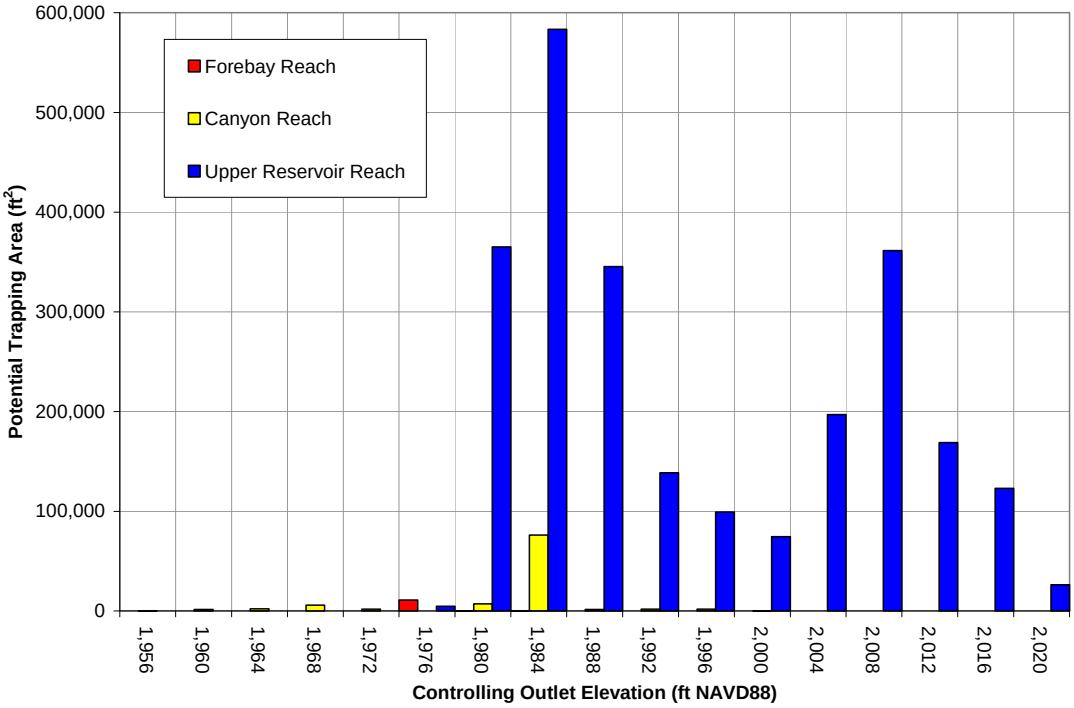



**Figure 5.1-3.** Potential trapping pool area for a given controlling outlet elevation within the Forebay, Canyon, and Upper Reservoir reaches.

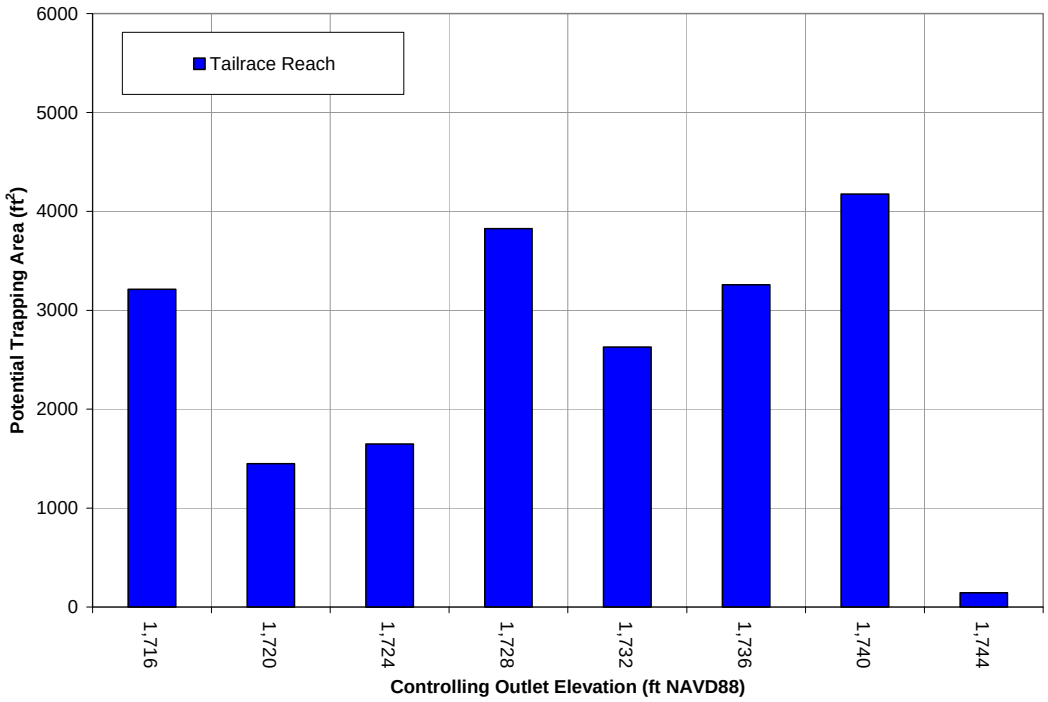



**Figure 5.1-4.** Potential trapping pool area for a given controlling outlet elevation within the Tailrace Reach.

## 5.2. Hydraulic Routing Model Results

The main purpose of the HRM was to provide the hourly water surface elevations and discharges at the habitat transects distributed throughout the study area that support evaluation of Project influences on various resources. The HRM primarily supported the habitat modeling for Study 7 as well as Study 8; to a lesser extent, it also provides information on water surface levels and fluctuations used in a variety of the other Boundary relicensing studies. In Study 7, the HRM provides the hourly water surface elevations and flow rates for the transects for the stranding and trapping analysis, downramping analysis, and the WUA determinations for submerged aquatic macrophytes, benthic macroinvertebrates, periphyton, and fish.

(Note: Throughout this section, the term "influence" is used to indicate a change in a specific hydraulic parameter [such as water surface elevation] at a specific point in the Boundary Reservoir attributed to Project operations.)

The historic hydrologic record was used to develop HRM runs for the wet, dry, and average years. The resulting hourly water surface elevations and flow rates are post-processed by the routines developed for evaluation of habitat indices such as the WUA calculations and other indicators of Project influences such as the downramping analysis. However, in addition to supporting the habitat analyses, the results of the HRM are useful in understanding the hydraulic conditions within the study area. A general understanding of these conditions and the influence of both the Project and natural riverine features on hydraulic conditions throughout the study area provides valuable insight for interpreting results of the habitat analyses.

The first portion of this section (Section 5.2.1) presents example HRM output from each of the three representative hydrologic years and a brief interpretation of the output. The second portion of Section 5.2 (Section 5.2.2) includes the results of HRM determination of wetted width and wetted surface area for a range of operational and hydrologic conditions. The third and fourth portions of Section 5.2 (Sections 5.2.3 and 5.2.4) present a variety of model results that are used to provide an understanding of the hydraulic behavior of the Pend Oreille River throughout the study area, culminating in the analysis of Project influence. Section 5.2.3 is dedicated to Boundary Reservoir and Section 5.2.4 is dedicated to Boundary tailrace. Aspects of the hydraulic behavior of the system that are addressed in Sections 5.2.3 and 5.2.4 include the following:

- Variation of flow rates throughout the Project resulting from Project operations and the ability of the HRM to model these "un-steady" flow conditions.
- The influence of natural hydraulic controls, particularly Metaline Falls, and their interaction with Project operations in shaping hydraulic conditions within portions of the study area.
- Water surface profiles that result from various combinations of forebay elevations and reach inflows (in the case of reaches upstream of Boundary Dam, the inflows are the releases from Box Canyon and the forebay elevation are those at Boundary Dam. For the Tailrace Reach below Boundary Dam, the inflows are the releases from the Project and the forebay elevations are those at Seven Mile Dam).
- The level of Project influence on water surface elevations and velocities and how the influence varies for a variety of Project inflow and forebay elevations.
- The varying response to Project influences based on distance upstream of the Project (Forebay, Canyon, and Upper Reservoir reaches) or distance downstream of the Project (Tailrace Reach).

Due to the large number of figures developed to present the results of the Project influence analysis, only a select number of example figures are included in this main report. All the figures for the Project influence analysis are included in Appendix 2.

### 5.2.1. Hydraulic Analysis of Representative Hydrologic Years

The calibrated Boundary Reservoir HRM and the calibrated Boundary Tailrace HRM were run for each of the three representative hydrologic years, using historical data compiled specifically for the relicensing studies. The years were selected to represent a wet year, a dry year, and an average year. The determination of the representative hydrologic years is documented in R2 Resource Consultants (2008) and was based on a relative comparison of the average annual flows as measured at USGS gage 12396500 for the 19-year period of record (1987–2005). The representative hydrologic years are calendar years and are defined as follows:

- Representative Wet Year—1997
- Representative Dry Year—2001
- Representative Average Year—2002

This section first presents the hydrologic input to the Boundary Reservoir HRM and the Boundary Tailrace HRM Boundary. Then, this section provides a cursory review of the model

output for each of three years. The output presented in this section of the report is intended strictly as an introduction to the hydraulic behavior of the Pend Oreille River upstream and downstream of Boundary Dam.

#### *5.2.1.1. Model Input*

Hourly input to the Boundary Reservoir HRM included the following hydrologic data, each of which was input to the model as a time series of instantaneous hourly data at the open boundaries of the hydraulic model:

- **Flow rate below Box Canyon Dam at USGS gage 12396500.** These instantaneous hourly data were developed from raw 15-minute data provided by the USGS. The data were smoothed to be consistent with reported daily average flows and were input as the upstream inflow to the Boundary Reservoir HRM
- **Flow rate for each of the named and unnamed tributaries between Box Canyon Dam and Boundary Dam.** These instantaneous hourly flow data were synthesized using stream gage records from Sullivan Creek and the Salmo River. The procedure used to synthesize the flow records for the named and unnamed tributaries is documented in R2 Resource Consultants (2008). These data were input into the model as tributary inflows.
- **Boundary Dam Forebay elevation.** These instantaneous hourly data were developed from average hourly data and were input as a downstream water surface elevation time series in the Boundary Reservoir HRM.

Hourly input to the Boundary Tailrace HRM included the following hydrologic data, each of which was input to the model as an hourly time series of data at the open boundaries of the hydraulic model:

- **Boundary Dam outflow.** These instantaneous hourly data were developed from average hourly data provided by SCL and were input as the upstream inflow to the Boundary Tailrace HRM.
- **Flow rate for Salmo River.** These instantaneous hourly data were developed from synthesized average Salmo River stream gage data and were input into the model as a tributary inflow.
- **Seven Mile Dam Forebay elevation.** These instantaneous hourly data were input as a downstream water surface elevation time series in the Boundary Tailrace HRM.

Tables 5.2-1 and 5.2-2 present a statistical side-by-side summary of the hydrologic data used as input to the Boundary Reservoir HRM and Boundary Tailrace HRM, respectively. Statistical summaries of the hydrologic conditions during each of the three years are included in each table. As a side note, according to R2 Resource Consultants (2008), the long-term average annual flow rate below Box Canyon Dam at USGS gage 12396500 for the 94-year period of record is 26,370 cfs.

Figure 5.2-1 is a comparative plot of the annual flow hydrographs (using instantaneous hourly data) in the Pend Oreille River downstream of Box Canyon Dam, as measured at USGS gage 12396500. These hydrographs were input into the upstream boundary condition of the Boundary

Reservoir HRM. Figure 5.2-2 is a comparative plot of the annual Boundary Dam outflow hydrographs (using instantaneous hourly data).

**Table 5.2-1.** Comparison of hydrologic input data summary statistics for Boundary Reservoir HRM for wet, dry, and average years.

| Hydrologic Condition | Calendar Year 1997 (Wet Year) | Calendar Year 2001 (Dry Year) | Calendar Year 2002 (Average Year) |
|---|---|---|---|
| **Flow Rate at USGG Gage 12396500 (cfs)** | | | |
| Maximum Hourly Flow | 134,776 | 30,244 | 93,881 |
| 10% Exceedance Hourly Flow | 108,890 | 23,238 | 67,100 |
| Average Hourly Flow | 40,387 | 13,414 | 26,203 |
| Median Hourly Flow | 24,800 | 10,723 | 16,873 |
| 90 % Exceedance Hourly Flow | 18,935 | 6,592 | 12,418 |
| Minimum Hourly Flow | 9,911 | 5,510 | 8,788 |
| **Boundary Dam Forebay (feet NAVD 88)** | | | |
| Maximum Hourly Stage | 1,994.92 | 1,994.43 | 1,994.63 |
| 10% Exceedance Hourly Stage | 1,992.79 | 1,992.97 | 1,992.74 |
| Average Hourly Stage | 1,989.67 | 1,989.35 | 1,989.25 |
| Median Hourly Stage | 1,989.94 | 1,990.35 | 1,989.58 |
| 90% Exceedance Hourly Stage | 1,986.06 | 1,984.45 | 1,985.22 |
| Minimum Hourly Stage | 1,976.98 | 1,963.20 | 1,974.59 |

**Table 5.2-2.** Comparison of hydrologic input data summary statistics for Boundary Tailrace HRM for wet, dry, and average years.

| Hydrologic Condition | Calendar Year 1997 (Wet Year) | Calendar Year 2001 (Dry Year) | Calendar Year 2002 (Average Year) |
|---|---|---|---|
| **Boundary Dam Outflow (cfs)** | | | |
| Maximum Hourly Flow | 143,580 | 50,072 | 100,181 |
| 10% Exceedance Hourly Flow | 111,185 | 30,508 | 66,940 |
| Average Hourly Flow | 40,710 | 13,898 | 26,914 |
| Median Hourly Flow | 30,348 | 13,087 | 22,109 |
| 90 % Exceedance Hourly Flow | 7,908 | 0 | 127 |
| Minimum Hourly Flow | 0 | 0 | 0 |
| **Seven Mile Dam Forebay (feet NAVD 88)** | | | |
| Maximum Hourly Stage | 1,734.41 | 1,733.53 | 1,734.09 |
| 10% Exceedance Hourly Stage | 1,733.00 | 1,730.08 | 1,732.22 |
| Average Hourly Stage | 1,727.56 | 1,725.17 | 1,725.52 |
| Median Hourly Stage | 1,728.44 | 1,726.05 | 1,726.21 |
| 90% Exceedance Hourly Stage | 1,720.90 | 1,718.99 | 1,717.85 |
| Minimum Hourly Stage | 1,706.13 | 1,707.38 | 1,703.05 |

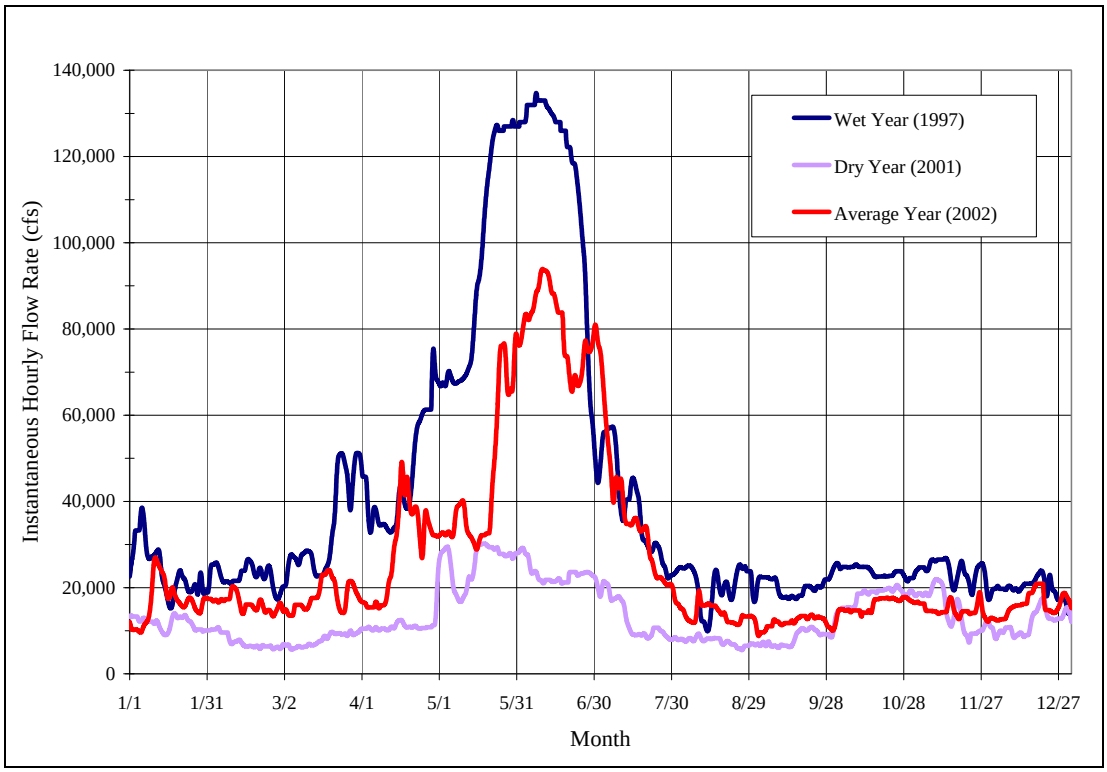



**Figure 5.2-1.** Annual flow hydrographs for Pend Oreille River downstream of Box Canyon Dam at USGS gage 12396500 for representative hydrologic years.

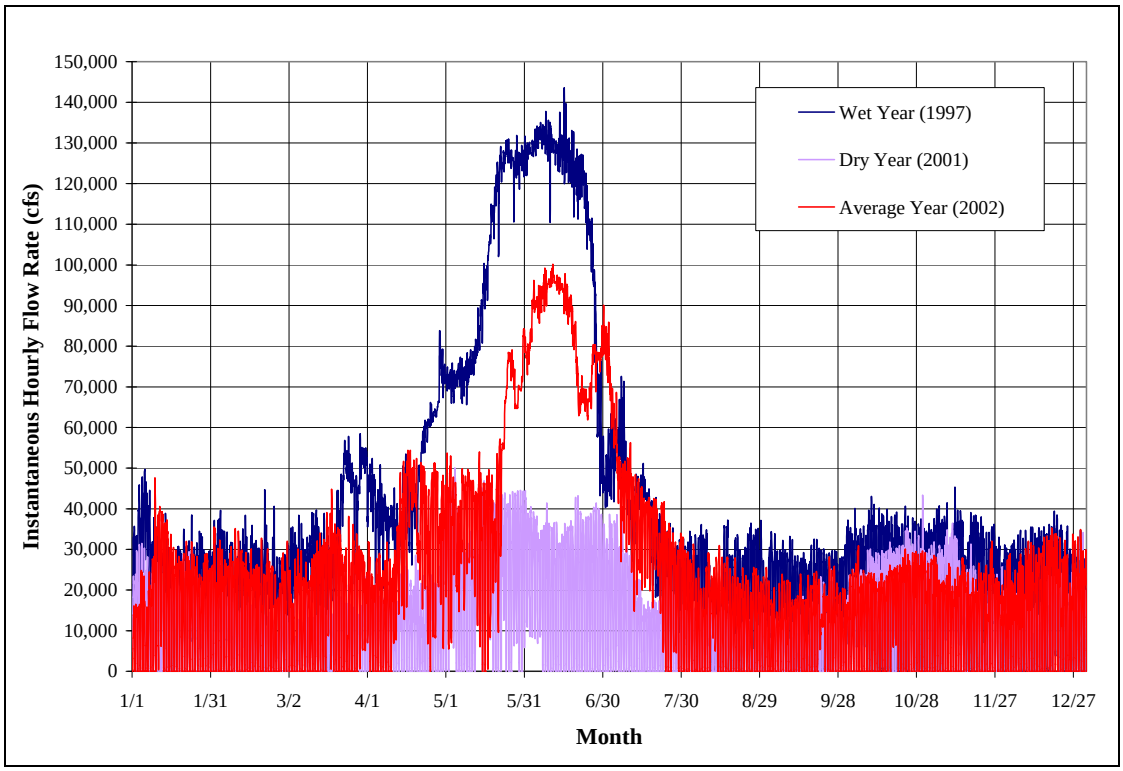



**Figure 5.2-2.** Annual flow hydrographs for Pend Oreille River downstream of Boundary Dam for representative hydrologic years.

#### 5.2.1.2. Interpretation of Model Output

Output from the Boundary Reservoir HRM and the Boundary Tailrace HRM is hourly time series of water surface elevation and flow rate at locations throughout Boundary Reservoir and Boundary Tailrace for each of the three hydrologic years.

The model output is also useful in providing an understanding of the dynamic hydraulic behavior of the Pend Oreille River within the Project area. This understanding is important when interpreting analyses results (i.e., downramping, stranding and trapping, and WUA) that are presented throughout this report. Therefore, in this section, model output is first presented to provide a sense of the overall hydraulic behavior of the portion of the Pend Oreille River within the Project area. Because the Mainstem Aquatic Habitat Model analysis considered conditions associated with flows less than or equal to 80,000 cfs, the discussion of hydraulic behavior in this section also focused on the conditions associated with flows less than or equal to 80,000 cfs. Specific topics that are addressed in this section include:

- When flows are less than or equal to 55,000 cfs (approximate turbine capacity of the Project), water surface fluctuations in Boundary Reservoir are primarily the result of fluctuating forebay elevations produced by Project operations and changes in inflow conditions. As flows increase above 55,000 cfs, water surface fluctuations in the Boundary forebay are reduced.

- Water surface fluctuations in the Boundary tailrace are the product of Project operations, namely fluctuating Project discharges, and Seven Mile Dam operations, namely fluctuations in Seven Mile Dam forebay elevations.

- The amplitude of the water surface fluctuation varies depending upon the location in the reservoir and the location in the tailrace. For example, in the Boundary Reservoir, the amplitude of a daily fluctuation gradually decreases through the Canyon Reach and the Upper Reservoir Reach. Upstream of Metaline Falls, there is a sharp reduction in this amplitude.

- When flow conditions in Boundary Reservoir are less than or equal to 55,000 cfs (approximate turbine capacity of the Project), the flow rate at a specific point-in-time can be highly variable throughout Boundary Reservoir and the Boundary Tailrace. This is due to the dynamically changing conditions associated with Project operations. As flows in Boundary Reservoir increase above 55,000 cfs, the Project ceases to operate in a load following mode and outflow from the Project is typically equal to the inflow. During these conditions, the flow rate throughout Boundary Reservoir and Boundary Tailrace is less variable.

- The morphology of the Pend Oreille River, including such natural hydraulic controls as Metaline Falls, influence how the water surface fluctuations that originate in the

forebay respond at other locations in Boundary Reservoir. Similarly, the morphology of the Pend Oreille River downstream of Boundary Dam influences how the water surface elevation fluctuations that originate in the forebay of Seven Mile Dam and in the tailrace of Boundary Dam respond at other locations in the Tailrace Reach.

#### *5.2.1.2.1. Boundary Reservoir*

Figures 5.2-3 through 5.2-6 are used as an introduction to the above topics specifically as they relate to Boundary Reservoir. Figures 5.2-3 through 5.2-5 include model output from the Boundary Reservoir HRM for the month of July for each of the three hydrologic years. Water surface elevations are shown at four locations in the Boundary Reservoir—in the forebay of Boundary Dam, immediately downstream of Metaline Falls, immediately upstream of Metaline Falls, and in the Box Canyon tailrace. The flow rate as measured at USGS gage 12396500, which as mentioned previously was an input parameter to the model, is plotted on the secondary y-axis of these figures. Figure 5.2-6 includes model output in the form of flow rates at the same four locations in Boundary Reservoir, including the flow rate as measured at USGS gage 12396500. The timeframe for Figure 5.2-6 is July 2002 (average year).

Reviewing the first three figures together, it is seen that water surface elevations throughout Boundary Reservoir fluctuate or change in response to both inflow conditions and Project operations. When incoming flows are less than the 55,000 cfs turbine capacity, the Project is operated in a load following mode resulting in a daily pattern of drawing down the reservoir during the day and refilling at night. When incoming flows exceed 55,000 cfs, the Project begins to spill excess volume and daily fluctuations in Boundary forebay are greatly reduced.

For example, during the first week of July 1997, flow rates into the reservoir were approximately equal to the generation capacity of the Project (55,000 cfs) and fluctuations at the forebay were minimized. By the end of the month, when the inflow rate dropped to approximately 25,000 cfs, daily fluctuations in the Boundary forebay resumed. A similar trend is seen during July 2002 (Figure 5.2-5). In 2002, the spring runoff extended into the early part of July and as a result water surface fluctuations in the Boundary forebay were minimal during the early part of the first week of July 2002. However, the water surface elevations at the three upstream locations are changing primarily in response to the changing conditions in flow rate. Downstream of Metaline Falls, the water surface is seen to be influenced by both the fluctuating forebay elevation and the gradually reducing inflow rate. However, at the two locations upstream of Metaline Falls, the water surface is primarily responding to just the gradual reduction in inflow as the hydrograph recedes. Figure 5.2-4 (July 2001) illustrates the fluctuations in water surface elevation during a period when inflows were less than the turbine capacity of the Project. The daily fluctuation cycle at the Project is evident throughout the month. However, the higher flow rate during the first two weeks allowed the Project to operate with a wider range of forebay fluctuation. Later in the month, as flows dropped below 10,000 cfs, fluctuations in the forebay were reduced to roughly a four foot range as there was a reduced volume of water available for daily refilling of the reservoir.

In all three of these figures, the amplitude of the water surface fluctuation is also seen to decrease in magnitude as distance from Boundary Dam increases. This is most evident when the Project is operating with daily fluctuations as seen in the plot for July 2002 (Figure 5.2-5). Throughout

the last three weeks of the month, the amplitude of the daily water surface elevation fluctuation in the Boundary forebay ranged between 7 and 10 feet. However, the amplitude of the responding fluctuation in the Box Canyon Dam tailrace is significantly less at no more than approximately 3 feet. A similar trend is seen during the first week of July 2001 (dry year). On the other hand, a contrasting condition is seen during the last two weeks of July 2001. Here, the daily fluctuations in Box Canyon tailrace nearly mimic the daily fluctuations in the Boundary forebay. During this period in July 2001, high water surface elevations in the Boundary forebay combined with a relatively low flow condition drown out and negate the hydraulic influence of Metaline Falls. This resulted in the entire 17.5-mile reach of the Pend Oreille River upstream of Boundary Dam responding directly to the influence of fluctuations of the Boundary forebay water surface elevation.

As will be discussed in more detail in Section 5.2.3, Metaline Falls, localized hydraulic controls in the Upper Reservoir Reach, and the general morphology of the Pend Oreille River all influence how the water surface elevation fluctuations originating in the Boundary forebay respond at other locations in the river. The degree of influence of these features is a function of inflow rate and the Boundary forebay elevation.

Finally, the other output that the Boundary Reservoir HRM supplied to the various relicensing study analyses was hourly flow rates at each of the habitat transect locations. The daily fluctuations in the Boundary forebay water surface combined with the variable outflow conditions from Box Canyon Dam creates a complex dynamic condition whereby the magnitude of the flow rate through the length of the reservoir at a specific point in time is rarely constant. Figure 5.2-6 illustrates typical dynamic flow conditions in Boundary Reservoir using HRM output for July 2002. This figure shows the hourly flow rate at four locations in the reservoir—Boundary forebay, immediately downstream of Metaline Falls, immediately upstream of Metaline Falls, and in the Box Canyon tailrace. At the upstream end of the reservoir, the flow hydrograph (Box Canyon outflow) is gradually varied; however, in the Boundary forebay, the flow rate is seen to rapidly change on a daily basis in response to Project operations. Brief periods are seen at the end of the month when the flow rate is near-zero as the Project completes the refill cycle. During this month, it is seen that there is rarely a point in time when the flow rate is equal at each of the four locations.

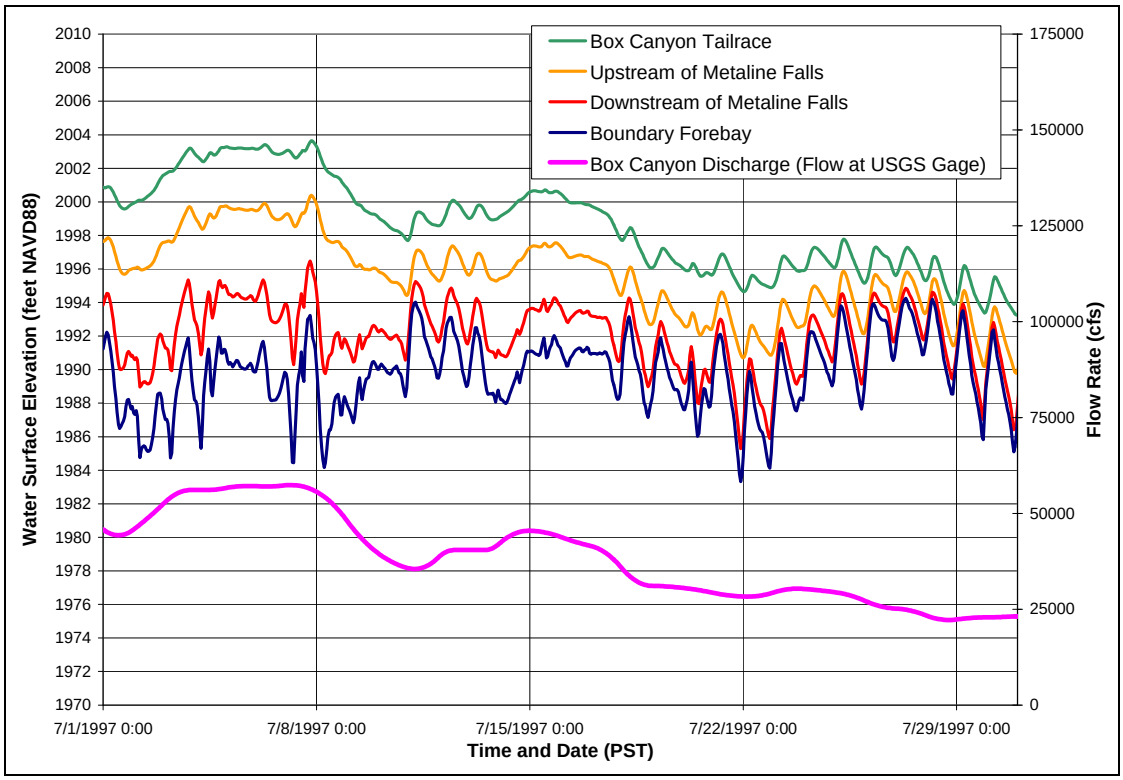



**Figure 5.2-3.** Boundary Reservoir HRM hourly water surface elevations for July 1997 (wet year).

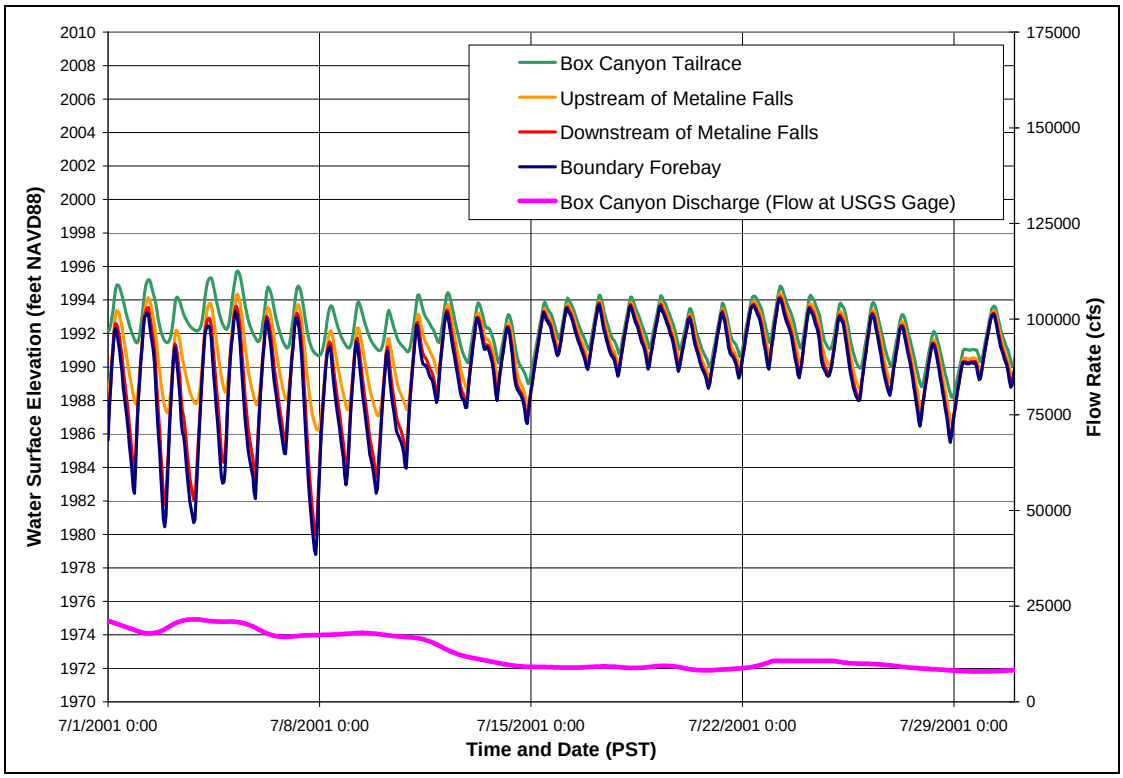



**Figure 5.2-4.** Boundary Reservoir HRM hourly water surface elevations for July 2001 (dry year).

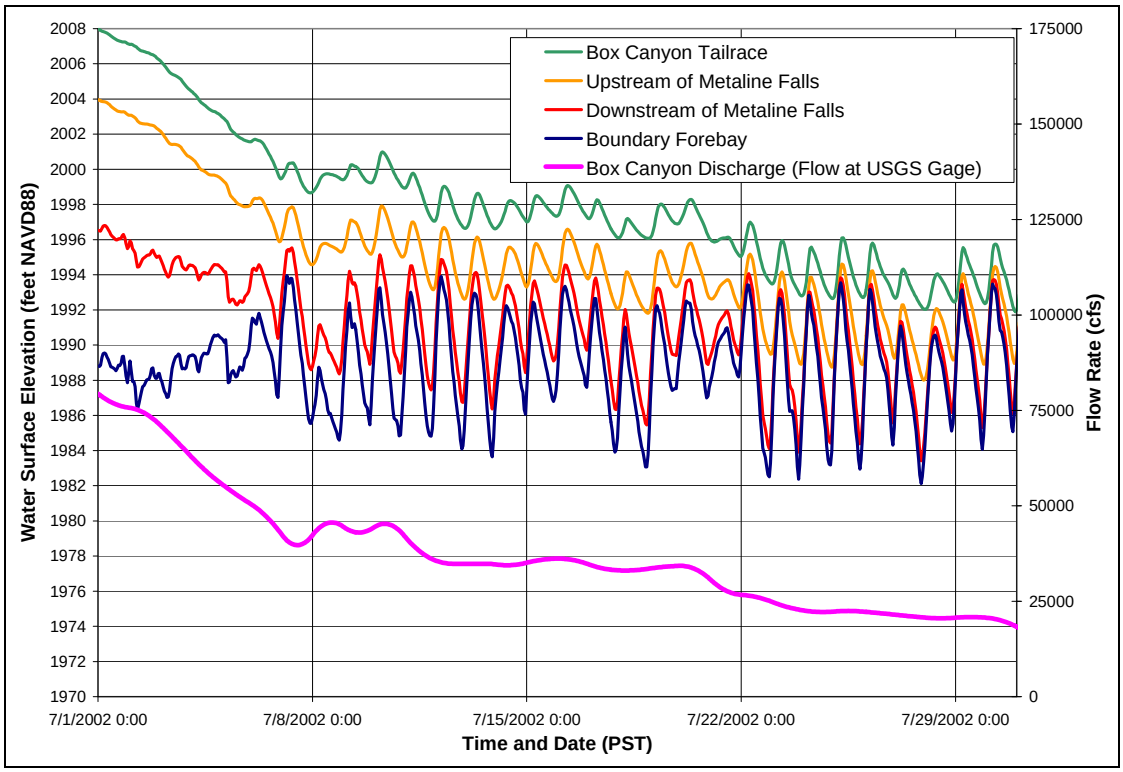



**Figure 5.2-5.** Boundary Reservoir HRM hourly water surface elevations for July 2002 (average year).

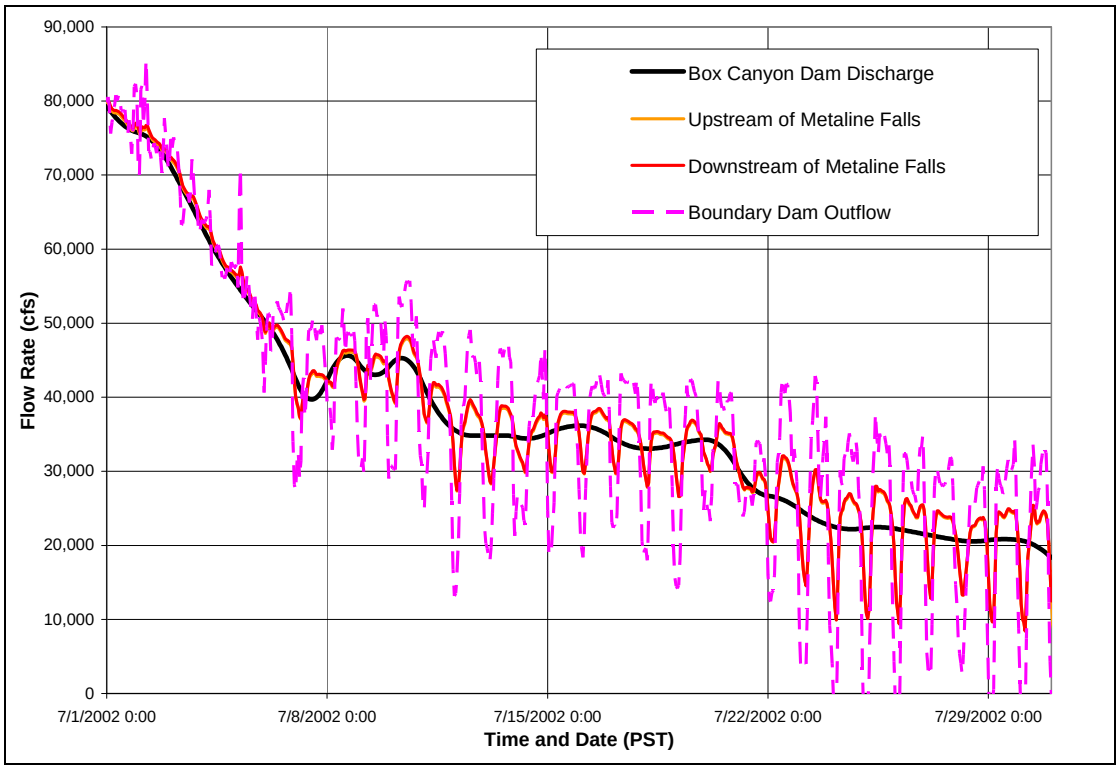



**Figure 5.2-6.** Boundary Reservoir HRM hourly flow rates for July 2002 (average year).

#### 5.2.1.2.2. Boundary Tailrace

As was done for Boundary Reservoir, Boundary Tailrace HRM output for the month of July for each of the three hydrologic years is used as the basis for an introductory discussion of the hydraulic behavior of the Tailrace Reach (Figures 5.2-7 through 5.2-10). In each of the first three figures, water surface elevations at hourly increments are shown for two locations in the Tailrace Reach: at the U.S.-Canada Border (PRM 16.0) and in the Boundary tailrace (PRM 17.0). The water surface elevation at the Seven Mile Dam forebay is also included in each figure and the Project outflow is shown at the bottom of each figure and is plotted on the secondary y-axis. Both of these time data were boundary condition inputs to the Boundary Tailrace HRM.

Reviewing the first three figures together, it is seen that the magnitude of the water surface elevation and the degree of water surface fluctuation occur in response to both changing Project outflows and to changing Seven Mile Dam forebay elevations. Unlike in the Boundary Reservoir, both of the two contributing causes of fluctuations in water surface elevations in the Boundary tailrace can exhibit large daily fluctuations in magnitude; further complicating the already complex hydraulic behavior in this portion of the Pend Oreille River.

Because the Project operates in a load-following mode, the outflow hydrograph from the Project is generally characterized by a series of daily peaks that occur during the daylight hours. This trend is best illustrated in Figure 5.2-8 of July 2001 (dry year) when the daily cycle of outflow is most evident. This daily cycle of discharges from the Project results in a cycle of daily increases in water surface elevation in the Tailrace Reach. At the same time, the forebay elevation in Seven Mile Dam is also fluctuating on a more or less daily cycle. High Seven Mile Dam forebay elevations can cause a backwater effect that extends up to the Boundary tailrace, further influencing the water surface elevation. If the forebay elevation in Seven Mile Dam drops low enough, backwater influence becomes negligible and the only influence on water surface elevations in the Tailrace Reach becomes Boundary Dam outflows.

A clear illustration of the interaction of these two influence occurred during the first week of July 2001 (Figure 5.2-8).The first six daily cycles show the water surface elevation in the Boundary tailrace consistently rising to a peak of approximately 1,736 feet NAVD 88 (1,732 feet NGVD 29) in response to daily cycles of Boundary Dam outflow that peak at approximately 35,000 cfs. At the same time, the forebay elevation at Seven Mile Dam is fluctuating with no apparent effect on the water surface elevation at Boundary tailrace. On the last cycle, the forebay elevation at Seven Mile is increased high enough to cause an increase in the peak water surface elevation at Boundary tailrace. Furthermore, the figure shows that the daily peak elevation attained in the Boundary Dam tailrace throughout the entire month is primarily influenced by the magnitude of the peak outflow from the Project. Throughout the first three weeks, the generally decreasing trend of daily peak elevations follows closely with the generally decreasing trend of peak outflows from the Project.

In the Tailrace Reach, there are two natural hydraulic controls located within 16,000 feet of Boundary Dam that influence the hydraulic behavior in this reach much in the same way that Metaline Falls influences the hydraulic behavior in the Boundary Reservoir. This topic is discussed in more detail in Section 5.2.4.

Finally, the other output that the Boundary Tailrace HRM supplies to the various relicensing study analyses is hourly flow rates at each of the habitat transect locations. As seen in the previous water surface elevation plots, the flow conditions in the Boundary Tailrace are typically represented by a series of daily outflow hydrographs resulting from the load following generation pattern of Boundary Dam. Seven Mile Dam also operates in a similar pattern with daily fluctuations in outflow. The operation of the two dams results in variable flow conditions on a daily scale throughout the Tailrace Reach, as illustrated in Figure 5.2-10. This figure illustrates the daily fluctuations in flow rate at two locations in the Tailrace Reach: Boundary Dam tailrace and the U.S.-Canada border. Seven Mile Dam outflows are also included in the figure.

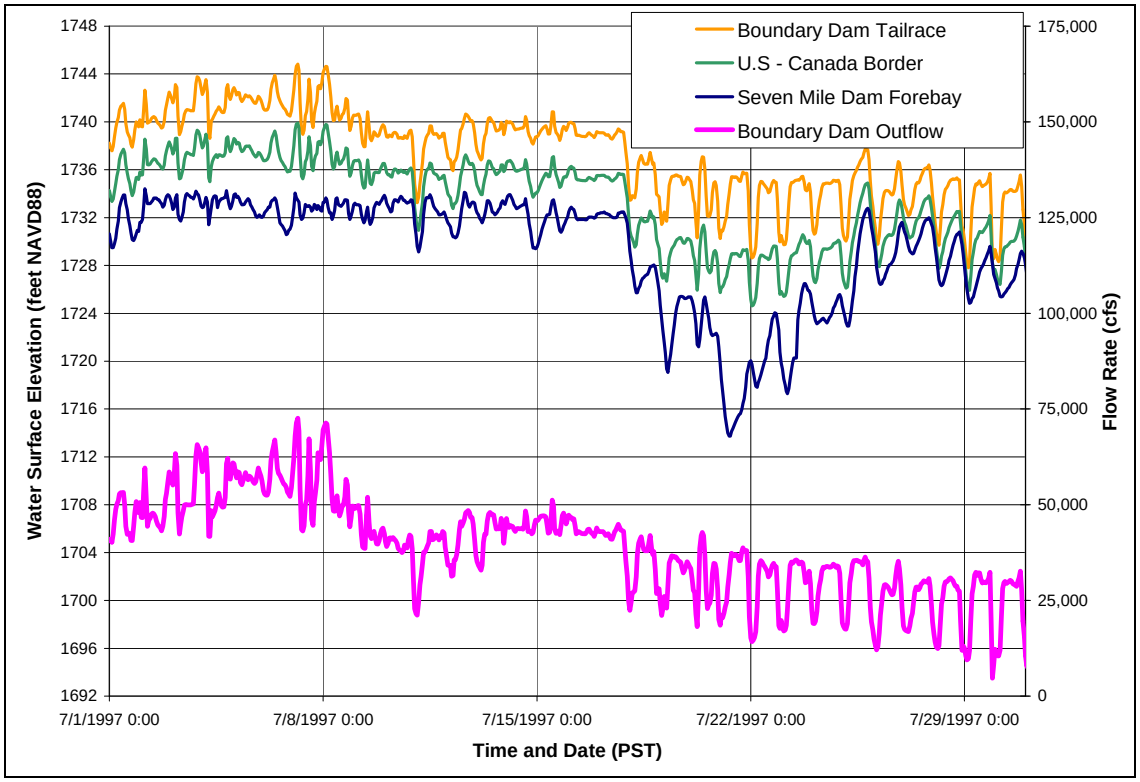



**Figure 5.2-7.** Boundary Tailrace HRM hourly water surface elevations for July 1997 (wet year).

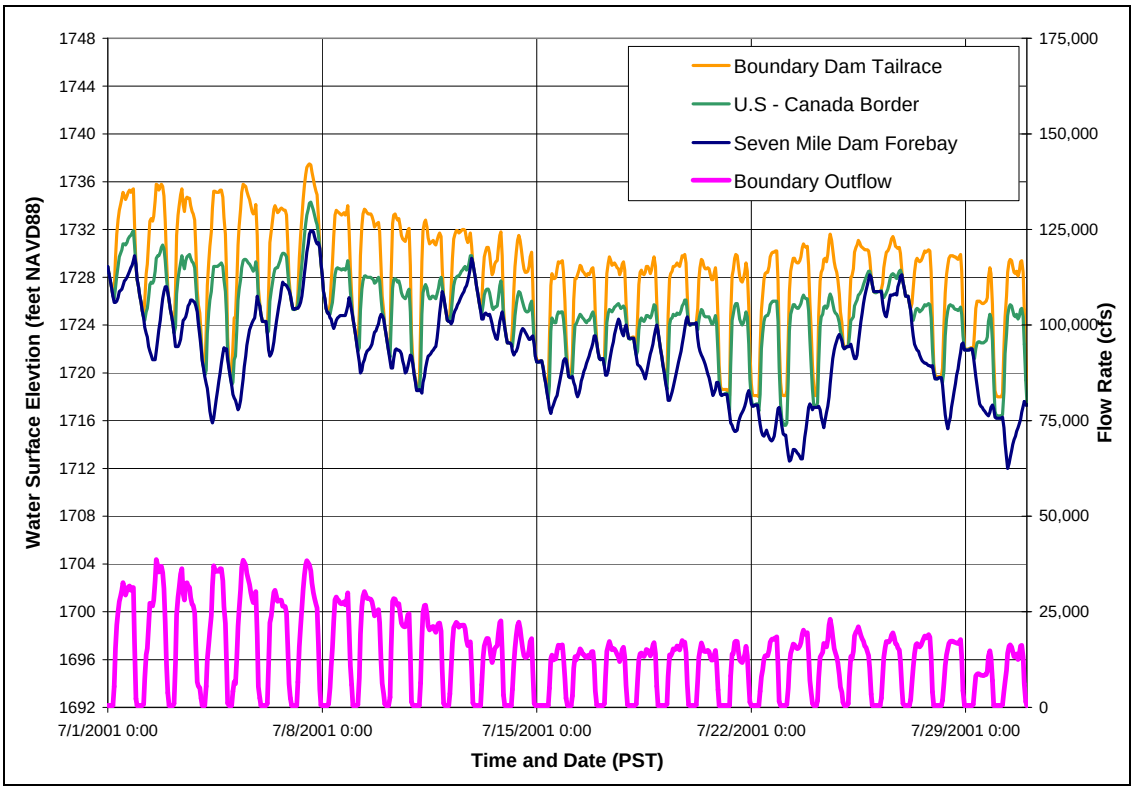



**Figure 5.2-8.** Boundary Tailrace HRM hourly water surface elevations for July 2001 (dry year).

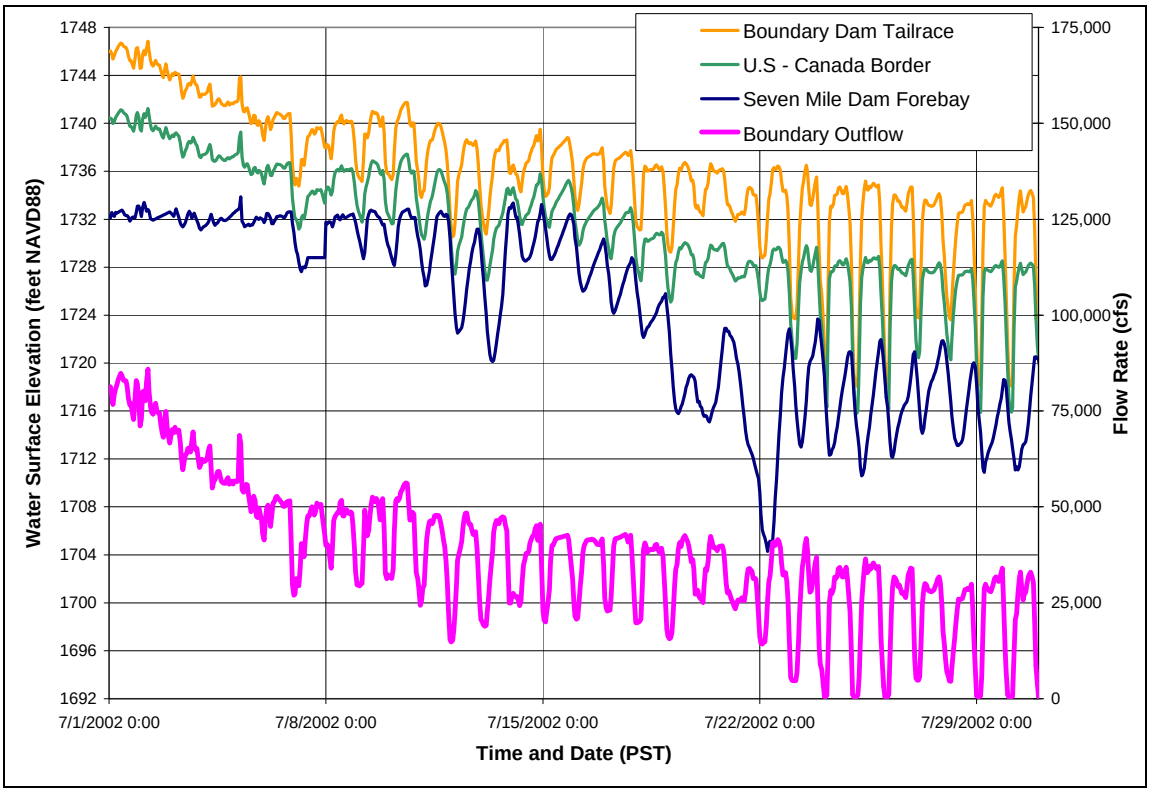



**Figure 5.2-9.** Boundary Tailrace HRM hourly water surface elevations for July 2002 (avg. year).

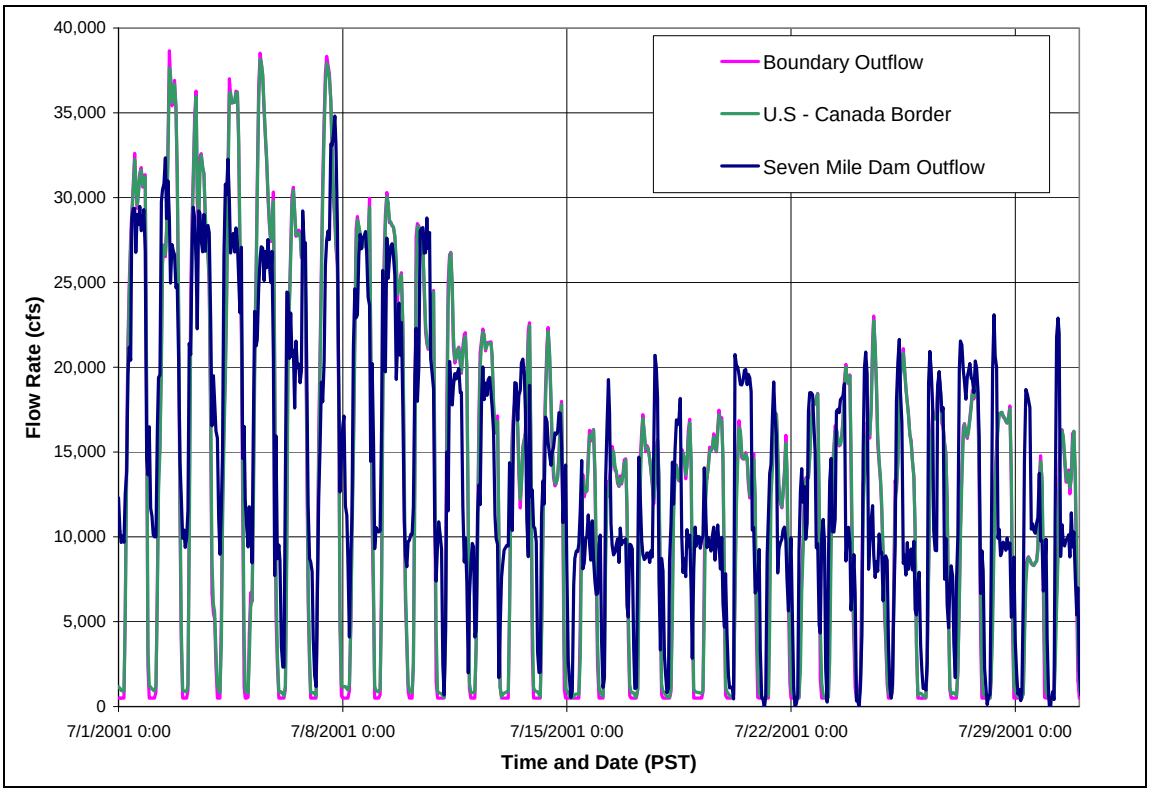



**Figure 5.2-10.** Boundary Tailrace HRM hourly flow rates for July 2001 (dry year).

### 5.2.2. Wetted Width and Wetted Surface Area in Reservoir and Tailrace

This section includes description of the variability of specific habitat related hydraulic characteristics in the Boundary Reservoir and the Boundary Tailrace, namely wetted width and wetted surface area. The Boundary Reservoir and Boundary Tailrace HRMs were used to quantify these characteristics for unique operational and hydrologic conditions that bracket the range of possible conditions. The results were used to assist in describing channel morphology and defining habitat characteristics.

#### *5.2.2.1. Wetted Width*

Calculation of wetted width within the study area was conducted to assist in describing channel morphology and defining habitat characteristics. Cross section weighted, reach-average wetted width values were determined for each of the three reaches in the Boundary Reservoir using the Boundary Reservoir HRM and for the Tailrace Reach using the Boundary Tailrace HRM. Wetted width was determined at each cross section of the hydraulic model, not solely at the habitat transect locations. Cross section wetted width was defined as the horizontal distance of the inundation extent, extending from bank to bank, excluding mid-channel islands or other local exposed high points within the cross section. The wetted width value for each hydraulic model cross section was weighted by the distance halfway to the upstream cross section plus the distance halfway to the downstream cross section. Cross section weighted, reach-averaged wetted width values were then computed.

For the three reaches in Boundary Reservoir, cross section weighted, reach-averaged wetted width values were determined for each of three specific hydrologic/operational conditions. Together, these three conditions bracket the range of typical hydrologic/operational conditions that occur in the reservoir. They are defined as follows:

- **Low Pool and Low Flow Condition—**The low pool was defined as a Boundary forebay elevation of 1,974 feet NAVD 88 (1,970 feet NGVD 29). The low flow condition was defined as 10,700 cfs. This flow rate is equal to the 90 percent exceedance value determined from the Boundary Reservoir total hourly inflow annual exceedance curve for the 1987–2005 period of record (R2 Resource Consultants 2008).
- **Median Pool and Median Flow Condition**—Defined as the median Boundary forebay elevation (1,989.77 feet NAVD 88 [1,985.77 feet NGVD 29]) combined with the median flow rate (19,500 cfs). Both values are based on the annual exceedance curves presented in R2 Resource Consultants (2008).
- **High Pool and High Flow Condition**—The full pool was defined as the maximum operating pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29). The high flow condition was defined as 55,000 cfs, which equals the approximate turbine capacity of the Project.

For the Tailrace Reach, cross section weighted, reach-averaged wetted width values were also determined for each of three specific hydrologic/operational conditions. Together, these three

conditions bracket the range of historical conditions that occurred in the tailrace for the 1987 to 2005 hydrologic period of record (R2 Resource Consultants 2008). They are defined as follows:

- **Low Pool and Low Flow Condition**—The low pool condition is defined as 1,715.68 feet NAVD 88 (1,711.68 feet NGVD 29), which equals the hourly 90 percent exceedance value for the Seven Mile Dam forebay elevation for the 1987 to 2005 hydrologic period of record (R2 Resource Consultants 2008). The low flow condition was defined as 5,900 cfs, which equals the hourly 80 percent exceedance value for flow releases from Boundary Dam for 1987 to 2005 hydrologic period of record (R2 Resource Consultants 2008).
- **Median Pool and Median Flow Condition**—Defined as the median Seven Mile Dam forebay elevation (1,727.00 feet NAVD 88 [1,723.00 feet NGVD 29) combined with the median Boundary Dam flow releases flow rate (22,600 cfs). Both values are based on the annual exceedance curves presented in R2 Resource Consultants (2008) for the 1987 to 2005 hydrologic period of record.
- **High Pool and High Flow Condition**—The high pool condition was defined as 1,732.28 feet NAVD 88 (1,728.28 feet NGVD 29), which equals the hourly 10 percent exceedance value for the Seven Mile Dam forebay elevation for the 1987 to 2005 hydrologic period of record (R2 Resource Consultants 2008). The high flow condition was defined as 55,000 cfs, which equals the current turbine capacity of the Project.

Table 5.2-3 summarizes the computed cross section weighted, reach-averaged wetted width values for each of the four reaches in the Project area, for each of the three previously defined operational/hydrologic conditions. This table also presents the cross section weighted, reach-averaged wetted width values for the entire Project area (total combined reaches). The presentation of the reservoir reach and tailrace reach results together in Table 5.2-3 is not meant to imply that the same operational/hydrologic condition would necessarily exist in the Boundary reservoir and Boundary tailrace at the same time. For example, due to the load following operation of the Project, a "Low Pool_Low Flow" condition may be prevailing at a point in time in the Project reservoir, while at that same point in time a "Median Pool_Median Flow" condition may be prevailing in the Project tailrace.

Within the Project area and within each of the four individual reaches, the distribution of the length weighted wetted width values was determined; these values are also summarized in Table 5.2-3. The percentage of channel length, by reach, where the wetted width was less than 0.5 times the reach average (or Project area average) was computed. Likewise, the percentage of channel length, by reach, where the wetted width was greater than 1.5 times the reach average (or Project area average) was computed. This determination provides a sense of the distribution of cross section weighted wetted width values within each of the reaches and within the Project area as a whole.

**Table 5.2-3.** Characterization of cross section weighted, reach-averaged wetted width values by reach.

| Hydrologic Condition and Project Reach | Reach Length (ft) | Cross Section Weighted, Reach-Averaged Wetted Width (ft) | Distribution of Cross Section Weighted, Reach-Averaged Wetted Width by Reach (%) | | |
|---|---|---|---|---|---|
| | | | Less than 0.5 Times Reach Average Top Width | Greater than 1.5 Times Reach Average Top Width | Between 0.5 and 1.5 Times Reach Average Top Width |
| **Low Pool_Low Flow Condition** | | | | | |
| Total Combined Reaches | 109,443 | 590 | 13 | 13 | 74 |
| Forebay Reach | 5,257 | 1,722 | 0 | 0 | 100 |
| Canyon Reach | 45,675 | 474 | 7 | 15 | 78 |
| Upper Reservoir Reach | 40,842 | 663 | 3 | 15 | 81 |
| Tailrace Reach | 17,669 | 383 | 2 | 10 | 88 |
| **Median Pool_Median Flow Condition** | | | | | |
| Total Combined Reaches | 109,443 | 772 | 21 | 16 | 63 |
| Forebay Reach | 5,257 | 1,831 | 0 | 0 | 100 |
| Canyon Reach | 45,675 | 538 | 9 | 13 | 78 |
| Upper Reservoir Reach | 40,842 | 1020 | 21 | 15 | 63 |
| Tailrace Reach | 17,669 | 491 | 2 | 10 | 88 |
| **High Pool_High Flow Condition** | | | | | |
| Total Combined Reaches | 109,443 | 836 | 21 | 18 | 61 |
| Forebay Reach | 5,257 | 1,849 | 0 | 0 | 100 |
| Canyon Reach | 45,675 | 553 | 10 | 13 | 77 |
| Upper Reservoir Reach | 40,842 | 1148 | 21 | 15 | 64 |
| Tailrace Reach | 17,669 | 544 | 2 | 11 | 87 |

Notes:
1 Values may not add up to 100 percent due to rounding.
2 The Boundary Reservoir HRM was used to determine the cross section weighted, reach-averaged wetted width values for the Forebay, Canyon, and Upper Reservoir Reaches.
3 The Boundary Tailrace HRM was used to determine the cross section weighted, reach-averaged wetted width values for the Tailrace Reach.

### *5.2.2.2. Wetted Surface Area*

Calculation of wetted surface area within the study area was conducted only as a means to assist in describing channel morphology and defining habitat characteristics. Consistent with the guidance presented in the RSP (SCL 2007a), the total wetted surface area of the Pend Oreille River channel from Box Canyon to the confluence of Red Bird Creek was determined. Additionally, the total wetted surface area having a depth greater than 10, 20, 30, 40, 50, and 100 feet was determined within each of the four reaches.

The wetted surface area was determined between Box Canyon Dam and the confluence of Red Bird Creek for a range of hydrologic/operational conditions using the Boundary Reservoir HRM and the Boundary Tailrace HRM in conjunction with ArcGIS tools. The Boundary Reservoir HRM was run for the same three reservoir hydrologic/operational conditions that were used in the determination of wetted width. Similarly, the Boundary Tailrace HRM was run for the same three tailrace hydrologic/operational conditions that were used in the determination of wetted width in the tailrace. The steady state model run results were exported to ArcGIS, where determination of wetted surface area was conducted.

Table 5.2-4 summarizes the total wetted surface area by depth and by reach for each of the three hydrologic/operational conditions. As was documented in the previous section, the presentation of the reservoir reach and tailrace reach results together in Table 5.2-4 is not meant to imply that the same operational/hydrologic condition would necessarily exist in the Boundary Reservoir and Boundary tailrace at the same time. The results are grouped by operational/hydrologic condition for purposes of interpretation only.

**Table 5.2-4.** Wetted surface area by depth and by reach.

| Hydrologic Condition and Project Reach | Total Wetted Surface Area (acres) | Total Wetted Surface Area by Depth (acres) | | | | | |
|---|---|---|---|---|---|---|---|
| | | >10 feet | > 20 feet | >30 feet | >40 feet | >50 feet | >100 feet |
| **Low Pool_Low Flow Condition** | | | | | | | |
| Total Combined Reaches | 1,428 | 1,047 | 747 | 606 | 527 | 461 | 260 |
| Forebay Reach | 279 | 268 | 255 | 243 | 231 | 220 | 162 |
| Canyon Reach | 444 | 416 | 382 | 324 | 274 | 227 | 95 |
| Upper Reservoir Reach | 559 | 266 | 59 | 10.0 | 2 | 1 | 1 |
| Tailrace Reach | 146 | 97 | 51 | 29 | 20 | 13 | 2 |
| **Median Pool_Median Flow Condition** | | | | | | | |
| Total Combined Reaches | 1,771 | 1,392 | 1,014 | 755 | 634 | 553 | 304 |
| Forebay Reach | 286 | 273 | 261 | 250 | 239 | 229 | 172 |
| Canyon Reach | 500 | 458 | 431 | 402 | 357 | 301 | 127 |
| Upper Reservoir Reach | 804 | 513 | 225 | 50 | 7 | 2 | 1 |
| Tailrace Reach | 181 | 147 | 98 | 54 | 31 | 21 | 3 |
| **High Pool_High Flow Condition** | | | | | | | |
| Total Combined Reaches | 1,970 | 1,756 | 1,369 | 990 | 731 | 606 | 324 |
| Forebay Reach | 307 | 297 | 281 | 268 | 256 | 244 | 181 |
| Canyon Reach | 519 | 481 | 448 | 418 | 386 | 329 | 138 |
| Upper Reservoir Reach | 942 | 802 | 505 | 218 | 46 | 6 | 1 |
| Tailrace Reach | 201 | 175 | 135 | 85 | 44 | 27 | 4 |

Note:
1 To convert from acres to square feet, multiply the values in the table by a 43,560 conversion factor.

### 5.2.3. Hydraulic Conditions in Boundary Reservoir

This section provides more detail regarding the hydraulic conditions in the Boundary Reservoir as a means of assisting in the interpretation of study analyses results. Specifically, the influence of Metaline Falls and other hydraulic controls in the Boundary Reservoir on the hydraulic behavior of the Pend Oreille River is illustrated using output from the Boundary Reservoir HRM from specific portions of the wet, dry, and average years. An understanding of the influence of these features will be useful, for example, when interpreting the results of the downramping analysis (Section 5.5). Furthermore, this section illustrates that the magnitude of the influence from these features varies depending upon the flow rate and the elevation range through which the Boundary forebay fluctuates.

The second part of this section presents analysis that quantifies the hydraulic influence of Project operations on upstream conditions throughout the reservoir. The hydraulic influence of Project operations on upstream water surface elevations and average cross section velocities was included in this analysis.

#### *5.2.3.1. Influence of Hydraulic Controls*

Metaline Falls is a localized bedrock high point in the thalweg profile of the Boundary Reservoir and is also a localized constriction of the canyon walls. Metaline Falls is located at PRM 26.8 and represents the natural dividing point between the Canyon Reach and the Upper Reservoir Reach. Metaline Falls influences the hydraulic behavior of the Boundary Reservoir in two ways.

First, the vertical and lateral bedrock constriction at Metaline Falls causes a localized increase in water surface elevation that in turn impacts the hydraulic conditions in the Upper Reservoir Reach. To illustrate the relative magnitude of this increase, Figures 5.2-11 and 5.2-12 show steady state water surface profiles generated from the Boundary Reservoir HRM. Each figure includes a water surface profile for a hypothetical high flow, moderate flow and a low flow condition for a specific Boundary forebay water surface elevation. Figure 5.2-11 shows the profiles associated with a maximum operating forebay elevation (1,994 feet NAVD 88 [1,990 feet NGVD 29]). Figure 5.2-12 depicts the profiles associated with a hypothetical lower forebay elevation of 1,974 feet NAVD 88 (1,970 feet NGVD 29). As seen in these figures, the depth of the water through Metaline Falls is significantly shallower than the depth immediately downstream. The shallow flow depth results in flow velocities through the falls that are substantially higher than downstream. This local increase in velocity results in a localized increase in the water surface elevation. The magnitude of the increase depends upon the flow rate and the Boundary forebay elevation.

The second way Metaline Falls influences the hydraulic behavior in the Boundary Reservoir is that it can partially or completely hydraulically disconnect the Upper Reservoir Reach from the lower reaches (the Canyon and the Forebay reaches). As seen in Figures 5.2-11 and 5.2-12, the thalweg elevation through the falls is higher than the upstream or downstream thalweg elevations. Therefore, under specific flow conditions, if the forebay elevation is drawn down low enough, the Upper Reservoir Reach can become hydraulically disconnected from the lower reaches. When this occurs, the Upper Reservoir Reach is no longer influenced by Project operations and is essentially functioning as a free-flowing riverine reach. However, under other

flow conditions, when the Boundary forebay elevation is high enough, the Upper Reservoir Reach can remain connected with the lower reaches and remain hydraulically influenced by Project operations.

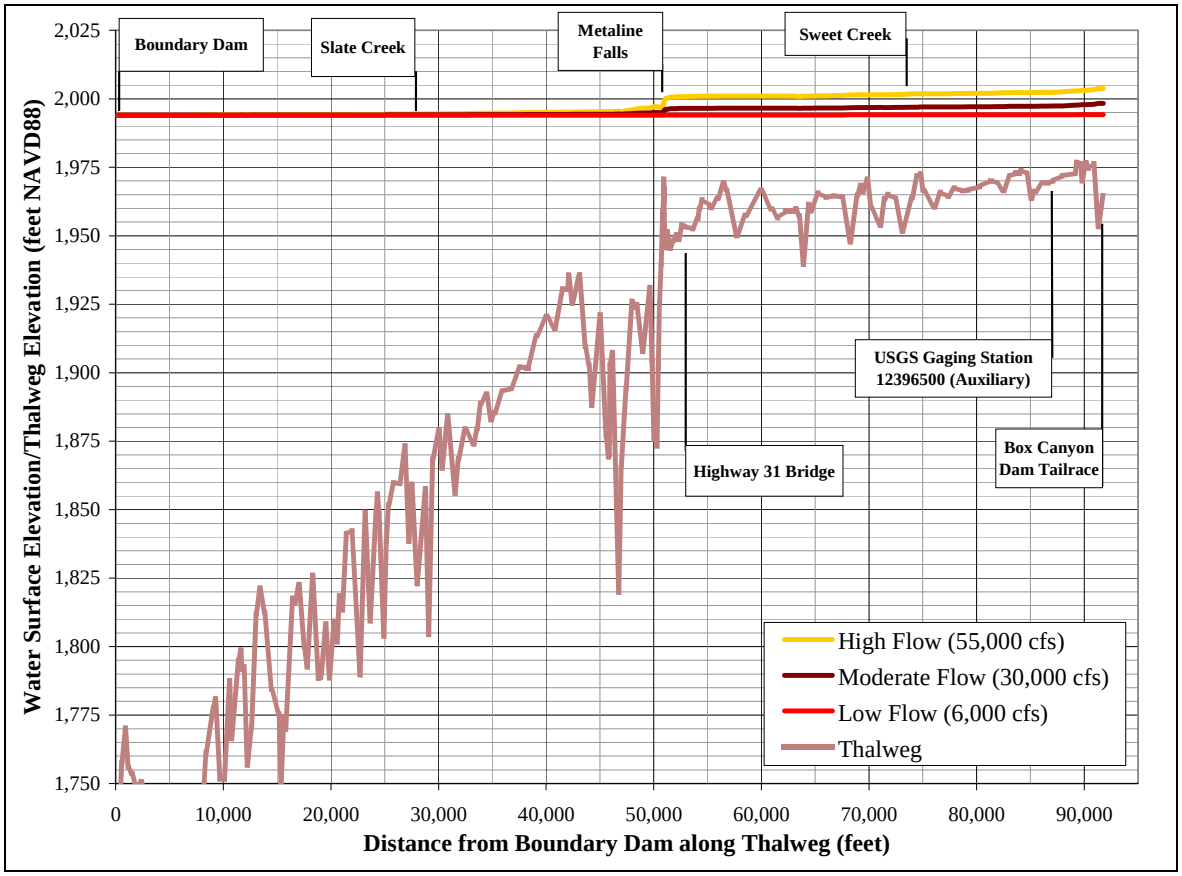



**Figure 5.2-11.** Thalweg and upstream water surface elevations from Boundary Reservoir HRM for high, moderate, and low flow conditions assuming a Boundary forebay water surface elevation of 1,994 feet NAVD 88.

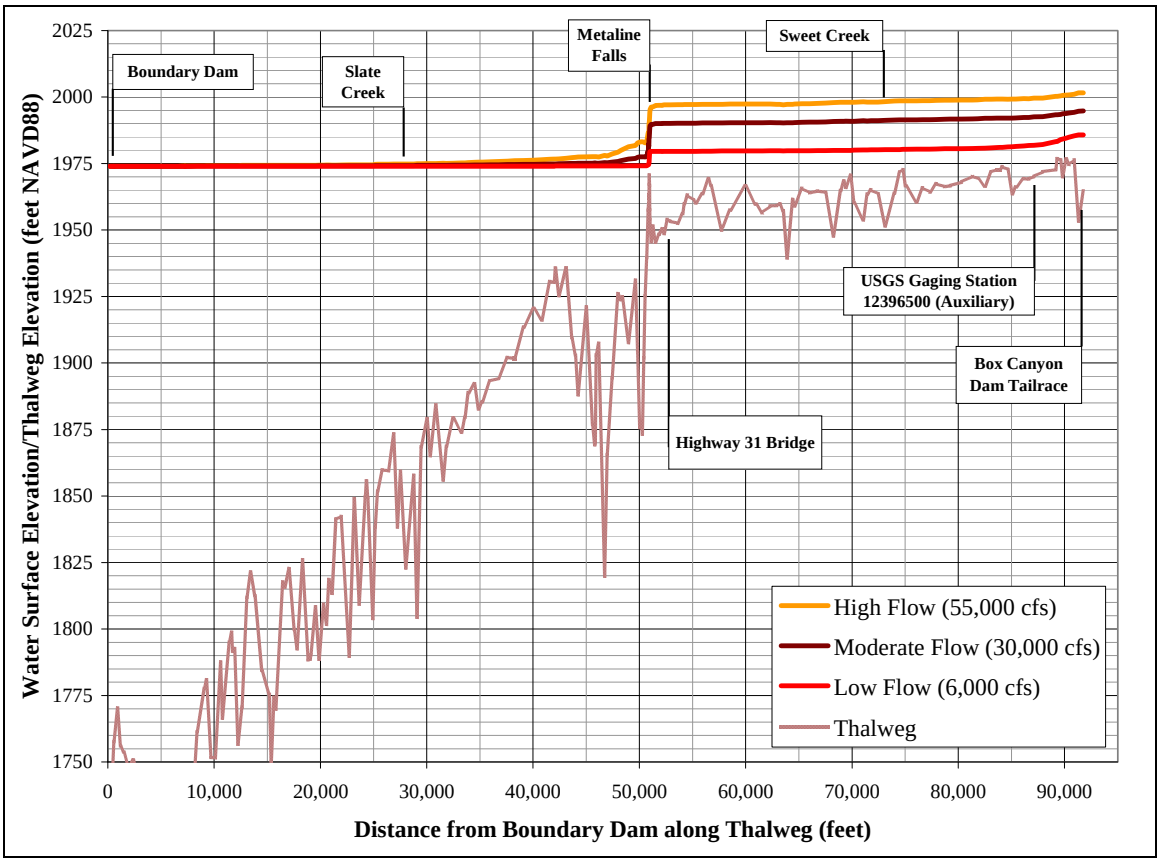



**Figure 5.2-12.** Thalweg and upstream water surface elevations from Boundary Reservoir HRM for high, moderate, and low flow conditions assuming a Boundary forebay water surface elevation of 1,974 feet NAVD 88.

This issue of hydraulic disconnection can be further illustrated with output from the Boundary Reservoir HRM. Figure 5.2-13 shows water surface elevations at four locations in the Boundary Reservoir–Boundary Dam forebay, immediately upstream of Metaline Falls, at Sweet Creek and in the Box Canyon Tailrace for a one-week period in September 2001 (dry year). The outflow from Box Canyon Dam is plotted on the secondary y-axis and was fairly constant throughout the week at approximately 9,200 cfs. For nearly a nearly 3-day period, the forebay elevation fluctuated between 1,980 and 1,985 feet NAVD 88 (1,976 and 1,981 feet NGVD 29). These 5-foot fluctuations in the forebay resulted in 2-foot fluctuations near Sweet Creek and less than 1-foot fluctuations in the Box Canyon tailrace. This particular period does not illustrate complete hydraulic disconnection between the Upper Reservoir Reach and the lower reaches because the Upper Reservoir Reach is still responding to changes made in the forebay. However, as shown in the figure, the response to forebay water surface fluctuations is dampened in the Upper Reservoir Reach by the presence of Metaline Falls.

The hydraulic disconnection of the Upper Reservoir Reach results in an influence on the timing of the responding water surface fluctuations in the Upper Reservoir Reach. When the forebay elevation is drawn down, the water surface in the Upper Reservoir does not immediately respond; there is a time delay in the response to the drawdown. More importantly, the rate of the

responding drawdown in the Upper Reservoir Reach is less than that in the Canyon or Forebay reaches, as illustrated in Figure 5.2-13. As the Boundary forebay elevation is drawn down, the water surface elevation in the Upper Reservoir Reach is reduced as it begins to drain. However, the rate at which the Upper Reservoir Reach drains is controlled by Metaline Falls. Initially, the rate is high but then gradually decreases as the depth of water upstream of the falls decreases. This is seen on the receding limb of the stage hydrographs shown in Figure 5.2-13 upstream of Metaline Falls. The rate of downramping starts off high as the Upper Reservoir Reach starts to drain. However, for each daily cycle, but most clearly on those that occur during the low forebay elevations, the downramping rate gradually diminishes.

In the Upper Reservoir Reach, the reduced magnitude of the responding water surface fluctuation, combined with the longer duration of time over which the fluctuation occurs, explains why the downramping rates in the Upper Reservoir Reach are so much less than those in the Canyon and Forebay reaches. The downramping analysis results presented in Section 5.5 further illustrate this phenomenon.

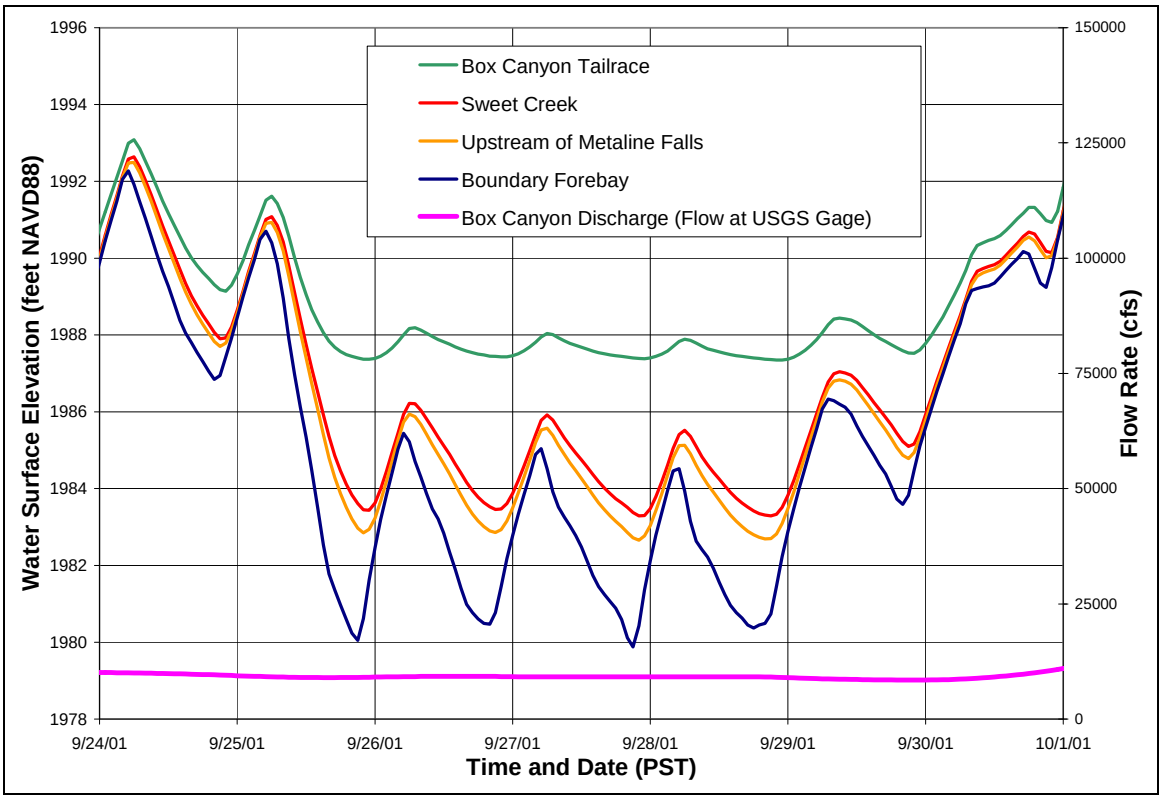



**Figure 5.2-13.** Boundary Reservoir HRM hourly water surface elevations for September 2001 (dry year) illustrating influence of Metaline Falls.

### *5.2.3.2. Hydraulic Influence of Project Operations in Boundary Reservoir*

Some degree of hydraulic influence from Project operations can extend up to the Box Canyon Dam tailrace. However, as was discussed in the previous section, and as will be further illustrated in this section, Metaline Falls functions as a localized hydraulic control that

attenuates (or dampens) the magnitude of this influence in the Upper Reservoir Reach. It will be shown in this section that the magnitude of the hydraulic influence varies, depending upon the location in the reservoir, the water surface elevation in the Boundary forebay and the flow rate through the Boundary reservoir.

This section presents figures and tables that quantify the influence of Project operations on the hydraulic conditions in the Boundary reservoir. The intent of this analysis is to graphically illustrate the range of influence Project operations can have on water surface elevations and average cross section velocities between Boundary Dam and Box Canyon Dam.

The quantification of hydraulic influence was made relative to the hydraulic conditions associated with the Project operating at the lowest pool limit of the current license: 1,954 feet NAVD 88 (1,950 feet NGVD 29). The Boundary Reservoir HRM was run for a set of discrete flow rates that ranged from 5,000 cfs to 80,000 cfs, coincident with the lowest operating pool elevation. The specific flow rates that were included in the analysis were 5,000; 10,000; 19,500; 30,000; 40,000; 55,000; and 80,000 cfs. The significance of the 19,500 cfs rate is that it represents the median hourly flow rate for the 1987 through 2005 period of record (R2 Resource Consultants 2008). The 55,000 cfs flow rate represents the turbine capacity of the Project and the 80,000 cfs flow rate represents the upper limit of flow rate considered in the Mainstem Aquatic Habitat Model for WUA analysis.

The next step in the analysis was to run the Boundary Reservoir HRM for incrementally higher forebay elevations while still using the same set of flow rates that were run for the 1,954-foot NAVD 88 condition. The forebay elevations included in the analysis were 1,974; 1,979; 1,984; 1,989; and 1,994 feet NAVD 88 (1,950; 1,970; 1,975; 1,980; 1,985; and 1,990 feet NGVD 29). The 1,994-foot elevation represents the maximum operating pool elevation.

The method used to quantify the hydraulic influence is best explained using Figure 5.2-14. This figure shows water surface elevations determined from steady state model runs of the Boundary Reservoir HRM. The water surface profiles in this figure are for a 40,000 cfs flow rate for the six different Boundary Dam forebay elevations. The lowest elevation represents the lowest operating pool elevation. The other five profiles are for incrementally higher forebay elevations, up to the maximum operating pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29). For a 40,000 cfs flow rate condition, the hydraulic influence (in this case change in water surface elevation) attributed to Project operations is determined by comparing the model results for the forebay elevation of interest to the model results for the lowest operating pool condition.

A similar approach was used to evaluate the hydraulic influence of Project operations in regards to average cross section velocities. Figure 5.2-15 plots average cross section velocities along the length of Boundary Reservoir for a 40,000 cfs flow rate and the range of Boundary forebay elevations. Similar to Figure 5.2-14, the Boundary forebay elevations that were included ranged from the lowest operating pool elevation of 1,954 feet NAVD 88 (1,950 feet NGVD 29) to the maximum operating pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29). For the 40,000 cfs flow rate, it is seen that Project operations generally reduce average cross section velocities as the forebay elevation increases. This is attributed to the backwater effect associated with incrementally increasing forebay elevations.

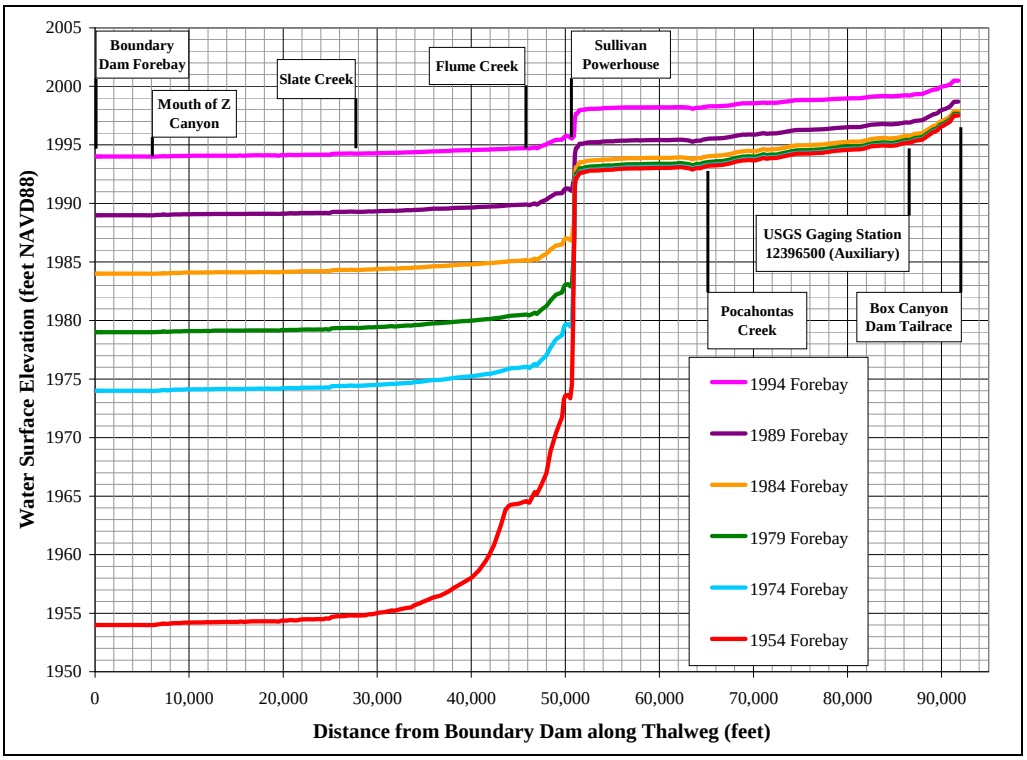



**Figure 5.2-14.** Boundary Reservoir HRM steady state water surface profiles for 40,000 cfs flow rate.

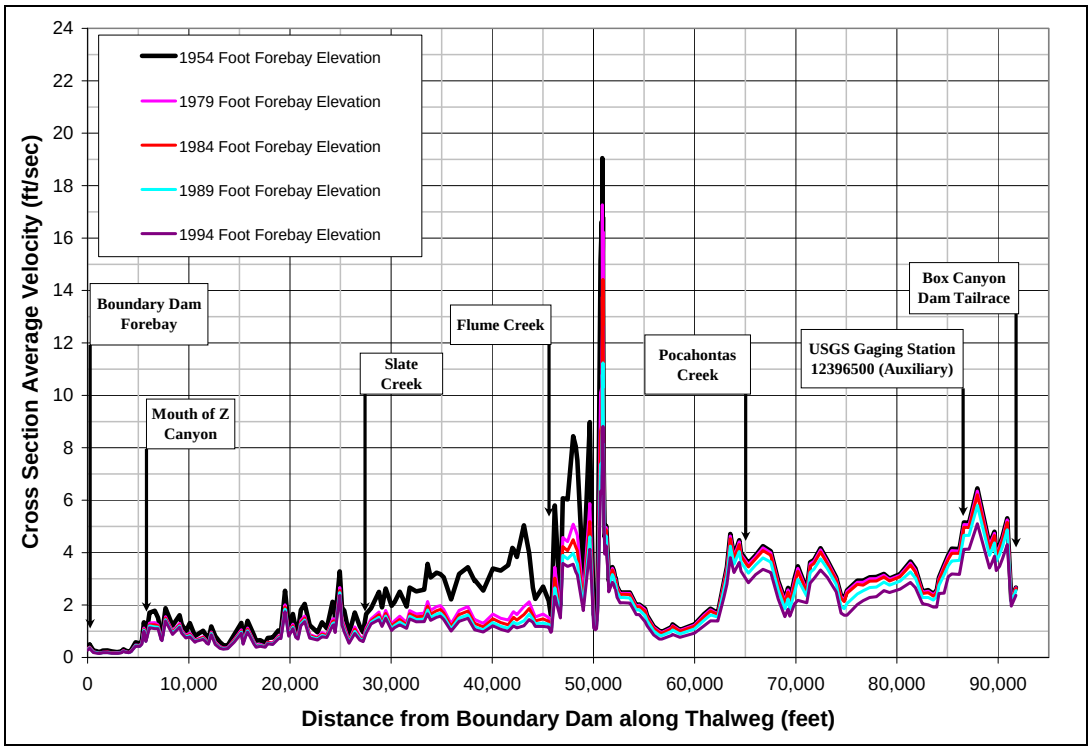



**Figure 5.2-15.** Upstream hydraulic influence of Project operations on average cross section velocity for 40,000 cfs flow rate.

The hydraulic influence of Project operations on upstream water surface elevations and velocities is a function of the three variables: 1) the distance from the Project, specifically whether the location being considered is upstream or downstream of Metaline Falls; 2) the Boundary Dam forebay elevation; and 3) the flow rate in the reservoir.

Figures 5.2-14 and 5.2-15 illustrate the first two variables. Incremental changes in forebay elevation (Project operations) are seen to result in larger changes in water surface elevation at locations downstream of Metaline Falls as compared to locations upstream of Metaline Falls. For this 40,000 cfs flow condition, it is not until the forebay elevation is increased above 1,974 feet NAVD 88 (1,970 feet NGVD 29) that any increase in water surface elevation is produced upstream of Metaline Falls. Thus, it can be said that for the 40,000 cfs flow condition, the Upper Reservoir Reach is essentially functioning without influence from Boundary Dam and is therefore hydraulically disconnected from the lower reaches when the Boundary forebay elevation is less than approximately 1,974 feet NAVD 88 (1,970 feet NGVD 29). At incrementally increasing forebay elevations, backwater conditions from the Project gradually extend upstream along the Upper Reservoir Reach, thereby incrementally reducing the free-flowing conditions in the reach.

A series of figures were developed to illustrate the magnitude of the hydraulic influence of Project operations on water surface elevations and on average cross section velocities. The figures were developed to present the results of the analysis as a function of the three variables (distance, forebay elevation, and flow rate). Each figure therefore presents the hydraulic influence attributed to Project operations for a specific flow rate for the range of flows considered (5,000 cfs to 80,000 cfs). All of the figures are included in Appendix 2; only the figures for the 19,500 cfs flow condition are included in this section as examples. Figure 5.2-16 shows the magnitude of the hydraulic influence of Project operations on water surface elevations, and Figure 5.2-17 shows the magnitude of the hydraulic influence of Project operations on average cross section velocities.

As seen in Figure 5.2-16, there is nearly an equal response to an increase (or decrease) in Boundary forebay elevation and the resulting increase (or decrease) in water surface elevation in the lower portion of the Canyon Reach below Slate Creek. This is due to the large area available for flow within the reservoir, resulting in low velocities which allow the water to be conveyed without loss of hydraulic head. It is head loss that causes a sloping water surface elevation. Downstream of Slate Creek, hydraulic influence is therefore not a function of the flow rate.

Between Slate Creek and Metaline Falls, average cross section velocities begin to increase due to the narrowing of the canyon walls and a reduction in the depth of the reservoir. Because of this, head loss can become significant and the water surface profile can develop a slope. The slope tends to increase as the flow rate increases. In this portion of the Canyon Reach, the influence of Project operations is no longer a one-to-one relationship with increased forebay elevations but is now a function of the flow magnitude and of the distance from the Project. This departure from the equal response to water surface elevation changes between these locations is greatest when flows are higher than 55,000 cfs.

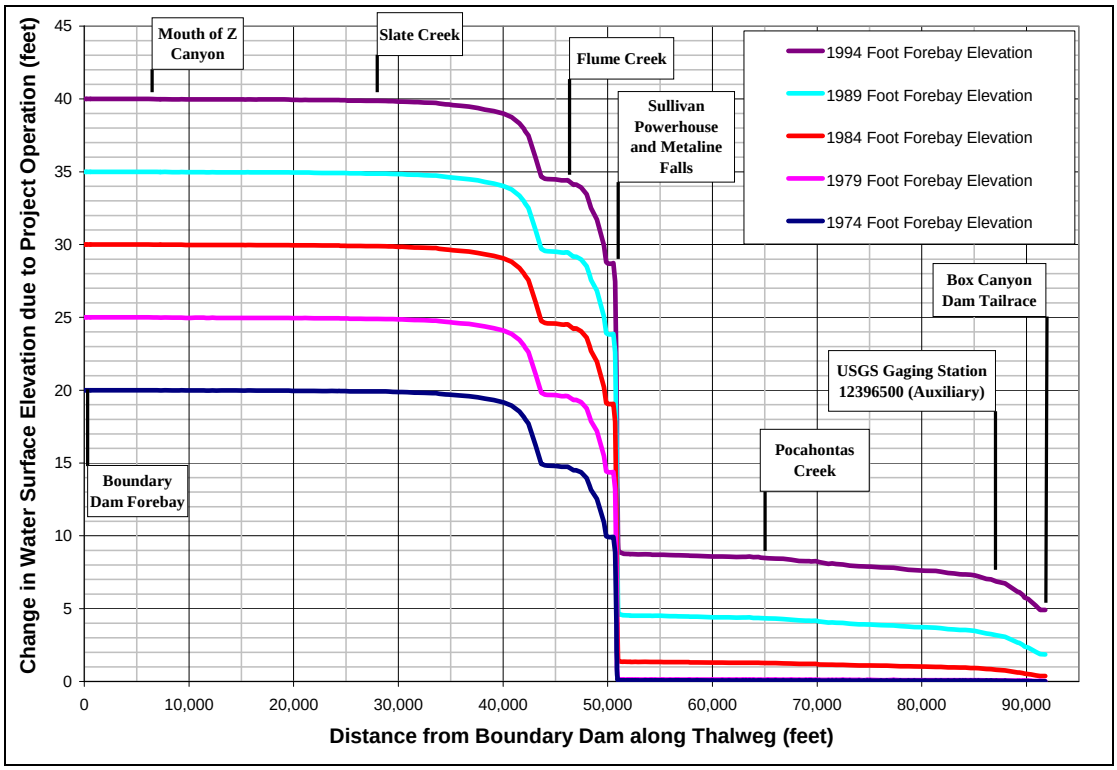



**Figure 5.2-16.** Upstream hydraulic influence of Project operations on water surface elevations for 19,500 cfs flow rate.

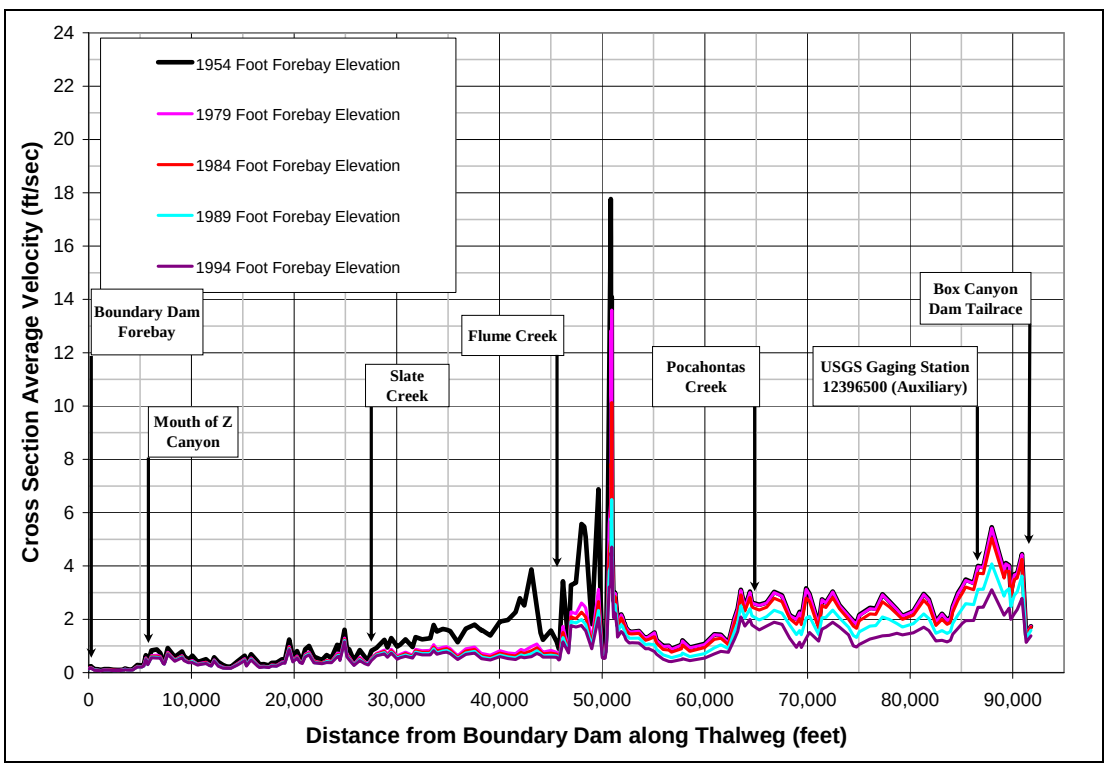



**Figure 5.2-17.** Upstream hydraulic influence of Project operations on average cross section velocities for 19,500 cfs flow rate.

In the Upper Reservoir Reach, the hydraulic influence of Project operations on water surface elevations is attenuated (or dampened) by the localized constriction at Metaline Falls. This is partly attributed to the fact that the Upper Reservoir Reach is hydraulically disconnected from the Canyon Reach when the Boundary forebay elevation is less than 1,979 feet NAVD 88 (1,975 feet NGVD 29) for the 19,500 cfs flow condition. This is seen in Figure 5.2-16 when there are large magnitude changes in water surface elevation in the Forebay and Canyon reaches with no commensurate changes in the water surface elevation upstream of Metaline Falls. As seen in Figure 5.2-16, the Upper Reservoir Reach gradually becomes hydraulically connected to reach downstream of Metaline Falls as the forebay elevation is incrementally increased above 1,979 feet NAVD 88 (1975-feet NGVD 29). This is evidenced when incremental changes in water surface elevation downstream of Metaline Falls result in incremental changes in water surface elevation upstream of Metaline Falls. For the 19,500 cfs flow condition, this begins to occur once the forebay elevation is increased above 1,979-feet NAVD 88 (1,975 feet NGVD 29). For forebay elevation range between 1.989 feet NAVD 88 and 1.994 feet NAVD 88 (1,985 feet NGVD 29 and 1,990 feet NGVD 29) changes in water surface elevations upstream of Metaline Falls more closely reflect the changes in the water surface elevations in the forebay. This is attributed to the diminished hydraulic influence of Metaline Falls on upstream water surface elevations for this particular flow condition.

Figure 5.2-17 shows that average cross section velocities in the Canyon Reach downstream of Flume Creek do not change significantly due to Project operations for the 19,500 cfs flow condition. Again, this is attributed to the large area available for flow within the reservoir, resulting in low velocities which allow the water to be conveyed without loss of hydraulic head. Upstream of Metaline Falls, the influence of Project operations on average cross section velocities is more noticeable. In the Upper Reservoir Reach, the highest velocities occur when backwater conditions from the Project are minimal. As the forebay elevation is increased, backwater from the Project begins to extend upstream of Metaline Falls, thereby decreasing average cross section velocities. This trend is seen in Figure 5.2-17. For example, at the USGS auxiliary gage location, the average cross section velocity is 4.0 feet per second (fps) when the forebay elevation is at 1,954 feet NAVD 88 (1,950 feet NGVD 29) and gradually decreases to a minimum values of 2.5 fps when the forebay elevation at 1,994 feet NAVD 88 (1,990 feet NGVD 29).

### 5.2.4. Hydraulic Conditions in Boundary Tailrace

This section provides more detail regarding the hydraulic conditions in the Boundary tailrace as a means of assisting in the interpretation of study analyses results. Specifically, the influence of local, natural hydraulic control features in the Boundary tailrace on the hydraulic behavior of the Pend Oreille River is illustrated using output from the Boundary Tailrace HRM from specific portions of the wet, dry, and average years. An understanding of the influence of these features will be useful, for example, when interpreting the results of the downramping analysis (Section 5.5). Furthermore, this section will illustrate that the magnitude of the influence from these features is affected by the magnitude of Project discharge and the coincident forebay elevation at Seven Mile Dam.

The second part of this section will present the analysis that quantifies the hydraulic influence of Project operations on downstream conditions throughout the Tailrace Reach. The hydraulic

influence of Project operations on downstream water surface elevations and average cross section velocities was included in this analysis.

#### *5.2.4.1. Influence of Hydraulic Controls*

In the Tailrace Reach, there are two natural high points in the Pend Oreille River thalweg profile. One is located approximately 15,500 feet downstream of Boundary Dam at PRM 14.1. The elevation of the thalweg at this location is 1,692 feet NAVD 88 (1,688 feet NGVD 29). The other hydraulic control is closer to Boundary Dam and is located approximately 5,800 feet downstream of Boundary Dam at PRM 15.9. The elevation of the thalweg at this location is 1,711 feet NAVD 88 (1,707 feet NGVD 29).

These two natural features locally constrict the flow rate and therefore influence the upstream water surface elevations in a similar manner as Metaline Falls influences water surface elevation in the Upper Reservoir Reach (see Section 5.2.3.1). The influence is manifested in two ways. First, the localized constriction in the flow rate causes a localized increase in water surface elevation that influences the upstream hydraulic behavior. Secondly, these localized features control the period of time required for the river system to reach an equilibrium condition as Project discharges are decreased. This second point is especially relevant during periods when the forebay elevation in Seven Mile Dam is far enough below the thalweg elevation of the controls where backwater conditions from Seven Mile Dam are minimal. When Project discharges are reduced to near zero magnitudes, the hydraulic controls determine the duration of time required for the upstream reach to drain (i.e., reach equilibrium).

Figures 5.2-18 and 5.2-19 illustrate the magnitude of the upstream influence on water surface elevations that these local controls have. The water surface profiles shown in these two figures were determined for two fixed Seven Mile Dam forebay elevations (1,734 feet and 1,694 feet NAVD 88 [1,730 and 1,690 feet NGVD 29]) and three hypothetical flow conditions (55,000 cfs, 30,000 cfs, and 5,000 cfs). The lower Seven Mile forebay elevation represents the lowest elevation in the 1987–2005 period of record whereas the higher elevation represents a typical maximum annual forebay elevation (see Table 5.2-2). When the Seven Mile Dam forebay elevation is high, backwater effects drown out the influence of the hydraulic controls (Figure 5.2-18). At the lower of the two forebay elevations (Figure 5.2-19), the influence of the hydraulic controls is at a maximum.

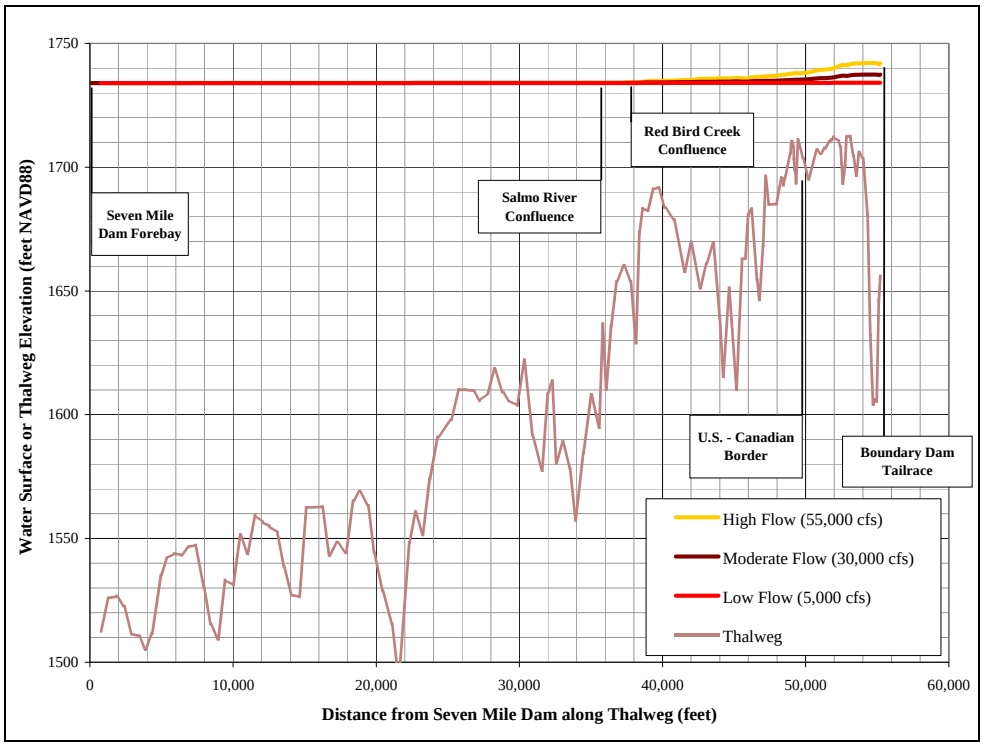



**Figure 5.2-18.** Thalweg and upstream water surface elevations from Boundary Tailrace HRM for high, moderate, and low flow conditions assuming a Seven Mile Dam forebay water surface elevation of 1,734 feet NAVD 88.

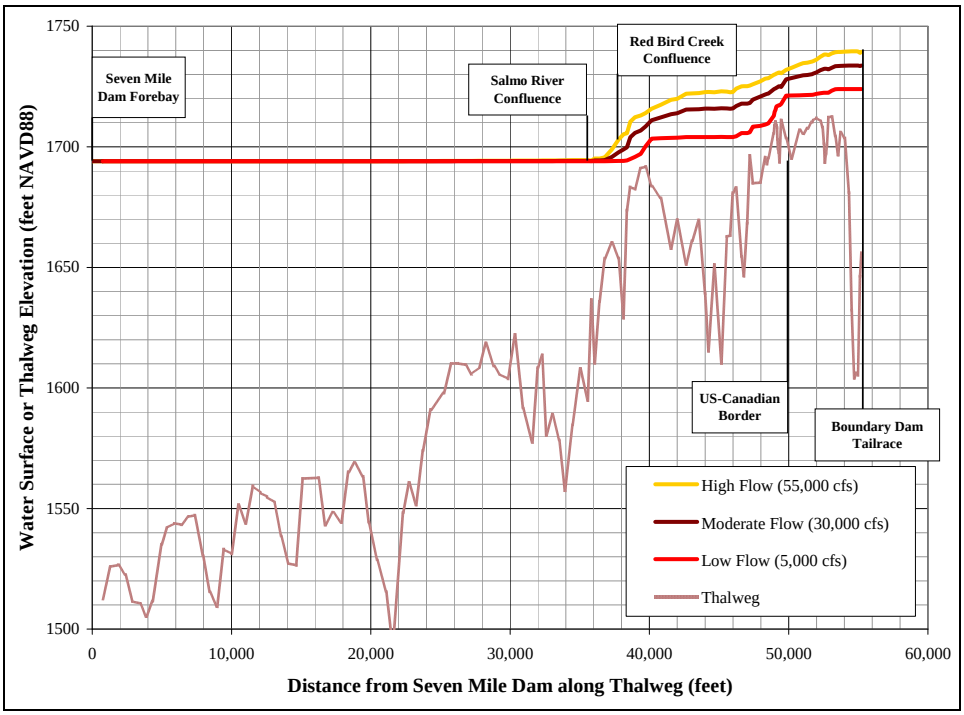



**Figure 5.2-19.** Thalweg and upstream water surface elevations from Boundary Tailrace HRM for high, moderate, and low flow conditions assuming a Seven Mile Dam forebay water surface elevation of 1,694 feet NAVD 88.

In regard to the second function that these controls have on the hydraulic behavior of the Tailrace Reach, consider a hypothetical example when the Seven Mile Dam forebay is at elevation 1,715.68 feet NAVD 88 (1,711.68 feet NGVD 29), which is equal to the 90 percent exceedance value for the 1987–2005 period of record. At this elevation, the backwater affect of Seven Mile Dam is negligible at the upstream-most hydraulic control. If the Project is operating at 55,000 cfs, the Boundary Tailrace HRM predicts the water surface elevation would look like the uppermost profile in Figure 5.2-20. If Project discharges are decreased to a nominal value of 500 cfs, given enough time, the resulting water surface elevation would look like the lowermost profile shown in Figure 5.2-20. However, a period of time after the flow was decreased to 500 cfs would be required for the Tailrace Reach to fall to the lowermost water surface profile. This is due to the flow regulating nature of these two hydraulic controls. In essence, the hydraulic controls create storage behind them. This storage is released quickly at first, when the flow depth over the control is greatest, but as the flow depth decreases, so does the rate of outflow. Therefore, it takes time for the storage upstream of the controls to completely drain and for the discharge to reach an equilibrium condition.

The Boundary Tailrace HRM was applied to this situation to determine the time required for the system to reach equilibrium. This duration represents the elapsed time for the uppermost portion of the Tailrace Reach to drain. The Seven Mile Dam forebay elevation was assumed as a constant 1,715.68 feet NAVD 88 (1,711.68 feet NGVD 29) elevation. The Project outflow was assumed equal to a constant 55,000 cfs flow rate that was suddenly decreased to a nominal value of 500 cfs. It was determined that it took approximately 4 hours for the Tailrace Reach to reach equilibrium (i.e., for flow past the control to fall to 500 cfs) for this hypothetical situation.

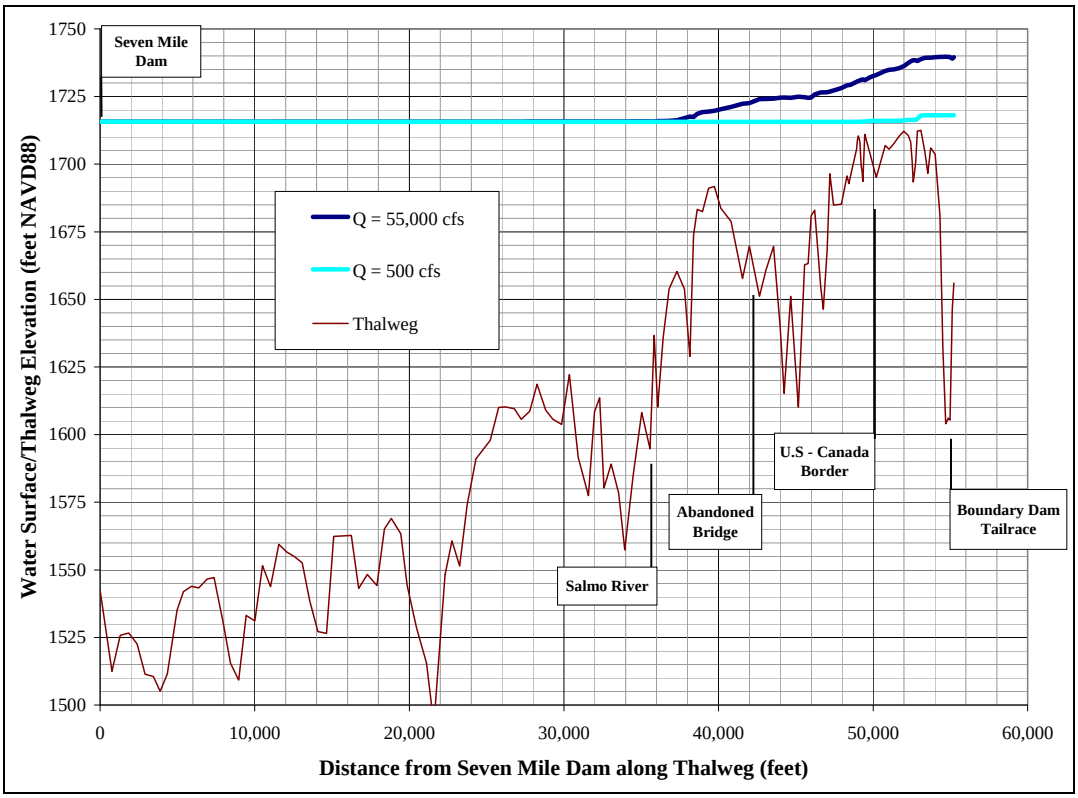



**Figure 5.2-20.** Water surface profiles associated with analysis for elapsed time to drain Tailrace Reach.

#### 5.2.4.2. Hydraulic Influence of the Project in Boundary Tailrace

An analysis was conducted to quantify the hydraulic influence of Project operations in the Tailrace Reach, between the Project and Red Bird Creek. The methodology was similar to that used for the analysis conducted for the Boundary Reservoir (see Section 5.2.3.2). The results of this analysis are used to illustrate the range of influence Project operations can have on water surface elevations and average cross section velocities along the length of the Tailrace Reach. In the Boundary Reservoir, the hydraulic influence attributed to Project operations is due to water surface fluctuations in the forebay. However, in the Tailrace Reach, the hydraulic influence attributed to Project operations is due to flow releases from the powerhouse (project outflows) that are either greater or less than the flow rate that is being conveyed in the Pend Oreille River upstream of Boundary Dam (Project inflows).

Some degree of hydraulic influence from Project operations can extend from Boundary Dam down to the confluence with Red Bird Creek (i.e., the Tailrace Reach). As discussed in the previous section, Seven Mile Dam Project operations can also produce a hydraulic influence in the Tailrace Reach. As will be shown in this section, the magnitude of the hydraulic influence attributed to Project operations is a function of the following three factors:

- *Downstream distance from the Project*—Similar to the upstream hydraulic influence of Project operations (see Section 5.2.3.2), the downstream hydraulic influence of Project operations varies throughout the length of the Tailrace Reach and therefore is a function of increasing distance from the Project.
- *Seven Mile Dam forebay elevation*—When Seven Mile Dam is operating at high pool elevations, it is possible for backwater conditions to extend up to the base of Boundary Dam, thereby affecting water surface elevations throughout the entire Tailrace Reach.
- *Magnitude of the Project discharge relative to the magnitude of the Pend Oreille River flow rate upstream of Boundary Dam*—When Project discharge is equal to the Pend Oreille River flow rate in the Boundary Reservoir (i.e., when Project outflow equals Project inflow), there is no influence of Project operations on the hydraulic conditions in the Tailrace Reach. It is only when outflows from the Project are greater or less than the Pend Oreille River flow rate in the Boundary Reservoir when the Project begins to have downstream hydraulic influence.

Two localized high points (hydraulic controls) in the thalweg profile, located approximately 15,500 feet and 5,800 feet (PRM 14.1 and PRM 15.9) downstream of Boundary Dam, are capable of functioning as hydraulic controls under certain flow conditions and Seven Mile forebay elevations. These hydraulic controls can affect upstream water surface elevations and therefore can affect the magnitude of the hydraulic influence of both Project operations and Seven Mile Dam operations in the Tailrace Reach.

As was the case for quantifying the upstream Project hydraulic influence, it was necessary to first establish the condition against which the results of Project operations are compared. To simplify the analysis, three unique Pend Oreille River flow conditions were combined with three unique Seven Mile Dam forebay elevation conditions to create nine unique conditions against which

results associated with Project operations could be compared. The matrix of the nine conditions used in the quantification of Project influence in the Tailrace Reach is defined in Table 5.2-5.

**Table 5.2-5.** Matrix of boundary conditions used as basis for evaluating hydraulic influence in the Tailrace Reach due to Project operations.

| **Seven Mile Dam Forebay Elevation Condition (ft NAVD 88)[2]** | **Pend Oreille River Flow Rate Condition Upstream of Boundary Dam (cfs)[1]** | | |
|---|---|---|---|
| | **90% Exceedance Value (10,700 cfs)** | **50% Exceedance Value (19,500 cfs)** | **10% Exceedance Value (43,100 cfs)** |
| 90% Exceedance Value (1,715.68 feet) | √ | √ | √ |
| 50% Exceedance Value (1,727.00 feet) | √ | √ | √ |
| 10% Exceedance Value (1,732.28 feet) | √ | √ | √ |

Notes:
1 Pend Oreille River flow rates obtained from annual flow duration curve in Pend Oreille River based on total hourly inflow to Boundary Reservoir for 1987–2005 period of record.
2 Seven Mile Dam forebay conditions obtained from annual frequency of exceedance curves for 1987–2005 period of record.

The Boundary Tailrace HRM was run to define the water surface elevation profiles in the Tailrace Reach for each of the nine conditions identified in Table 5.2-5. Steady state conditions were assumed for each of these nine runs. The resulting water surface elevation profiles are shown in Figures 5.2-21 through 5.2-23 and provide the conditions against which the results of Project operations can be compared to evaluate the hydraulic influence of the Project. Together, these three figures clearly illustrate the factors that influence water surface elevations in the Tailrace Reach. Figure 5.2-21 shows the influence of the hydraulic controls during a low Seven Mile Dam forebay elevation. Figure 5.2-22 shows the elimination of the effect of the downstream hydraulic control when the Seven Mile Dam forebay is at the median elevation. Finally, Figure 5.2-23 shows the backwater influence of Seven Mile Dam during a high Seven Mile Dam forebay elevation.

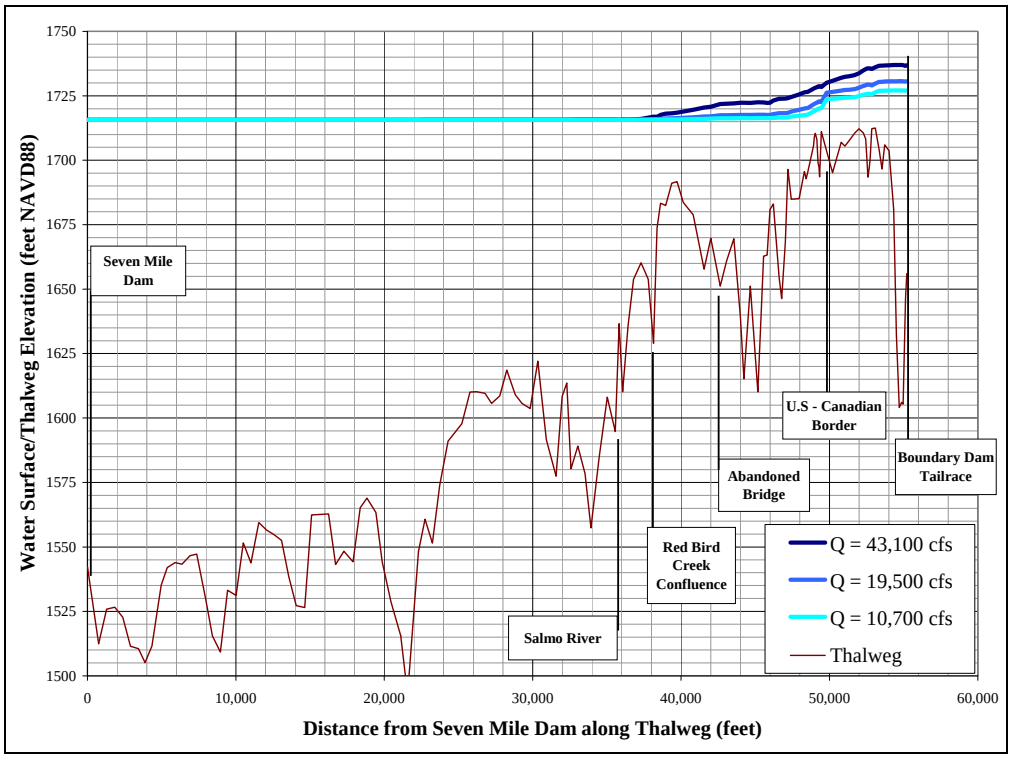



**Figure 5.2-21.** Water surface profiles for Seven Mile Dam forebay at 1,715.68 feet NAVD 88 (90 percent exceedance).

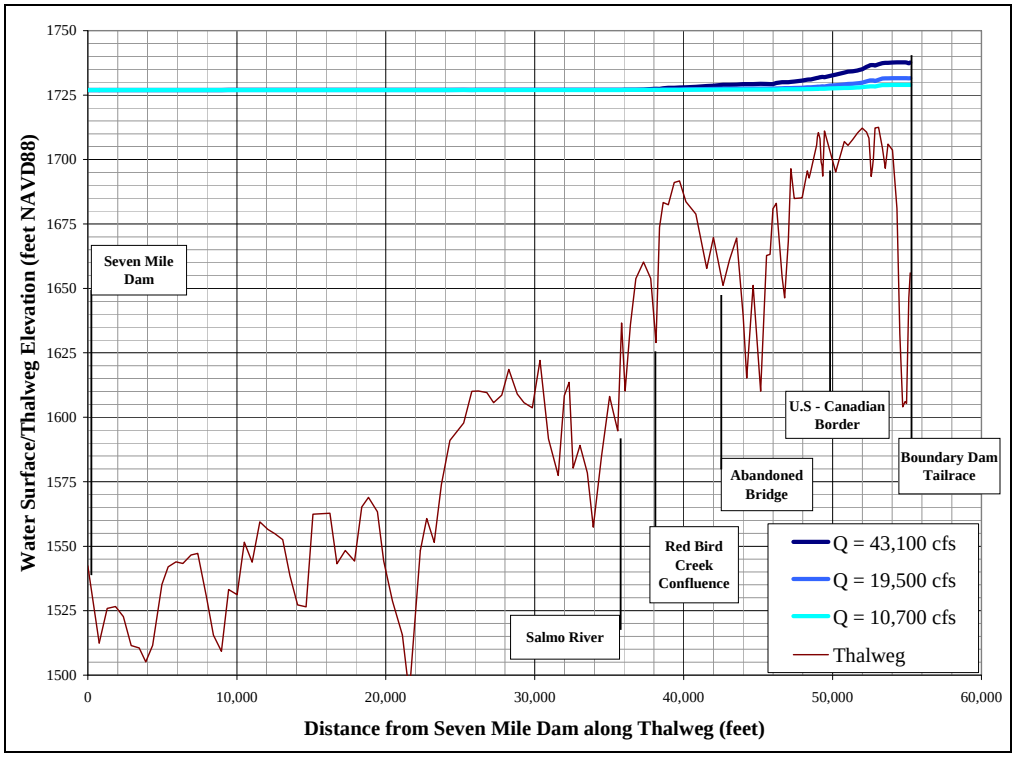



**Figure 5.2-22.** Water surface profiles for Seven Mile Dam forebay at 1,727.00 feet NAVD 88 (50 percent exceedance).

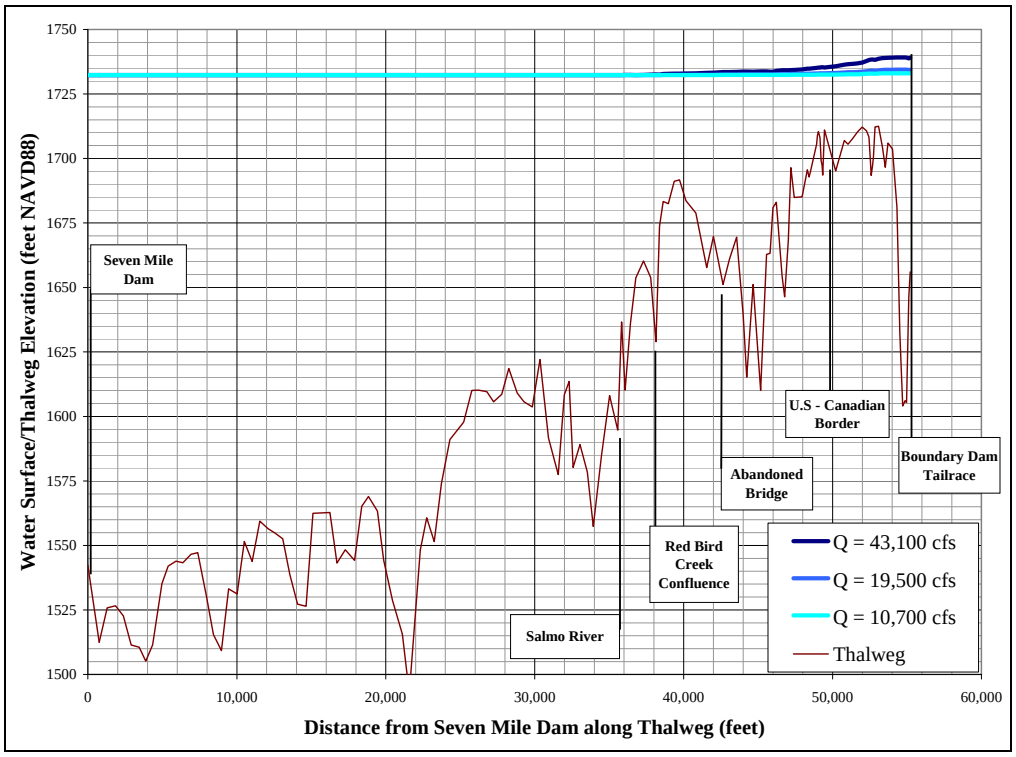



**Figure 5.2-23.** Water surface profiles for Seven Mile Dam forebay at 1,732.28 feet NAVD 88 (10 percent exceedance).

The Boundary Tailrace HRM was then run for six hypothetical Project outflow conditions coincident with each of the three Seven Mile Dam forebay conditions identified in Table 5.2-5. The six hypothetical Project outflow conditions included 5,000; 15,000; 25,000; 35,000; 45,000; and 55,000 cfs. The 55,000 cfs condition is the approximate turbine capacity of the Project and represents the upper bound of conditions for which Project hydraulic influence was determined. When inflows to Boundary Reservoir exceed this magnitude, the Project generally ceases to operate in a load-following manner and begins to pass excess flows through the spillway. Hence, the downstream hydraulic influence of the Project is minimized since Project outflows approximately equal Project inflows.

The results of these hypothetical model runs were then compared to the results of the initial model runs identified in Table 5.2-5. The resulting comparison was organized using a series of figures that illustrate the magnitude of hydraulic influence of Project operations on water surface elevations and average cross section velocities. The figures were developed in such a manner as to present the results of the analysis as a function of the three factors (distance, Seven Mile Dam forebay elevation, and ratio of Project outflow to Project inflow). Each figure therefore graphically summarizes the hydraulic influence attributed to Project operations relative to each of the nine conditions identified in Table 5.2-5. (All of the figures are included in Appendix 2; only select example figures are included in this section.)

Figure 5.2-24 shows the magnitude of the hydraulic influence of Project operations on water surface elevations and Figure 5.2-25 shows the magnitude of the hydraulic influence of Project operations on average cross section velocities. Both of these example figures illustrate Project hydraulic influence relative to the condition associated with a 1,727.00 foot NAVD 88 (1,723.00 foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value).

Figure 5.2-24 shows the change in water surface elevation in the Tailrace Reach relative to the condition associated with a 1,727.00-foot NAVD 88 (1,723.00-foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value). The change in water surface elevation is attributed to Project outflows being either greater or less than the 10,700 cfs Project inflow condition. The change is plotted on the y-axis and the distance downstream of Boundary Dam is plotted on the x-axis. A positive value for the change in water surface elevation occurs when the Project is discharging at a flow rate that is greater than the inflow to the Project. Conversely, a negative value for the change in water surface elevation occurs when the Project is discharging at a rate that is less than the inflow to the Project. For example, when the Project outflow is greater than 10,700 cfs, Project operations result in increased water surface elevations in the Tailrace Reach.

It is seen in Figure 5.2-24 that the increase in water surface elevation due to Project operations generally decreases with distance from the Project. For Project outflows that are significantly higher than the 10,700 cfs Project inflow condition, the hydraulic influence extends farther downstream than is the case when Project outflows are less than the 10,700 cfs Project inflow condition. The hydraulic influence is more than 1 foot for virtually the entire Tailrace Reach when Project outflows are 55,000 cfs. On the other hand, when Project outflows are 25,000 cfs, the hydraulic influence is more than 1 foot for approximately 7,500 feet of the Tailrace Reach (to approximately 2,000 feet downstream of the U.S.-Canada border).

Figure 5.2-25 shows the average cross section velocity in the Tailrace Reach relative to the condition associated with a 1,727.00-foot NAVD 88 (1,723.00 foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value). Average cross section velocity is plotted on the y-axis and the distance downstream of Boundary Dam is plotted on the x-axis. The seven average cross section velocity profiles shown in this figure are oriented such that the profile for the lowest flow rate (in this case 5,000 cfs) is at the bottom of the graph and the profile for the highest flow rate (in this case 55,000 cfs) is at the top. These two conditions provide the lower and upper bounds, respectively, for the analysis of the hydraulic influence. The average cross section velocity profile for the 10,700 cfs Project inflow condition is shown in the heaviest line type. The localized spikes in velocity occur at locations in the Tailrace Reach were the flow is naturally restricted, generally in the vicinity of riffles in the river. As seen in this figure, the increased velocity in the vicinity of these restrictions is more pronounced for higher flow rates.

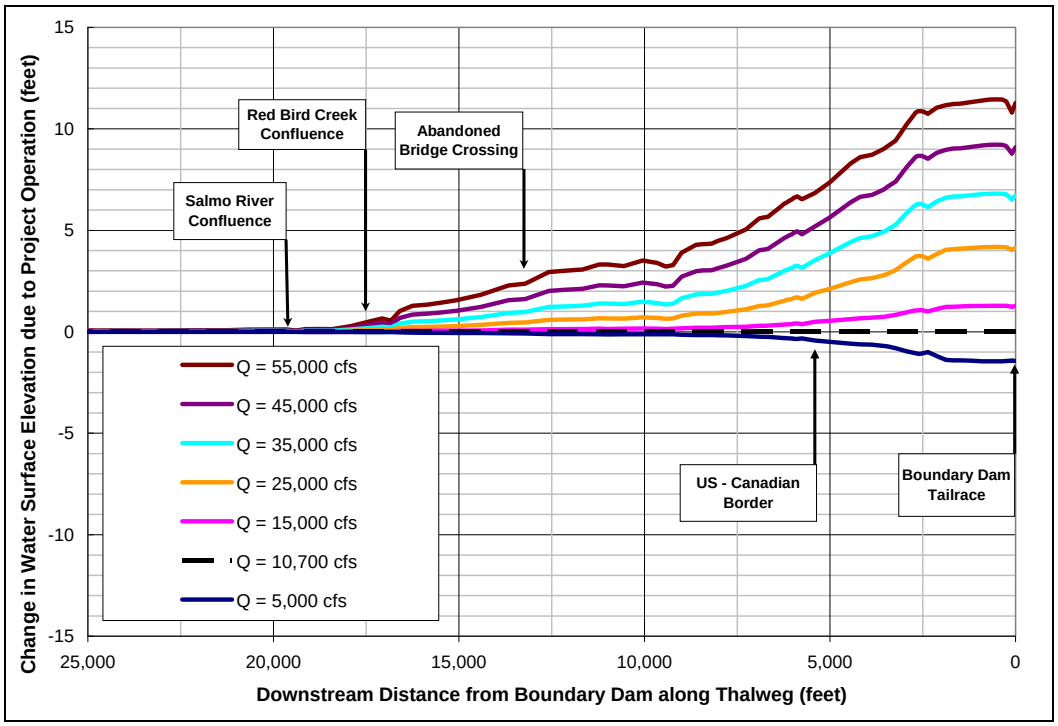



**Figure 5.2-24.** Downstream hydraulic influence of Project operations on water surface elevations relative to the condition associated with 1,727.00-foot NAVD 88 Seven Mile Dam forebay and 10,700 cfs Project inflow.

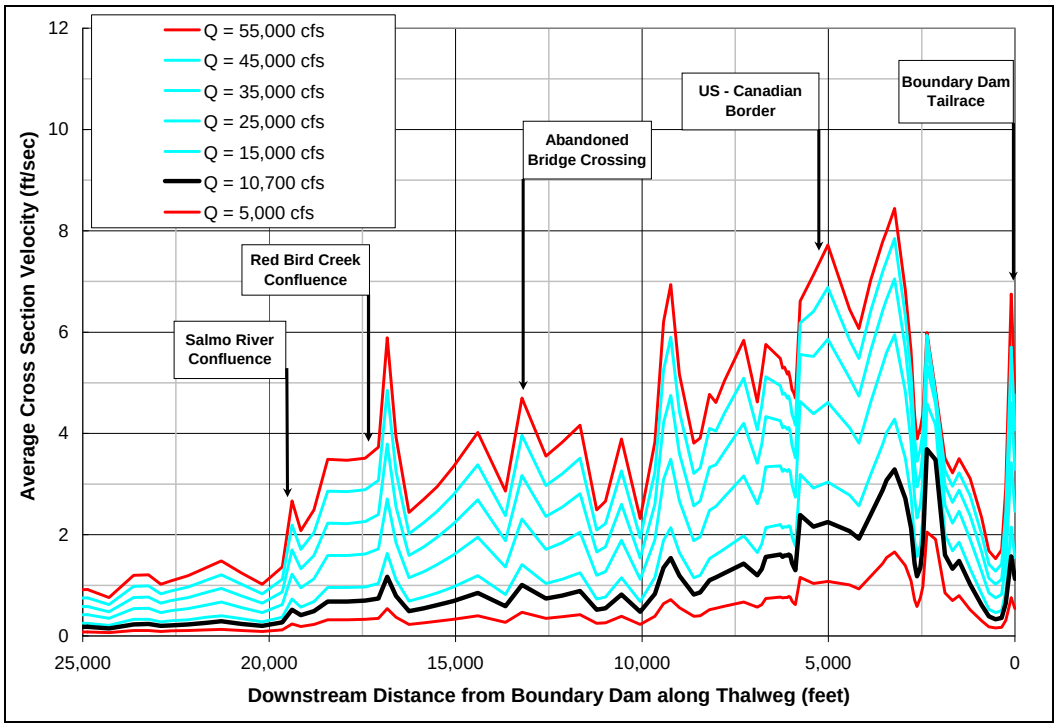



**Figure 5.2-25.** Downstream hydraulic influence of Project operations on average cross section velocities relative to the condition associated with 1,727.00-foot NAVD 88 Seven Mile Dam forebay and 10,700 cfs Project inflow.

## 5.3. Fish Periodicity

Interim periodicity tables were developed for the species of interest to describe the temporal periods when each species and life stage of interest was expected to occur in the Project area (Table 5.3-1). Additional periodicity dates were also developed for other fish species (suckers, yellow perch, largemouth bass, and sunfishes) to represent the time periods when spawning and fry life stages may be vulnerable to stranding and trapping during operations scenarios. These periodicities were determined by visual reference to literature-based estimates with validation of dates, where possible, with actual site-specific capture of fish during Study 9 electrofishing surveys or fish stranding surveys (SCL 2009b). Periodicity dates from literature sources were plotted together along a common timeline, and then site-specific fish captures were added to the timeline (mostly for fry as few spawning observations were made). Interim periodicities for each species and life stage were then visually estimated by giving greater weight to data from geographically similar locations, with less weight to data from distant sources or from general literature reviews, which tend to produce very broad periodicities. These interim periodicities were then compared to site-specific capture data from the Project area (as of August 2008 sampling) and the dates were adjusted accordingly. These interim periodicity dates were discussed with relicensing participants during two meetings (July 17 and August 27, 2008). Table 4.3-3 presented the periodicity dates for all fish species and life stages of interest (data on mountain whitefish spawning are being collected in fall 2008 and winter 2008/2009 and may result in some changes to spawning, incubation, and fry dates).

The results developed were combined with indices for stranding and trapping to determine the species and life stages affected by pool elevation fluctuations. The combination of periodicity and stranding and trapping information also reported times during the year when life stages for individual species may be affected by variations in hydrologic conditions. The periodicity of the fish species and life stage combination of interest within Boundary Reservoir and tailrace is summarized in Figure 5.3-1.

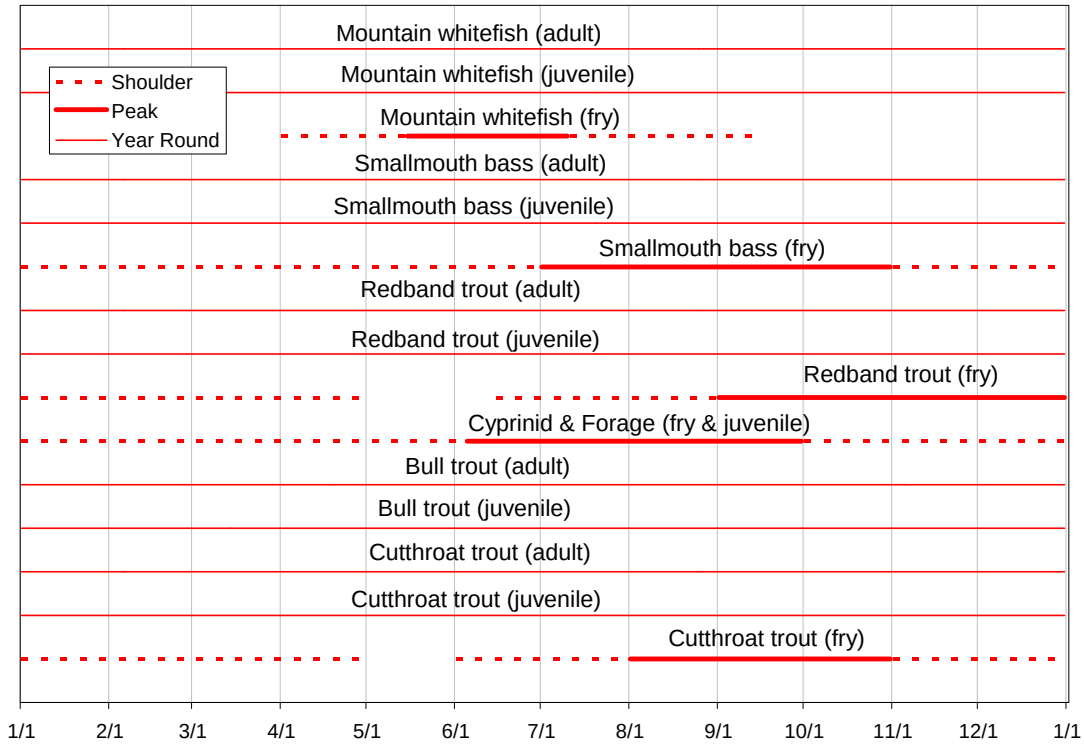



**Figure 5.3-1.** Periodicities of fish species and life stage combination within Boundary Reservoir and tailrace.

## 5.4. Stranding and Trapping Model Results

The results presented in this section provide an indices-based evaluation of the potential for stranding and trapping under existing Project operations. Fish trapping and fish stranding are separate indices. Stranding involves the beaching of fish as the water level recedes and is typically associated with low gradient shoreline areas or cover conditions that result in fish remaining in an area as it is dewatered. Mortality occurs in stranding as fish are left beached on the dewatered shoreline. Trapping is the retention of fish in pools formed by depressions as the water level recedes. Stress and potential mortality to trapped fish occur from several mechanisms including temperature fluctuations, reduction in dissolved oxygen, predation, and stranding as the water in the pool infiltrates into the substrate. The indices for stranding and trapping were based on equations that relate physical characteristics of the stranding and trapping sites to the potential for stranding and trapping to occur. It should be noted that the indices are relative indicators of the potential for stranding and trapping to occur and do not quantify actual fish mortality. Two models, one for stranding and one for trapping, were developed to evaluate the potential within Boundary reservoir and tailrace. Specific information regarding the development of the indices and modeling procedures is found within Section 4.4 and in Appendix 4.

Modeling of stranding and trapping was completed for historic Project operations during wet (1997), dry (2001), and average (2002) years. These years were selected as representative of wet, dry, and average conditions using factors like average annual flows (R2 Resource Consultants 2008). For reference, the flow hydrographs for the wet, dry, and average years were previously presented in Figures 5.0-1 through 5.0-3, respectively, and a comparison of the flow hydrographs across these three years was shown in Figure 5.0-4.

The stranding index is calculated once for each stranding event and does not have a time component (duration) associated with it. As discussed in Section 4.4, it was assumed that the one-hour time interval of the modeling is sufficient to cause mortality for the vast majority of fish stranded for this length of time. The trapping index is calculated once per trapping event and represents the likelihood that fish will be trapped in the pool when the pool becomes disconnected from the mainstem flow, and the potential for fish mortality that is dependent on the duration of the trapping event. Results from the two indices are in general influenced by the following:

- Fluctuations of forebay water surface elevations
- Inflow hydrograph into Boundary Reservoir
- Presences of macrophytes

The influence of fluctuations in forebay water surface elevations due to operations has an impact on the magnitude of the potential stranding and trapping modeled. Under normal operations, the period of greatest stranding and trapping potential occurs during moderate flows and when load following operations are occurring. Fluctuations of water surface elevations due to load following operations typically decrease as inflows into Boundary Reservoir increase/decrease above/below a moderate flow rate. In general, the severity of fluctuations during load following operations is reduced as inflows approach the maximum conveyance capacity of the turbines (approximately 55,000 cfs). Conversely, as inflows decrease the duration it takes to fill the reservoir during periods of flows below a moderate inflow rate limits the range of drawdown that can occur.

The inflow hydrograph also has an influence on the magnitude of potential stranding and trapping modeled. The Project offers no flood storage during periods of high flows and as a result must pass all inflows into Boundary Reservoir. During the rising limb of a flood hydrograph, stranding and trapping is reduced since water surface elevations are increasing. As mentioned above, the ability of the Project to fluctuate water surface elevations during this period is reduced further reducing any potential stranding or trapping. As flood waters recede, the potential for stranding and trapping increases as water surface elevations drop. Trapping in the higher pools during the recession of flood flows often results in the maximum trapping potential since many of the pools will not be rewetted until the following year. The maximum area exposed to potential stranding risk may also occur as flood water receded to a normal fluctuation zone.

The presence of aquatic macrophytes also has an impact on both stranding and trapping indices modeled. Based on field observations, areas with macrophytes present often resulted in higher stranding or trapping mortality. Cover factors for both stranding and trapping (as presented in Section 4.4.2) were based on these field observations and incorporated a periodicity component

of aquatic macrophytes within Boundary Reservoir. Potential stranding and trapping risk was generally higher during periods of peak macrophyte growth (July 16–October 31) compared to the winter resting period (December 16–April 15).

The discussion of stranding and trapping potential by reaches is further divided into regions. During the development of the stranding and trapping analysis approach and field survey program, the study was divided into 23 regions. The regions represent areas with the highest stranding and trapping potential based on reconnaissance surveys in the summer of 2007, review of aerial photographs, and review of the bathymetric maps. The stranding and trapping region locations are provided in Figure 5.4-1 (see Appendix 1c, Attachment A for additional maps).

For discussion purposes, the periodicity of a specified fish species may be referenced when discussing the stranding and trapping modeling results. The periodicity of the fish species and life stage combinations of interest within Boundary reservoir and tailrace were shown in Figure 5.3-1 (see Appendix 3 for additional information). Suckers represent the predominant fish species observed stranded or trapped during the 2007 and 2008 field activities. Mountain whitefish represent the predominant salmonid fry observed within the mainstem of the reservoir during the 2007 and 2008 field activities. However, no mountain whitefish fry were observed stranded during the 2007 and 2008 field activities. The only salmonid observed trapped or stranded was an adult rainbow trout in 2007.

### 5.4.1. Stranding Model

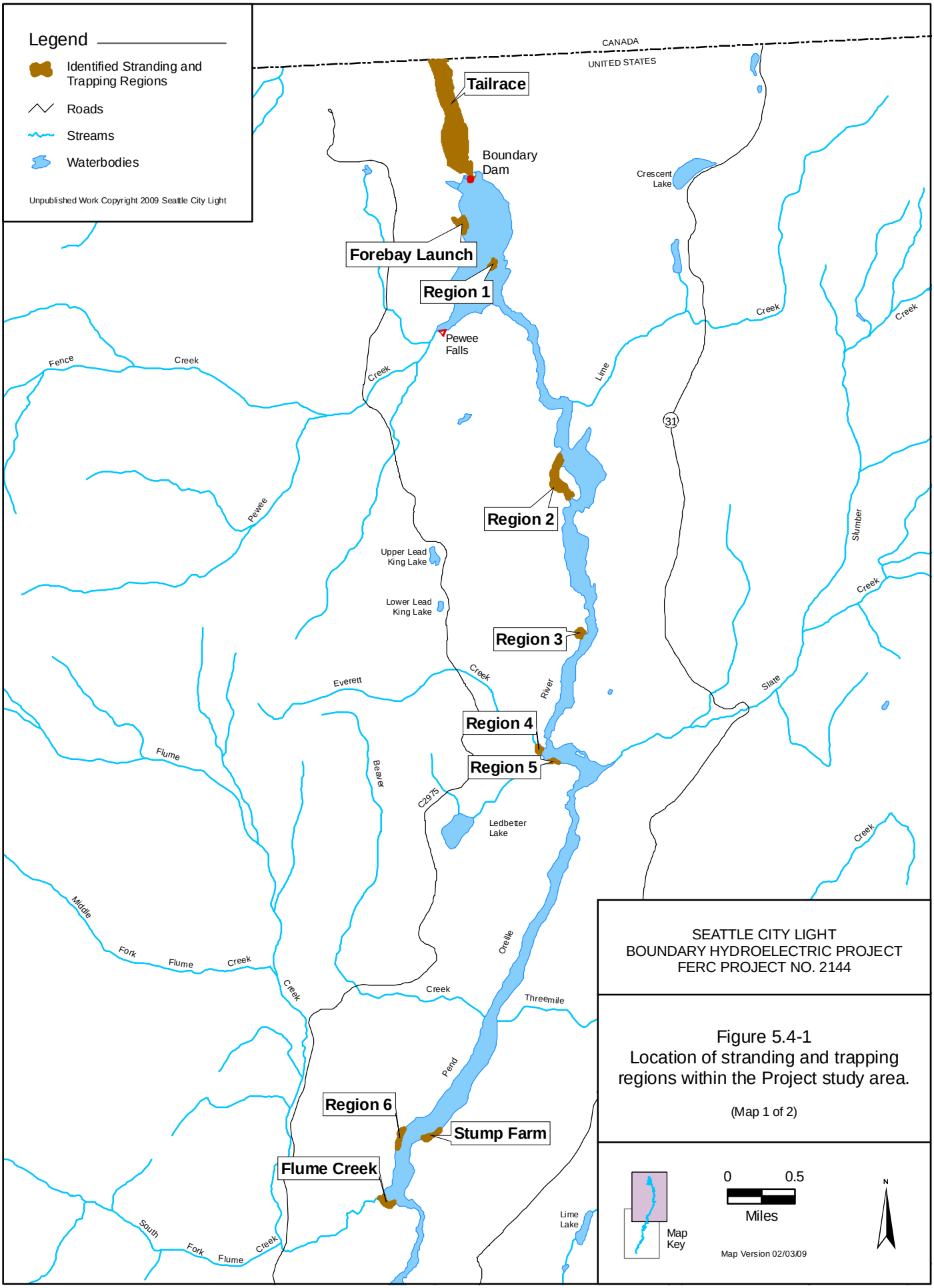
This section presents the results and interpretation of the stranding model. An SI value was calculated based on methods discussed in Section 4.4.1. Hourly SI values were calculated by 1-ft elevation bands for all potential stranding areas within the Boundary reservoir and tailrace for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. Results have been summarized by the four reaches in the following order: Forebay, Canyon, Upper Reservoir, and Tailrace. As previously mentioned earlier, results have also been summarized by the 23 stranding and trapping regions identified. Stranding areas not covered within the stranding and trapping areas were also tabulated into four additional regions and are referred to as “additional area” within the designated reach of interest.

#### *5.4.1.1. General Discussions of the Stranding Model Results*

Annual SI values as well as the average daily weighted channel width of exposed stranding area are presented in Table 5.4-1. The exposed stranding areas values in Table 5.4-1 were developed by dividing the annual SI values by 365 (days per year) and the appropriate reach length. The width is considered weighted since the SI includes a cover factor that has a value ranging from 1 to 30.

Hydrologic conditions experienced during the dry year (2001) produced the largest SI value of the three years modeled. The average year (2002) resulted in the second largest SI value followed by the wet year (1997) producing the smallest annual SI value. A higher SI value meant that the occurrence of stranding was more likely. This was anticipated because lower flows occurring during a dry year would result in greater littoral area exposure and subsequently a high stranding potential. It follows then that hydrologic conditions during the wet year would

result in less littoral area being exposed and subsequently a smaller stranding potential. However, this could be counterbalanced by lack of water in the dry year to fluctuate the reservoir pool as much as during the average or wet year. In the wet and average years, stranding occurs for flows in excess of 55,000 cfs. For these high flows, water level changes are primarily a result of changes in inflow from Box Canyon since the generation capacity of the Project is exceeded.


Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
CANADA
UNITED STATES
Tailrace
Boundary Dam
Crescent Lake
Forebay Launch
Region 1
Pewee Falls
Fence
Creek
Creek
Lime
Creek
Creek
31
Pewee
Region 2
Slumber
Upper Lead King Lake
Lower Lead King Lake
Creek
Region 3
Everett
Creek
River
Slate
Region 4
Region 5
Flume
Beaver
C2975
Ledbetter Lake
Creek
Middle
Fork
Flume
Creek
Creek
Creek
Threemile
Orville
Pend
Region 6
Stump Farm
Flume Creek
Lime Lake
South
Fork
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 5.4-1
Location of stranding and trapping regions within the Project study area.
(Map 1 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
N

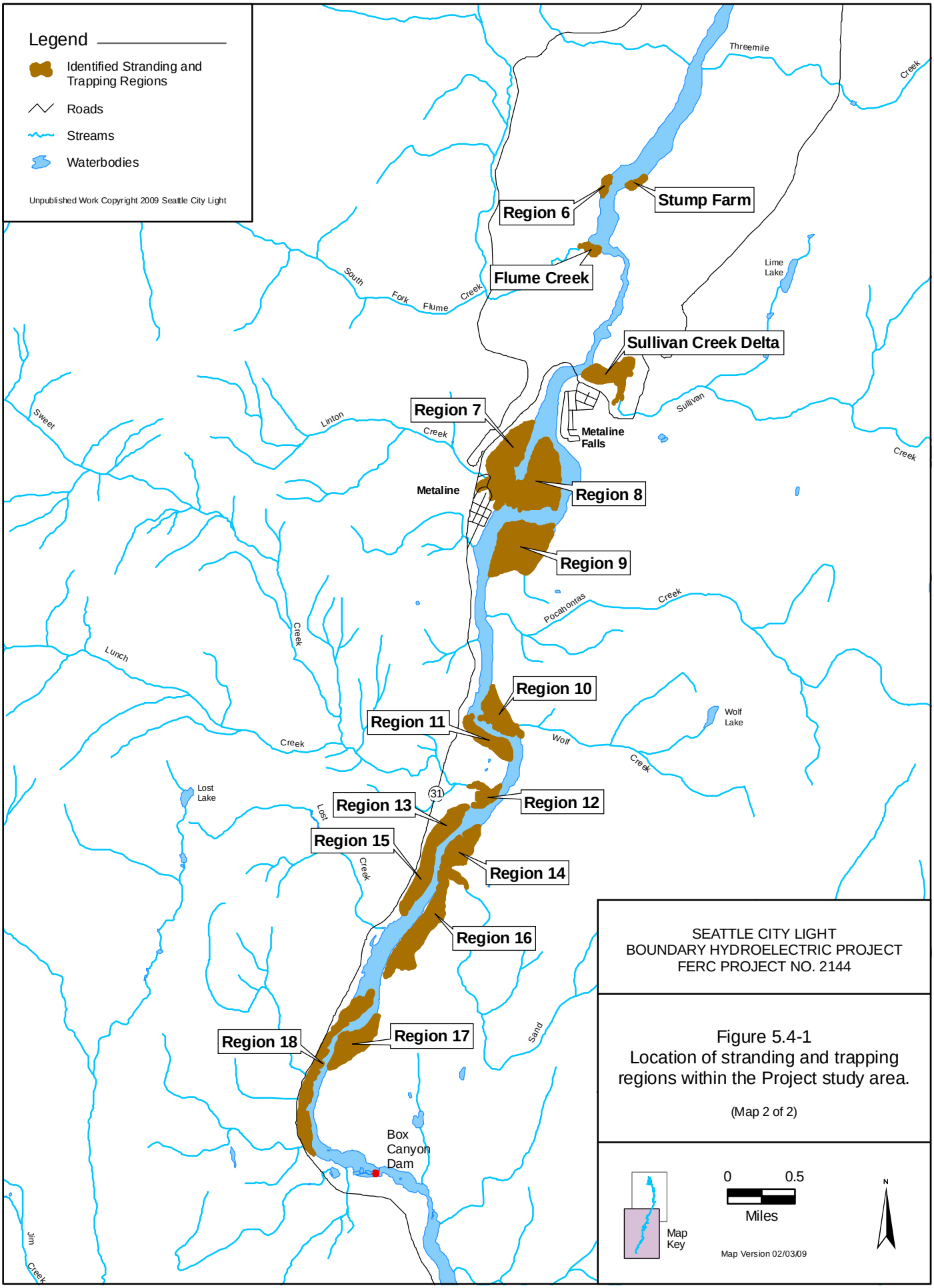

Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
Threemile
Creek
Region 6
Stump Farm
Flume Creek
South
Fork
Flume
Creek
Lime Lake
Sullivan Creek Delta
Sullivan
Creek
Sweet
Linton
Creek
Region 7
Metaline Falls
Metaline
Region 8
Region 9
Pocahontas
Creek
Lunch
Creek
Region 10
Region 11
Wolf Lake
Wolf
Creek
Creek
Lost Lake
31
Region 13
Region 12
Lost
Region 15
Creek
Region 14
Region 16
Region 18
Region 17
Sand
Box Canyon Dam
Jim
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 5.4-1
Location of stranding and trapping regions within the Project study area.
(Map 2 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
N

**Table 5.4-1.** Summary of annual total stranding index (SI) value and average daily weighted channel width of exposed stranding area for the wet (1997), dry (2001), and average year (2002).

| Reach | Reach Length (ft) | Potential Stranding Risk Area ($ft^2$) | Average Channel Width of Potential Stranding Risk Area (ft) | Wet Year (1997) | | Dry Year (2001) | | Average Year (2002) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Strand-ing Area (ft) |
| Forebay | 5,360 | 281,200 | 52 | 1,250 | 6.4 | 940 | 4.8 | 400 | 2.0 |
| Canyon | 44,156 | 538,200 | 12 | 7,075 | 4.4 | 3,668 | 2.3 | 2,700 | 1.7 |
| Upper Reservoir | 38,549 | 11,896,900 | 309 | 88,943 | 63.2 | 168,200 | 119.5 | 128,112 | 91.1 |
| Total Boundary Reservoir | 88,065 | 12,716,300 | 144 | 97,267 | 31 | 172,808 | 55 | 131,212 | 42 |
| Tailrace | 15,613 | 285,300 | 18 | 2,473 | 4.3 | 2,490 | 4.4 | 2,600 | 4.6 |
| **Total Project** | **103,678** | **13,001,600** | **125** | **99,740** | **26** | **175,297** | **46** | **133,813** | **35** |

Results presented in Table 5.4-1 show that in all cases, the greatest potential for stranding occurred in the Upper Reservoir Reach. The total SI computed for the three representative years that occurred within the Upper Reservoir Reach accounts for 94 percent of the combined total stranding potential calculated for the study area. The smallest total SI value was in the Forebay Reach accounting for 0.6 percent of the combined total stranding potential calculated for the study area.

### *5.4.1.2. Review of Stranding Results by Reach*

This section discusses the stranding results predicted from modeling of the four reaches. Discussions of the individual reaches will focus on the specific stranding regions where the greatest SI values were modeled. The locations of the stranding regions were provided in Figure 5.4-1. Additional plots of the regions not discussed in detail within this report can be found in Appendix 4, Attachment D.

#### *5.4.1.2.1. Forebay Reach*

The monthly SI value during the three representative years for the Forebay Reach is shown in the Figure 5.4-2. Compared with the other three reaches (Tailrace, Canyon, and Upper Reservoir), the SI values calculated for the Forebay Reach were the smallest. Review of the individual SI values for the Forebay Reach for the three representative year shows the majority of the stranding potential occurred from July through October.

This period coincided with the peak season of macrophytes growth (July 14–October 31). It is noteworthy that 96 percent of the Forebay Reach stranding area has the presence of aquatic macrophytes. Approximately 25 percent of the area with the presence of aquatic macrophytes had slopes 4 percent or less.

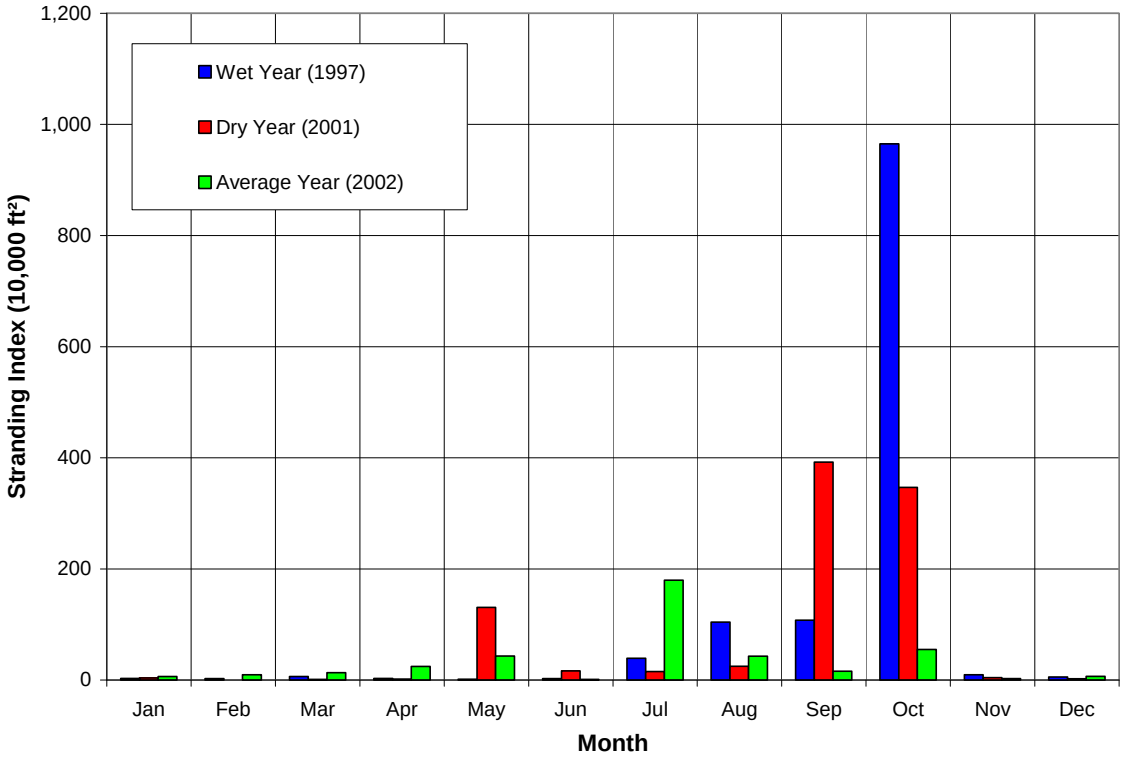



**Figure 5.4-2.** Monthly total stranding index values for the Forebay Reach for the wet (1997), dry (2001), and average year (2002).

There are two regions, Forebay Launch and Region 1, within the Forebay Reach. Monthly SI values are tabulated by region for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions in Table 5.4-2.

**Table 5.4-2.** Summary of Forebay Reach monthly cumulative stranding index (SI) value by region for the wet (1997), dry (2001), and average year (2002).

| Region | Year | Stranding Index (10,000 ft$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Forebay Launch | Wet | 3.1 | 2.4 | 6.2 | 2.9 | 1.4 | 2.4 | 9.0 | 15 | 17 | 318 | 9.7 | 5.6 |
| | Dry | 3.8 | 0.2 | 1.2 | 1.9 | 131 | 17 | 6.4 | 5.3 | 151 | 157 | 4.6 | 2.1 |
| | Average | 6.4 | 9.4 | 13 | 24 | 43 | 1.2 | 41 | 9.6 | 2.9 | 13 | 2.5 | 6.5 |
| Region 1 | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 47 | 48 | 339 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 5.0 | 11 | 127 | 101 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 71 | 18 | 6.8 | 22 | 0 | 0 |
| Additional Forebay | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 42 | 43 | 308 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 4.0 | 8.7 | 114 | 88 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 68 | 16 | 6.1 | 20 | 0 | 0 |

Overall the total annual SI value calculated for the Forebay Reach was small when compared with the Upper Reservoir Reach. The Forebay Reach accounted for 0.6 percent of the combined total SI value calculated for the three representative years. Review of the individual regions within the Forebay Reach shows that stranding potential on an annual basis was the greatest in the Forebay Launch Region. Comparison of the SI values for the three regions show similar magnitudes in stranding potential from July through October. During the remaining months (November–June), stranding events were limited to the Forebay Launch. Discussions in this section are limited to the Forebay Launch region because model results indicate that stranding potential is more frequent at this location than at Region 1 or the additional area not located within a designated stranding or trapping region.

The Forebay Launch is situated adjacent to the boat launch located at the Forebay Recreational Area. The region primarily consists of a relatively flat bench having a predominant substrate of fine sediment. Approximately 94 percent of the stranding area within this region has the presence of macrophytes, of which 37 percent has slopes 4 percent or less. The stranding area within the region ranges from an elevation of 1,957 feet NAVD 88 (1,953 feet NGVD 29) to 1,988 feet NAVD 88 (1,984 feet NGVD 29). As forebay water surface elevations are lowered to 1,977 feet NAVD 88 (1,973 feet NGVD 29) portions of the bench becomes exposed. As forebay water surface elevations are further lowered to 1,970 feet NAVD 88 (1,966 feet NGVD 29), the majority bench is exposed.

Weekly SI values modeled in the Forebay Launch Region are plotted in Figure 5.4-3. Review of this figure shows a spike in SI values occurring in mid-May of the dry year (2001). This period coincides with the forebay water surface elevation lowered approximately 10 feet for maintenance activities to a minimum elevation of 1,965 feet NAVD 88 (1,961 feet NGVD 29). SI values during this period can be directly attributed to the reduced forebay elevation.

Additional spikes in mid-October during both the dry and wet years occurred during periods of load-following operations where water surface elevation within the forebay fluctuated below

1,980 feet NAVD 88 (1,976 feet NGVD 29) exposing the bench at the launch. Review of the periodicity for fry (Figure 5.3-1), which are the lifestage most vulnerable to stranding, indicate that in late October there are smallmouth bass fry are at their peak period.

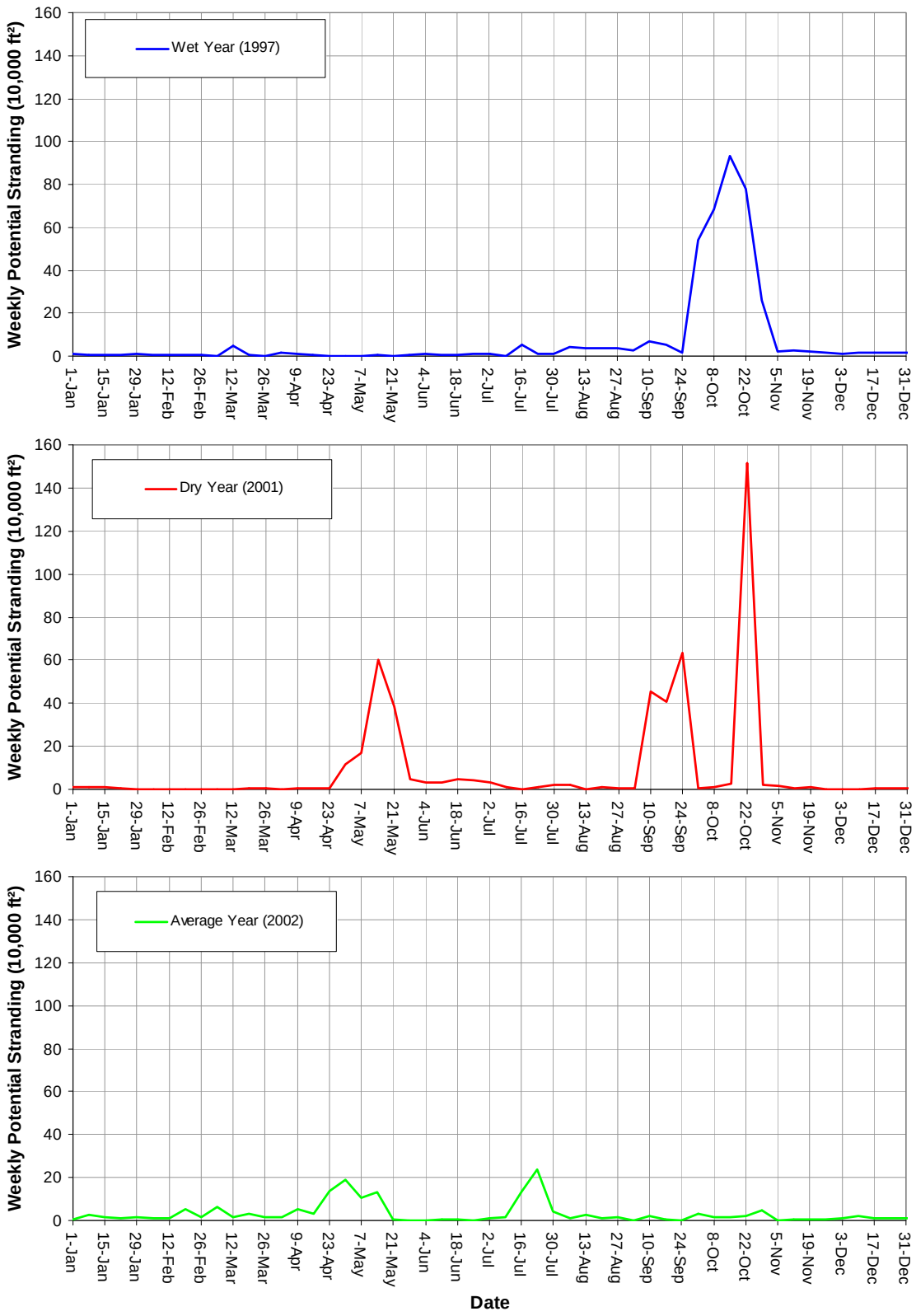



**Figure 5.4-3.** Comparison of Forebay Launch Region weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

### 5.4.1.2.2. Canyon Reach

Monthly stranding results for the Canyon Reach are presented in Figure 5.4-4. In general, there was an elevated period of stranding potential from July through October. Similar to the findings presented in the Forebay Reach, the influence from the presence of aquatic macrophytes during the peak growth season (July 15 through October 31) resulted in a substantial increase in SI values.

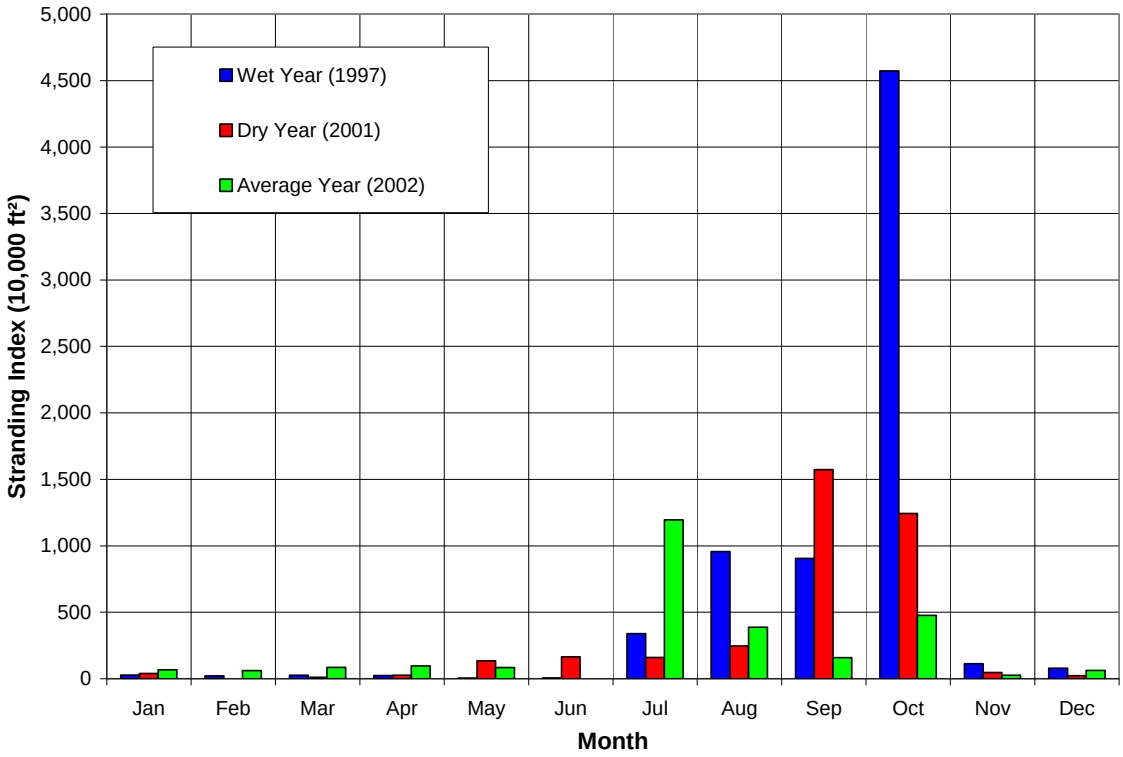



**Figure 5.4-4.** Monthly total stranding index values for the Canyon Reach for the wet (1997), dry (2001), and average year (2002).

There are eight stranding and trapping regions within the Canyon Reach. Monthly SI values are summarized by region plus the additional area not within a designated region for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions in Table 5.4-3. Review of the results presented in Table 5.4-3 show that the highest potential for stranding occurs in Region 2 (Everett Island). Annual totals during the three representative years are at a least 7 times greater than the other regions within the reach. In order to focus on the area where stranding potential is greatest, discussion is limited to Region 2. Additional plots of the remaining regions within the Canyon Reach can be found within Appendix 4, Attachment D. Overall the total annual SI value calculated for the Canyon Reach was small when compared with the Upper Reservoir Reach. The Canyon Reach accounted for 3 percent of the combined total SI value calculated for the three representative years.

**Table 5.4-3.** Summary of Canyon Reach monthly cumulative stranding index value (SI) by region for the wet (1997), dry (2001), and average year (2002).

| Region | Year | Stranding Index (10,000 ft$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Region 2 | Wet | 11 | 9.1 | 12 | 12 | 3.9 | 3.2 | 208 | 607 | 560 | 2,894 | 69 | 42 |
| | Dry | 17 | 0.0 | 4.2 | 14 | 85 | 103 | 92 | 130 | 950 | 705 | 27 | 11 |
| | Average | 32 | 28 | 41 | 53 | 52 | 0.1 | 771 | 212 | 89 | 264 | 13 | 30 |
| Region 3 | Wet | 8.4 | 6.2 | 6.1 | 5.2 | 0.4 | 1.4 | 13 | 23 | 23 | 102 | 17 | 16 |
| | Dry | 10 | 0.4 | 3.1 | 5.7 | 16.5 | 20.7 | 11 | 9.6 | 39 | 35 | 9.6 | 5.4 |
| | Average | 15 | 14 | 17 | 17 | 12 | 0.0 | 31 | 14 | 4.7 | 17 | 5.7 | 14 |
| Region 4 | Wet | 1.1 | 1.0 | 1.2 | 0.9 | 0 | 0.3 | 11 | 29 | 29 | 121 | 4.0 | 3.2 |
| | Dry | 1.6 | 0 | 0.6 | 1.0 | 3.8 | 4.4 | 5.4 | 9.1 | 42 | 36 | 2.2 | 0.9 |
| | Average | 2.6 | 2.6 | 3.1 | 2.9 | 2.5 | 0.0 | 32 | 14 | 4.5 | 15 | 1.2 | 2.7 |
| Region 5 | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 37 | 33 | 210 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 3.8 | 8.1 | 77 | 60 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 14 | 5.4 | 17 | 0 | 0 |
| Stump Farm | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 88 | 90 | 262 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 37 | 95 | 102 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 84 | 50 | 20 | 62 | 0 | 0 |
| Region 6 | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 2.0 | 5.4 | 5.9 | 20 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 0.8 | 1.9 | 7.0 | 6.2 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 6.3 | 2.6 | 0.9 | 3.3 | 0 | 0 |
| Flume Creek | Wet | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0.1 | 0.1 | 46 | 0 | 0 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 15 | 0 | 0 |
| | Average | 0 | 0 | 0 | 0 | 0 | 0 | 5.0 | 0 | 0 | 1.2 | 0 | 0 |
| Additional Canyon | Wet | 6.6 | 5.4 | 6.6 | 5.7 | 0.1 | 1.1 | 62 | 167 | 164 | 917 | 24 | 18 |
| | Dry | 11 | 0.1 | 2.1 | 4.9 | 29 | 36 | 34 | 52 | 340 | 284 | 8.8 | 6.1 |
| | Average | 18 | 16 | 25 | 24 | 19 | 0.1 | 217 | 80 | 35 | 98 | 5.1 | 16 |

## Region 2

Region 2 is located at the area commonly referred to as Everett Island. The region is located along the side channel west of the island. The substrate of the region consists of fine sediment. Approximately 99 percent of the stranding area within this region has the presence of macrophytes of which 7 percent has slopes 4 percent or less. The stranding area within the region ranges from an elevation of 1,967 NAVD 88 (1,963 NGVD 29) to 1,989 NAVD 88 (1,985 NGVD 29).

Results presented in Table 5.4-4 for Region 2 during the wet year show a peak monthly SI value of 2,894 that occurred in October. Water surface elevations modeled from the Boundary Reservoir HRM at Region 2 during this month fluctuated from 1,977 feet NAVD 88 (1,973 feet

NGVD 29) to 1,994 feet NAVD 88 (1,990 feet NGVD 29). The majority of the stranding area in Region 2 exists between the elevations of 1,979 feet NAVD 88 (1,975 feet NGVD 29) to 1,986 feet NAVD 88 (1,982 feet NGVD 29). Daily fluctuations of water surface elevations of up to 10 feet occurred in October as shown in Figure 5.4-5. Review of this figure shows that as the fluctuation in water surface elevations trend downward towards a lower elevation, the resulting stranding index number in general increases. Likewise, as the water surface elevations are increased to a higher level, the resulting stranding index number decreases. An example of this occurred from October 24 to October 29, 1997. Water surface elevations were allowed to increase just prior to midnight on October 24. Over the next successive days, load-following operations continued to lower the fluctuation zone of water surface elevations at Region 2. During each day as the lower bound of fluctuation decreased, the resulting SI value increased.

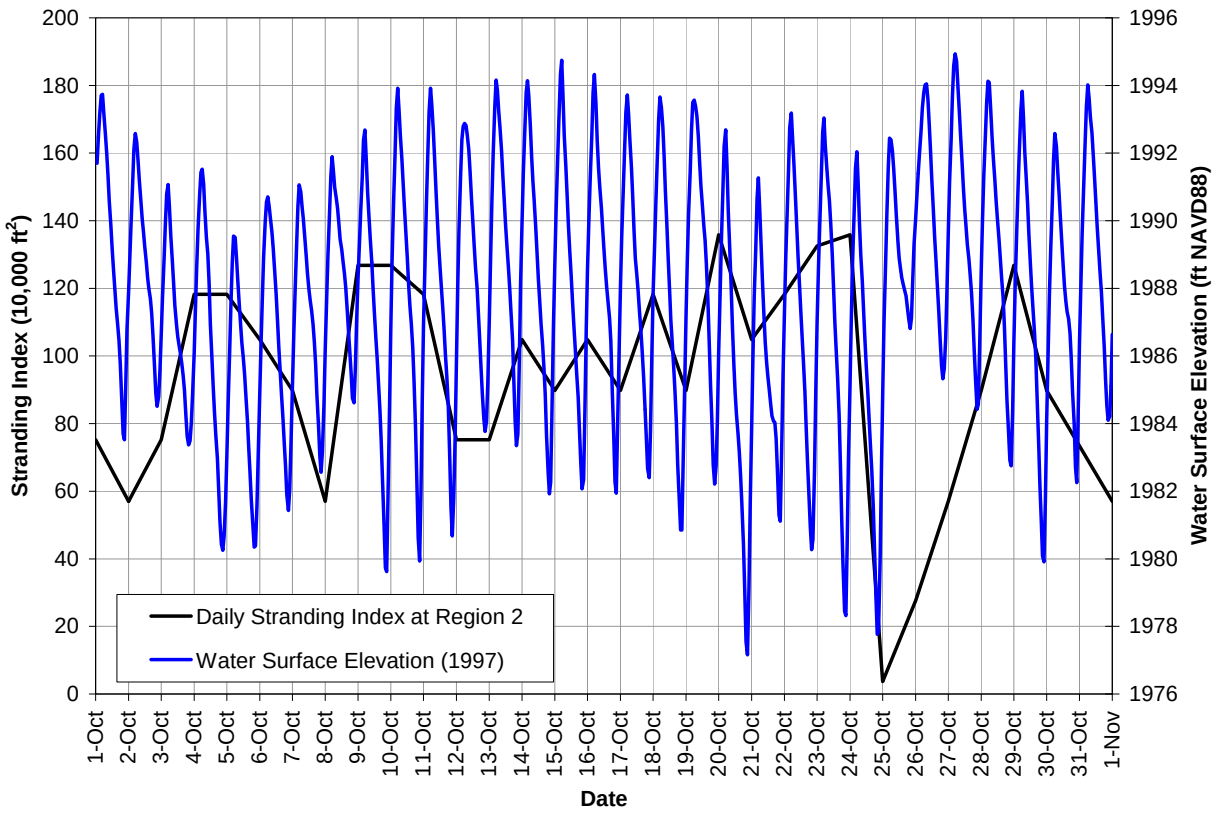



**Figure 5.4-5.** Daily stranding index values and water surface elevation that occurred from October 1, 1997, through October 31, 1997, at Region 2.

Weekly modeled SI values for the three representative years are shown on Figure 5.4-6. Fry periodicity (see Figure 5.3-1) shows that the highest abundance of cyprinids and other forage fish occurs during the greatest stranding potential for the wet, and dry year, and to a lesser extent, the average year. Cyprinids and other forage fish represent the most frequently observed fish stranded during field activities in 2007 and 2008 within Region 2. Mountain whitefish periodicity shows that peak fry abundance coincides with a high risk of stranding during the

average year and partially during the dry years. However, no mountain whitefish were observed stranded during the 2007 and 2008 field activities.

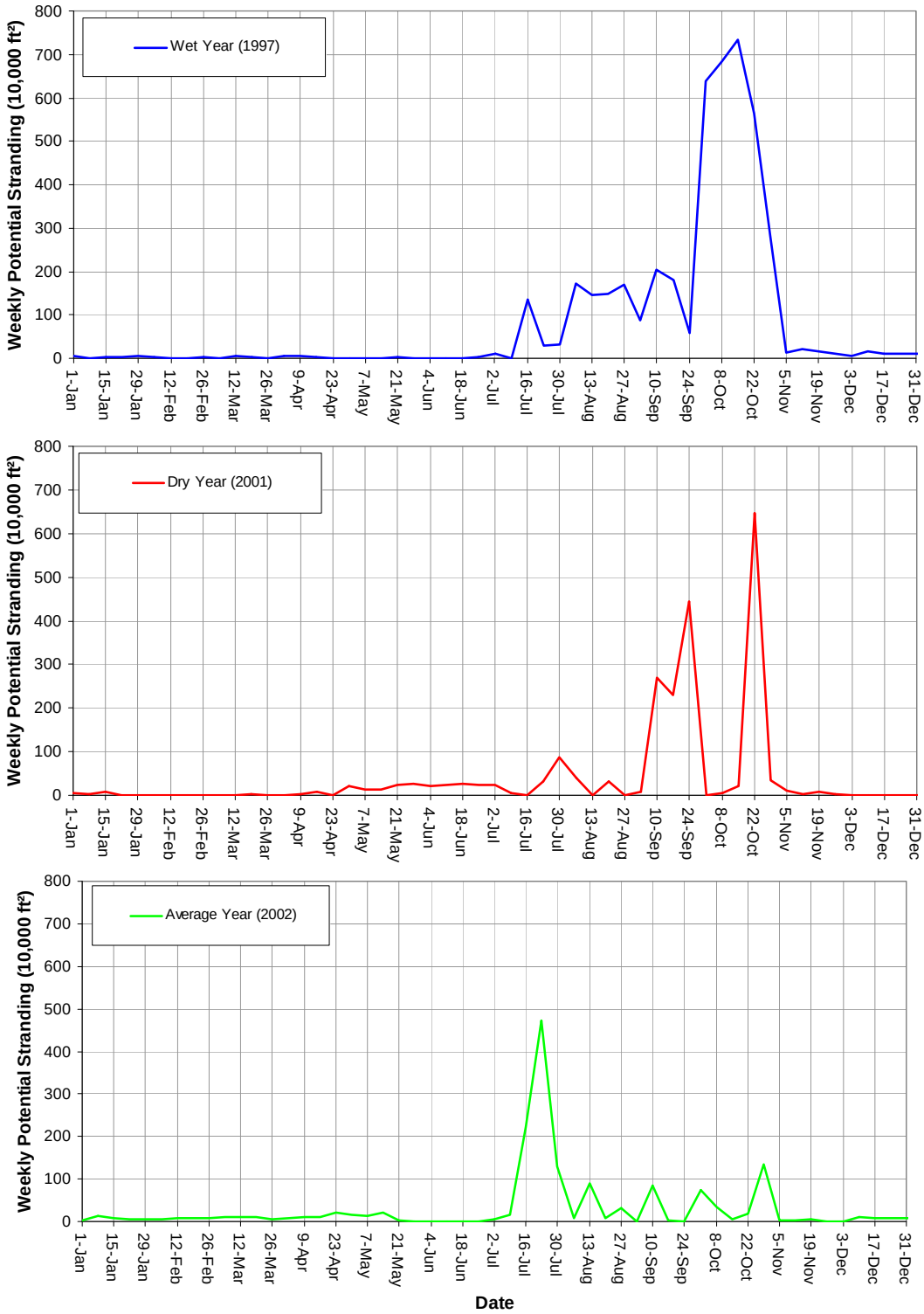



**Figure 5.4-6.** Comparison of Region 2 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

### 5.4.1.2.3. Upper Reservoir Reach

The Upper Reservoir Reach is located above Metaline Falls (PRM 26.8) to the tailrace of Box Canyon Dam (PRM 34.5). There are 13 stranding and trapping regions within the Upper Reservoir Reach. Monthly SI values are summarized for the entire reach in Figure 5.4-7 and by region for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions in Table 5.4-4.

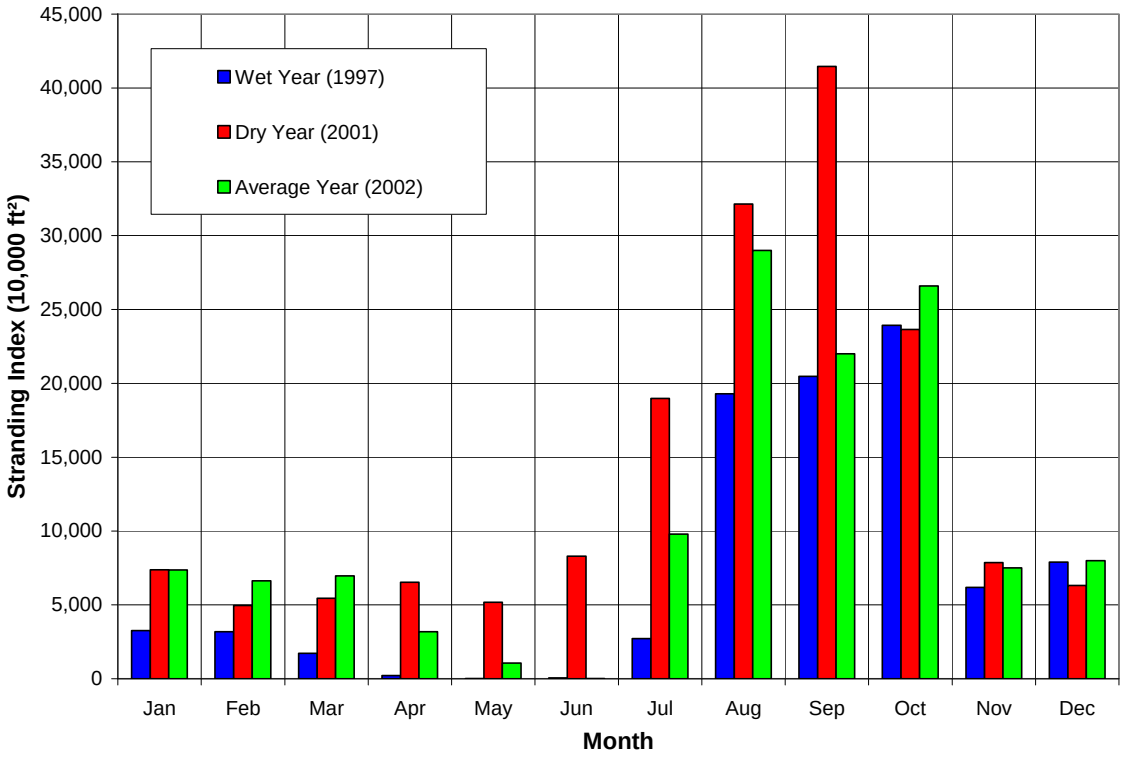



**Figure 5.4-7.** Monthly total stranding index values for the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

**Table 5.4-4.** Summary of Upper Reservoir Reach monthly cumulative stranding index (SI) value by region for the wet (1997), dry (2001), and average year (2002).

| Region | Year | Stranding Index (10,000 ft$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Sullivan Creek | Wet | 114 | 111 | 77 | 31 | 2.1 | 8.8 | 59 | 170 | 179 | 212 | 193 | 238 |
| | Dry | 198 | 102 | 139 | 164 | 165 | 207 | 187 | 144 | 121 | 194 | 190 | 164 |
| | Average | 205 | 198 | 203 | 124 | 76 | 6 | 118 | 192 | 159 | 197 | 182 | 206 |
| Region 7 | Wet | 89 | 83 | 52 | 13 | 2.0 | 3.2 | 39 | 439 | 226 | 225 | 134 | 159 |
| | Dry | 156 | 95 | 101 | 134 | 127 | 135 | 410 | 923 | 1,565 | 464 | 153 | 128 |
| | Average | 144 | 133 | 150 | 87 | 50 | 2.4 | 100 | 361 | 327 | 325 | 134 | 153 |
| Region 8 | Wet | 40 | 50 | 38 | 0 | 3.9 | 24 | 55 | 2,069 | 1,549 | 1,783 | 228 | 316 |
| | Dry | 657 | 77 | 243 | 404 | 287 | 469 | 1,898 | 4,710 | 11,061 | 2,252 | 570 | 327 |
| | Average | 438 | 536 | 727 | 275 | 5.8 | 1.9 | 720 | 2,555 | 1,753 | 2,259 | 355 | 557 |
| Region 9 | Wet | 833 | 765 | 485 | 116 | 0 | 1.7 | 1,608 | 8,595 | 9,281 | 10,564 | 1,617 | 1,783 |
| | Dry | 1,387 | 930 | 987 | 1,441 | 1,437 | 2,013 | 6,544 | 11,540 | 12,379 | 10,160 | 1,851 | 1,287 |
| | Average | 1,464 | 1,244 | 1,354 | 795 | 542 | 0.7 | 4,322 | 11,713 | 9,124 | 11,344 | 1,706 | 1,664 |
| Region 10 | Wet | 183 | 163 | 104 | 6.6 | 0 | 0 | 59 | 258 | 303 | 353 | 290 | 370 |
| | Dry | 361 | 253 | 277 | 293 | 244 | 371 | 364 | 263 | 199 | 313 | 326 | 295 |
| | Average | 364 | 319 | 326 | 147 | 54 | 0 | 126 | 353 | 313 | 353 | 326 | 364 |
| Region 11 | Wet | 55 | 20 | 48 | 2.3 | 0 | 0 | 53 | 2,702 | 3,648 | 4,574 | 299 | 425 |
| | Dry | 500 | 94 | 269 | 351 | 253 | 780 | 3,339 | 7,070 | 6,736 | 3,736 | 607 | 272 |
| | Average | 437 | 459 | 494 | 187 | 7 | 0 | 1,890 | 6,180 | 4,036 | 5,091 | 455 | 613 |
| Region 12 | Wet | 18 | 16 | 8.3 | 0.7 | 0 | 0.1 | 7.1 | 21 | 23 | 24 | 23 | 27 |
| | Dry | 22 | 18 | 18 | 20 | 19 | 26 | 20 | 12 | 9.3 | 24 | 22 | 20 |
| | Average | 22 | 19 | 19 | 10 | 8 | 0 | 10 | 23 | 21 | 25 | 22 | 22 |
| Region 13 | Wet | 65 | 64 | 33 | 1.7 | 0 | 0.1 | 59 | 781 | 780 | 784 | 132 | 164 |
| | Dry | 232 | 97 | 153 | 185 | 128 | 220 | 989 | 2,078 | 2,201 | 1,000 | 233 | 167 |
| | Average | 196 | 203 | 218 | 99 | 22 | 0.1 | 417 | 1,525 | 1,092 | 1,270 | 189 | 229 |
| Region 14 | Wet | 93 | 80 | 41 | 8.4 | 0 | 0.4 | 54 | 398 | 410 | 454 | 138 | 167 |
| | Dry | 169 | 105 | 124 | 140 | 112 | 156 | 442 | 737 | 1,178 | 497 | 162 | 140 |
| | Average | 156 | 145 | 153 | 77 | 35 | 0.2 | 209 | 647 | 516 | 579 | 146 | 158 |
| Region 15 | Wet | 102 | 90 | 56 | 0 | 0 | 0.1 | 25 | 372 | 392 | 417 | 232 | 422 |
| | Dry | 521 | 221 | 357 | 375 | 149 | 439 | 701 | 887 | 1,560 | 477 | 420 | 361 |
| | Average | 516 | 511 | 497 | 198 | 1.8 | 0 | 190 | 665 | 539 | 563 | 403 | 518 |
| Region 16 | Wet | 122 | 86 | 54 | 23 | 1.7 | 2.6 | 266 | 544 | 417 | 554 | 165 | 152 |
| | Dry | 41 | 34 | 29 | 64 | 127 | 104 | 73 | 36 | 52 | 550 | 104 | 68 |
| | Average | 61 | 50 | 45 | 68 | 92 | 2.0 | 292 | 294 | 218 | 340 | 72 | 53 |
| Region 17 | Wet | 265 | 270 | 141 | 21 | 0 | 2.1 | 119 | 603 | 560 | 619 | 387 | 455 |
| | Dry | 338 | 290 | 283 | 341 | 318 | 411 | 645 | 948 | 1,242 | 662 | 395 | 343 |
| | Average | 371 | 306 | 324 | 158 | 96 | 0 | 238 | 774 | 640 | 697 | 381 | 363 |

**Table 5.4-4, continued…**

| Region | Year | Stranding Index (10,000 ft$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| **High Stranding Area in Region 17** | Wet | 1,277 | 1,384 | 576 | 0 | 0 | 0 | 299 | 1,935 | 2,406 | 3,072 | 2,327 | 3,197 |
| | Dry | 2,714 | 2,637 | 2,434 | 2,578 | 1,788 | 2,937 | 2,985 | 1,806 | 1,243 | 2,917 | 2,775 | 2,703 |
| | Average | 2,948 | 2,453 | 2,379 | 933 | 59 | 0 | 1,022 | 3,168 | 2,857 | 3,121 | 3,114 | 3,049 |
| **Region 18** | Wet | 0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.0 | 3.6 | 1.7 | 0.2 | 0.3 | 2.0 |
| | Dry | 19 | 2.6 | 8.3 | 11 | 1.8 | 1.6 | 10 | 18 | 74 | 1.5 | 19 | 9.0 |
| | Average | 7 | 10 | 14 | 5.1 | 0.2 | 0.3 | 0.6 | 4.7 | 5.7 | 3.6 | 4.3 | 9.4 |
| **Additional Upper Reservoir** | Wet | 4.3 | 3.2 | 2.9 | 1.8 | 1.1 | 5.5 | 16 | 402 | 297 | 303 | 10 | 18 |
| | Dry | 59 | 9.1 | 25 | 37 | 15 | 19 | 366 | 979 | 1,838 | 404 | 45 | 29 |
| | Average | 35 | 43 | 61 | 21 | 3.4 | 2.9 | 130 | 551 | 396 | 435 | 23 | 37 |

In order to assess where the greatest potential for stranding occurs within the Upper Reservoir Reach, the combined annual total SI values for all regions were summarized in Figure 5.4-8. Tabulated results in Table 5.4-4 and visual representations in Figure 5.4-8 show that the greatest stranding potential is estimated to occur in Regions 9, 11, and 17 (based on the combination of Region 17 and the high density stranding area within Region 17). The combination of the four regions accounts for 73 percent of the total SI value of the combination of the wet, dry, and average year. Discussions will be focused on these four regions. An additional region, Region 10, will also be discussed in detail because there were several stranding observations made at this area and it is the largest region that has a dominant cobble substrate. Additional plots of the remaining regions within the Upper Reservoir Reach can be found within Appendix 4, Attachment D. The regions of interest are presented below in order of occurrence traveling upstream.

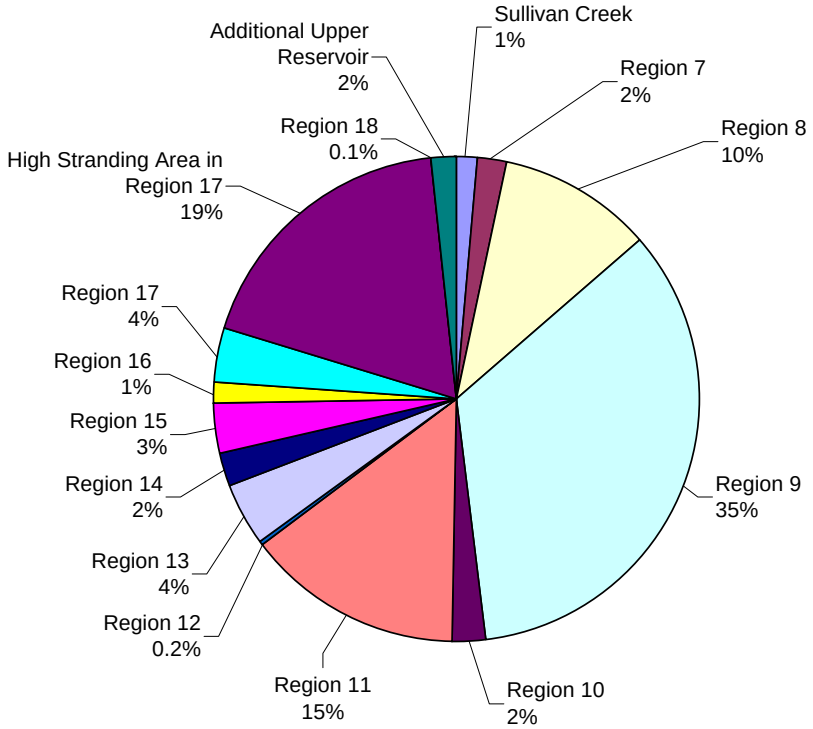



**Figure 5.4-8.** Percent of the combined annual total stranding index values for the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

## Region 9

Region 9 is located east of the town of Metaline along the right bank looking downstream. The area is composed of several vegetated bars threaded by several small side channels. The substrate of the region consists of fine sediment. Approximately 83 percent of the stranding area within this region has the presence of macrophytes of which 49 percent has slopes 4 percent or less. The stranding area within the region ranges from an elevation of 1,976 feet NAVD 88 (1,972 feet NGVD 29) to 2,005 feet NAVD 88 (2,001 feet NGVD 29). The presence of beached fish within Region 9 was observed during the field activities in 2007 and in 2008.

Review of Figure 5.4-9 shows that the majority of the potential stranding occurred during the periods corresponding to the peak growth season of aquatic macrophytes (July through October). SI values during this period were six times greater than SI values during the remaining portions of the year. The greatest potential for stranding at Region 9 occurs during this period. Periodicity results (Figure 5.3-1) indicate the peak of the cyprinid and other forage fish abundance coincides with the peak period of aquatic macrophyte biomass. On the other hand, the peak for the mountain whitefish is nearing completion as the peak season for macrophyte biomass begins.

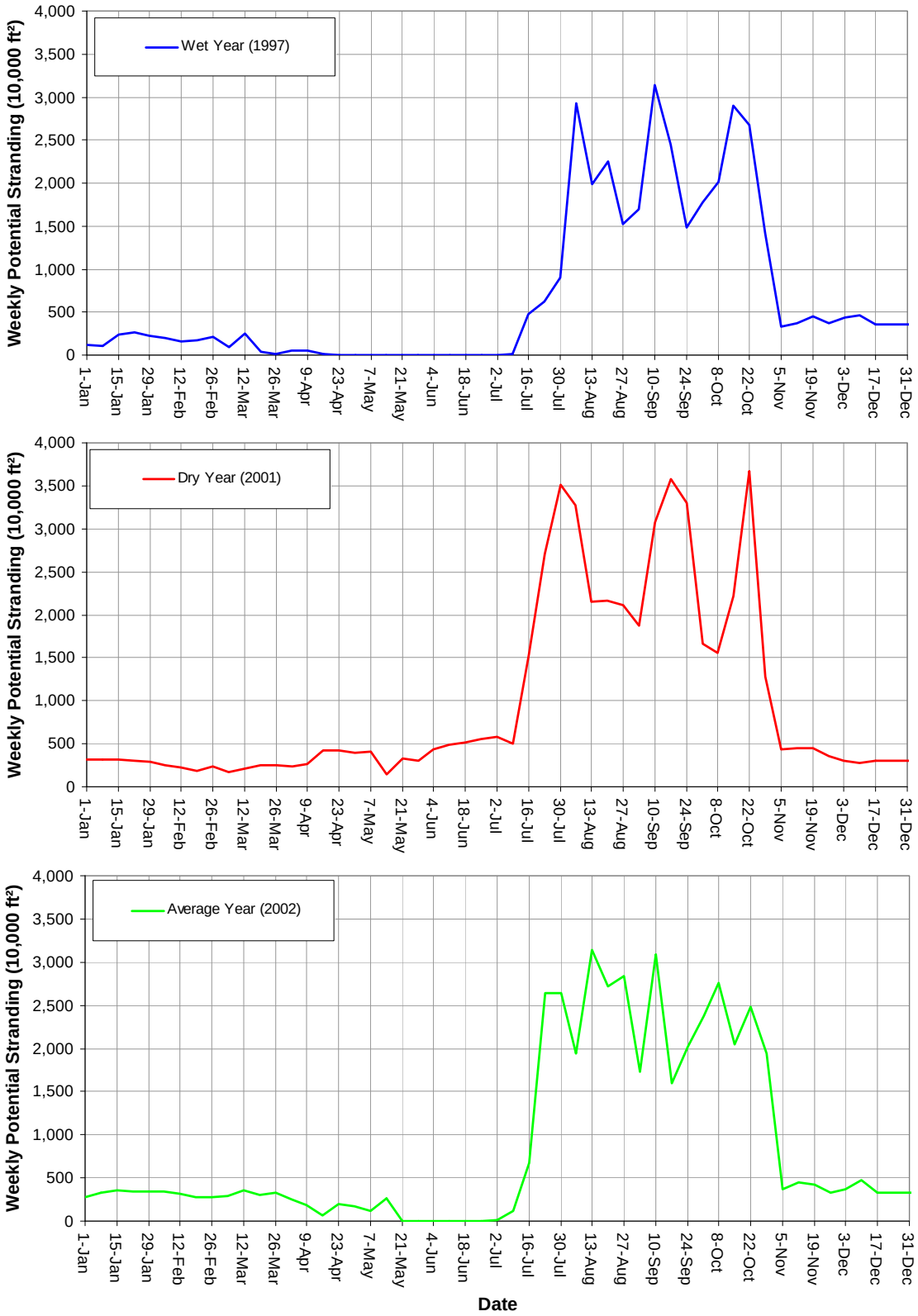



**Figure 5.4-9.** Comparison of Region 9 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

## Region 10

Region 10 is located at the area commonly referred to as the "Cobble Islands." The region is located along the inside of a river bend at PRM 30.3. In keeping with its name, the predominant substrate at the Cobble Islands consists of cobble sediment. Approximately 6 percent of the stranding area within this region has the presence of macrophytes of which there is no area with slopes 4 percent or less. The stranding area within the region ranges from an elevation of 1,978 feet NAVD 88 (1,974 feet NGVD 29) to 2,002 feet NAVD 88 (1,998 feet NGVD 29).

SI values for Region 10 are presented in Figure 5.4-10. During periods of high flows, water surface elevations increased resulting in a decrease in stranding potential. During the recession of the high flows, the stranding potential increased. An example of this is shown during weeks March 16 though July 30 of the wet and average year. The spring freshet was occurring during this period resulting in a decrease in SI values. As flows receded and water surface elevations resumed to fluctuate form Project operations, the stranding potential increased.

Stranding potential during the dry year occurs year round and with an approximate average SI value of $75 \times 10^4$. However the range of fluctuation in SI values during the average and wet year increases with periods of no stranding occurring during both. The duration of the period without stranding occurring is greater during the wet year than the average due to high inflows into Boundary Reservoir and a longer duration of elevated water surface elevations. This is due to minimal stranding area above an elevation of 2,002 feet NAVD 88 (1,998 feet NGVD 29).

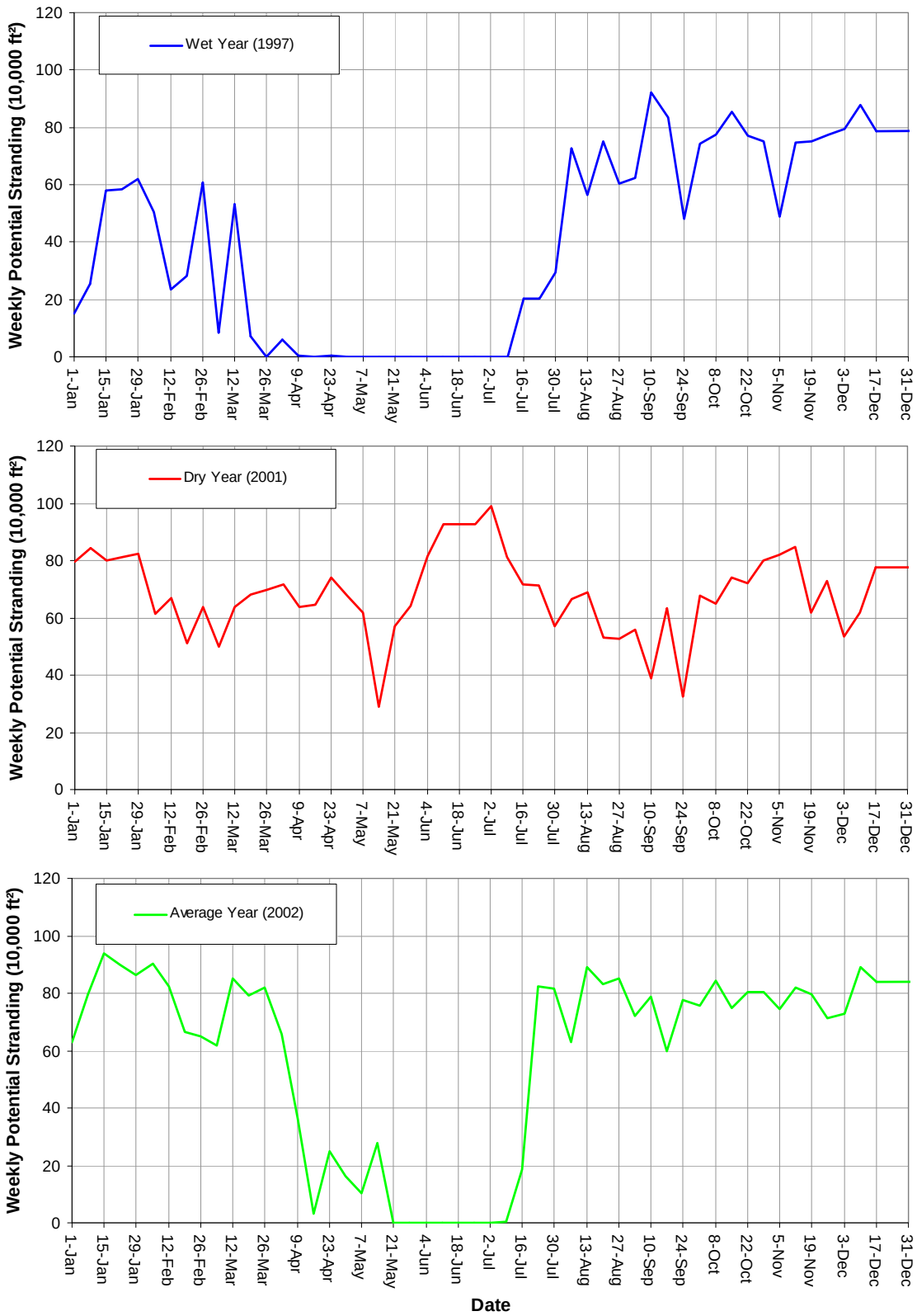



**Figure 5.4-10.** Comparison of Region 10 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

## Region 11

Region 11 is located adjacent to Region 10. The region consists of a vegetated bar along the upstream portion of the region transitioning to a shallow water embayment. The substrate of the region consists of fines. Approximately 99 percent of the stranding area within this region has been mapped with macrophytes, of which 45 percent has slopes 4 percent or less. The stranding area within Region 11 ranges from an elevation of 1,978 feet NAVD 88 (1,974 feet NGVD 29) to 1,995 feet NAVD 88 (1,991 feet NGVD 29).

Weekly SI values for the three representative years are shown on Figure 5.4-11 for Region 11. Similar to Region 9, review of Figure 5.4-12 shows that the majority of the stranding potential occurred during the period of peak macrophyte growth (July 16 through October). The highest magnitude of stranding potential occurred during the first week of August during the dry year (2001). This was caused by a decrease in water surface elevations at Region 11.

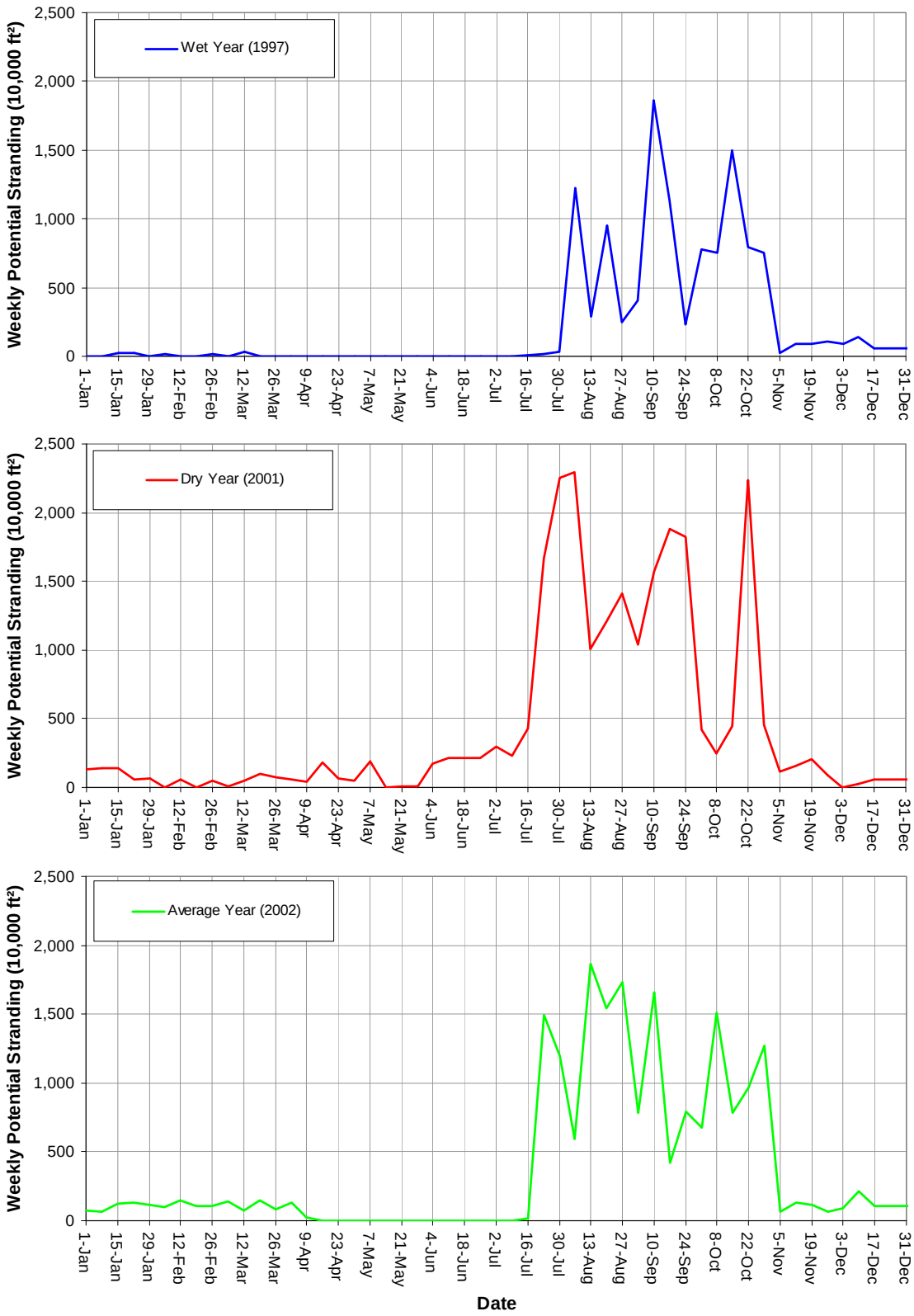



**Figure 5.4-11.** Comparison of Region 11 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

## Region 17

Region 17 is located directly across from the Box Canyon Motel near PRM 33.0. The region consists of several vegetated islands connected by a series of slough channels. The substrate of the region consists of fine sediment. Approximately 42 percent of the stranding area within this region has the presence of macrophytes of which 25 percent has slopes 4 percent or less. The stranding area within the region ranges from an elevation of 1,979 feet NAVD 88 (1,975 feet NGVD 29) to 2,024 feet NAVD 88 (2,020 feet NGVD 29).

Observations during the 2007 and 2008 field activities led to the development of a high density stranding area defined within Region 17. Results presented in Figure 5.4-13 show just the SI values associated with the area not included within the high density stranding area. SI values calculated for the high density stranding area are presented separately in the section below.

Figure 5.4-12 shows the fry rearing periodicity of mountain whitefish and suckers along with the weekly modeled SI values for the three representative years.

The presence of macrophytes has an influence on the stranding potential modeled. SI values during this period (July 16 through October 29) were three to five times greater than SI values during the periods without macrophytes. It can be inferred that the greatest stranding potential at Region 17 occurs during this period.

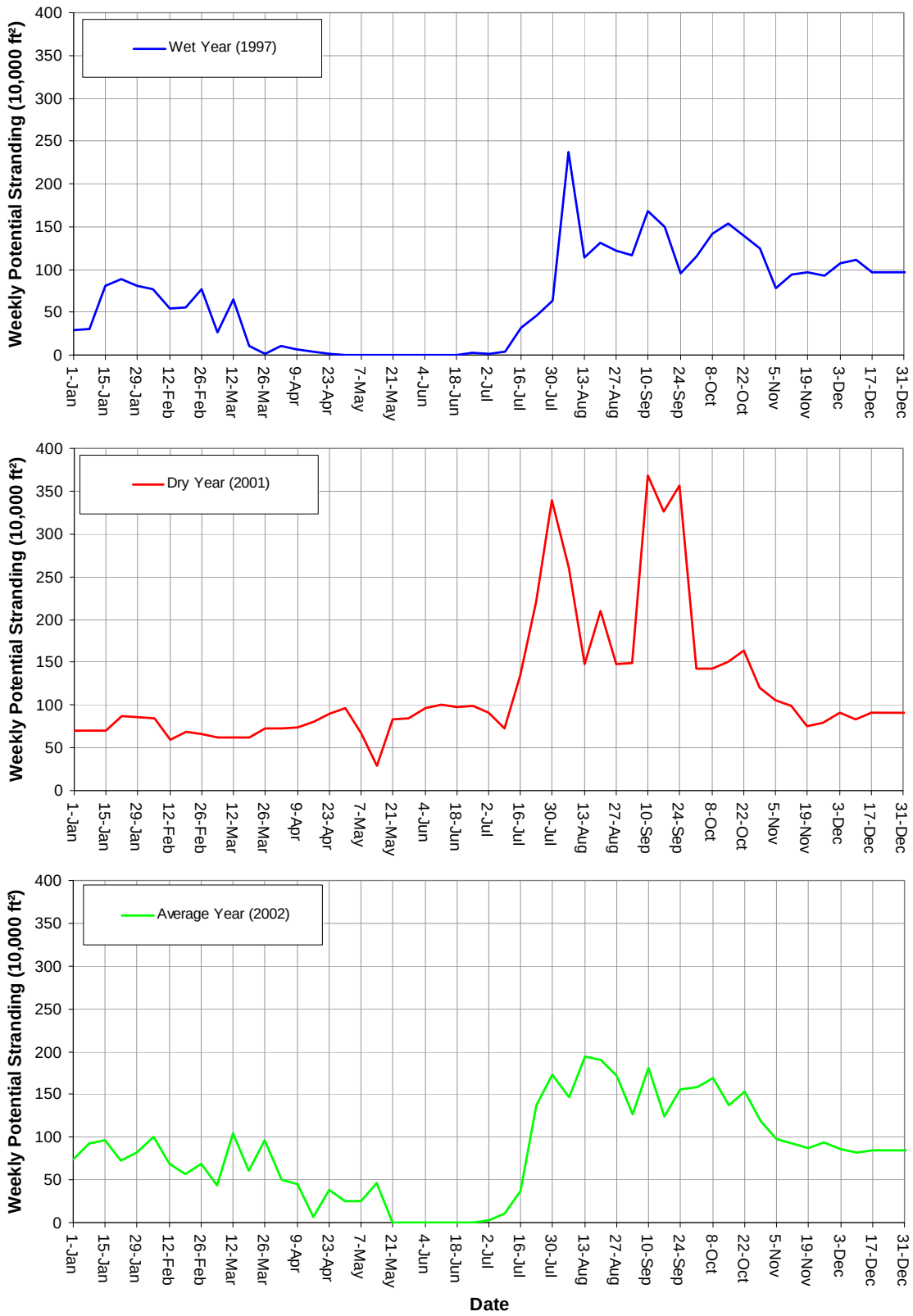



**Figure 5.4-12.** Comparison of Region 17 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

### *High Density Stranding Area within Region 17*

A high density stranding area was identified based on field observation as discussed in further detail in Appendix 4. The high density stranding area identified within Region 17 consists of a low gradient area of approximately 41,400 square feet (0.9 acre) lying primarily between the elevations of 1,990 and 1,993 feet NAVD 88 (1,986 and 1,989 feet NGVD 29). Weekly SI values calculated for the high density stranding area within Region 17 are presented in Figure 5.4-13.

With the presence of large contributing basin area and flat slopes, the potential for stranding remained constant throughout the course of the year. The average magnitude of SI values was also twice as large as the peak SI value modeled for the remaining area in Region 17. The relatively constant SI values during the course of the year in the high stranding area accounted for over 84 percent of the combined annual total SI values for the wet, dry, and average year within this region.

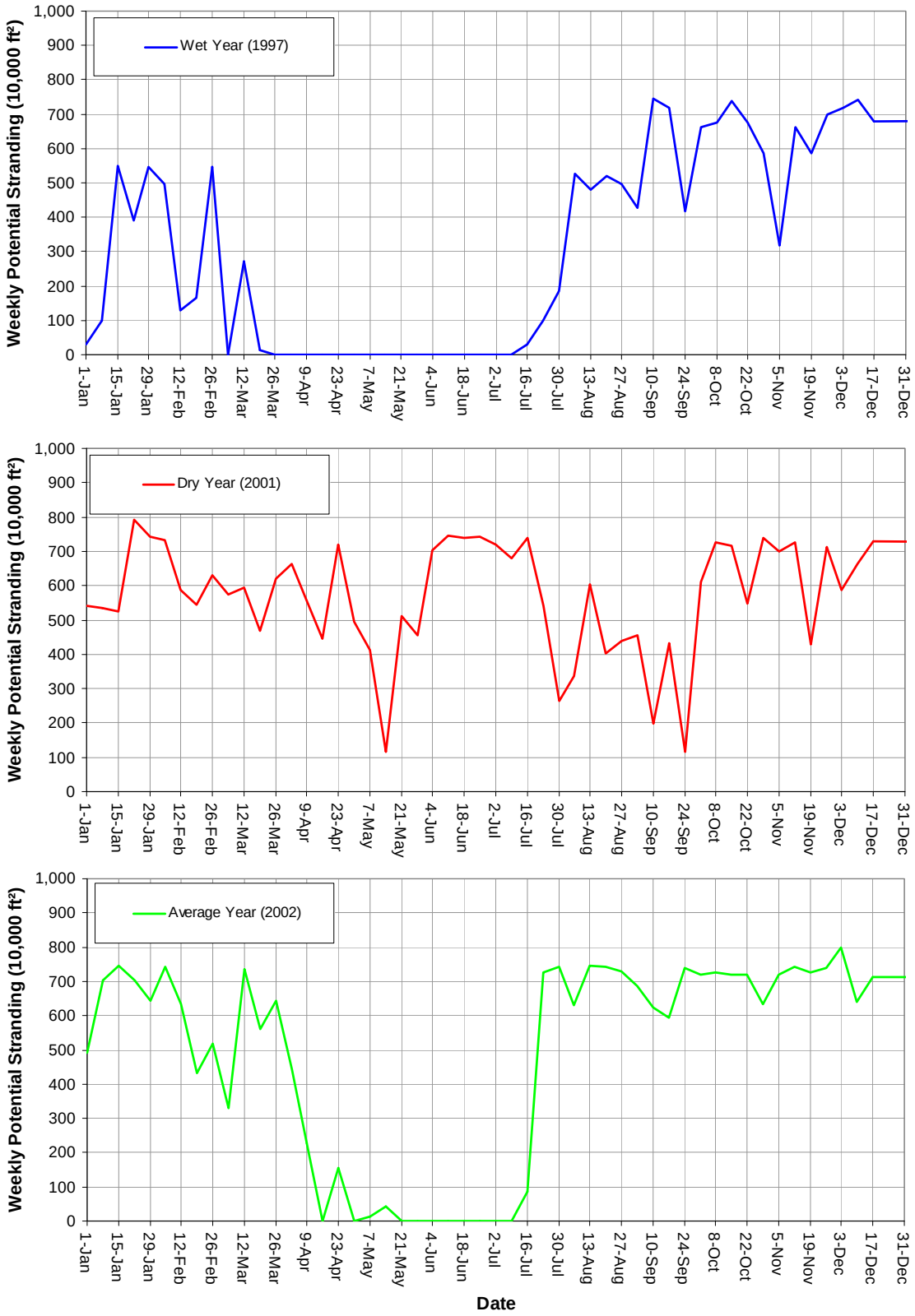



**Figure 5.4-13.** Comparison of high density stranding area of Region 17 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

### 5.4.1.2.4. Tailrace Reach

Figure 5.4-14 presents the monthly stranding results for the Tailrace Reach. There is a single region, Tailrace Region, located within the Tailrace Reach. The monthly SI values for the Tailrace Region are tabulated in Table 5.4-5.

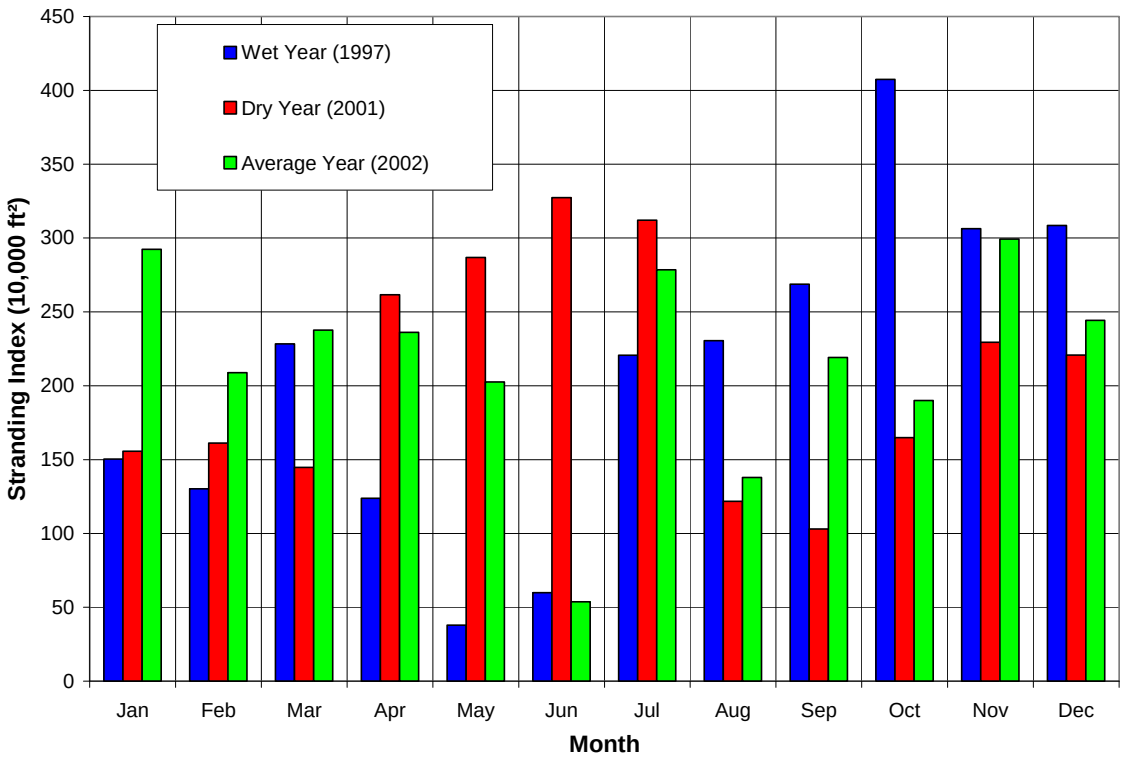



**Figure 5.4-14.** Monthly total stranding index values for the Tailrace Reach for the wet (1997), dry (2001), and average year (2002).

**Table 5.4-5.** Summary of Tailrace Reach monthly cumulative stranding index (SI) value by region for the wet (1997), dry (2001), and average year (2002).

| Region | Year | Stranding Index (10,000 ft$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Tailrace | Wet | 150 | 130 | 228 | 124 | 38 | 60 | 221 | 231 | 269 | 407 | 306 | 309 |
| | Dry | 156 | 161 | 145 | 262 | 287 | 327 | 312 | 122 | 103 | 165 | 229 | 221 |
| | Average | 292 | 209 | 238 | 236 | 202 | 54 | 278 | 138 | 219 | 190 | 299 | 244 |
| Additional Tailrace | Wet | 30 | 34 | 151 | 91 | 38 | 55 | 154 | 85 | 87 | 170 | 112 | 85 |
| | Dry | 8.4 | 38 | 31 | 68 | 87 | 117 | 103 | 23 | 8.3 | 17 | 57 | 68 |
| | Average | 87 | 44 | 53 | 93 | 105 | 54 | 152 | 7.0 | 61 | 43 | 82 | 63 |

The SI values on a monthly basis for the three representative years are presented in Figure 5.4-14. A comparison shows that SI values decreased during periods of high flow coinciding with the spring "freshet." The Project does not provide flood storage, and consequently during periods of high flow all inflows into Boundary Reservoir are discharged into the tailrace. Flows into the Tailrace Reach closely match inflow during this period until flood waters recede and normal load following operations resumed.

An example of the conditions described above is shown in Figure 5.4-14 for the wet year. During the period of May–June, flows coinciding with the spring "freshet" increased to a peak discharge of 134,000 cfs reported at USGS gage 12396500. As a result of the high flows, the modeled SI values during the spring freshet period were minimal. Potential stranding events increased during the recession limb of the flood hydrograph and normal operations resumed in the mid-July. A similar condition existed during the average year (2002) where the peak flow was 100,000 cfs. It should be noted that water surface fluctuations in the tailrace are influenced by Seven Mile Dam operations.

Potential stranding conditions during the dry year differed from those predicted SI values during wet and average years. Flows during the spring freshet during the dry year condition were significantly less (approximately 32,000 cfs). Normal load-following operations continued though the period where high flows would typically limit this type of operation. As a result, SI values calculated during May and June were high and reflected a greater potential for stranding to occur.

Overall the total annual SI value calculated for the Tailrace Reach was small when compared with the Upper Reservoir Reach. The Tailrace Reach accounted for 1 percent of the combined total SI value calculated for the three representative years.

### 5.4.2. Trapping Model

This section presents the results and interpretation of the trapping model. A TI value was calculated based on methods discussed in Section 4.4.2. Hourly TI values were calculated for each of the trapping pools for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions.

#### *5.4.2.1. General Discussion of the Trapping Model Results*

Annual TI values are presented in Table 5.4-6. In general, hydrologic conditions experienced during the dry year (2001) produced the largest TI value of the three years modeled. The average year (2002) resulted in the second largest TI value followed by the wet year (1997) producing the smallest annual TI value. This was anticipated because lower flows occurring during a dry year would result in a greater littoral area being exposed and subsequently a high trapping potential. It follows then that hydrologic conditions during the wet year would result in extended periods of higher flows, less littoral area exposure and, subsequently, a smaller trapping potential.

**Table 5.4-6.** Summary of annual total trapping index (TI) value for the wet (1997), dry (2001), and average year (2002).

| Reach | Total Area of Trapping Pool ($ft^2$) | Annual Total Trapping Index (10,000 $ft^2$) | | |
|---|---|---|---|---|
| | | Wet Year (1997) | Dry Year (2001) | Average Year (2002) |
| Forebay | 11,300 | 1.1 | 2.4 | 1.0 |
| Canyon | 99,800 | 163 | 160 | 93 |
| Upper Reservoir | 2,487,200 | 1,616 | 3,916 | 2,478 |
| Total Boundary Reservoir | 2,598,300 | 1,780 | 4,079 | 2,572 |
| Tailrace | 20,300 | 139 | 213 | 163 |
| **Annual Total** | **2,618,600** | **1,920** | **4,292** | **2,735** |

Results presented in Table 5.4-6 show that in all cases, the greatest potential for trapping occurred in the Upper Reservoir Reach. The combined total SI computed for the three representative years within the Upper Reservoir Reach accounts for 90 percent of the total trapping potential calculated for Boundary reservoir and tailrace. The Canyon Reach and Tailrace Reach equally contributed approximately 5 percent of the combined total TI computed for the three representative years. The Forebay Reach accounted for less than 0.1 percent of the trapping potential.

### *5.4.2.2. Review of Trapping Results by Reach*

This section discusses the trapping results modeled for the four reaches and are presented in the following order: Forebay, Canyon, Upper Reservoir, and Tailrace Reach. Discussions of the individual reaches will focus on the specific stranding and trapping regions where the greatest TI values were modeled. Discussions will also be included for some of the trapping pools which were surveyed in 2007 and 2008. The locations of the stranding and trapping regions were presented in Figure 5.4-1. Additional plots of the trapping model results not discussed in detail within the following subsections are summarized by region in Appendix 4, Attachment E.

#### *5.4.2.2.1. Forebay Reach*

The combined total TI value for the three representative years accounted for 0.05 percent of the trapping potential modeled for the four reaches. Annual TI values presented above in Table 5.4-6 show TI values a minimum of 90 times greater in the other reaches (Canyon, Upper Reservoir, and Tailrace) than those modeled in the Forebay Reach. There are minimal depressions in the forebay area that would serve as trapping habitat for fish.

#### *5.4.2.2.2. Canyon Reach*

Similar to the Tailrace Reach, annual trapping results in the Canyon Reach accounted for 5 percent of the combined total annual trapping estimated for the three years (see Table 5.4-6). Monthly TI values calculated for the wet, dry, and average year are plotted in Figure 5.4-15.

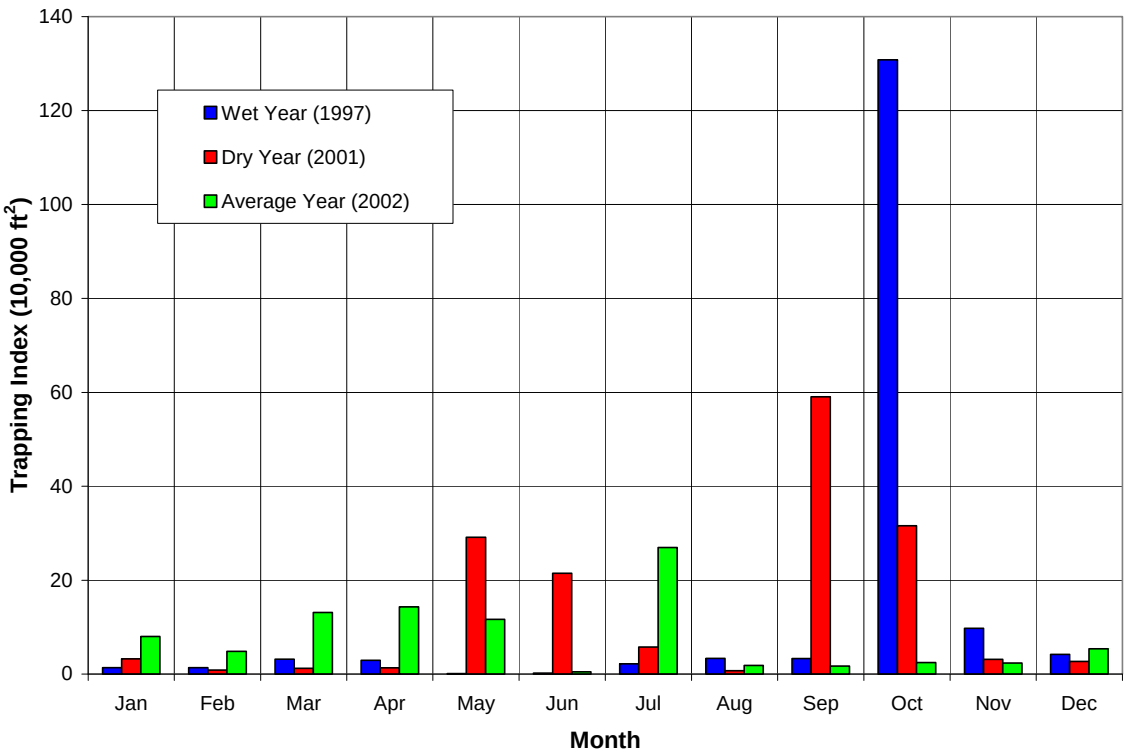



**Figure 5.4-15.** Monthly total trapping index values for the Canyon Reach for the wet (1997), dry (2001), and average year (2002).

Results presented in Figure 5.4-15 show a large peak in TI that occurred in October of the wet year (1997). Moderate inflows into Boundary Reservoir ranging from 21,000 to 26,000 cfs in October 1997 were conducive to load-following, which caused an increase in TI values within the Canyon Reach. Review of the trapping model results show that the majority of the trapping occurred in Region 2. Specifics regarding this event are presented in further detail in the section below.

Further review of the trapping model results also shows that Region 2 had the highest annual TI values within the Canyon Reach for all three years simulated. An annual total TI value of 1,471,400; 1,402,100; and 739,700 was modeled for Region 2 during the wet (1997), dry (2001), and average (2002) year, respectively. This represents 87 percent of the combined total TI value calculated for the Canyon Reach. The second highest trapping occurred in at the Flume Creek Region.

Overall the total annual TI value calculated for the Canyon Reach is small when compared with the Upper Reservoir Reach. Similar to the Tailrace Reach, the Canyon Reach also accounts for 5 percent of the combined total TI value calculated for the three representative years.

## Region 2

Region 2 is located west of Everett Island and has 20 identified trapping pools. The total area of the trapping pools is approximately 82,000 square feet and makes up 87 percent of the total trapping area within the Canyon Reach. Outlet elevations within Region 2 range from 1,977 feet NAVD 88 (1,973 feet NGVD 29) to 1,984 NAVD 88 (1,980 feet NGVD 29). Pool depths range from 0.3 to 7.7 feet. Substrate of the pool bottoms consisted of fines and macrophytes were mapped in all pools within this region.

As previously discussed, water surface elevations in October of 1997 resulted in higher than expected TI values for that period. The daily fluctuations in water surface elevations associated with load-following operations and the corresponding daily TI value for Region 2 for this period in 1997 is presented in Figure 5.4-16. In general, as the rate of water surface fluctuation increases, there is a similar increase in TI values. As the rate of fluctuation decreases, so does the corresponding TI value. An exception to this occurred on October 5, 1997, when water surface elevations dropped from 1,990 feet NAVD 88 (1,986 feet NGVD 29) to 1,980 feet NAVD 88 (1,976 feet NGVD 29). During this drop in reservoir water surface elevation, approximately 10 pools representing 93 percent of the total trapping pool area reported a TI value. The drop in reservoir water surface elevation resulted in the majority of the trapping area within Region 2 becoming disconnected from the mainstem.

Figure 5.4-17 presents the comparison of the weekly TI values for the representative hydrologic years. With the exception of the average year (2002), weekly TI values for Region 2 show that the greatest magnitude of trapping occurs from September 1 through November 5. Weekly TI values calculated for the average year were greatest from July 9 through July 30.

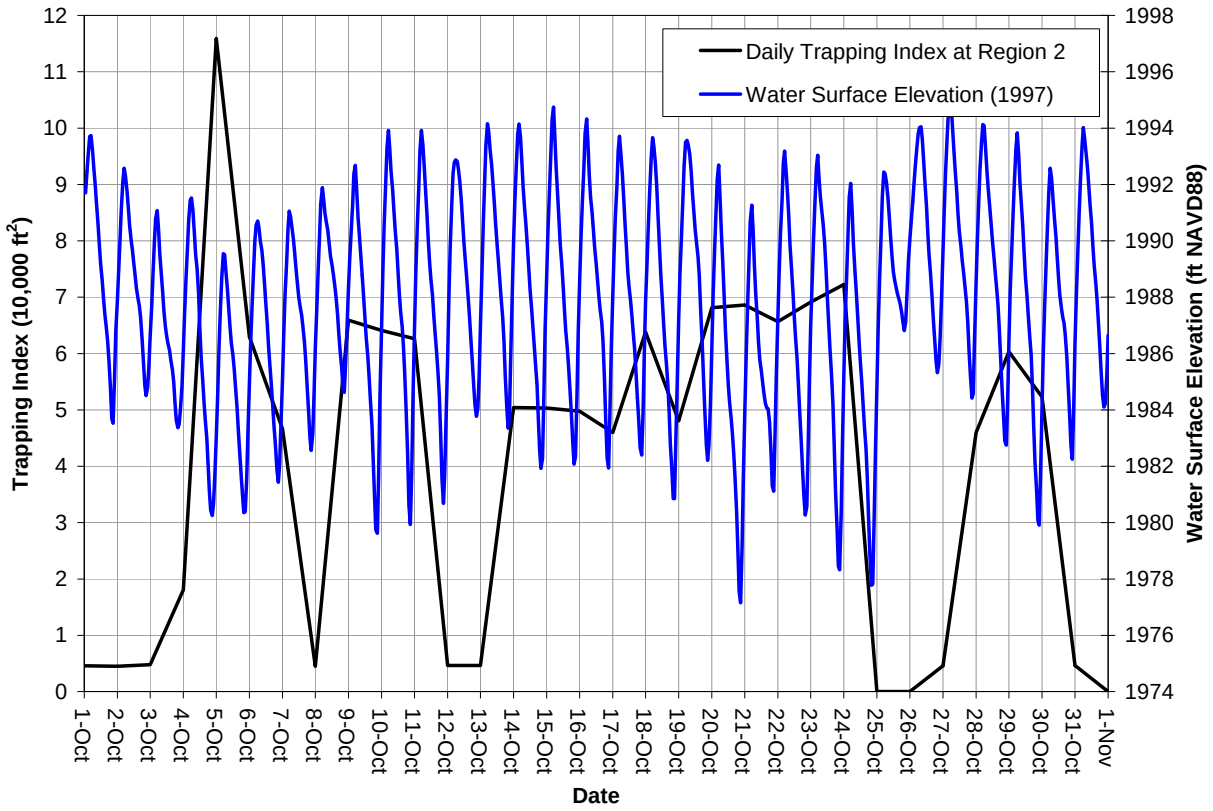



**Figure 5.4-16.** Daily trapping index values and water surface elevation that occurred from October 1, 1997, through October 31, 1997, at Region 2.

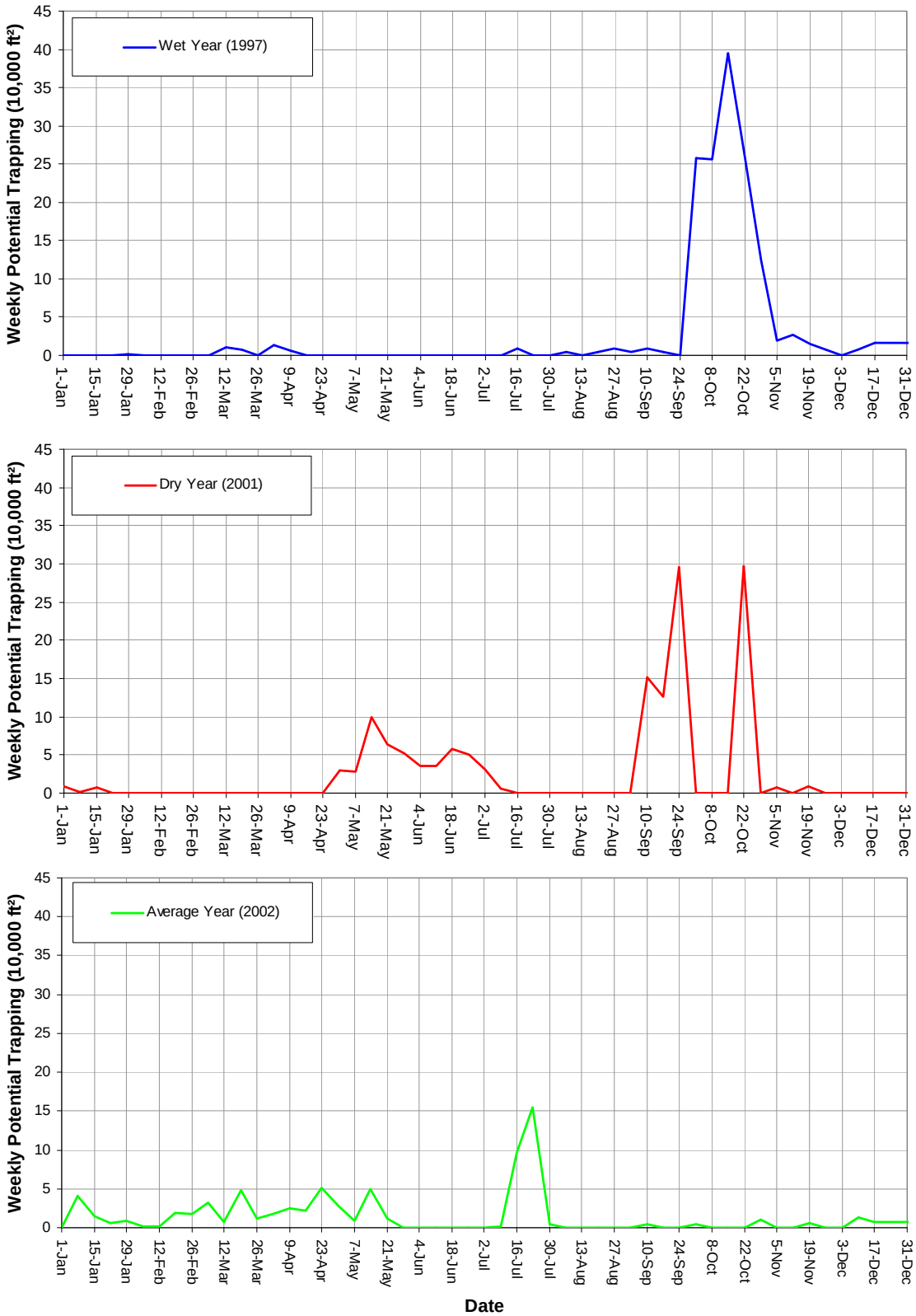



**Figure 5.4-17.** Comparison of Region 2 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

### 5.4.2.2.3. Upper Reservoir Reach

During the three hydrologic years modeled, 90 percent of exposed trapping area within the four reaches occurred in the Upper Reservoir (see Table 5.4-6). Monthly TI values calculated for the wet, dry, and average year are plotted in Figure 5.4-18.

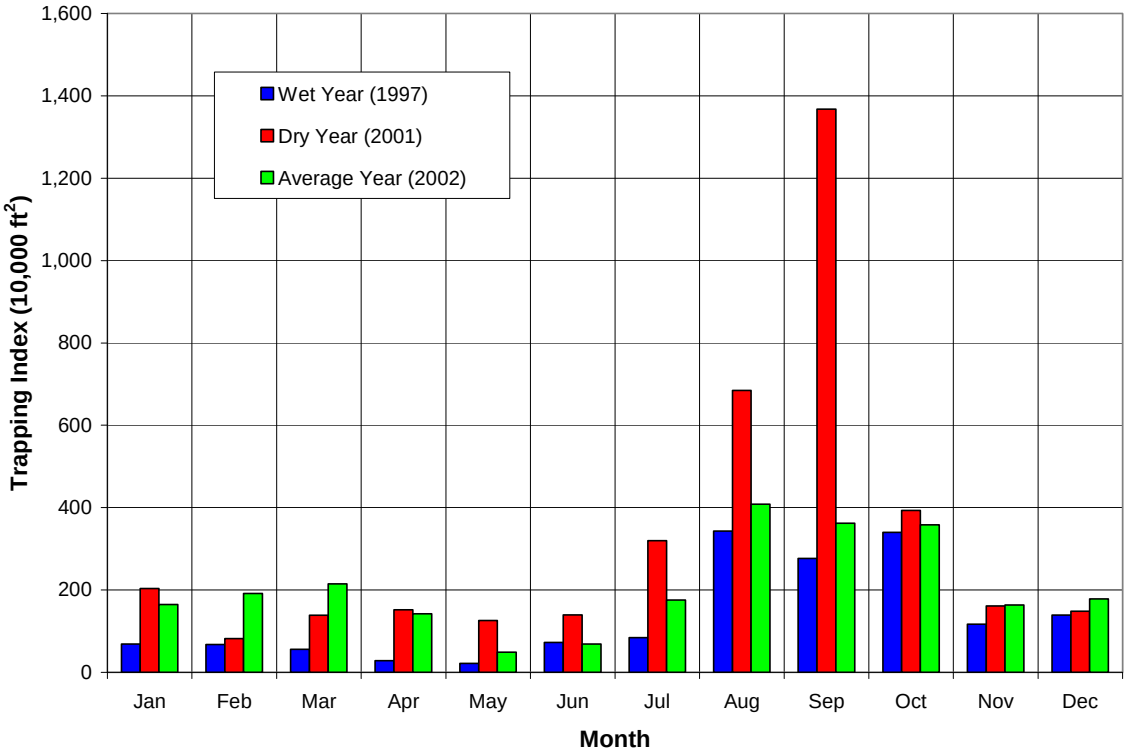



**Figure 5.4-18.** Monthly total trapping index values for the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

Review of Figure 5.4-18 shows that monthly TI values are the highest during the dry year (2001) and the lowest for the wet year (1997). During November, December, February, and March, the monthly TI values were highest during the average year.

Results presented in Figure 5.4-18 show a noticeable increase in TI values for the months of July through October for the three representative years. This time period corresponded to the peak growth period of aquatic macrophytes. As discussed in Appendix 4, Section 6.6.2, the presence of macrophytes has been shown to increase the potential of trapping by serving as a barrier to escapement. As a result, trapping cover factors during the period of peak macrophyte growth is higher than the remainder of the year. There are 271 pools having the combined pool area of 1,059,100 square feet in the Upper Reservoir Reach having the presence of macrophytes. This represents 50 percent of the trapping pools in the Upper Reservoir Reach.

Trapping model results of the individual regions show that the majority of trapping during the combined years occurs in Region 9, Region 10, Region 16, and in Region 17. These regions

represent 73 percent of the combined annual total TI value for the three representative years. The proportion of the combined total TI values for a given region is presented graphically in Figure 5.4-19.

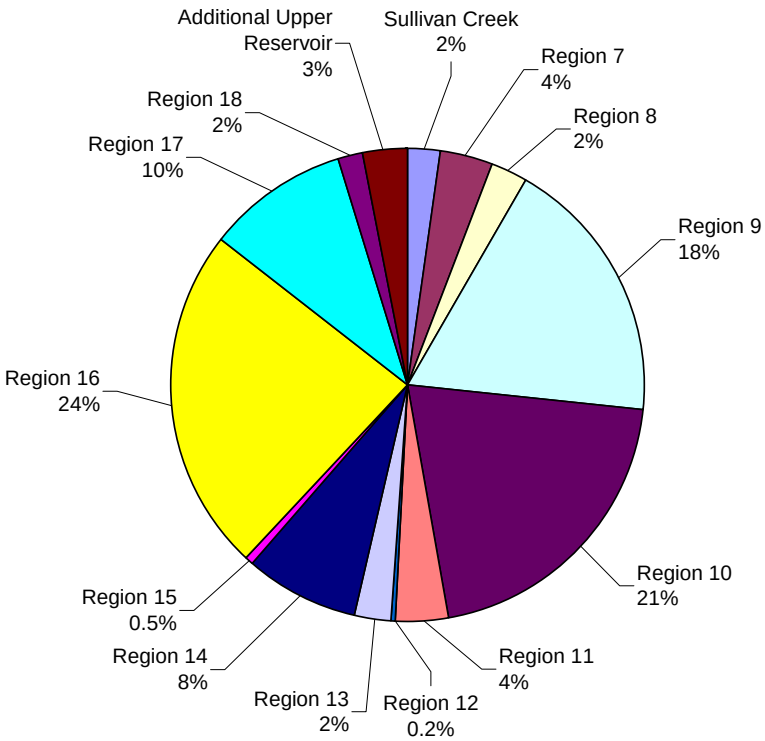



**Figure 5.4-19.** Percent of the combined annual total trapping index values for the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

Discussions will be limited to the regions mentioned above. As previously mentioned, these regions (Regions 9, 10, 16, and 17) have the highest combined annual TI values over the three representative years. Additional plots of the remaining regions within the Upper Reservoir Reach not discussed can be found within Appendix 4, Attachment E. The regions of interest are presented below in order of occurrence traveling upstream.

## Region 9

Region 9 is located east of the town of Metaline. There are a total of 121 trapping pools identified within the region. The total area of the trapping pools is approximately 252,600 square feet and makes up 10 percent of the total trapping area within the Upper Reservoir Reach. Trapping pool outlet elevations within Region 9 range from 1,975 feet NAVD 88 (1,971 feet NGVD 29) to 2,003 feet NAVD 88 (1,999 feet NGVD 29). Pool depths range from 0.1 to 4.6 feet. Substrate of the pool bottoms consisted of fines. The risk of trapping increased in response to growth of macrophytes (Figure 5.4-20); macrophytes were mapped in 81 pools and represent 85 percent of the total pool area within the region.

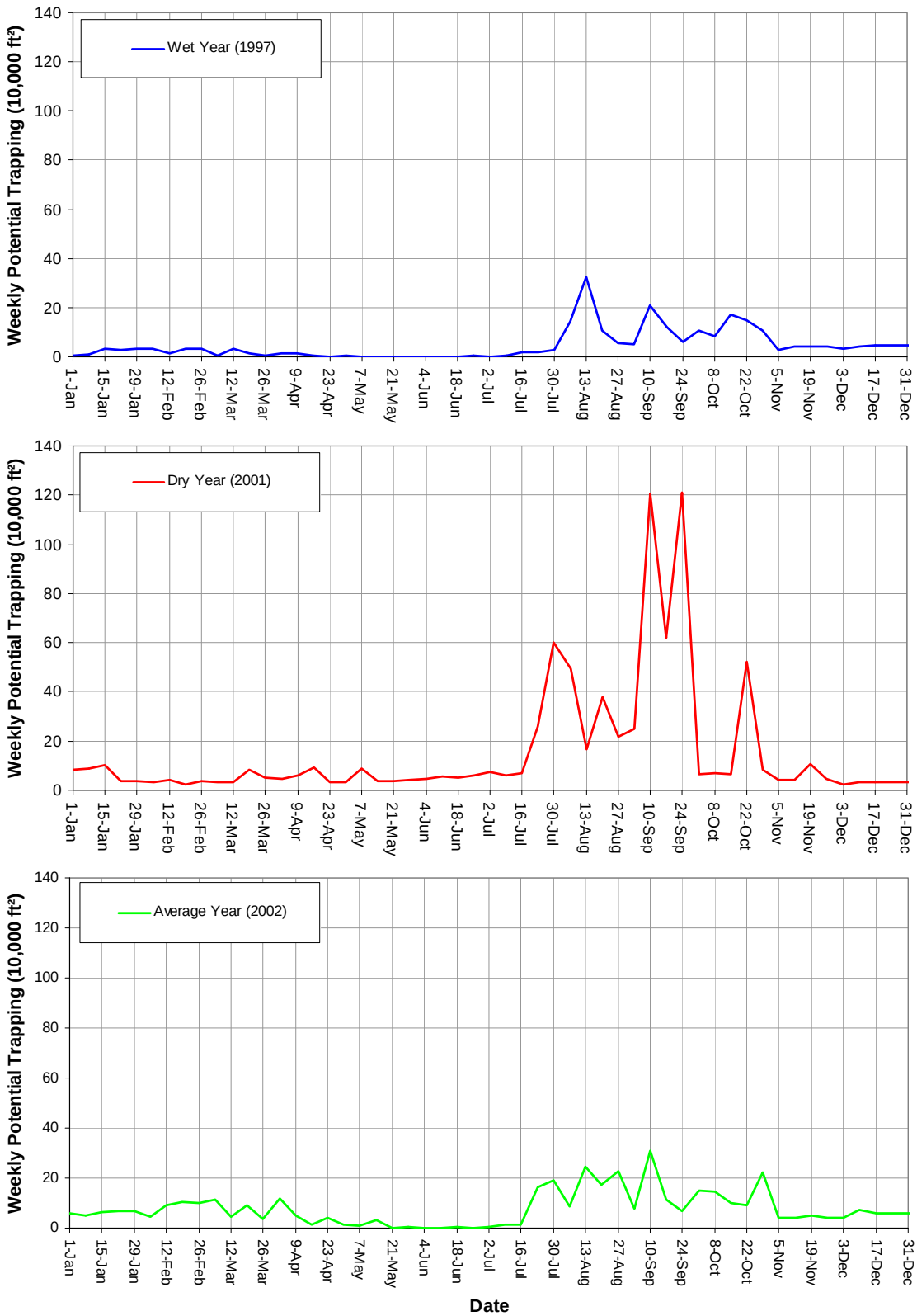



**Figure 5.4-20.** Comparison of Region 9 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

## Region 10

Region 10 is located at the area commonly referred to as the Cobble Islands. The Cobble Islands are remnants of aggregate mining activities that occurred prior to construction of Boundary Dam. The pools and depressions created by this pre-Project aggregate mining have persisted through nearly 50 years of Project operations and contribute to the trapping of aquatic life during pool level fluctuations.

The region is located along the inside of a river bend at PRM 30.3. In keeping with its name, the predominant substrate at the Cobble Islands consists of cobble sediment. There are a total of 24 trapping pools identified within the region. The total area of the trapping pools is approximately 86,100 square feet and makes up 4 percent of the total trapping area within the Upper Reservoir Reach. Outlet elevations within Region 10 range from 1,981 feet NAVD 88 (1,977 feet NGVD 29) to 1,998 feet NAVD 88 (1,994 feet NGVD 29). Pool depths range from 0.1 to 8.7 feet. No macrophytes were found in the trapping pools at this region.

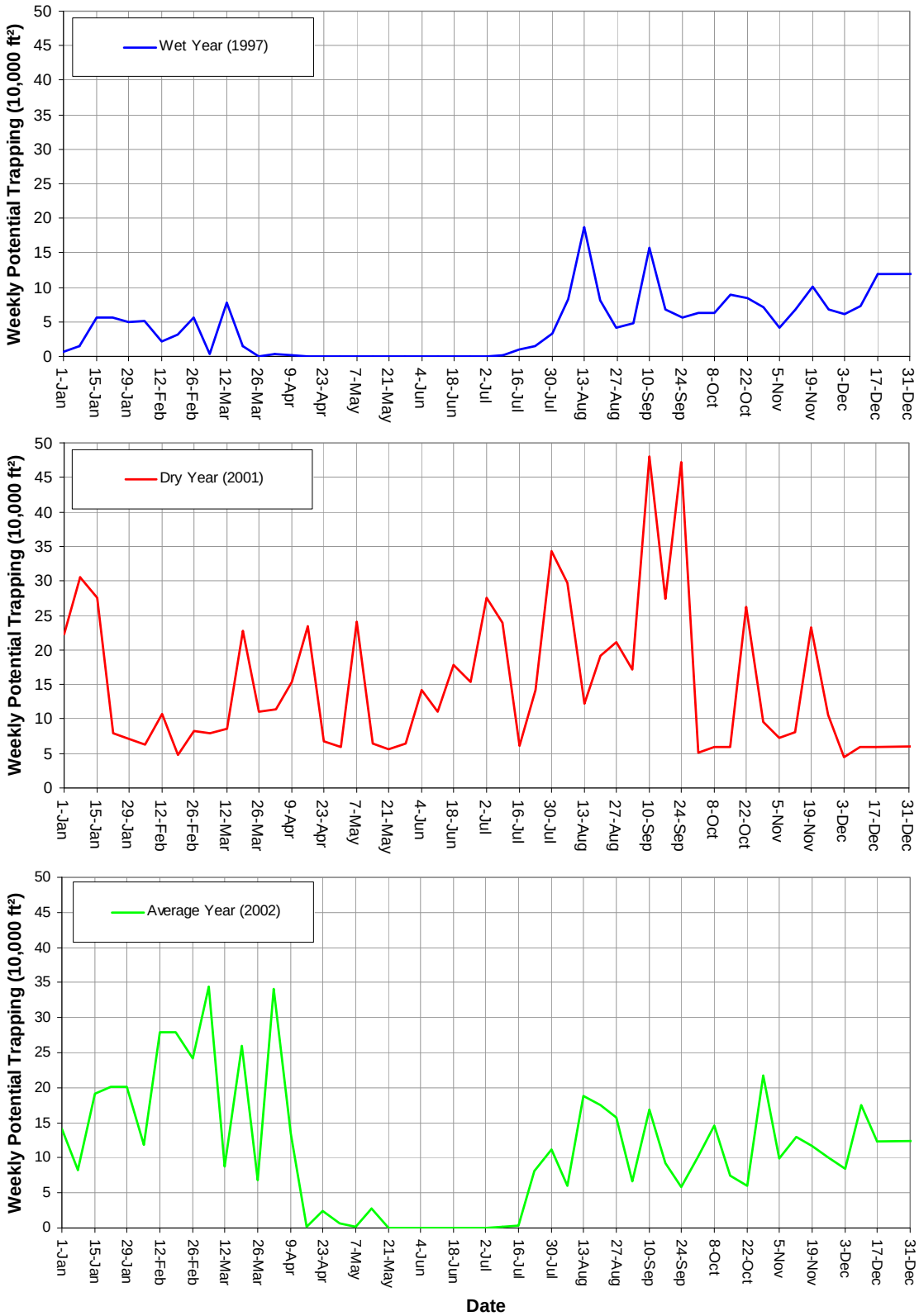



**Figure 5.4-21.** Comparison of Region 10 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

Weekly TI values for Region 10 present graphically the greatest magnitude of potential trapping varies between the three representative years. Review of Figure 5.4-21 shows the dry year having a peak trapping potential occurring from September 9 through 30. Flows during this period resulted in water surface elevations ranging between 1,982 to 1,994 feet NAVD 88 (1,978 to 1,990 feet NGVD 29). The majority of the potential trapping pool area has a controlling elevation of approximately 1,989 feet NAVD 88 (1,985 feet NGVD 29), representing 56 percent of the total potential trapping pool area available at Region 10. During the dry year, water surface elevations during the period of increased trapping potential were below this elevation 8 times for a duration ranging from several hours to several days. During the average year, the peak magnitude of potential trapping occurred in early spring from February 12 through April 4. In the wet year the highest trapping potential was associated with brief spikes occurring August 13–19 and September 10–16. During these periods, similar fluctuations and ranges of water surface elevations at Region 10 occurred due to load-following activities and were conducive to increased trapping potential.

### Region 16

Region 16 is located at the Boundary Wildlife Refuge area. There are a total of 139 trapping pools identified within the region. The total area of the trapping pools is approximately 317,900 square feet and makes up 13 percent of the total trapping area within the Upper Reservoir Reach. Outlet elevations within Region 16 range from 1,991 feet NAVD 88 (1,987 feet NGVD 29) to 2,015 feet NAVD 88 (2,011 feet NGVD 29). Pool depths range from 0.3 to 12 feet. Substrate of the pool bottoms consisted of fines. The presence of macrophytes was mapped in 4 pools and represents 12 percent of the total pool area within the region.

Figure 5.4-22 shows the weekly TI values for the three representative years. Weekly TI values for Region 16 show that the greatest magnitude of potential trapping occurred from July 16 through November 5 for the dry and average years. This period coincided with the peak biomass period for aquatic macrophytes. During the wet year the peak magnitude of trapping potential occurred later, beginning on August 6. The end of the peak trapping during the wet year occurred November 5 similar to the dry and average years. During most of the period of elevated trapping for all three representative years, based on fish periodicity (as displayed in Figure 5.3-1), the population of cyprinid and forage fish fry is at its peak. It should be noted that the period of elevated trapping occurs during the shoulder season of mountain whitefish fry.

The majority of the potential trapping pool area within Region 16 is located at higher elevations (2,008 to 2,011 feet NAVD 88 [2,004 to 2,007 feet NGVD 29]) and represents 53 percent of the total potential trapping pool area within this region. Water surface elevations during the peak periods of trapping potential however were much lower. They ranged from approximately 1,982 to 1,998 feet NAVD 88 (1,978 to 1,994 feet NGVD 29) where approximately 19 percent of the available potential trapping pool area resides, or approximately 59,300 square feet. It can be inferred that, although a small percentage of the total trapping area was being dewatered, fluctuations in water surface elevations coupled by the presence of macrophytes plays an important component in trapping within Region 16.

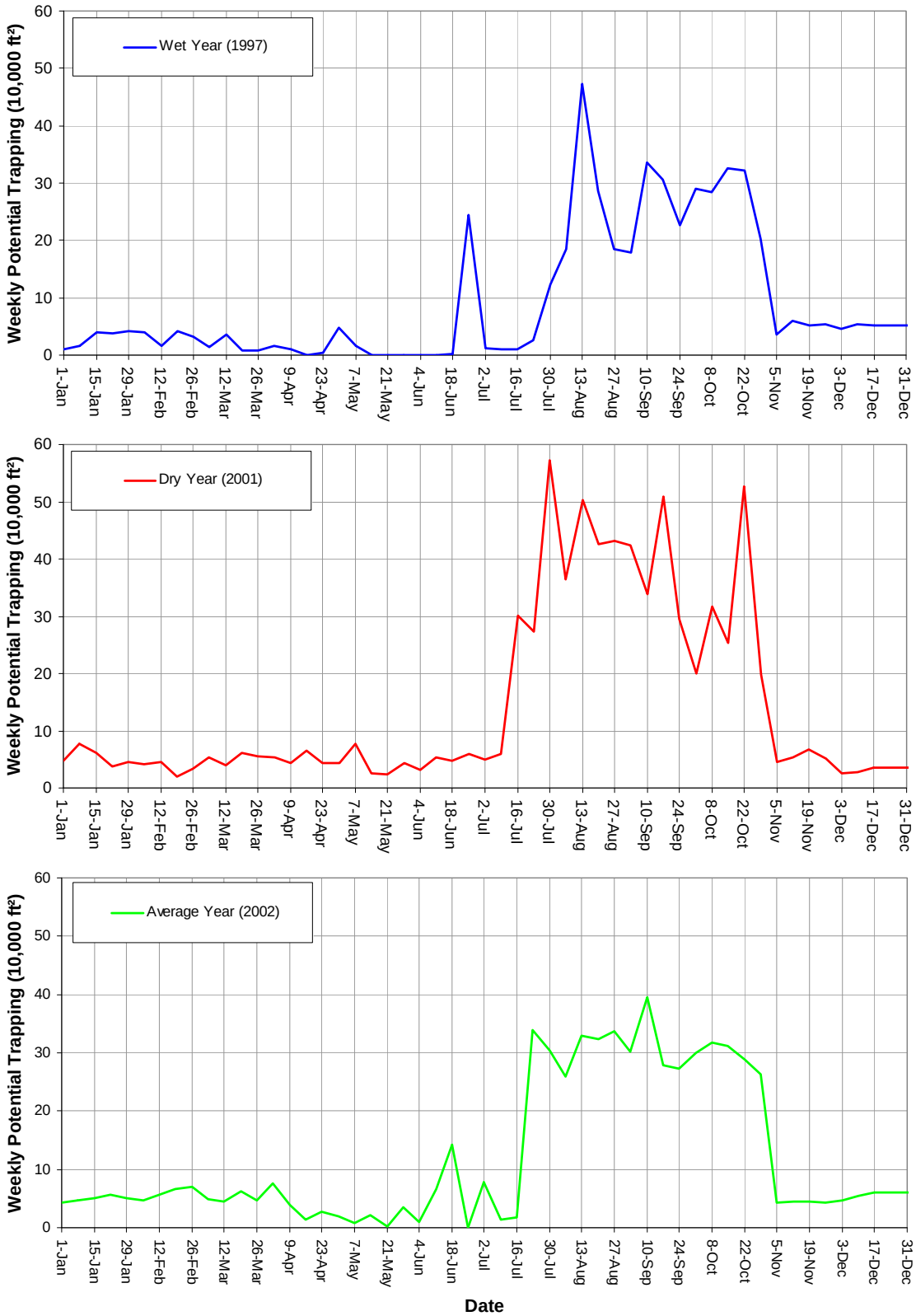



**Figure 5.4-22.** Comparison of Region 16 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

## Region 17

Region 17 is located directly across from the Box Canyon Motel near PRM 33.0. There are a total of 61 trapping pools identified within the region. The total area of the trapping pools is approximately 40,200 square feet and makes up 2 percent of the total trapping area within the Upper Reservoir Reach. Outlet elevations within Region 17 range from 1,979 feet NAVD 88 (1,975 feet NGVD 29) to 2,005 feet NAVD 88 (2,001 feet NGVD 29). Pool depths range from 0.1 to 4.3 feet. Substrate of the pool bottoms consisted of fines. Macrophytes were mapped in 8 pools and represents 43 percent of the total pool area within the region.

Weekly modeled TI values for the three representative years on Figure 5.4-23. Weekly TI values show a similar temporal pattern modeled in Region 16 exists in Region 17. Review of Figure 5.4-23 shows the greatest magnitude of trapping potential in Region 17 occurs from July 16 through November 5 for the dry and average years and coincided with the peak growth season of aquatic macrophytes. During the wet year, the peak magnitude of trapping potential occurred later beginning on August 6. The end of the peak trapping during the wet year occurred similar to the dry and average years. During the periods of elevated trapping, fish periodicity (Figure 5.3-1) shows the population of cyprinid and forage fish fry is at its peak for all three representative years. The mountain whitefish fry population is in shoulder season during this period of peak trapping.

Review of the trapping pools being dewatered during the period of increased trapping potential period (July 16 through November 5) suggests that although water surface elevations during this period were similar to those experienced in Region 16 (1,982 to 1,998 feet NAVD 88 [1,978 to 1,994 feet NGVD 29]), the area of potential trapping pools affected accounts for 82 percent of the available trapping pool area, or approximately 33,100 square feet. The period of high trapping potential for this region result primarily form water surface elevation fluctuations from load-following activities and the presence of macrophytes.

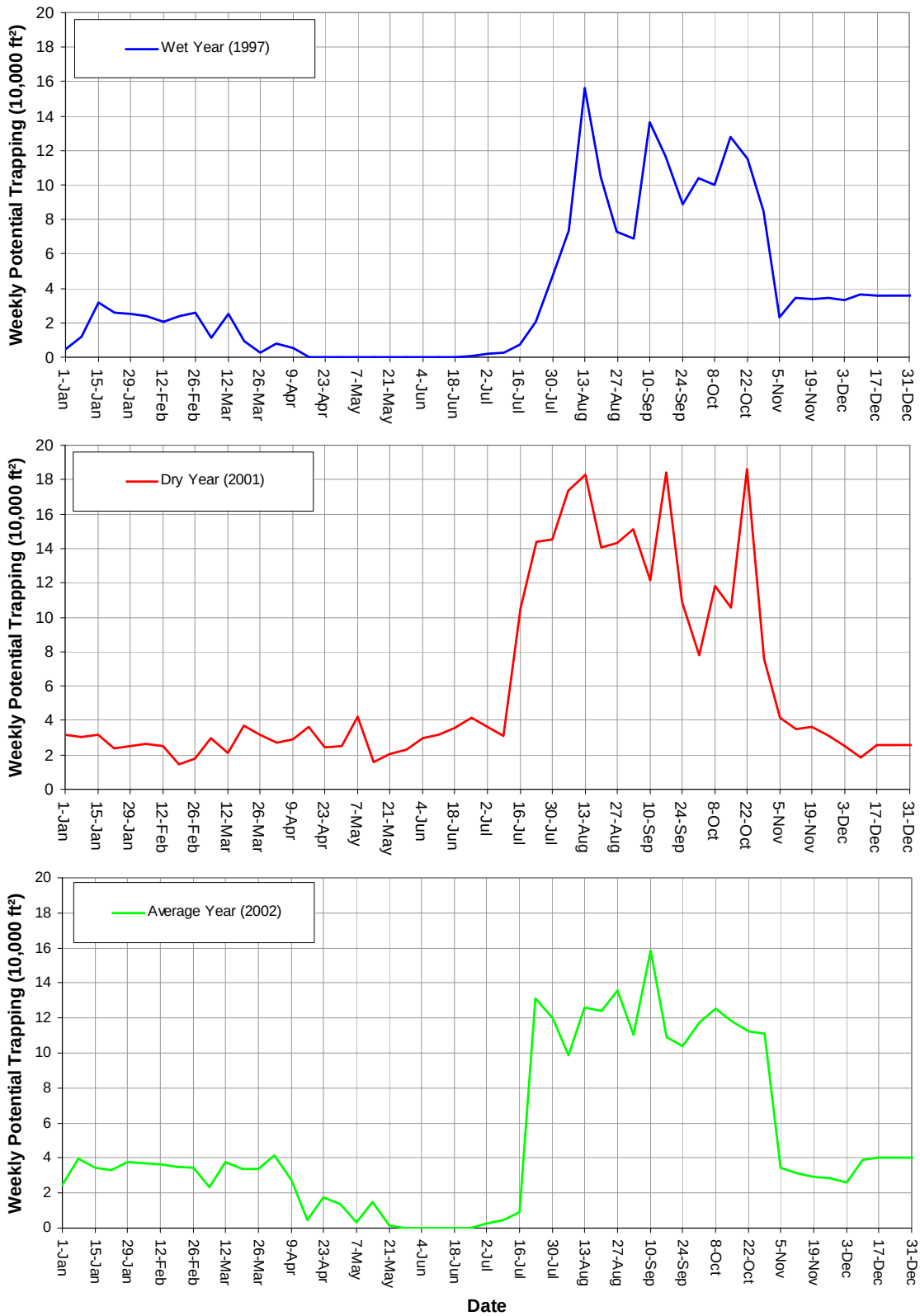



**Figure 5.4-23.** Comparison of Region 17 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

### 5.4.2.2.4. Tailrace Reach

Annual trapping results in the Tailrace Reach accounted for 5 percent of the combined total annual trapping estimated for the three years (see Table 5.4-6). On a monthly basis, trapping results for the Tailrace Reach indicated there was a higher potential of trapping during the dry year (2001) than during the wet year (1997) (Figure 5.4-24).

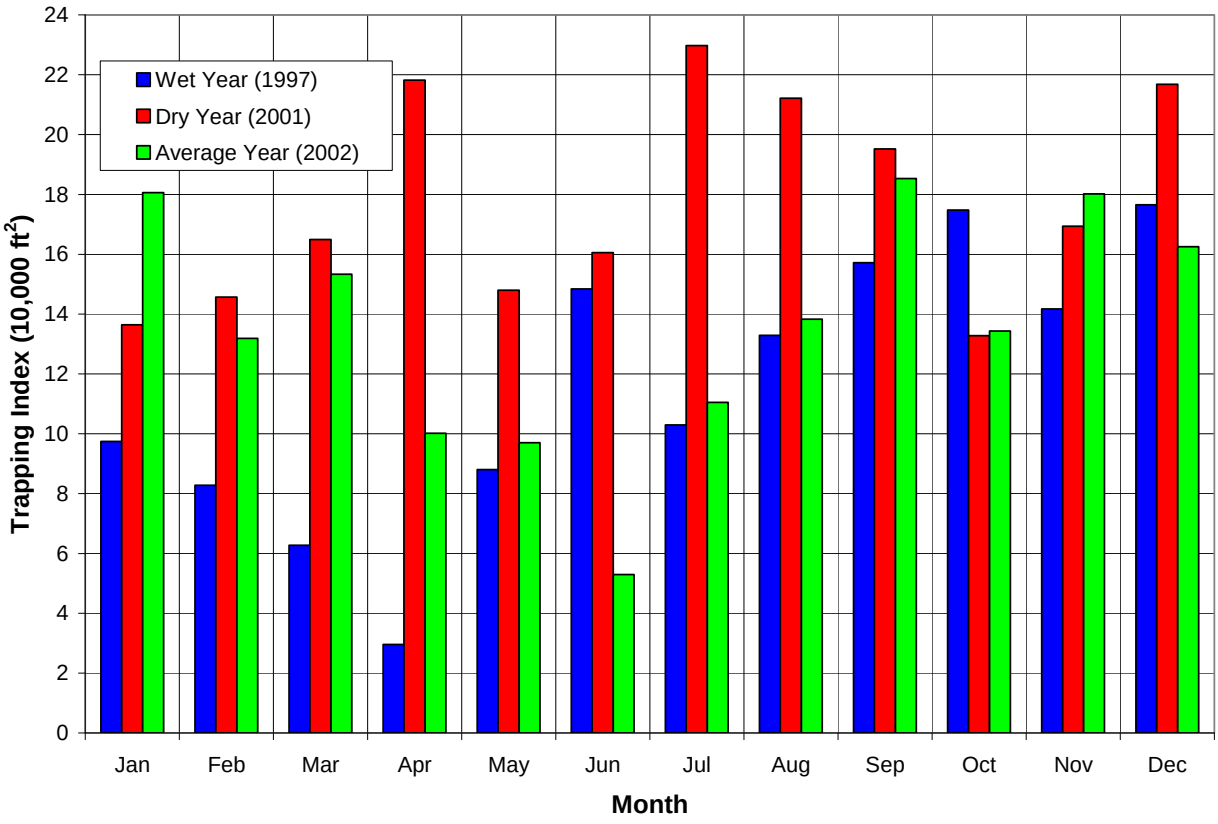



**Figure 5.4-24.** Monthly total trapping index values for the Tailrace Reach for the wet (1997), dry (2001), and average year (2002).

The TI values on a monthly basis for the three representative years are presented in Figure 5.4-24. Comparison of the three years on a monthly basis show that TI values decrease during periods of high flow coinciding with the spring freshet. The Project does not provide any flood storage and during periods of when inflow exceeds Project generation, inflows to Boundary Reservoir are discharged into the tailrace. Flows into the Tailrace Reach closely match inflow during this period until flood waters recede and normal load following operations resume.

An example of the conditions described above is shown in Figure 5.4-24 for the wet year. During the period of May–June, flows coinciding with the spring freshet increased to a peak discharge of 134,000 cfs reported at USGS gage 12396500. As a result of the high flows, the modeled TI values during the spring freshet period were minimal. Potential trapping events

increased during the recession limb of the flood hydrograph as water surface elevations receded. Normal load following operations resumed in mid-July. It should be noted that water surface fluctuations in the tailrace are also influenced by Seven Mile Dam.

Potential trapping conditions during the dry year differed from those predicted TI values during wet and average years. Flows during the spring "freshet" for the dry year condition were significantly less (approximately 32,000 cfs). Normal load following operations continued through the spring freshet period where high flows would typically limit this type of operation. As a result, TI values calculated during May and June were high and reflect a greater potential for trapping to occur.

Overall, the total annual TI value calculated for the Tailrace Reach was small when compared with the Upper Reservoir Reach. The Tailrace Reach accounted for 5 percent of the combined total TI value calculated for the three representative years.

## 5.5. Downramping Analysis

This section summarizes the results of the downramping analysis. The results include determination of hourly downramping rates at each habitat transect for each hydrologic year and determination of the downramping rate exceedance curves for the transect-weighted, reach-averaged downramping conditions. A detailed presentation of the results is included in Appendix 5.

### 5.5.1. Hourly Downramping Rates

Hourly downramping rates were determined at each of the 49 habitat transect locations in the Boundary Reservoir and at each of the 14 habitat transect locations in the Boundary tailrace for each of the three hydrologic years. As mentioned previously in Section 5.2, downramping rates were only determined when the Pend Oreille River flow rate (as measured at the USGS gage 12396500) was greater than 80,000 cfs. This was an appropriate threshold flow rate for the downramping analysis because, for flow rates greater than about 55,000 cfs, the Project typically curtails the load-following mode of operation. Extending the analysis to 80,000 cfs more than encompasses the range of flows in which Project-related downramping occurs. An additional reason why this threshold flow rate is appropriate is because on the receding limb of the annual hydrograph, downramping rates in the Boundary Reservoir are typically dominated by the natural recession of the flow rate, not Project operations.

Appendix 5 includes example graphs that illustrate the hourly downramping rates throughout each of the three hydrologic years at four locations in the Boundary Reservoir: 1) in the Boundary forebay at habitat transect F-1; 2) immediately downstream of Metaline Falls at habitat transect C-24; 3) immediately upstream of Metaline Falls at habitat transect U-1; and 4) in the Box Canyon Dam tailrace at habitat transect U-24.

At each habitat transect location, the number of hours of downramping within each of the five numeric categories were quantified. These location-specific frequency distributions were then transect weighted and reach averaged to produce transect-weighted, reach-averaged frequency distributions for downramping for each of the four reaches in the Project area (Forebay, Canyon,

Upper Reservoir, and Tailrace) for each of the three representative hydrologic years (1997, 2001, and 2002).

The remainder of this section documents the results of the downramping analysis in the form of cumulative frequency distributions. The results are first presented in a tabular format. However, supplemental graphics are used to support the subsequent discussion regarding the interpretation of the results. The discussion in this section focuses on the following topics:

- Variability of hourly downramping rates within each of the four reaches in the Project area for a given year. Specifically, the results are presented graphically so as to illustrate that downramping rates in the Forebay and Canyon reaches within any given year are fairly similar. However, in the Upper Reservoir Reach, downramping rates are influenced by the hydraulic control of Metaline Falls. This results in downramping rates in the Upper Reservoir Reach that are much lower than those in the Canyon and Forebay reaches when comparing the results within a given year.
- Variability in downramping rates amongst the three hydrologic years. The three years in the analysis were a wet year (1997), a dry year (2001), and an average year (2002). Within each of these three years, Project operations were reflective of real-time and forecasted hydrologic conditions and regional power demands. As such, the resulting downramping rates and the distribution of downramping rates were noticeably different between each of these three years.
- Variability in downramping rates by month or by season. Project operations responded to monthly and seasonal changes in hydrologic inflow conditions and regional power demands; downramping rates reflected these monthly and seasonal changes. For example, in the wet year (1997) the number of hours of downramping was very low in May and June when compared to these same months in the dry year (2001) and the average year (2002).

Table 5.5-1 summarizes the results of the downramping analysis by hydrologic year and by Project reach. This table includes the cumulative number of hours when downramping rates were in excess of 0, 2, 4, 8, and 12 inches per hour.

Table 5.5-1 shows that within each year, there are significantly fewer hours of downramping in the Upper Reservoir Reach with downramping rates that exceed 8 inches per hour compared to the Forebay and Canyon reaches. For example, in the wet year (1997), the transect-weighted, reach-averaged hours of downramping with rates exceeding 8 inches per hour was 1,036 for the Forebay Reach. However, in the Upper Reservoir Reach there were approximately 3 hours of downramping with rates in excess of 8 inches per hour. As described in Section 5.2, Metaline Falls behaves as a hydraulic control on the system. When the water surface elevation in the forebay is reduced as a result of Project operations, there is not necessarily a commensurate reduction in water surface elevation upstream of Metaline Falls. Metaline Falls functions as a localized restriction that controls the rate of flow from the Upper Reservoir Reach into the Canyon Reach, much like a hydraulic weir. For those conditions when the water surface elevation in the Boundary forebay is dropping, the flow rate through Metaline Falls represents the rate at which the Upper Reservoir Reach is draining, and can often be less than the outflow from the Project. As such, the rate at which the water surface elevation in the Upper Reservoir Reach drops is less than the rate at which the water surface elevation drops in the Canyon and

Forebay reaches. Therefore, downramping rates in the Upper Reservoir Reach are less than those in the Forebay and Canyon reaches.

**Table 5.5-1.** Transect-weighted, reach-averaged cumulative distribution of hours of downramping by rate, by hydrologic year, and by reach.

| Downramping Rate | Number of Downramping Hours | | | |
|---|---|---|---|---|
| | **Forebay Reach** | **Canyon Reach** | **Upper Reservoir Reach** | **Tailrace Reach** |
| **1997 – Wet Hydrologic Year** | | | | |
| > 0 in/hr | 4,566 | 4,581 | 4,626 | 3,416 |
| > 2 in/hr | 3,672 | 3,654 | 2,759 | 2,558 |
| > 4 in/hr | 2,756 | 2,703 | 991 | 1,963 |
| > 8 in/hr | 1,036 | 977 | 3 | 1,234 |
| > 12 in/hr | 194 | 169 | 0 | 780 |
| **2001 – Dry Hydrologic Year** | | | | |
| > 0 in/hr | 5,192 | 5,198 | 5,324 | 3,790 |
| > 2 in/hr | 4,219 | 4,224 | 3,876 | 2,706 |
| > 4 in/hr | 2,816 | 2,796 | 1,558 | 2,014 |
| > 8 in/hr | 1,106 | 1,058 | 33 | 1,059 |
| > 12 in/hr | 376 | 331 | 0 | 586 |
| **2002 – Average Hydrologic Year** | | | | |
| > 0 in/hr | 5,034 | 5,042 | 5,173 | 3,655 |
| > 2 in/hr | 4,286 | 4,274 | 3,602 | 2,646 |
| > 4 in/hr | 3,151 | 3,103 | 1,444 | 2,005 |
| > 8 in/hr | 1,132 | 1,074 | 13 | 1,154 |
| > 12 in/hr | 283 | 249 | 0 | 647 |

Note:
1 Values in the table have been rounded to the nearest integer value.

### 5.5.2. Downramping Rate Exceedance Curves

Figures were developed to facilitate discussion and interpretation of the results in Table 5.5-1. Figures 5.5-1 through 5.5-3 present the tabular results from Table 5.5-1 illustrating the differences in downramping rates amongst each of the four reaches. These figures are referred to as downramping rate exceedance curves. A separate figure is used to summarize the results for each year. Each figure shows the number of hours per year when the transect-weighted, reach-averaged downramping rate was in excess of specific threshold values.

Using these three figures and the information presented in Table 5.5-1, several general observations can be made. (More detailed discussion and interpretation are included in Appendix 5.) First, by comparing the Forebay Reach downramping results between the three hydrologic years, it is seen that the wet year had the least amount of time associated with

downramping (4,566 hours) as compared with the other two years. This is explained by the fact that, for the 2½-month period from mid-April 1997 through the end of June 1997, inflow to the reservoir was greater than the turbine capacity of 55,000 cfs. For much of this 2½-month period, Project discharge (turbine plus spill) approximately equaled inflow thereby resulting in fewer instances of downramping. At the other extreme, the dry year had the most number of downramping hours in the Boundary forebay (5,192 hours). The number of hours of downramping in the Boundary forebay during the average year (5,034 hours) was less than the dry year but more than the wet year.

A second observation concerns the effect of Metaline Falls on downramping rates. Figures 5.5-1 through 5.5-3 show downramping rates in the Forebay and Canyon reaches in excess of 8 inches per hour. However, in the Upper Reservoir Reach, there are only a few instances of downramping rates between 8 and 12 inches per hour and there are no instances of downramping rates in excess of 12 inches per hour for any of the years.

A third observation concerns the downramping rates in the Tailrace Reach. Figures 5.5-1 through 5.5-3 show that the frequency of downramping in the Tailrace Reach does not vary significantly from year to year. However, as was the case for the upstream reaches, the wet year had the fewest instances of downramping (3,416 hours) as compared with both the dry year (3,790 hours) and the average year (3,655 hours).

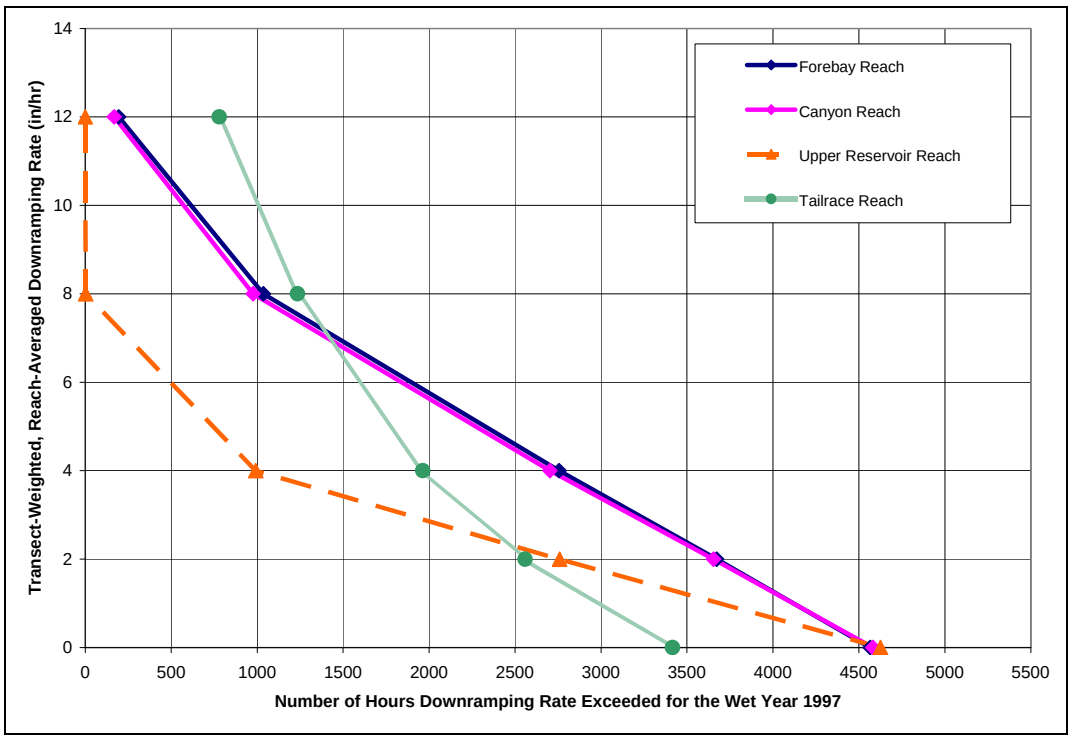



**Figure 5.5-1.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative wet year 1997.

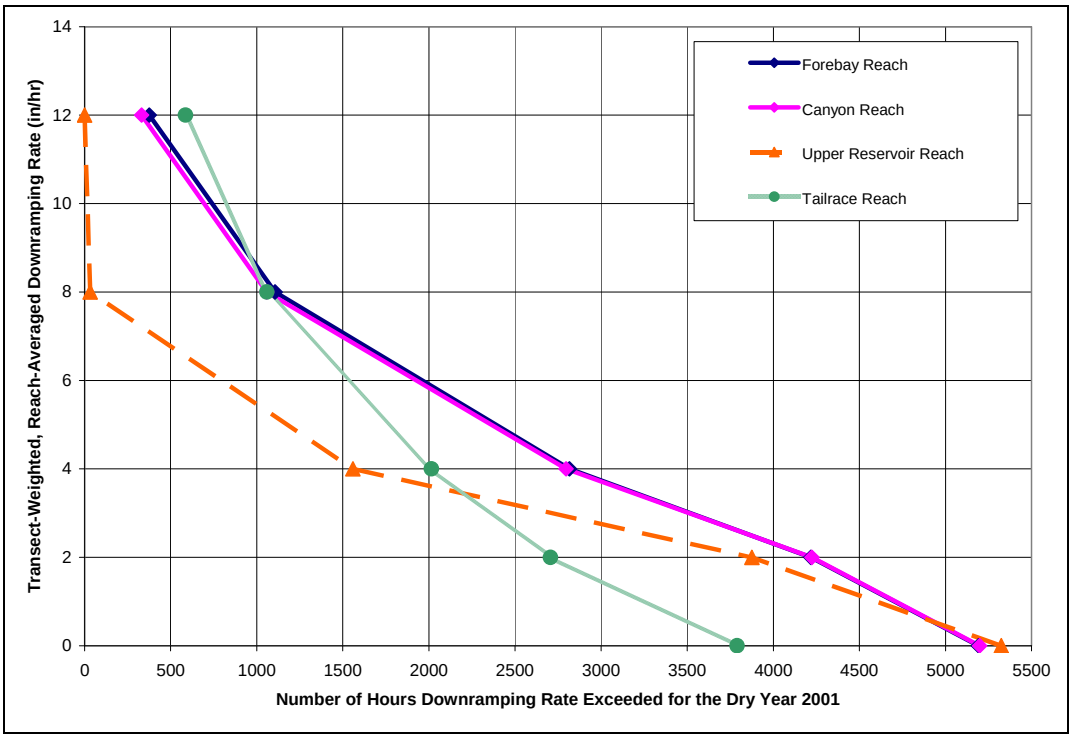



**Figure 5.5-2.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative dry year 2001.

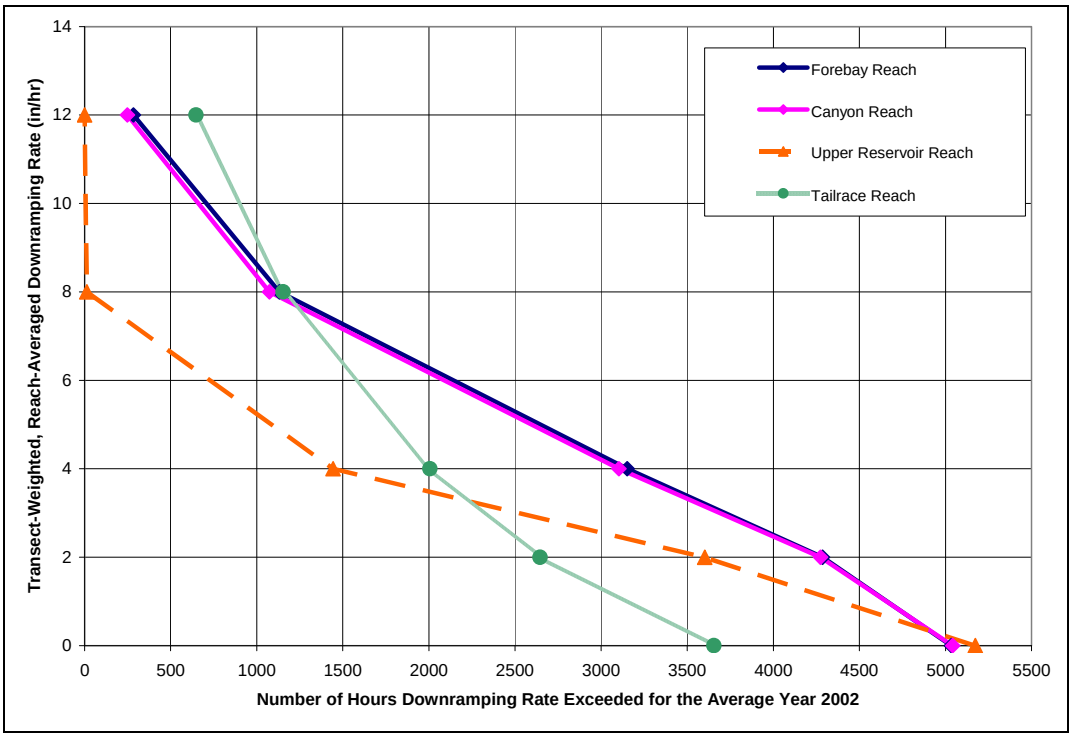



**Figure 5.5-3.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative average year 2002.

The distribution of downramping rates varies monthly and seasonally. For example, during the spring runoff period of wetter years, there were fewer instances of downramping compared to the spring runoff period during drier years. This is because Project operations during years with high spring runoff are more constant and do not load-follow as much as during drier years.

To illustrate seasonal and monthly variability in downramping conditions, transect-weighted, reach-averaged downramping rates were calculated by month. The methodology used was similar to that used to determine the transect-weighted, reach-averaged downramping rates for the entire year. For each month, the frequency distributions of downramping rates at each transect location were transect-weighted and then reach-averaged. The incremental frequency distributions were then converted to cumulative downramping rate exceedance curves, similar to the set of curves developed for annual series.

Figures 5.5-4 and 5.5-5 illustrate the transect-weighted, reach-averaged downramping rate exceedance curves for the months of January and June of the wet year (1997) for each of the four reaches in the Project area. Appendix 5 includes similar figures for all months within each of the three hydrologic years.

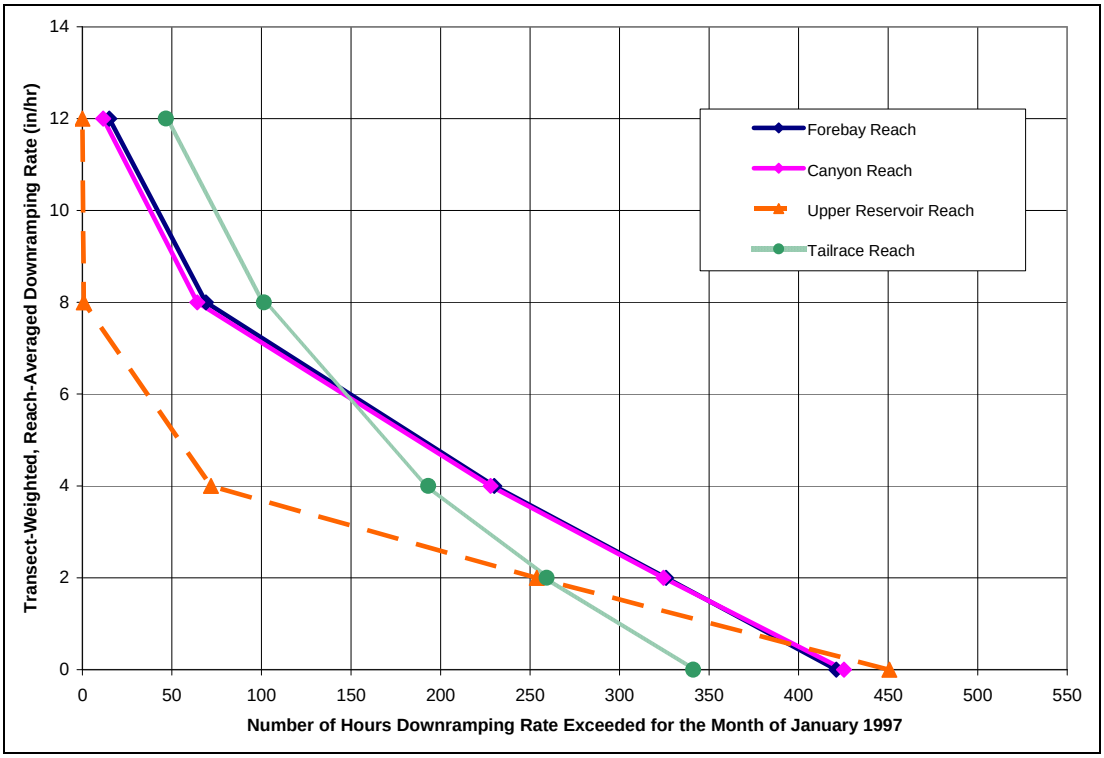



**Figure 5.5-4.** January of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

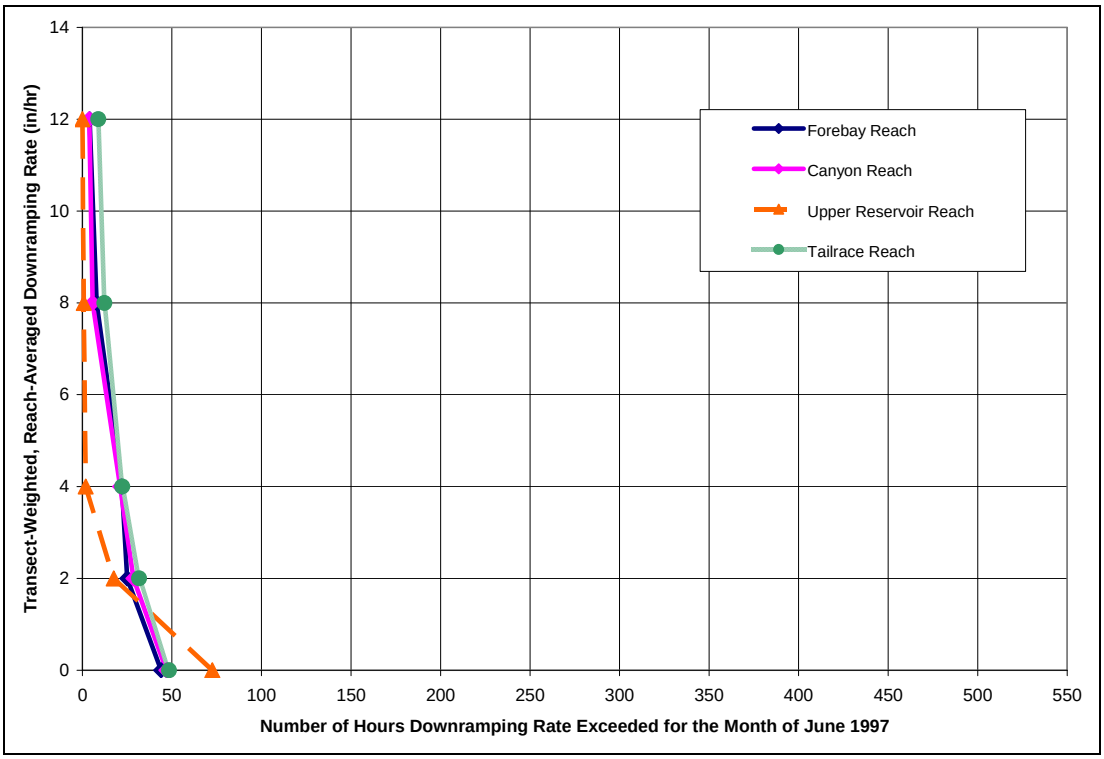



**Figure 5.5-5.** June of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

Based on Figures 5.5-4 and 5.5-5, as well as the figures included in Appendix 5, some general observations can be made about the variability of downramping conditions by month. (More specific discussion regarding the monthly variability of downramping conditions is included in Appendix 5.)

The total number of downramping hours can vary significantly by month. This is due to seasonal/monthly changes in regional power demands combined with seasonal/monthly changes in the annual runoff hydrograph. The characteristic of the daily drawdown (the rate and the amount of drawdown) that occurs at the Project is affected by the inflow volume during a particular month. During months with lower inflow rates to the reservoir, Project operations would reflect the operational decision to limit the magnitude of the daily reservoir fluctuation to only that which will allow the reservoir to be subsequently refilled.

Secondly, the monthly number of hours of downramping (and the associated downramping rates) in Boundary Reservoir were found to be lower during months when flow rates into Boundary Reservoir were approaching or greater than the turbine capacity. This is seen by comparing the downramping rates in the Forebay Reach for the months of May, June, and July for each of the three years (see Appendix 5) against all other months. These three months are when high spring runoff can occur. In the wet year (1997), downramping conditions were reduced significantly in May and June as inflows to the reservoir were in excess of the turbine capacity throughout the duration of these months. Conversely, Project operations during May and June of the dry year

(2001) resulted in the some of the highest number of downramping hours for that particular year and some of the highest rates of downramping. During the average year (2002), releases from Box Canyon did not exceed the turbine capacity of the Project until near the end of May and for all of June. The reduction in the number of hours of downramping in May and June 2002 reflects this hydrologic condition.

## 5.6. Macrophyte Habitat Development and Modeling Efforts

This section presents the results of the macrophyte habitat modeling effort in the mainstem of the Pend Oreille River including Boundary Reservoir and its tailrace. Results are presented by each of the four reaches (Forebay, Canyon, Upper Reservoir, and Tailrace) within the study area. The final macrophyte HSI curves were used in the Mainstem Aquatic Habitat Model to quantify the response of macrophytes in Boundary Reservoir to hourly water surface fluctuations. WUA is a measure of available potential habitat on an hourly time step. The following subsections provide a summary of the model results for macrophyte WUA by reach and for each hydrologic condition. The data are summarized by month. A more detailed discussion of macrophyte production can be found in the Study 11 Final Report (SCL 2009c).

Modeling of WUA for macrophyte habitat potential was completed for historic Project operations during wet (1997), dry (2001), and average (2002) years. These years were selected as representative of wet, dry, and average conditions using factors like average annual flows (R2 Resource Consultants 2008). For reference, the flow hydrographs for the wet, dry, and average years are presented in Figures 5.0-1 through 5.0-3, respectively, and a comparison of the flow hydrographs across these three years are shown in Figure 5.0-4. WUA results presented in the following sections did not consider flows exceeding 80,000 cfs. Once flows exceeded this volume, the calculated WUA for a given species was not considered in the determination of the WUA. The plotted results do not show WUA values for flows in excess of 80,000 cfs. Likewise, the WUA values for flows in excess of 80,000 cfs were not included in the tabulated numerical results. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs ensured the incorporation of all flows potentially influenced by Project operations. When flows exceed 55,000 cfs, pool level fluctuations are typically dominated by inflow hydrology not Project operations as shown by the HRM.

Hourly time-step data describing WUA estimates were summarized by monthly summary statistics and with summary statistics for specific twice monthly time periods in May, July, and September. These two week summary statistics were reported for select reaches and more closely analyzed for Project operations effects on macrophytes in the Forebay and Upper Reservoir reaches.

### 5.6.1. Forebay Reach

The Mainstem Aquatic Habitat Model results for macrophyte WUA in the Forebay Reach are shown in Figure 5.6-1 and summarized by month in Table 5.6-1. Data absent during the wet and average years in Figure 5.6-1 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated macrophyte WUA was significantly lower in the Forebay Reach compared to other reaches within Boundary Reservoir and much less variable throughout the year. The maximum potential macrophyte WUA in the Forebay Reach (at any time) was determined by the model to be 60 (x 10,000 square feet) and occurred in April

and September of a dry water year and July and October of an avearage water year (Table 5.6-1). The lowest macrophyte WUA at any given time over the model simulation was determined to be 24 (x 10,000 square feet) occurring in May of the dry water year. On average, potential macrophyte WUA in the Forebay Reach was very similar throughout the year and over all three hydrologic conditions.

Most of the daily variation in macrophyte WUA seen in Figure 5.6-1 and summarized as standard deviations in Table 5.6-1 is due to the hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. This translates to a stable environment for aquatic macrophytes within the Forebay Reach. Establishment of macrophyte beds in the Forebay Reach is likely due to adequate substrate and velocities that promote sustained presence and expansion of existing beds. The average suitable habitat available in the Forebay Reach was only approximately 48 (x 10,000 square feet) due to existing conditions in that area.

Relative uniformity in WUA estimates for macrophytes was observed during all three hydrologic years (wet, dry, and average) in the Forebay Reach. Suitability of macrophyte habitat diminished during portions of October and November for the wet hydrologic year, May during the dry hydolgic year and late April in the average hydrologic year. The average WUA estimates for macrophytes across all hydrologic years only ranged from 47 to 48, but were still influenced by the hourly water surface elevation fluctuations (based on minimum WUA estimates). Water surface elevation fluctuation was greatest in the Forebay Reach, but WUA calculations showed little variability on the hourly time-step. The suitability factors used to determine WUA, like dewatering and depth, may have narrowed optimal macrophyte habitat availability in the Forebay Reach. Bathymetric maps show that much of the Forebay Reach shoreline has a steep gradient and rapidly falls out of the optimal depth ranges for macrophyte beds. Sediment sampling results from Study 4, Toxics Assessment: Evaluation of Contaminant Pathways Final Report (SCL 2009g), showed that much of the Forebay Reach shoreline comprises shale, gravel, and cobble-sized substrate. Only the deepest portions of the Forebay Reach have sediment that would be considered optimal for macrophyte growth, but are outside of the optimal depth range. In addition, increased duration and frequency for dewatering would severely limit available habitat for growth of macrophyte beds in the Forebay Reach, which is a high-water-surface fluctuation area. These disturbance factors that limit macrophyte bed habitat are less pronounced in the Upper Reservoir Reach than in the Forebay Reach.

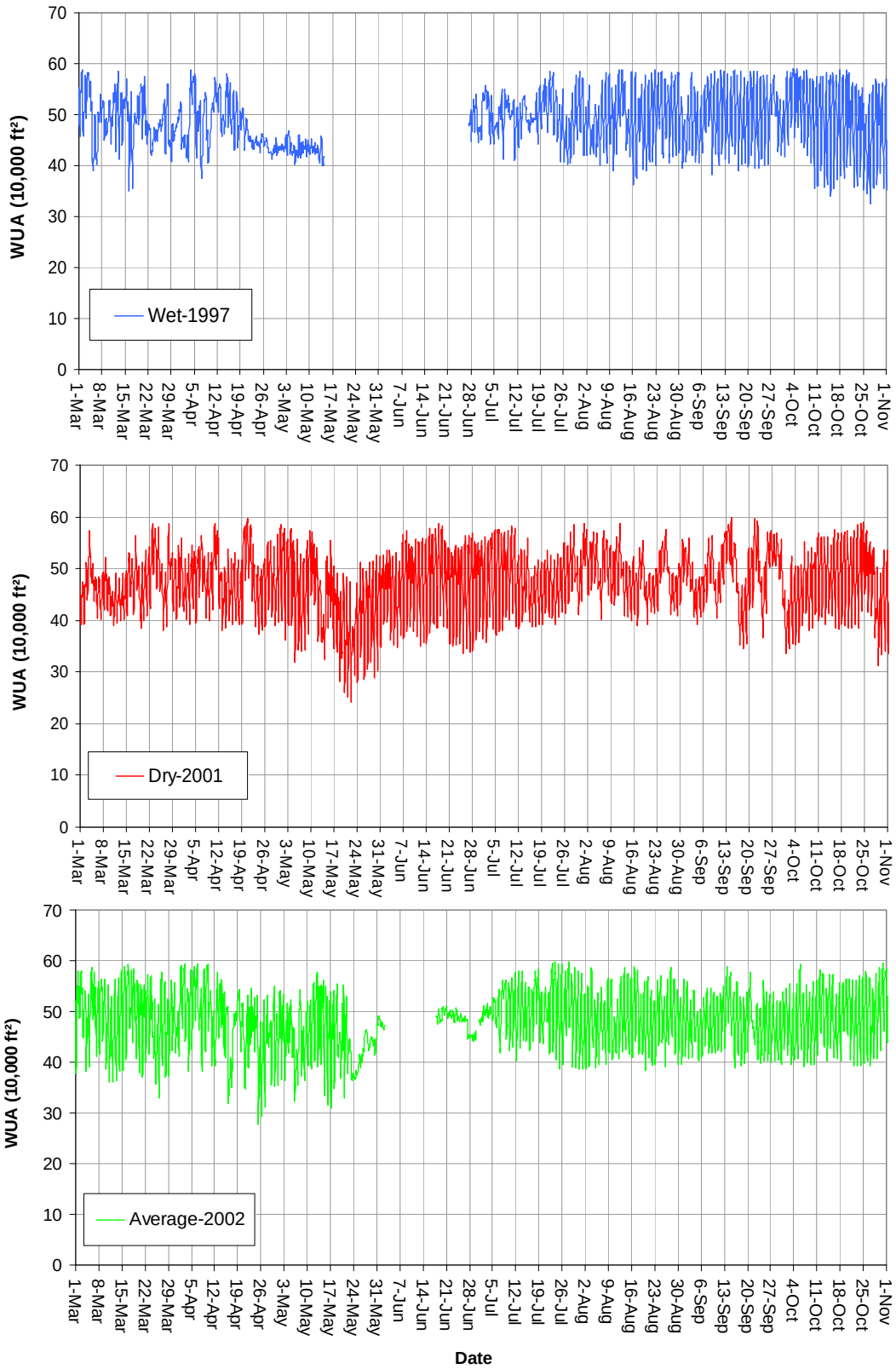



**Figure 5.6-1**. Habitat WUA for macrophytes in the Forebay Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.6-1.** Summary of monthly macrophyte WUA (x 10,000 sq. ft.) in the Forebay Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** |
| January | --[1] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| February | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| March | 49 | 58 | 35 | 4.3 | 47 | 59 | 38 | 4.2 | 49 | 59 | 33 | 5.6 |
| April | 48 | 59 | 38 | 4.4 | 48 | 60 | 37 | 5.0 | 48 | 59 | 28 | 6.4 |
| May | 43 | 47 | 40 | 1.3 | 43 | 58 | 24 | 7.2 | 45 | 58 | 31 | 5.3 |
| June | 49 | 54 | 45 | 2.3 | 47 | 59 | 34 | 6.0 | 48 | 51 | 44 | 1.8 |
| July | 50 | 59 | 40 | 3.9 | 48 | 59 | 36 | 5.0 | 50 | 60 | 39 | 4.6 |
| August | 49 | 59 | 36 | 5.3 | 49 | 59 | 39 | 4.1 | 48 | 59 | 38 | 5.0 |
| September | 50 | 59 | 38 | 5.1 | 49 | 60 | 34 | 5.2 | 48 | 59 | 39 | 4.4 |
| October | 49 | 59 | 33 | 6.3 | 48 | 59 | 31 | 5.9 | 49 | 60 | 39 | 5.1 |
| November | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| December | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Note:
1 Hyphens indicate no viable macrophyte habitat during the winter months in Boundary Reservoir.

Two-week averages and related statistics are reported for macrophyte WUA estimates and corresponding water surface elevations for three representative months. May was selected to represent spring run-off conditions (i.e., higher velocity, increased turbidity), July was selected to represent growing season conditions (i.e., increased clarity and reduced flow, depth, and velocity), and September was selected to represent end of growing season conditions (i.e., lowest flow of the year, reduced photoperiod and cooler water temperatures) in the Forebay Reach (Table 5.6-2). The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter timeframe (i.e., two weeks) was to determine how macrophyte WUA estimates in the Forebay Reach respond to Project operations. These comparisons within a shorter time period were used to determine the influence of individual model variables on the WUA estimates in each season and hydrologic year.

**Table 5.6-2.** Summary of macrophyte WUA (x 10,000 sq. ft.) and water surface elevations at Boundary Dam for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** |
| **Macrophyte WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 41 | 56 | 24 | 6.6 | 44 | 56 | 31 | 4.8 |
| July | 50 | 59 | 40 | 4.3 | 47 | 59 | 39 | 4.3 | 51 | 60 | 39 | 5.2 |
| September | 50 | 59 | 39 | 5.1 | 49 | 60 | 34 | 5.7 | 47 | 58 | 39 | 4.3 |
| **Water Surface Elevation (feet NAVD 88) at Boundary Dam** | | | | | | | | | | | | |
| May | 1,988.6 | 1,992.9 | 1,984.4 | 1.8 | 1,981.8 | 1,993.5 | 1,963.2 | 7.3 | 1,989.5 | 1,994.2 | 1,976.5 | 3.6 |
| July | 1,990.0 | 1,994.3 | 1,983.3 | 2.2 | 1,990.9 | 1,994.1 | 1,985.3 | 1.8 | 1,988.8 | 1,993.6 | 1,982.1 | 2.8 |
| September | 1,989.8 | 1,993.8 | 1,984.2 | 2.3 | 1,986.6 | 1,993.8 | 1,977.1 | 3.9 | 1,991.3 | 1,994.0 | 1,986.2 | 1.7 |

Note:
1 Macrophyte WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

There were very small, if any, real differences in WUA estimates for macrophytes in the Forebay Reach between the monthly and representative two-week summaries (Table 5.6-1 and Table 5.6-2, respectively). The comparison between WUA estimates and water surface elevations for May demonstrates a restricted range of response by macrophytes to water surface elevation fluctuations (Figure 5.6-2). Water surface elevation increases in a dry year during May resulted in an inverse response in macrophyte WUA estimates, likely due to changes in depth and light penetration during this time period. Sustained and higher water surface elevations during the average year decreased the fluctuation in macrophyte WUA estimates.

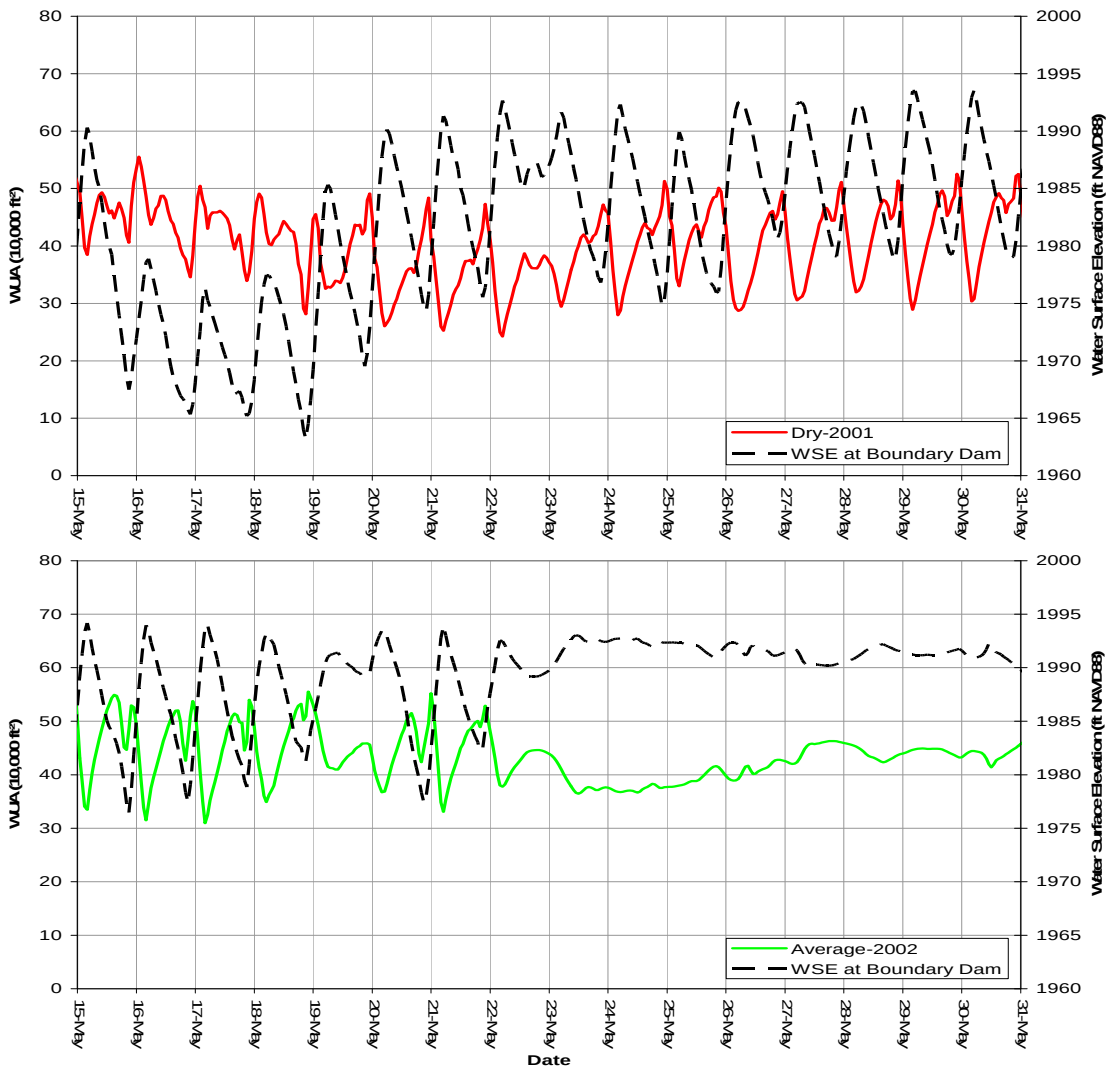



**Figure 5.6-2.** Habitat WUA for macrophytes in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during May 15–31; WUA was determined by the mainstem habitat model for dry and average years.

Note: Macrophyte WUA for the wet year was held constant due to a bounding condition of 80,000 cfs; therefore, no graph is presented.

WUA estimates for macrophytes during the last two weeks of July indicate that sustained higher water surface elevations occurring during wet and dry years (Figure 5.6-3) resulted in a decline in WUA estimates. Conversely, lower water surface elevations during the wet and dry years produced increasing WUA estimates. The inundation response by macrophytes to water surface elevation peaks lagged by approximately one day; WUA estimates responded one day later than when the water surface elevation was either at a minimum or a maximum within a two-day period. Water surface elevation fluctuations that were almost 10 feet during the average year resulted in the largest differences between minimum and maximum macrophyte WUA estimates (Figure 5.6-3).

Variation in WUA estimates for macrophytes during the last two weeks of September was greatest during the dry hydrologic year. Water surface elevation fluctuations were highest during the two-week period in the dry year than the wet and average years (Figure 5.6-4). Pool elevations that fluctuated greater than 10 feet in the dry year promoted the largest difference between peak and trough in a WUA response. Sustained water surface elevation near 1,990 feet NAVD 88 (1,986 feet NGVD 29) resulted in greater WUA estimates in the wet year compared to the average year (Figure 5.6-4 and Table 5.6-2).

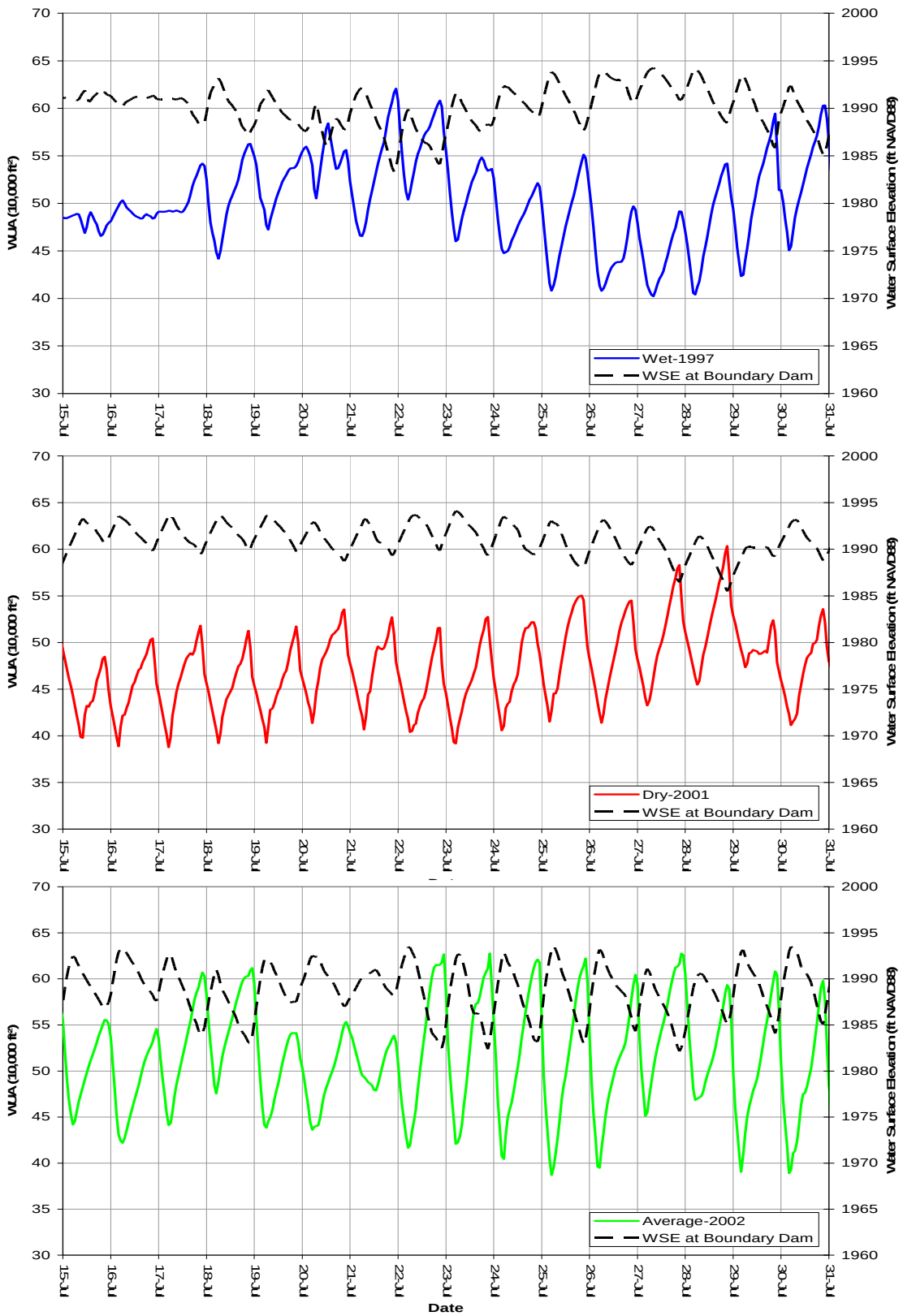



**Figure 5.6-3.** Habitat WUA for macrophytes in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during July 15–31 for wet, dry, and average years.

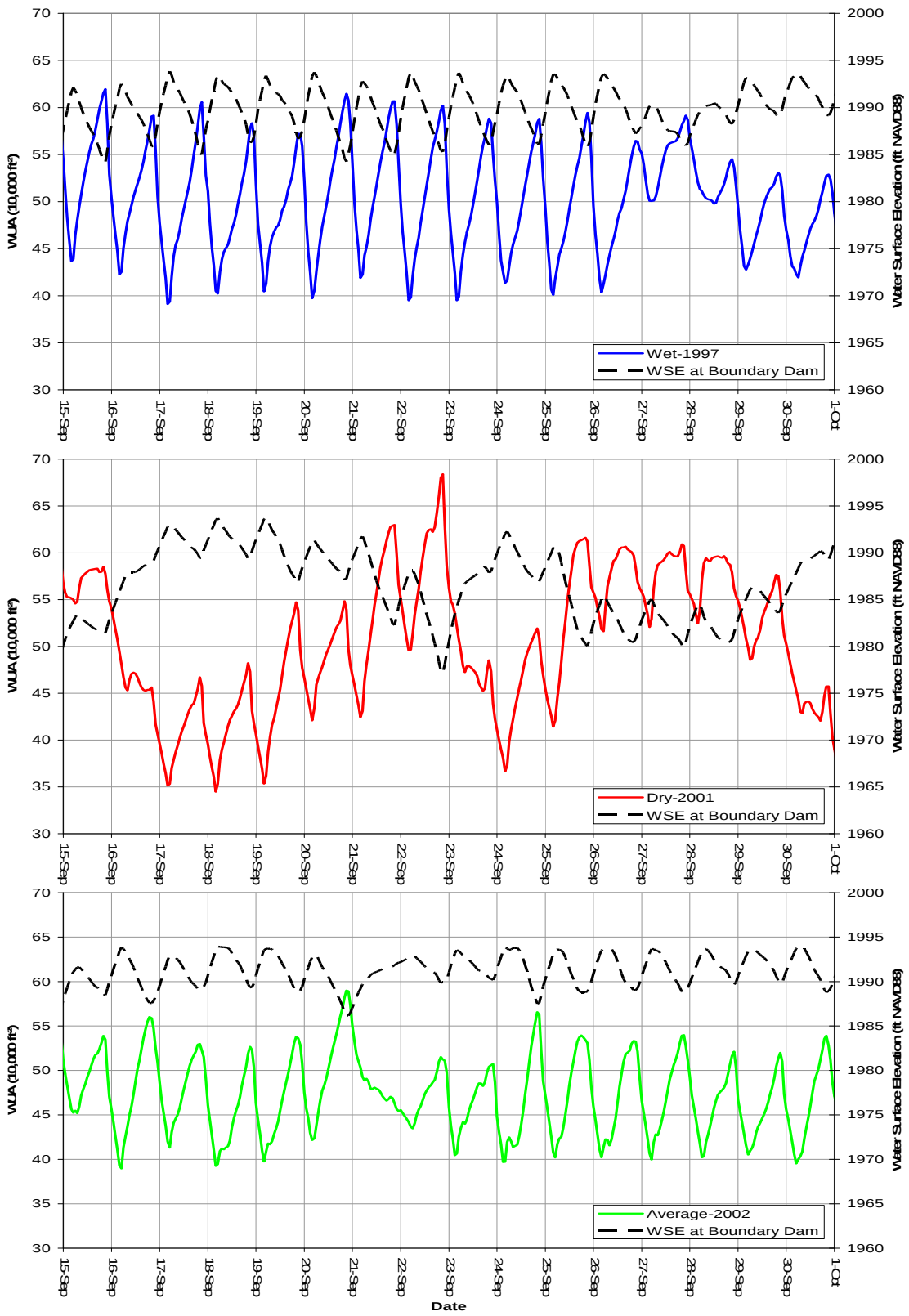



**Figure 5.6-4.** Habitat WUA for macrophytes in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during September 15–31 for wet, dry, and average years.

### 5.6.2. Canyon Reach

The Mainstem Aquatic Habitat Model results for macrophyte WUA estimates in the Canyon Reach are shown in Figure 5.6-5 and summarized by month in Table 5.6-3. Data absent during the wet and average years in Figure 5.6-5 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated macrophyte WUA in the Canyon Reach was higher than in the Forebay Reach. The maximum potential macrophyte WUA in the Canyon Reach (at any time) was determined by the model to be 182 (x 10,000 square feet) and occurred in October of an average hydologic year (Table 5.6-3). The lowest macrophyte WUA at any given time was determined to be 40 (x 10,000 square feet) and occurred in May of a dry hydrologic year. There was a decrease in macrophyte WUA estimates during May and June of wet and dry hydrologic years and during April to May during an average hydrologic year. Declines in WUA estimates were also observed in October during the wet hydrologic year. Overall, estimated macrophyte WUA in the Canyon Reach was significantly less than that determined for the Upper Reservoir Reach. There was also significantly less variability through the year in macrophyte WUA in the Canyon Reach than in the Upper Reservoir Reach (Figure 5.6-5).

Most of the daily variation in macrophyte WUA seen in Figure 5.6-5 and summarized as standard deviations in Table 5.6-3 is due to hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Other HSI parameters for macrophytes (velocity and substrate) have very little to no variability on an hourly timescale. Variation in velocity due to different seasonal flow conditions and substrate would be reflected in seasonal changes of macrophyte WUA. The average suitable habitat available in the Canyon Reach was 144 (x 10,000 square feet), or approximately three times greater, compared to the Forebay Reach. This difference was attributed to the greater length of the littoral area in the Canyon Reach versus the Forebay Reach. Likewise, the standard deviation in WUA is also significantly larger in the Canyon Reach, reflecting a greater influence of pool fluctuation on WUA in that area.

The Canyon Reach had only one-fifth the WUA estimated for macrophytes as for the Upper Reservoir Reach. The variability for estimated suitable habitat for macrophytes was uniformly low in the Canyon Reach during all months when established beds of macrophytes occur in Boundary Reservoir. Variability over hourly time-steps was much higher in the Canyon Reach compared to the Forebay Reach, but significantly lower than in the Upper Reservoir Reach. This indicates that in addition to dewatering due to water surface elevation fluctuations, other factors such as depth limit macrophyte estimates. Depths in the Canyon Reach can be much greater than in the other areas. Rock wall faces define the margin of the river and represent greater than optimal depths for macrophytes, thereby reducing the quantity of habitable areas within the Canyon Reach. The highest WUA estimates were slightly higher during the dry hydrologic year than compared to the wet or average years. This may be due to lower water surface elevation fluctuations in the Canyon Reach and an expansion of areas where depth is not as limiting in wet and average hydrologic years.

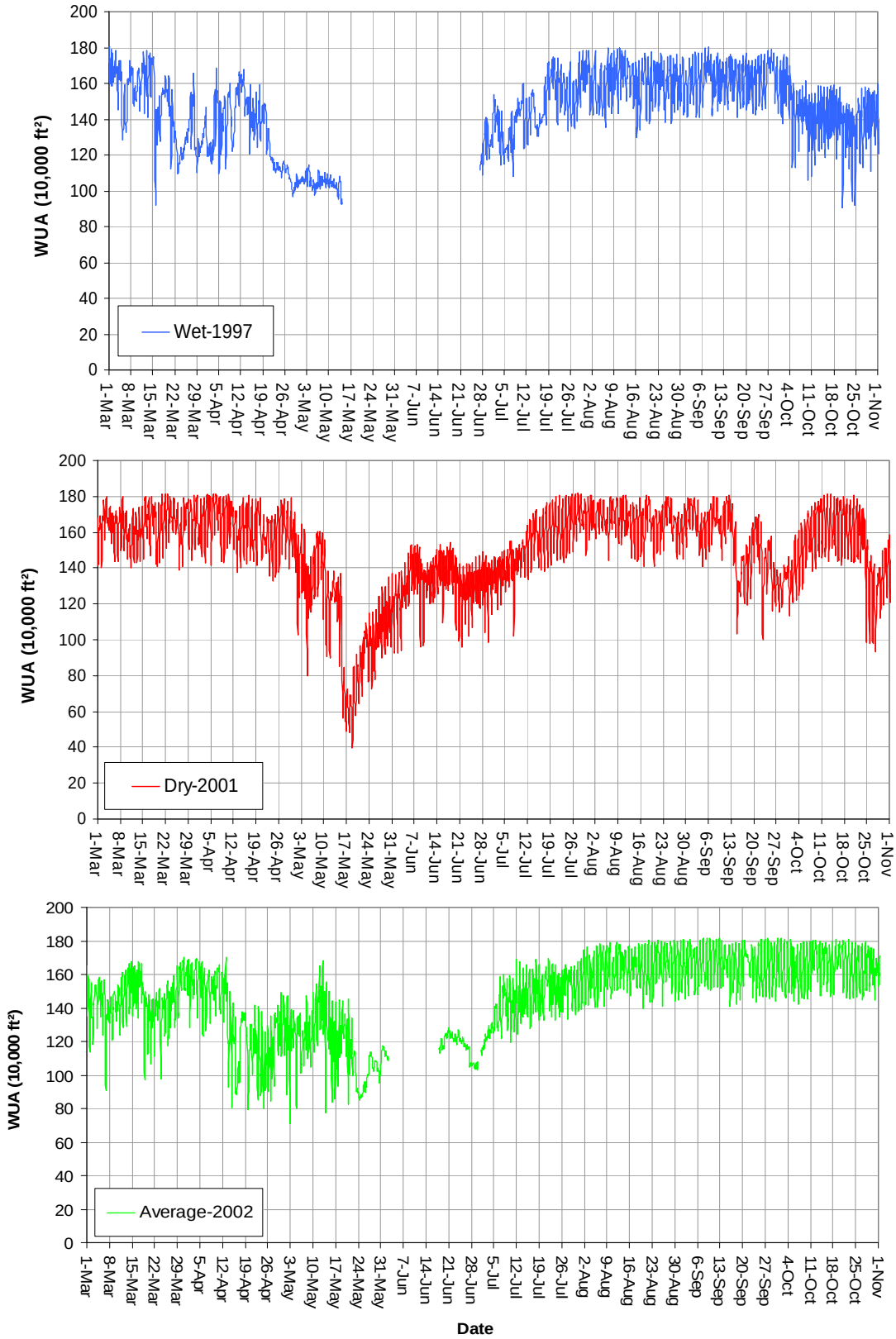



**Figure 5.6-5.** Habitat WUA for macrophytes in the Canyon Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.6-3.** Summary of monthly macrophyte WUA (x 10,000 sq. ft.) in the Canyon Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| January | --[1] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| February | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| March | 146 | 178 | 92 | 18.6 | 164 | 182 | 139 | 9.7 | 144 | 170 | 91 | 13.1 |
| April | 131 | 169 | 97 | 18.5 | 163 | 181 | 133 | 10.8 | 133 | 170 | 79 | 22.7 |
| May | 104 | 114 | 92 | 4.0 | 110 | 171 | 40 | 28.2 | 117 | 168 | 71 | 17.5 |
| June | 124 | 141 | 109 | 7.6 | 132 | 154 | 93 | 11.6 | 117 | 128 | 103 | 6.8 |
| July | 147 | 178 | 108 | 15.1 | 156 | 182 | 102 | 14.9 | 145 | 170 | 112 | 13.4 |
| August | 160 | 180 | 130 | 10.5 | 167 | 180 | 141 | 8.5 | 164 | 180 | 139 | 10.2 |
| September | 162 | 180 | 141 | 9.4 | 151 | 181 | 100 | 17.9 | 166 | 182 | 141 | 10.1 |
| October | 141 | 176 | 91 | 13.5 | 152 | 181 | 93 | 18.2 | 165 | 182 | 142 | 9.9 |
| November | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| December | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Note:
1 Hyphens indicate no viable macrophyte habitat during the winter months in Boundary Reservoir.

### 5.6.3. Upper Reservoir Reach

The Mainstem Aquatic Habitat Model results for macrophyte WUA estimates in the Upper Reservoir Reach are shown in Figure 5.6-6 and summarized by month in Table 5.6-4. Data absent during the wet and average years in Figure 5.6-6 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated macrophyte WUA was significantly higher in the Upper Reservoir Reach, but much more variable throughout the year, compared to other reaches in Boundary Reservoir. The maximum macrophyte WUA in the Upper Reservoir Reach determined by the model was 1122 (x 10,000 square feet) and occurred during March in a dry hydrologic year (Table 5.6-4). The lowest macrophyte WUA was determined to be 170 (x 10,000 square feet) and occurred during May of a wet water year. Throughout the years, the macrophyte WUA estimates were extremely variable, with habitat decreasing in the spring during wet and average years (Figure 5.6-6). Macrophyte WUA variability is greatest in the Upper Reservoir Reach, which has greater available habitat and highly variable physical conditions compared to other reaches. For example, the Canyon Reach is more uniform in velocity and substrate than the Upper Reservoir Reach.

Some of the variation in macrophyte WUA seen in Figure 5.6-6, and summarized as standard deviations in Table 5.6-4, is due to hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Low pool fluctuations are observed in the Upper Reservoir Reach compared to the Canyon and Forebay reaches, so the impact of the HSI curves, depicting duration of dewatering and inundation, on macrophyte WUA

was not as great. However, there is greater variability throughout the Upper Reservoir Reach in terms of velocity and substrate conditions, resulting in significantly more variability in macrophyte WUA.

Estimates for WUA for macrophyte beds were highest in the Upper Reservoir Reach compared to other reaches within and below the Boundary Reservoir. The water surface elevation fluctuations were lowest in this reach, resembling pre-Project conditions (see Appendix 7, Figure 6.1-2). Low macrophyte WUA estimates occurred during the spring runoff period during May and June during wet and average years (Figure 5.6-6). Although macrophyte beds were already established in Boundary Reservoir prior to these months, suitability for macrophytes was diminished by several events during this time of year. Higher flows reduce light availability through increased turbidity and deeper water reduces the suitability for the establishment for macrophytes. The high variability on an hourly time-step basis indicates how sensitive the model predictions are to the combination of depth and dewatering events during wet and average hydrologic years. Hydrologic conditions during the dry year appear to minimize the variation in WUA estimates for macrophytes.

WUA estimates during spring in the wet hydrologic year were some of the lowest recorded when compared to other seasons. Water surface elevations periodically falling below 1,986 feet NAVD 88 (1,982 feet NGVD 29) during early spring (March) of the average water year corresponded with the lowest WUA estimates. Water surface elevations falling below this depth interval occurred mainly in the vicinity of Pocahontas Creek. The water surface elevation measured during this time interval was the same in the downstream area adjacent to Metaline. The broad channel in this area contains a large quantity of habitat suitable for established macrophyte beds.

Reduced WUA estimates during the dry hydrologic year that occurred in September (Figure 5.6-6) coincided with the lowest water surface elevations recorded in the points along the Upper Reservoir Reach. The very low water surface elevations occurred mostly from Pocahontas Creek and upstream beyond Sand Creek in the Upper Reservoir Reach where WUAs for macrophytes were substantially reduced. Water surface elevations that fell below 1,986 feet NAVD 88 (1,982 feet NGVD 29) and lasted over several days were apparently related to the reduction of macrophyte WUA estimates.

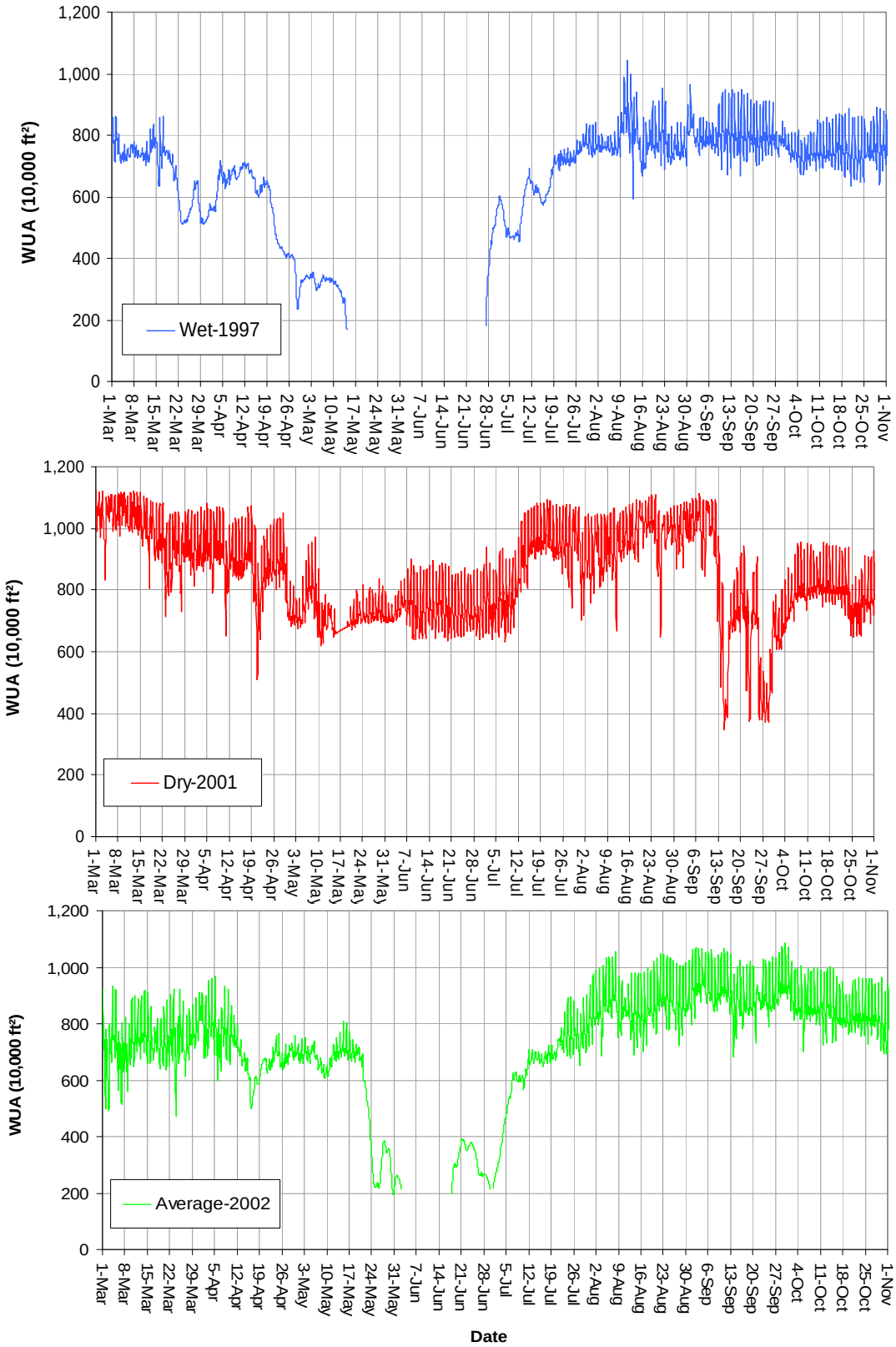



**Figure 5.6-6.** Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.6-4.** Summary of monthly macrophyte WUA (x 10,000 sq. ft.) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** |
| January | --[1] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| February | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| March | 677 | 863 | 510 | 96.0 | 998 | 1,122 | 715 | 83.6 | 734 | 934 | 474 | 80.4 |
| April | 563 | 719 | 234 | 131.2 | 896 | 1,080 | 511 | 94.2 | 700 | 968 | 500 | 80.4 |
| May | 315 | 356 | 170 | 33.7 | 721 | 971 | 620 | 52.5 | 566 | 809 | 195 | 180.7 |
| June | 430 | 565 | 180 | 99.0 | 734 | 899 | 637 | 54.9 | 307 | 392 | 199 | 54.6 |
| July | 646 | 838 | 452 | 101.1 | 889 | 1,094 | 631 | 118.5 | 646 | 938 | 230 | 141.0 |
| August | 785 | 1,044 | 594 | 62.3 | 966 | 1,111 | 648 | 80.7 | 870 | 1,056 | 687 | 73.4 |
| September | 792 | 949 | 668 | 48.3 | 780 | 1,113 | 347 | 230.8 | 913 | 1,085 | 682 | 71.4 |
| October | 745 | 892 | 637 | 46.2 | 777 | 956 | 608 | 69.5 | 846 | 1,069 | 692 | 67.8 |
| November | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| December | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Note:
1 Hyphens indicate no viable macrophyte habitat during the winter months in Boundary Reservoir.

Two-week averages and related statistics are reported for macrophyte WUA estimates and corresponding water surface elevations for three representative months (Table 5.6-5). May was selected to represent spring run-off conditions (i.e., higher velocity, increased turbidity), July was selected to represent growing season conditions (i.e., increased clarity and reduced flow, depth, and velocity), and September was selected to represent end of growing season conditions (i.e., lowest flow of the year, reduced photoperiod and cooler water temperatures) in the Upper Reservoir Reach. The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter time frame (i.e., two weeks) was to determine how macrophyte WUA estimates in the Upper Reservoir Reach respond to Project operations. These comparisons within a shorter time period were used to determine the influence of individual model variables on the WUA estimates in each season and hydrologic year.

**Table 5.6-5.** Summary of macrophyte WUA (x 10,000 sq. ft.) in Boundary Reservoir and water surface elevations at Metaline Bridge for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** | **Mean** | **Max.** | **Min.** | **Stdev.** |
| **Macrophyte WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 707 | 836 | 655 | 32.6 | 472 | 809 | 195 | 198.6 |
| July | 717 | 838 | 575 | 60.2 | 967 | 1,094 | 704 | 72.2 | 735 | 938 | 650 | 58.1 |
| September | 791 | 947 | 668 | 48.9 | 623 | 943 | 368 | 158.4 | 901 | 1,085 | 731 | 65.1 |
| **Water Surface Elevation (feet NAVD 88) at Metaline Bridge** | | | | | | | | | | | | |
| May | 2012.6 | 2014.8 | 2007.1 | 2.4 | 1991.3 | 1995.1 | 1989.5 | 1.4 | 1999.0 | 2004.9 | 1990.3 | 4.8 |
| July | 1993.9 | 1997.7 | 1989.8 | 1.9 | 1991.4 | 1994.4 | 1986.3 | 1.6 | 1992.6 | 1996.7 | 1988.1 | 2.1 |
| September | 1991.9 | 1995.1 | 1987.9 | 1.7 | 1987.6 | 1994.0 | 1981.6 | 3.3 | 1992.0 | 1994.4 | 1987.8 | 1.5 |

Note:
1 Macrophyte WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

WUA estimates for macrophytes during the last two weeks of May responded directly to water surface elevation fluctuations between 1,989 and 1,995 feet NAVD 88 (1,985 and 1,991 feet NGVD 29) during the dry hydrologic year and between 1,990 and 2,004 feet NAVD 88 (1,986 and 2,000 feet NGVD 29) during the average year (Figure 5.6-7). In May, when water surface elevations in the average year were consistently higher than 1,995 feet NAVD 88 (1,991 feet NGVD 29) the macrophyte WUA estimates were the lowest throughout this two-week period. Both depth and mean channel velocity contribute to the lower WUA estimates during May.

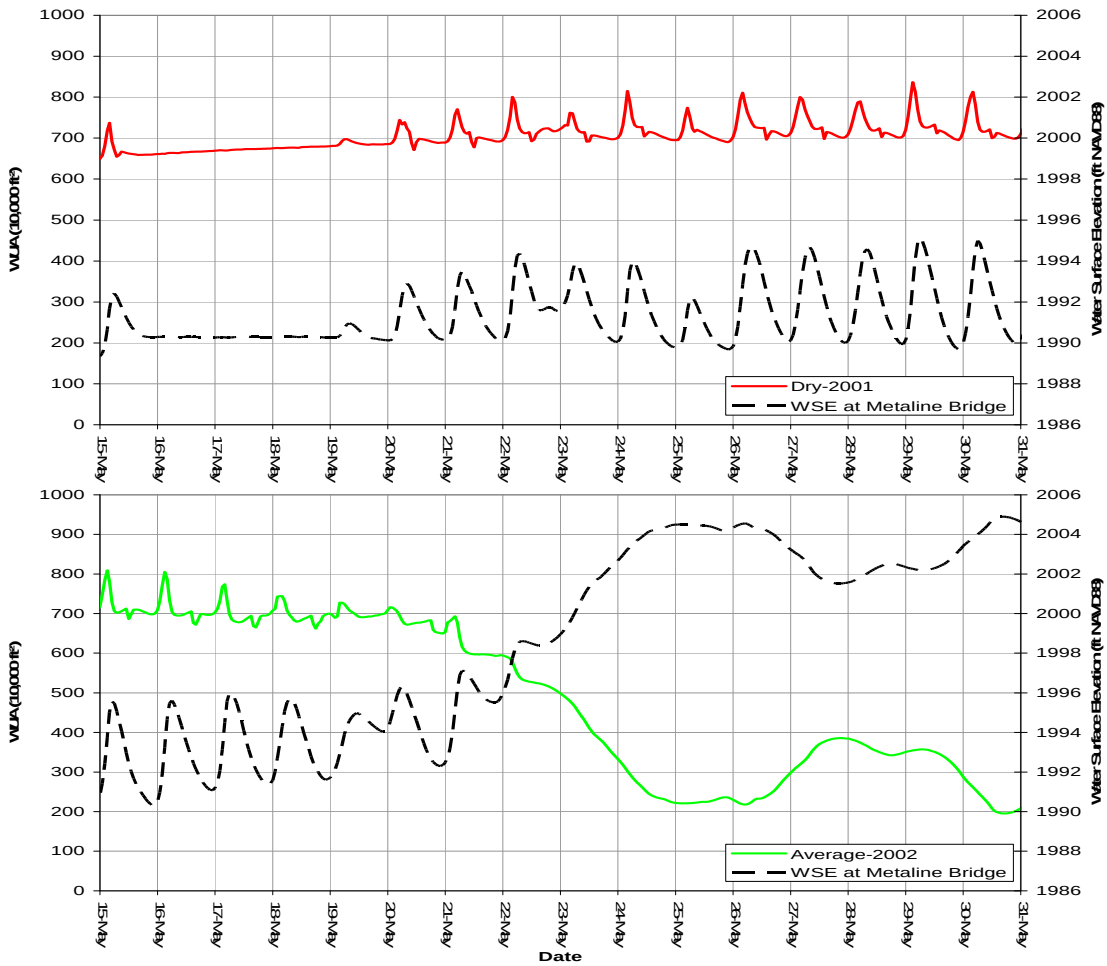



**Figure 5.6-7.** Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during May 1531; WUA determined by the mainstem habitat model for dry and average years.

Note: Macrophyte WUA for the wet year was held constant due to a bounding condition of 80,000 cfs; therefore, no graph is presented.

WUA estimates for macrophytes during July in the Upper Reservoir Reach responded directly to water surface elevation fluctuation (Figure 5.6-8). Water surface elevations were relatively stable throughout the two-week period, particularly in the dry hydrologic year when WUA estimates were highest. The water surface elevations that were consistently at or above 1,994 feet NAVD 88 (1,990 feet NGVD 29) in the Upper Reservoir Reach in a wet hydrologic year resulted in lower WUA estimates for macrophyte habitat suitability. A consistent decline in peak water surface elevation over the two-week period in July increased WUA estimates for macrophytes over the latter interval when low water surface elevations were at or below 1,992 feet NAVD 88 (1,988 feet NGVD 29).

Macrophyte WUA estimates during the last two weeks in September directly responded to water surface elevation fluctuations (Figure 5.6-9). The highest WUA estimates corresponded with the greatest pool level fluctuations during the average hydrologic year.

In all three years, macrophyte WUA estimates declined in response to reductions in water surface elevations. This may have been a result of the smaller ramping rate interval (predominantly 2 to 4 inches/hour) that occurred in this reach and that suitability of habitat remains higher for an extended period of time following the beginning of water level decline. Water surface elevations consistently above 1,988 feet NAVD 88 (1,984 feet NGVD 29) and 1,992 feet NAVD 88 (1,988 feet NGVD 29) resulted in higher sustained WUA estimates for macrophytes during the last two weeks of September (compare wet and dry years). A sustained water fluctuation interval of 4 feet during the average year (1,990–1,994 feet NAVD 88 [1,986–1,990 feet NGVD 29]) resulted in the highest sustained WUA estimates for macrophytes during the last two weeks of September.

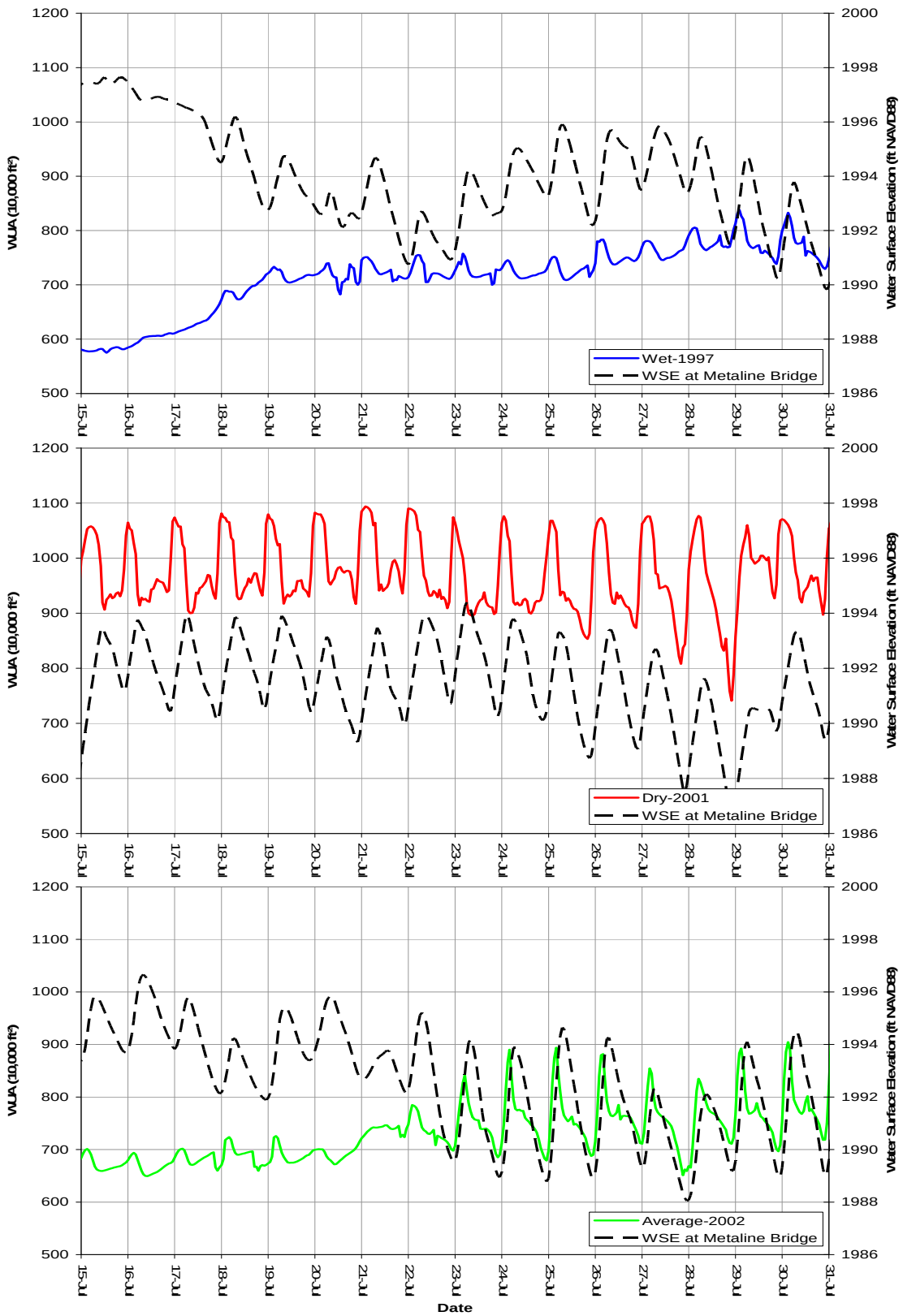



**Figure 5.6-8**. Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during July 15–31 for wet, dry, and average years.

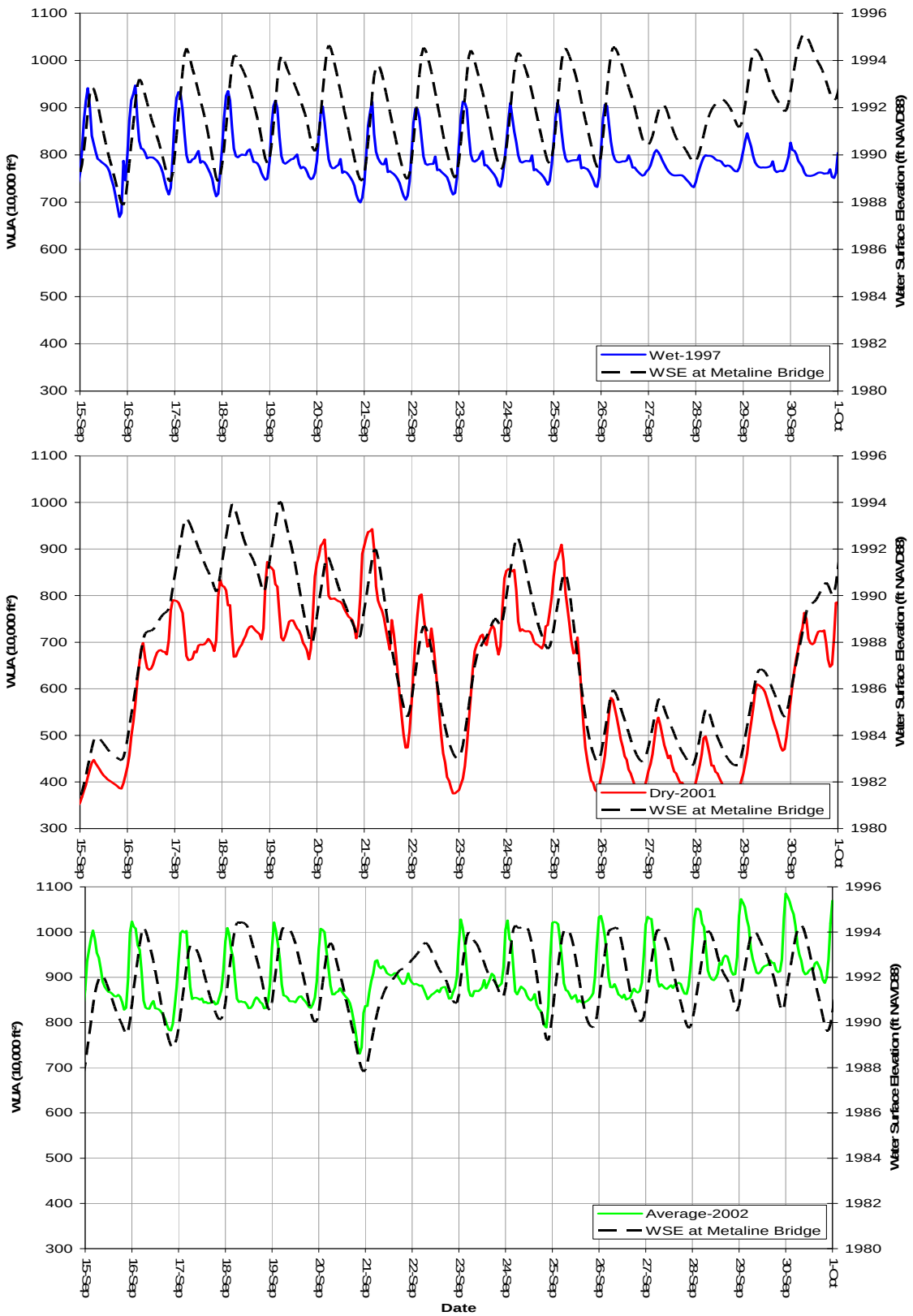



**Figure 5.6-9**. Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during September 15–31 for wet, dry, and average years.

### 5.6.4. Tailrace Reach

The Mainstem Aquatic Habitat Model results for macrophyte WUA in the Tailrace Reach are shown in Figure 5.6-10 and summarized by month in Table 5.6-6. Data absent during the wet and average years in Figure 5.6-10 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated macrophyte WUA in the Tailrace Reach was significantly lower than the WUA determined for the Upper Reservoir and Canyon reaches, but similar to the WUA determined for the Forebay Reach. The maximum WUA in this reach (at any time) was determined to be 58 (x 10,000 square feet) and occurred in March of a dry hyrologic year (Table 5.6-6). The lowest macrophyte WUA at any given time was determined to be 10 (x 10,000 square feet) and occurred in April of a wet hydrologic year. Variability in macrophyte WUA in the Tailrace Reach was similar to that seen in the Forebay Reach (Figure 5.6-1 and Table 5.6-1) and Canyon Reach (Figure 5.6-5 and Table 5.6-3). Most of the variation in macrophyte WUA in the Tailrace Reach was due to extreme pool fluctuations and depth, similar to macrophyte WUA in the Forebay and Canyon reaches. Velocity is more variable in the Tailrace Reach than in the Forebay or Canyon reaches and therefore may have influenced the variation in WUA. Substrate in the Tailrace Reach, however, is fairly uniform throughout the reach and therefore does not contribute to the variation observed in the Upper Reservoir Reach.

The Tailrace Reach had the lowest overall WUA estimates for macrophytes of all reaches. This reach had higher velocities and coarse substrate, conditions that were not considered optimal for macrophyte establishment. This reach had flow fluctuations synchronized with Forebay Reach water surface elevation fluctuations. Additional factors that minimized WUA estimates included duration of dewatering and the frequency of these events. The highest average WUA for macrophytes was estimated for the dry hydrologic year. Lower WUA in wet and average years indicates that velocity, in addition to frequency and duration of dewatering events, has a larger impact on habitat suitability during higher flow conditions than lower flow conditions. Macrophyte establishment in areas such as the Tailrace Reach may benefit from an increase in stabilized flows when other important factors like suitable substrate are limiting.

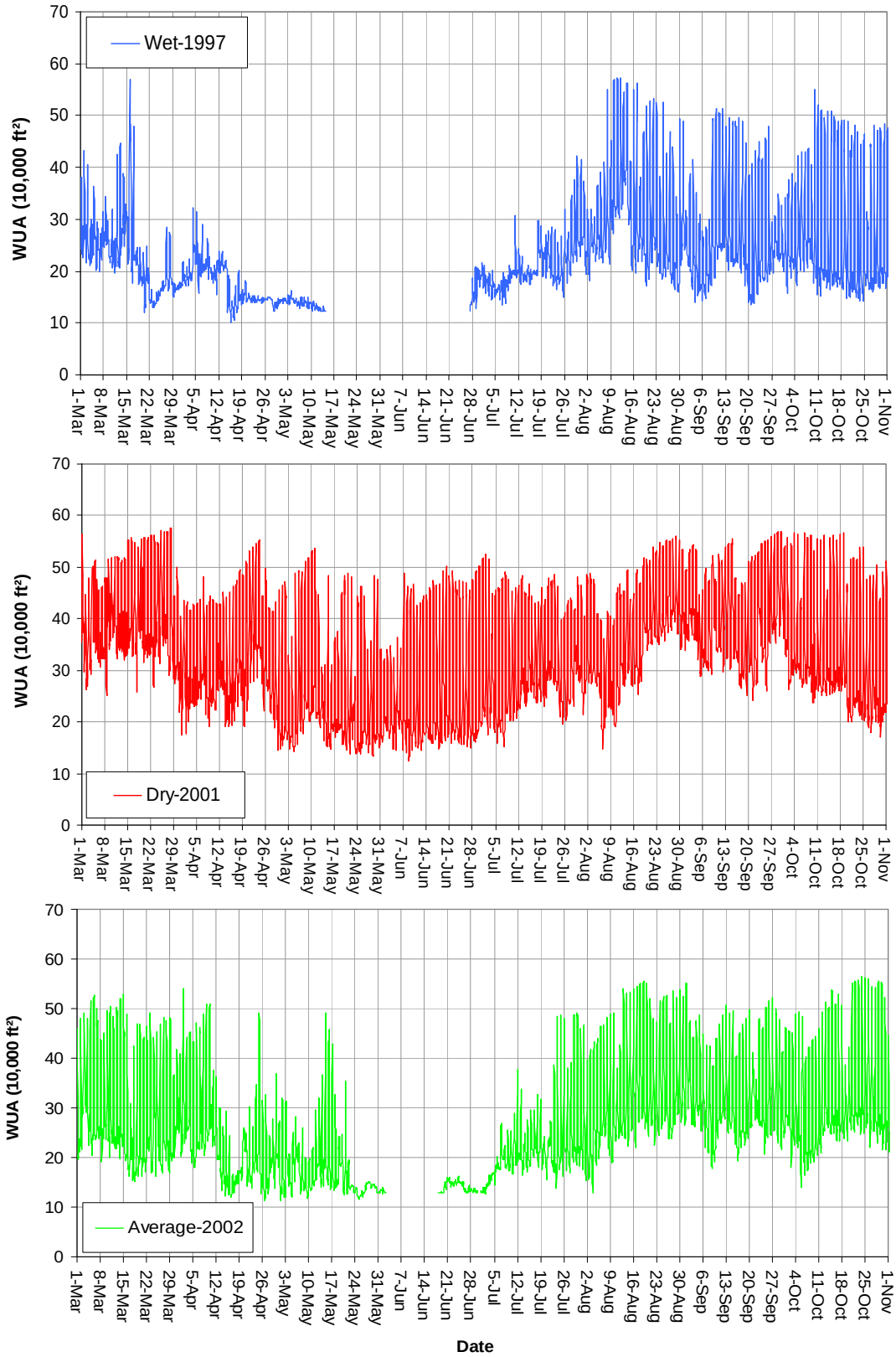



**Figure 5.6-10.** Habitat WUA for macrophytes in the Tailrace Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.6-6.** Summary of monthly macrophyte WUA (x 10,000 sq. ft.) in the Tailrace Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| January | --[1] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| February | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| March | 23 | 57 | 12 | 7.1 | 40 | 58 | 18 | 8.8 | 29 | 53 | 15 | 10.2 |
| April | 17 | 32 | 10 | 3.9 | 32 | 55 | 15 | 9.4 | 23 | 54 | 11 | 8.8 |
| May | 14 | 16 | 12 | 0.8 | 25 | 54 | 13 | 10.2 | 17 | 49 | 11 | 6.0 |
| June | 17 | 21 | 12 | 2.5 | 25 | 50 | 13 | 10.6 | 14 | 16 | 13 | 1.0 |
| July | 21 | 42 | 14 | 4.6 | 31 | 52 | 15 | 9.6 | 22 | 49 | 13 | 6.8 |
| August | 30 | 57 | 16 | 10.3 | 37 | 56 | 15 | 9.7 | 32 | 56 | 13 | 10.3 |
| September | 26 | 51 | 14 | 9.2 | 40 | 57 | 24 | 9.0 | 32 | 55 | 18 | 8.8 |
| October | 27 | 55 | 14 | 10.8 | 33 | 57 | 17 | 10.5 | 32 | 56 | 14 | 10.3 |
| November | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| December | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Note:
1 Hyphens indicate no viable macrophyte habitat during the winter months in Boundary Reservoir.

## 5.6.5. Aquatic Macrophyte Drawdown Control Overview

Partial management of invasive aquatic plants in Boundary Reservoir may theoretically be accomplished operationally by water-level drawdown. Dewatering invasive macrophyte beds exposes plant stems, root crowns, and seeds to dry and cold or dry and hot conditions, resulting in desiccation and reduced biomass as well as aerial coverage. The extent that biomass may be reduced depends on a matrix of variables including environmental conditions, substrata characteristics, groundwater, duration of exposure, relative humidity, and plant biology. The response of plant species to drawdown is highly variable.

### *5.6.5.1. Environmental Variables*

#### *5.6.5.1.1. Precipitation*

Sufficient atmospheric moisture, as rainfall, snow, fog, dew, frost et cetera, interferes with sediment drying. Whether a drawdown occurs during the winter or summer, sediments must be dry for a sufficient time and depth for reproductive plant parts to fully desiccate. In the Pend Oreille River area, seasonal precipitation is greatest during late fall, winter, and spring, but summer storms and fog add to the difficulty in sustaining a dry period for drawdown effectiveness.

#### *5.6.5.1.2. Temperature*

Sufficient exposure of plant parts to extreme hot or cold conditions may compensate for fully dried sediments. For example, hydrosoils exposed to temperature of -12°C or less for 7 days will

have the same effect as the same hydrosoils exposed to -2°C for 45 days. In contrast, a summer average air high temperature at greater than 30°C dries the hydrosoils four times as fast as average air temperatures of 20°C.

#### *5.6.5.1.3. Bathymetry*

The slope of the nearshore environment determines, in part, the level to which drawdown must occur to fully expose the sediment where macrophytes are rooted. Areas with the most gradual shore zone slopes will likely have the greatest biomass and therefore dictate drawdown level.

#### *5.6.5.1.4. Sediment Characteristics*

The texture and density of sediment determines its moisture retention capacity. For example, clay has a higher soil moisture retention capacity compared to sand and would require longer exposure periods to dry, the same for high organic content versus low organic content. Sediment texture also determines soil nutrient availability for plant growth, influencing rooting depth and, by extension, the depth to which drying must occur to kill rhizomes that could propagate more plants.

#### *5.6.5.1.5. Hydrology*

Subsurface water flow through the drawdown zone could substantially delay the drying period such that extreme cold or hot temperatures would be required.

#### *5.6.5.1.6. Plant Biology*

The submersed aquatic plants in the Pend Oreille River are known to spread primarily by vegetative means such as stem fragments. Eurasian watermilfoil stem fragments are easily released naturally through autofragmentation (fragments produced at natural abscission points) at the end of the growing season. A drawdown occurring prior to the release of autofragments would be advantageous in preventing further spread. In addition to spreading by stem fragments, curlyleaf pondweed produces turions in late summer resulting in the capacity for advective expansion of weed beds upon sprouting. Water drawdown must therefore be sufficient to control a variety of reproductive plant parts.

### *5.6.5.2. Seasonal Water Level and Duration Considerations*

Biomass of curlyleaf pondweed and Eurasian watermilfoil has been shown to decline from winter water level drawdown (Nichols 1975; Goldsby et al. 1978; Crosson 1994; Wagner and Falter 2002). Summer drawdown have not been demonstrated to be as effective in immediate of carryover biomass reduction (Welch and Jacoby 2004; Cooke et al. 2005).

#### July through September Control Drawdown

In order for summer time drawdown to be effective, a prolonged period of exposure would be needed (45 to 60 days). At water surface elevations of 1,984 feet NAVD 88 (1,980 feet NGVD 29) at Boundary Dam, there would be an exposure of only 6 vertical feet of aquatic macrophyte beds in the Forebay and Canyon reaches at flows ranging between 6,000 and 40,000 cfs. Above Metaline Falls, aquatic macrophyte beds would only begin to be exposed at flows below 20,000

cfs, and at less than 10,000 cfs only 4 to 5 vertical feet of aquatic macrophyte exposure would occur, resulting in minimal impact on aquatic macrophyte coverage and biomass.

At a water surface elevation of 1,974 feet NAVD 88 (1,970 feet NGVD 29) at Boundary Dam, there would be an exposure of 16 vertical feet of aquatic macrophyte beds or approximately 50 percent of the plant bed area in the Forebay and Canyon Reaches at flows ranging between 6,000 and 40,000 cfs. Above Metaline Falls, aquatic macrophyte beds would only begin to be exposed at flows below 20,000 cfs and only 6 to 8 feet of vertical aquatic macrophyte bed would be exposed at 10,000 cfs, thus exposing approximately 25 percent of the bed area.

#### March through May Drawdown

In order for a late winter/early spring drawdown to be effective, a prolonged period of exposure would be needed (at least 30 days). At water surface elevations of 1,984 feet NAVD 88 (1,980 feet NGVD 29) at Boundary Dam, there would be an exposure of only 6 vertical feet of aquatic macrophyte beds in the Forebay and Canyon reaches at flows ranging between 6,000 and 40,000 cfs. Above Metaline Falls aquatic macrophyte beds would only begin to be exposed at flows below 20,000 cfs and at less than 10,000 cfs only 4 to 5 vertical feet of aquatic macrophyte exposure would occur, resulting in minimal impact on aquatic macrophyte coverage and biomass.

At a water surface elevation of 1,974 feet NAVD 88 (1,970 feet NGVD 29) at Boundary Dam there would be an exposure of 16 vertical feet of aquatic macrophyte beds or approximately 50 percent of the bed area in the Forebay and Canyon reaches at flows ranging between 6,000 cfs and 40,000 cfs. Above Metaline Falls, aquatic macrophyte beds would only begin to be exposed at flows below 20,000 cfs and only 6 to 8 feet of vertical aquatic macrophyte bed would be exposed at 10,000 cfs, thus exposing approximately 25 percent of the bed area. At flows of 6,000 cfs an additional 2 to 3 feet of bed would be exposed, for a maximum of 40 percent of aquatic macrophyte bed being exposed.

Regardless of the drawdown period or timing, a multiple-year program would be needed to have any effective carry-over control for more than a year or two. Specifically, three years of repeated drawdown would yield two to three years of control, whereas a single drawdown would only yield an effect for that year.

## 5.7. Periphyton Habitat Development and Modeling Efforts

This section presents the results of the periphyton habitat modeling effort in the mainstem of the Pend Oreille River including Boundary Reservoir and its tailrace. Results are presented by each of the four reaches (Forebay, Canyon, Upper Reservoir, and Tailrace) within the study area. The final periphyton HSI curves were used in the Mainstem Aquatic Habitat Model to quantify the response of periphyton in Boundary Reservoir to hourly water surface elevations. The following subsections provide a summary of the model results and discussion for periphyton WUA by reach and for each model simulation. More detailed discussion of periphyton production is provided in the Study 11 Final Report (SCL 2009c).

Modeling of WUA for periphyton habitat potential was completed for historic Project operations during wet (1997), dry (2001), and average (2002) years. These years were selected as representative of wet, dry, and average conditions using factors such as average annual flows (R2 Resource Consultants 2008). For reference, the flow hydrographs for the wet, dry, and average years are presented in Figures 5.0-1 through 5.0-3, respectively, and a comparison of the flow hydrographs across these three years is shown in Figure 5.0-4. WUA results presented in the following sections did not consider flows exceeding 80,000 cfs. Once flows exceeded this volume, the calculated WUA for a given species was not considered in the determination of the WUA. The plotted results do not show WUA values for flows in excess of 80,000 cfs. Likewise, the WUA values for flows in excess of 80,000 cfs were not included in the tabulated numerical results. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs ensured the incorporation of all flows potentially influenced by Project operations. When flows exceed 55,000 cfs, pool level fluctuations are typically dominated by inflow hydrology not Project operations as shown by the HRM.

Hourly time-step data describing WUA estimates were summarized with monthly summary statistics and with two-week summary statistics for specific twice-monthly time periods in May, July, and September. These two-week summary statistics were reported for select reaches and more closely analyzed for Project operations effects on periphyton in the Forebay and Upper Reservoir reaches.

### 5.7.1. Forebay Reach

The Mainstem Aquatic Habitat Model results for periphyton WUA estimates in the Forebay Reach are shown in Figure 5.7-1 and summarized by month in Table 5.7-1. Data absent during the wet and average years in Figure 5.7-1 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated periphyton WUA was the lowest in the Forebay Reach compared to other reaches within Boundary Reservoir and much less variable throughout the year. The maximum potential periphyton WUA in the Forebay Reach (at any time) was determined by the model to be 25 (x 10,000 square feet) and occurred May of a wet hydrologic year (Table 5.7-1). The lowest potential periphyton WUA at any given time over the model simulation was determined to be 3.1 (x 10,000 square feet) and occurred during May of a dry hydrologic year. On average, potential periphyton WUA in the Forebay Reach was very similar throughout the seasons during wet and average years. Greater seasonal variation was observed in a dry year (Figure 5.7-1).

Most of the daily variation in periphyton WUA seen in Figure 5.7-1 and summarized as standard deviation in Table 5.7-1 is due to the hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Other HSI parameters for periphyton (velocity and substrate) have little to no variability on an hourly timescale, thus no influence on daily variation in periphyton WUA in the Forebay Reach. Variations in potential periphyton WUA are influenced by daily pool fluctuations, but are small (e.g., 10 percent difference between maximum and minimum daily estimates) when compared against variation in monthly averages for wet, dry, or average (e.g., 20 percent difference between maximum and minimum monthly estimates) hydrologic years.

Seasonal patterns were observed for periphyton WUA in the Forebay Reach during a dry year; however, seasonal fluctuations were less than those estimated for other reaches. Water surface elevation fluctuations were highest in the Forebay Reach compared to other reaches upstream of Boundary Dam where usable habitat for periphyton colonization may have been exposed to desiccation for various period of time. This continuous disturbance through some frequency of dewatering depressed WUA estimates for all hydrologic years and diminished the amplitude for seasonal WUA estimates described for other reaches. The primary factor influencing WUA in the Forebay Reach, as compared to other reaches, was the duration of dewatering and increased water surface elevation fluctuations.

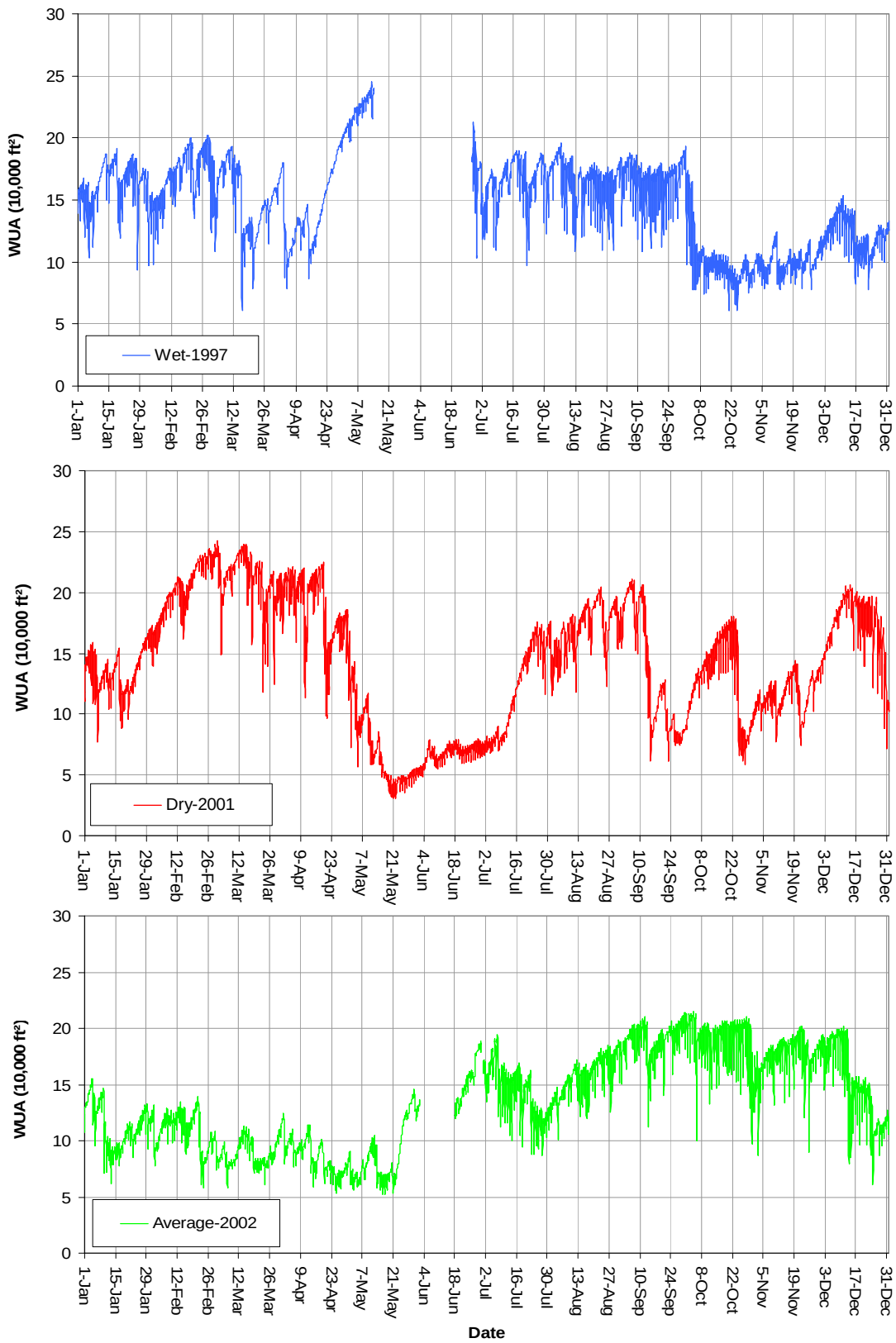



**Figure 5.7-1.** Habitat WUA for periphyton in the Forebay Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.7-1.** Summary of monthly periphyton WUA (x 10,000 sq. ft.) in the Forebay Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 16 | 19 | 9 | 1.6 | 14 | 17 | 7.7 | 1.8 | 11 | 16 | 6.1 | 1.9 |
| February | 17 | 20 | 10 | 2.1 | 20 | 24 | 15 | 2.0 | 11 | 14 | 5.8 | 1.6 |
| March | 15 | 20 | 6.1 | 2.7 | 21 | 24 | 12 | 2.2 | 9.0 | 12 | 5.8 | 1.2 |
| April | 14 | 20 | 7.8 | 3.1 | 19 | 22 | 10 | 2.8 | 8.6 | 12 | 5.3 | 1.4 |
| May | 22 | 25 | 20 | 1.1 | 6.9 | 17 | 3.1 | 2.9 | 8.6 | 15 | 5.3 | 2.4 |
| June | 17 | 21 | 10 | 2.5 | 6.8 | 7.9 | 4.8 | 0.7 | 15 | 19 | 12 | 1.9 |
| July | 16 | 19 | 10 | 1.7 | 12 | 18 | 6.6 | 3.6 | 14 | 19 | 8.7 | 2.3 |
| August | 16 | 20 | 11 | 1.8 | 17 | 20 | 12 | 1.9 | 16 | 19 | 10 | 1.6 |
| September | 17 | 19 | 11 | 1.6 | 13 | 21 | 6.1 | 4.8 | 19 | 21 | 11 | 1.6 |
| October | 10 | 19 | 6.1 | 2.2 | 13 | 18 | 5.9 | 3.1 | 19 | 22 | 10 | 2.1 |
| November | 10 | 12 | 7.8 | 0.9 | 12 | 14 | 7.5 | 1.4 | 17 | 20 | 9 | 1.7 |
| December | 12 | 15 | 7.8 | 1.3 | 17 | 21 | 7.1 | 2.6 | 15 | 20 | 6.1 | 3.4 |

Two-week averages and summary statistics were reported for periphyton WUA estimates and corresponding water surface elevations for three representative months and the hydrologic conditions in the Forebay reach (Table 5.7-2). The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter timeframe (i.e., two weeks) was to determine how periphyton WUA estimates in the Forebay were responding to Project operations, season, and hydrologic year.

**Table 5.7-2.** Summary of periphyton WUA and water surface elevations at Boundary Dam for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| **Periphyton WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 4.7 | 6.8 | 3.1 | 0.7 | 9.4 | 15 | 5.3 | 2.9 |
| July | 17 | 19 | 10 | 1.7 | 15 | 18 | 11 | 1.7 | 13 | 17 | 8.7 | 1.9 |
| September | 16 | 19 | 11 | 1.6 | 9.5 | 13 | 6.1 | 1.5 | 19 | 21 | 14 | 1.4 |
| **Water Surface Elevation (feet NAVD 88) at Boundary Dam** | | | | | | | | | | | | |
| May | 1,988.6 | 1,992.9 | 1,984.4 | 1.8 | 1,981.8 | 1,993.5 | 1,963.2 | 7.3 | 1,989.5 | 1,994.2 | 1,976.5 | 3.6 |
| July | 1,990.0 | 1,994.3 | 1,983.3 | 2.2 | 1,990.9 | 1,994.1 | 1,985.3 | 1.8 | 1,988.8 | 1,993.6 | 1,982.1 | 2.8 |
| September | 1,989.8 | 1,993.8 | 1,984.2 | 2.3 | 1,986.6 | 1,993.8 | 1,977.1 | 3.9 | 1,991.3 | 1,994.0 | 1,986.2 | 1.7 |

Note:
1 Periphyton WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

The comparison between WUA estimates and water surface elevations for May demonstrates that periphyton WUA range of response is narrow, and is suppressed when wide water surface elevation fluctuations occur on a daily basis (Figure 5.7-2). Periphyton WUA estimates in the Forebay Reach are low and show a small difference between minimum and maximums, while water surface elevation fluctuations remained high in the dry hydrologic year during May (Figure 5.7-2). An increase in potential WUA during the average hydrologic year occurred when water surface elevations were stable and remained above 1,990 feet NAVD 88 (1,986 feet NGVD 29). The potential WUA in the Forebay Reach only increased when inundation was sustained for longer than one day as indicated by a reduction in large differences in water surface elevation fluctuations occurring on a daily basis.

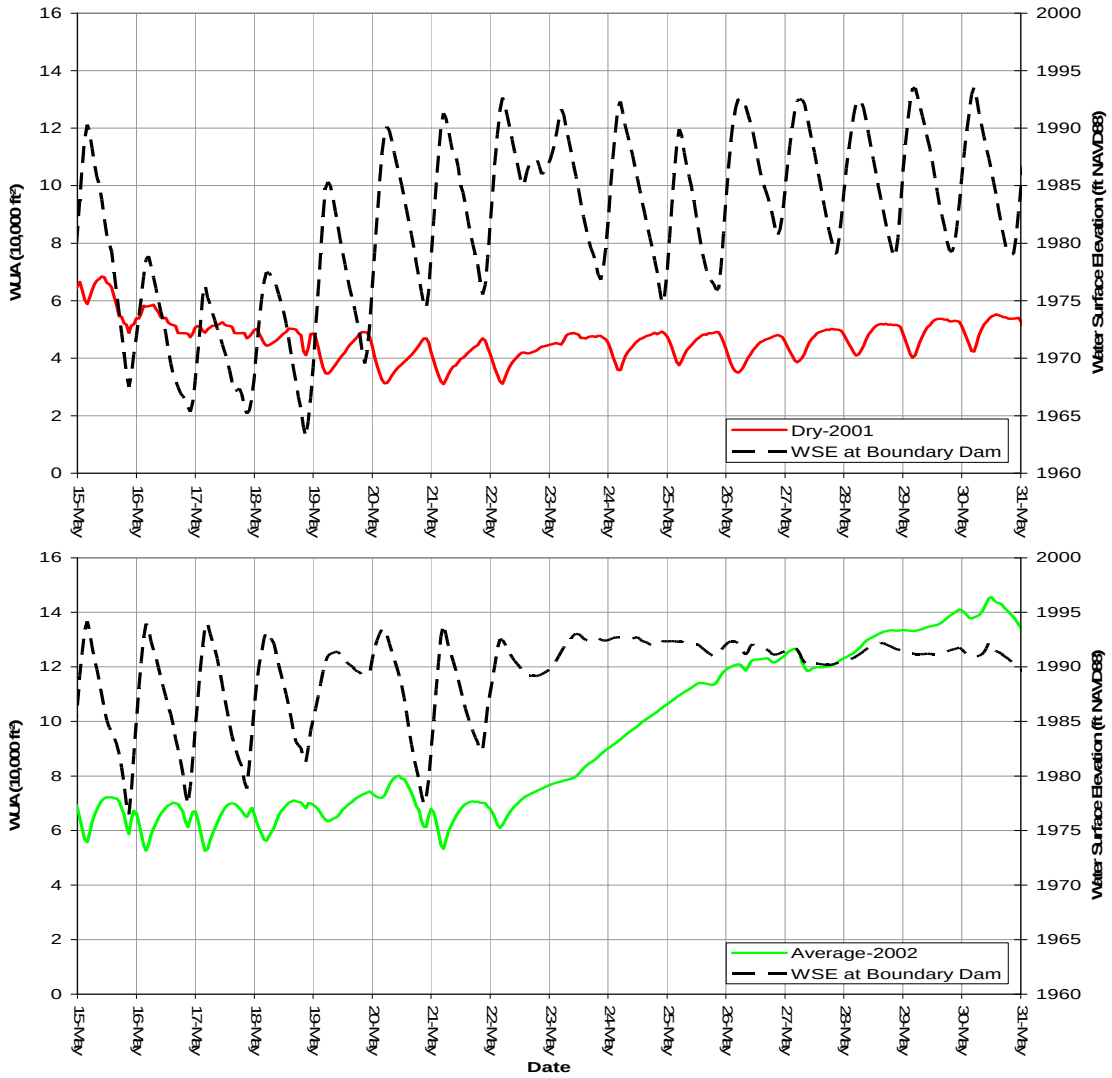



**Figure 5.7-2.** Habitat WUA for periphyton in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during May 15–31; WUA determined by the mainstem habitat model for dry and average years.

Periphyton WUA estimates during July were highest when water surface elevation fluctuations in the Forebay Reach remained at or above 1,990 feet NAVD 88 (1,986 feet NGVD 29) (Figure 5.7-3). Potential WUA for periphyton decreased with water surface elevation when minimum elevations were consistently below 1,990 feet NAVD 88 (1,986 feet NGVD 29) for all three hydrologic years. The lowest average WUA estimates for periphyton occurred during an average hydrologic year. The lower WUA estimates may have been due to the duration of de-watering where warmer air temperatures could accelerate desiccation of periphyton cells. The highest average WUA estimates occurred during a wet hydrologic year (Figure 5.7-3). Colonization by periphyton appears to be a rapid process when suitable habitat is inundated above 1,990 feet NAVD 88 (1,986 feet NGVD 29) in the Forebay Reach during July, and potential increases are sustained when fluctuations do not fall below this elevation.

Water surface elevations in the Forebay Reach during wet and average years at the end of September did not fall below 1,985 feet NAVD 88 (1,981 feet NGVD 29) resulting in WUA estimates for periphyton that were directly synchronized with fluctuations (Figure 5.7-4). Water surface elevations frequently fell below 1,985 feet NAVD 88 (1,981 feet NGVD 29) for the two-week interval at the end of September during the dry year, resulting in the lowest WUA estimates for periphyton. Habitable area for periphyton is already limited in the Forebay Reach and water surface elevations that are less than 1,985 feet NAVD 88 (1,981 feet NGVD 29) result in dewatering that dramatically reduces optimal habitat.

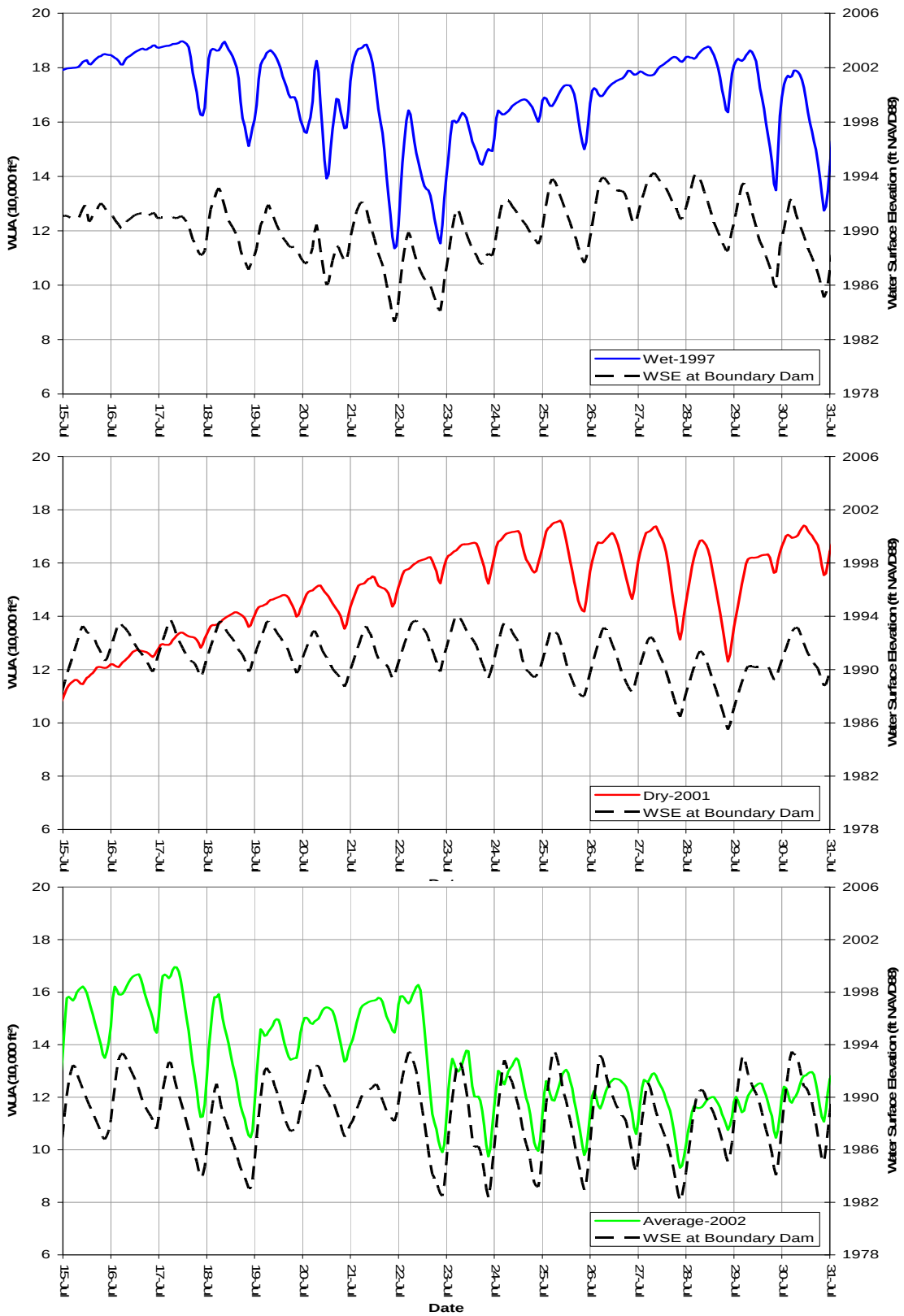



**Figure 5.7-3.** Habitat WUA for periphyton in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during July 15–31 for wet, dry, and average years.

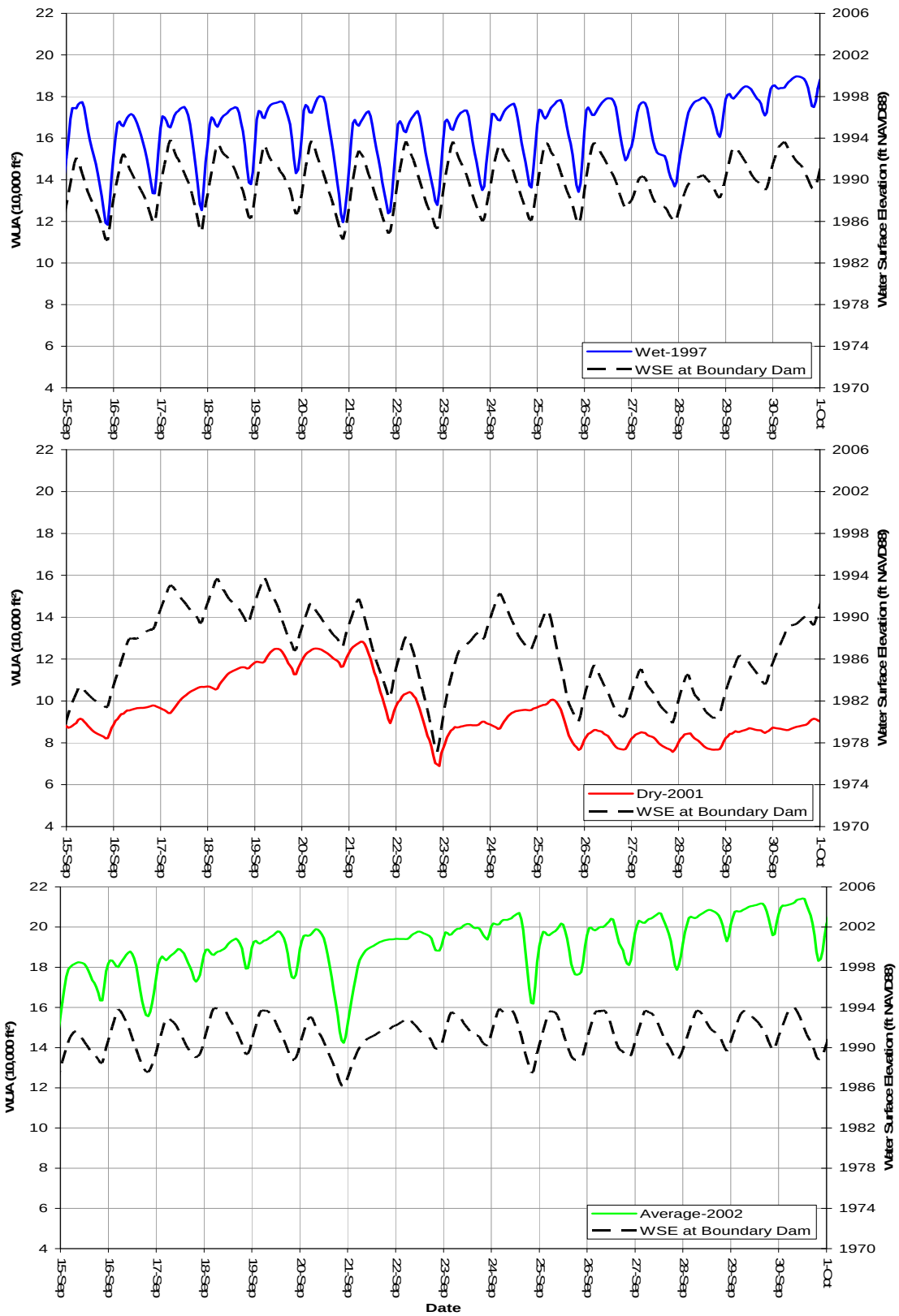



**Figure 5.7-4.** Habitat WUA for periphyton in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during September 15–31 for wet, dry, and average years.

### 5.7.2. Canyon Reach

The Mainstem Aquatic Habitat Model results for periphyton WUA in the Canyon Reach are shown in Figure 5.7-5 and summarized by month in Table 5.7-3. Data absent during the wet and average years in Figure 5.7-5 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated periphyton WUA in the Canyon Reach was significantly lower than the WUA determined for the Upper Reservoir Reach but greater than the Forebay Reach. The maximum potential periphyton WUA in the Canyon Reach (at any time) was determined by the model to be 392 (x 10,000 square feet) and occurred during February of an average hydrologic year (Table 5.7-3). The lowest relative periphyton WUA at any given time was determined to be 142 (x 10,000 square feet) and occurred during May of a dry hydrologic year. There was also significantly less variability through the year in relative periphyton WUA in the Canyon Reach than in the Upper Reservoir Reach (Figure 5.7-5). On average, relative periphyton WUA in the Canyon Reach was very similar throughout seasons and over all three model simulations. The one exception was the slightly lower average relative periphyton WUA in in a wet hydrologic year (Table 5.7-3).

Most of the daily variation in periphyton WUA seen in Figure 5.7-5 and summarized as standard deviation in Table 5.7-3 is due to the hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Other HSI parameters for periphyton (velocity and substrate) have very little to no variability on an hourly timescale. The Canyon Reach is considered to be a high pool fluctuation zone and daily variation in periphyton WUA is attributed to pool level fluctuation. Daily variation in periphyton WUA in the Canyon Reach is not due to variability in velocity and substrate because these two environmental factors are relatively uniform throughout the reach. Monthly averages describing WUA potential for periphyton are similar among the wet, dry, and average hydrologic years as is the magnitude of variation.

The physical setting of the Canyon Reach does not have the same type of colonizable habitat found in the Upper Reservoir Reach. For example, water depths are greater, especially along most of the shoreline, and other factors that promote growth of periphyton communities like photoperiod are diminished due to the narrow channel bounded by canyon rock walls. Compared to other reaches, habitat for periphyton colonization is substantially reduced; however, potential periphyton WUA in the Canyon Reach is second only to that in the Forebay Reach. The similarity of average WUA estimates during all hydrologic years indicated that one or more factors comprising the HSI are uniform throughout this reach and do not promote the highest quality habitat available in the reservoir for periphyton production.

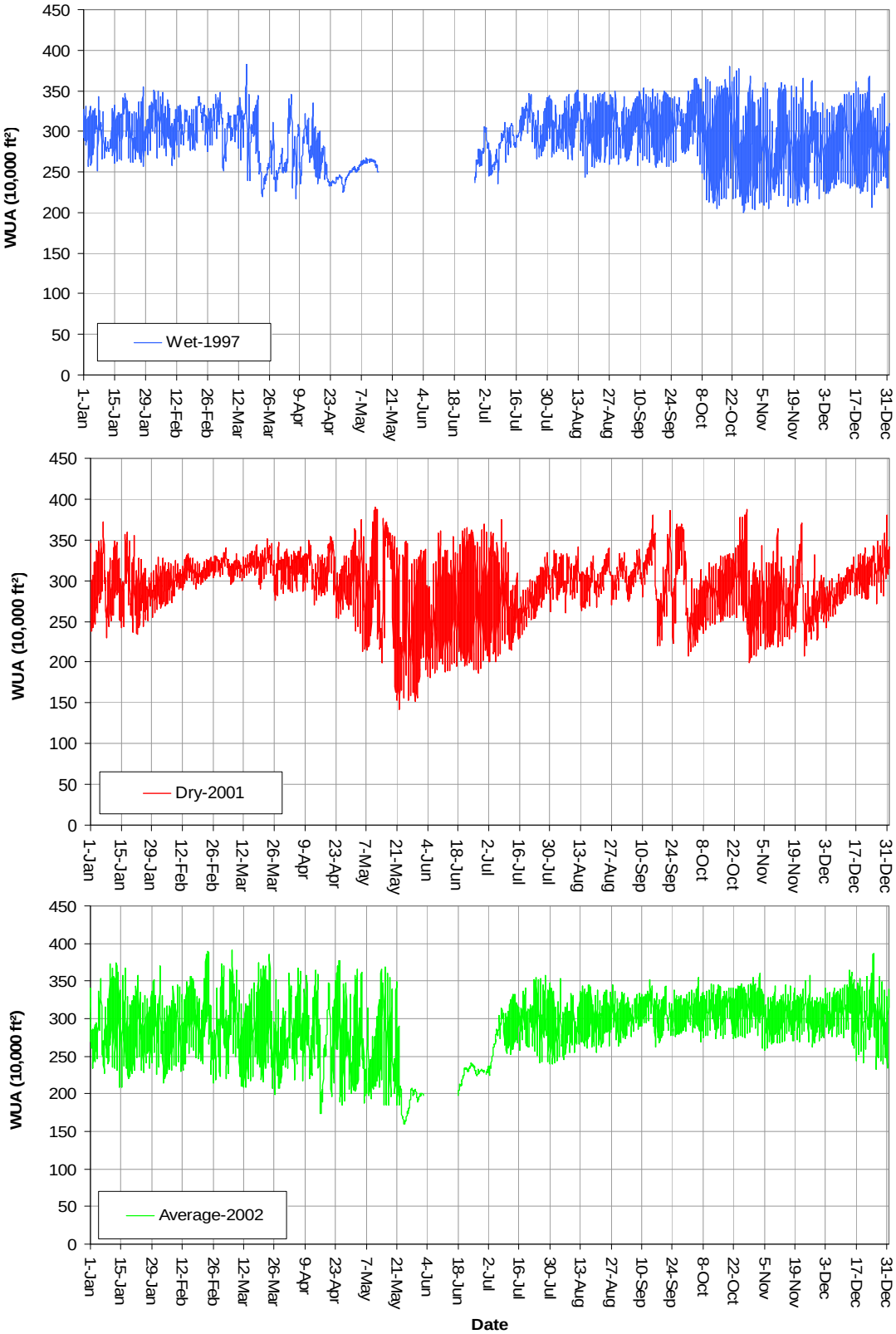



**Figure 5.7-5.** Habitat WUA for periphyton in the Canyon Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.7-3.** Summary of monthly periphyton WUA (x 10,000 sq. ft.) in the Canyon Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 300 | 355 | 251 | 20.7 | 291 | 372 | 230 | 29.0 | 288 | 374 | 209 | 35.0 |
| February | 311 | 350 | 258 | 18.3 | 307 | 333 | 266 | 13.4 | 292 | 392 | 214 | 36.4 |
| March | 290 | 382 | 220 | 34.6 | 319 | 351 | 276 | 12.0 | 286 | 377 | 200 | 43.1 |
| April | 265 | 346 | 217 | 28.5 | 311 | 355 | 253 | 20.5 | 280 | 369 | 174 | 46.8 |
| May | 258 | 267 | 246 | 5.5 | 279 | 389 | 142 | 61.0 | 239 | 373 | 160 | 53.6 |
| June | 263 | 279 | 236 | 10.7 | 268 | 369 | 181 | 50.8 | 225 | 241 | 197 | 12.0 |
| July | 295 | 347 | 235 | 23.1 | 278 | 375 | 200 | 33.1 | 290 | 357 | 225 | 30.4 |
| August | 306 | 351 | 244 | 24.1 | 304 | 341 | 260 | 16.5 | 297 | 354 | 242 | 24.4 |
| September | 307 | 353 | 255 | 23.5 | 308 | 387 | 220 | 33.9 | 308 | 352 | 262 | 17.7 |
| October | 295 | 380 | 200 | 44.2 | 285 | 387 | 199 | 36.3 | 315 | 355 | 269 | 19.5 |
| November | 279 | 365 | 203 | 39.3 | 274 | 370 | 208 | 32.5 | 307 | 360 | 257 | 20.8 |
| December | 285 | 368 | 207 | 34.5 | 302 | 380 | 242 | 23.7 | 307 | 386 | 233 | 27.7 |

### 5.7.3. Upper Reservoir Reach

The Mainstem Aquatic Habitat Model results for periphyton WUA in the Upper Reservoir Reach are shown in Figure 5.7-6 and summarized by month in Table 5.7-4. Data absent during the wet and average years in Figure 5.7-6 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated periphyton WUA was significantly higher in the Upper Canyon Reach compared to other reaches within Boundary Reservoir. The maximum relative periphyton WUA in the Upper Reservoir Reach determined by the model was 1,512 (x 10,000 square feet) and occurred during March of a dry hydrologic year (Table 5.7-4). The lowest relative periphyton WUA was determined to be 301 (x 10,000 square feet), occurring in May of an average hydrologic year. Estimated periphyton WUA was extremely variable throughout all hydrologic years, with potential habitat decreasing in the spring during wet and average years and decreasing during the summer of a dry year (Figure 5.7-6). The decrease in periphyton WUA in the spring was most likely due to increased flows resulting in increased velocities and water depths. Periphyton WUA variability is greatest in the Upper Reservoir Reach and is attributed to greater potential habitat and widely variable conditions compared to other reaches. For example, the Canyon Reach is more uniform in velocity and substrate than the Upper Reservoir Reach. This would explain the standard deviations measured (Table 5.7-4) in what is considered a low pool fluctuation zone. On average, the highest estimated periphyton WUA was available during a dry hydrologic year in winter and summer and the lowest relative periphyton WUA during the summer of wet and average hydrologic years. The highest average periphyton WUA occurred during the fall of an average hydrologic year.

Some of the variation in periphyton WUA seen in Figure 5.7-6 and summarized as standard deviation in Table 5.7-4 is due to hourly pool fluctuations influenced by Project operations.

These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. The Upper Reservoir Reach experiences low pool fluctuations in comparison to the Canyon and Forebay reaches, so the impact of the duration of dewatering and inundation HSI curves on periphyton WUA is not as great. However, variability in periphyton WUA may be attributed to even subtle differences in velocity and substrate conditions throughout the Upper Reservoir Reach.

The WUA for all hydrologic years was lowest during spring and early summer when high flows from spring runoff increased water depth, turbidity, and absolute velocity of water moving over potential areas where periphyton could be established. Periphyton WUA estimates during the dry hydrologic year were relatively stable throughout the spring given the absence of the high flows before and after this runoff period. Disturbance of substrate materials, including movement of existing substrate and sedimentation of localized habitat, are important factors that can influence the rate and success for colonization of periphyton communities. The Upper Reservoir Reach resembled natural riverine conditions compared with other reaches in the reservoir; having lower water surface elevation fluctuations and hydrologic conditions that resembled pre-Project conditions.

Although dry hydrologic year conditions were stable throughout the spring, water surface elevation fluctuations frequently were below 1,990 feet NAVD 88 (1,986 feet NGVD 29) as compared to wet and average years during the early winter season. Once flows stabilized and were higher (above 1,990 feet NAVD 88 [(1,986 feet NGVD 29]) into February, WUA estimates for periphyton were higher and more stable than estimates for wet and average hydrologic years (Figure 5.7-6). The period of stable water surface elevation, i.e., reduced dewatering of optimal habitat, promoted higher periphyton WUA estimates.

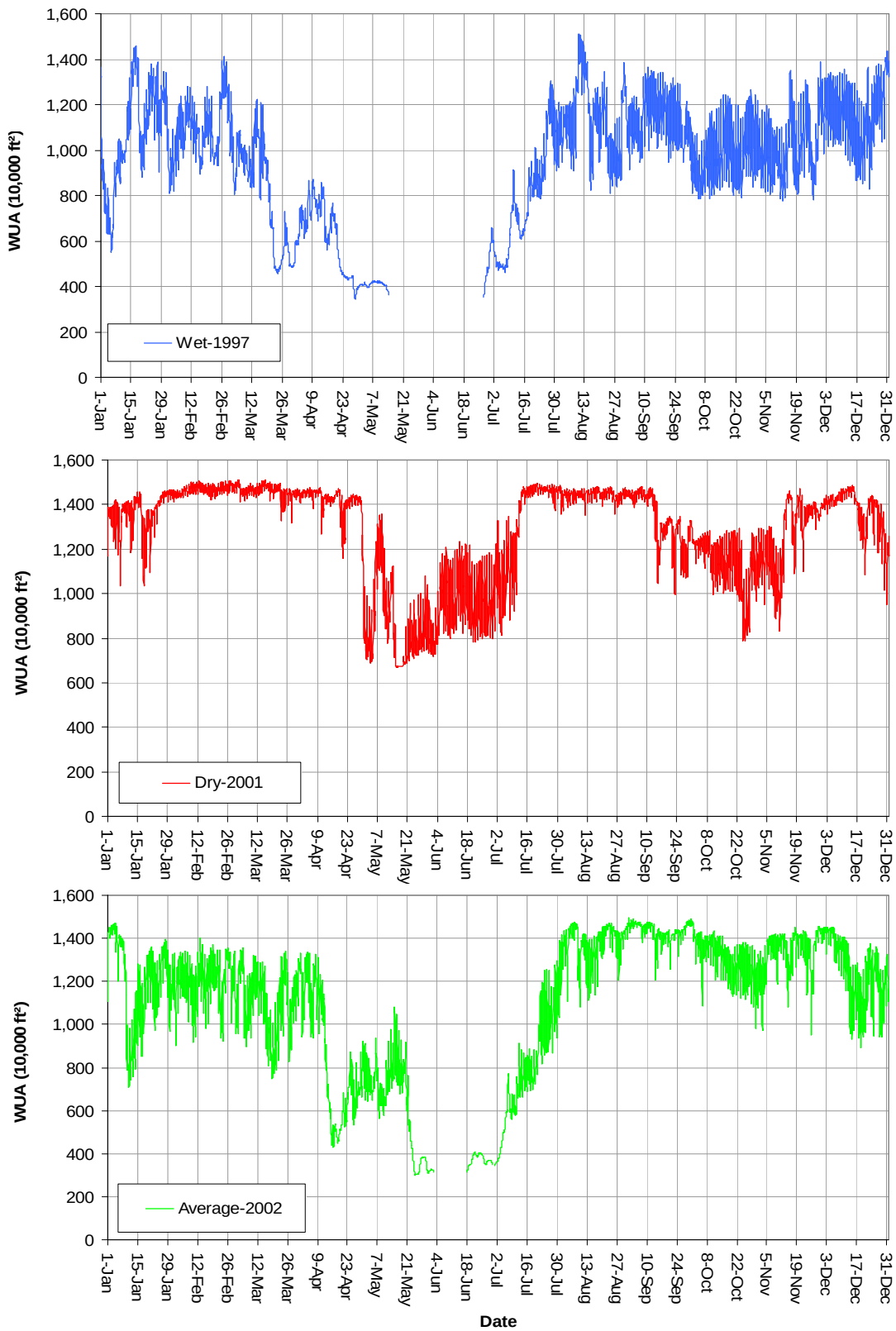



**Figure 5.7-6.** Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.7-4.** Summary of monthly periphyton WUA (x 10,000 sq. ft.) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 1,066 | 1,460 | 553 | 219.5 | 1,367 | 1,468 | 1,034 | 85.6 | 1,196 | 1,469 | 709 | 198.3 |
| February | 1,081 | 1,411 | 810 | 127.1 | 1,468 | 1,507 | 1,421 | 17.7 | 1,202 | 1,401 | 901 | 110.9 |
| March | 814 | 1,287 | 458 | 231.7 | 1,463 | 1,512 | 1,320 | 27.5 | 1,102 | 1,356 | 749 | 151.1 |
| April | 611 | 870 | 346 | 144.3 | 1,408 | 1,476 | 776 | 99.0 | 831 | 1,334 | 431 | 283.1 |
| May | 409 | 426 | 360 | 11.7 | 856 | 1,357 | 670 | 171.3 | 617 | 1,080 | 301 | 196.9 |
| June | 478 | 622 | 351 | 74.7 | 950 | 1,232 | 720 | 124.6 | 369 | 407 | 315 | 25.5 |
| July | 776 | 1,305 | 460 | 221.5 | 1,336 | 1,496 | 813 | 188.2 | 794 | 1,392 | 346 | 248.9 |
| August | 1,136 | 1,509 | 808 | 166.1 | 1,444 | 1,482 | 1,353 | 22.3 | 1,378 | 1,473 | 1,081 | 84.5 |
| September | 1,142 | 1,363 | 914 | 101.8 | 1,330 | 1,480 | 994 | 119.4 | 1,433 | 1,495 | 1,205 | 44.1 |
| October | 971 | 1,266 | 784 | 114.8 | 1,134 | 1,292 | 788 | 115.1 | 1,305 | 1,478 | 980 | 95.6 |
| November | 1,011 | 1,389 | 775 | 137.6 | 1,268 | 1,472 | 833 | 144.8 | 1,338 | 1,455 | 950 | 95.9 |
| December | 1,162 | 1,435 | 826 | 134.6 | 1,373 | 1,487 | 949 | 100.4 | 1,251 | 1,452 | 892 | 145.8 |

Two-week averages and summary statistics were reported for periphyton WUA estimates and corresponding water surface elevations for three representative months and the hydrologic conditions in the Upper Reservoir Reach (Table 5.7-5). The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter timeframe (i.e., two weeks) was to determine how periphyton WUA estimates in the Upper Reservoir were responding to Project operations. These comparisons within a shorter timeframe were used to determine the influence of individual model variables on the WUA estimates in each season and hydrologic year.

**Table 5.7-5.** Summary of periphyton WUA in Boundary Reservoir and water surface elevations at Metaline Bridge for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| **Periphyton WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 764 | 1,079 | 670 | 87.7 | 525 | 1,080 | 301 | 215.7 |
| July | 925 | 1,305 | 623 | 173.5 | 1,465 | 1,496 | 1,358 | 20.9 | 964 | 1,392 | 685 | 178.1 |
| September | 1,138 | 1,343 | 944 | 100.0 | 1,245 | 1,347 | 994 | 86.6 | 1,423 | 1,493 | 1,257 | 37.0 |
| **Water Surface Elevation (feet NAVD 88) at Metaline Bridge** | | | | | | | | | | | | |
| May | 2012.6 | 2014.8 | 2007.1 | 2.4 | 1991.3 | 1995.1 | 1989.5 | 1.4 | 1999.0 | 2004.9 | 1990.3 | 4.8 |
| July | 1993.9 | 1997.7 | 1989.8 | 1.9 | 1991.4 | 1994.4 | 1986.3 | 1.6 | 1992.6 | 1996.7 | 1988.1 | 2.1 |
| September | 1991.9 | 1995.1 | 1987.9 | 1.7 | 1987.6 | 1994.0 | 1981.6 | 3.3 | 1992.0 | 1994.4 | 1987.8 | 1.5 |

Note:
1 Periphyton WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

Periphyton WUA estimates during the last two weeks of May directly responded to water surface elevation fluctuations in the dry and average hydrologic years (Figure 5.7-7). The highest WUA estimates for periphyton during this season occurred when water surface elevation was at 1,995 feet NAVD 88 (1,991 feet NGVD 29). Sustained water surface elevations above 1,997 feet NAVD 88 (1,993 feet NGVD 29) resulted in the lowest WUA estimates for useable periphyton habitat, as was observed for macrophyte WUA estimates (Figure 5.7-7).

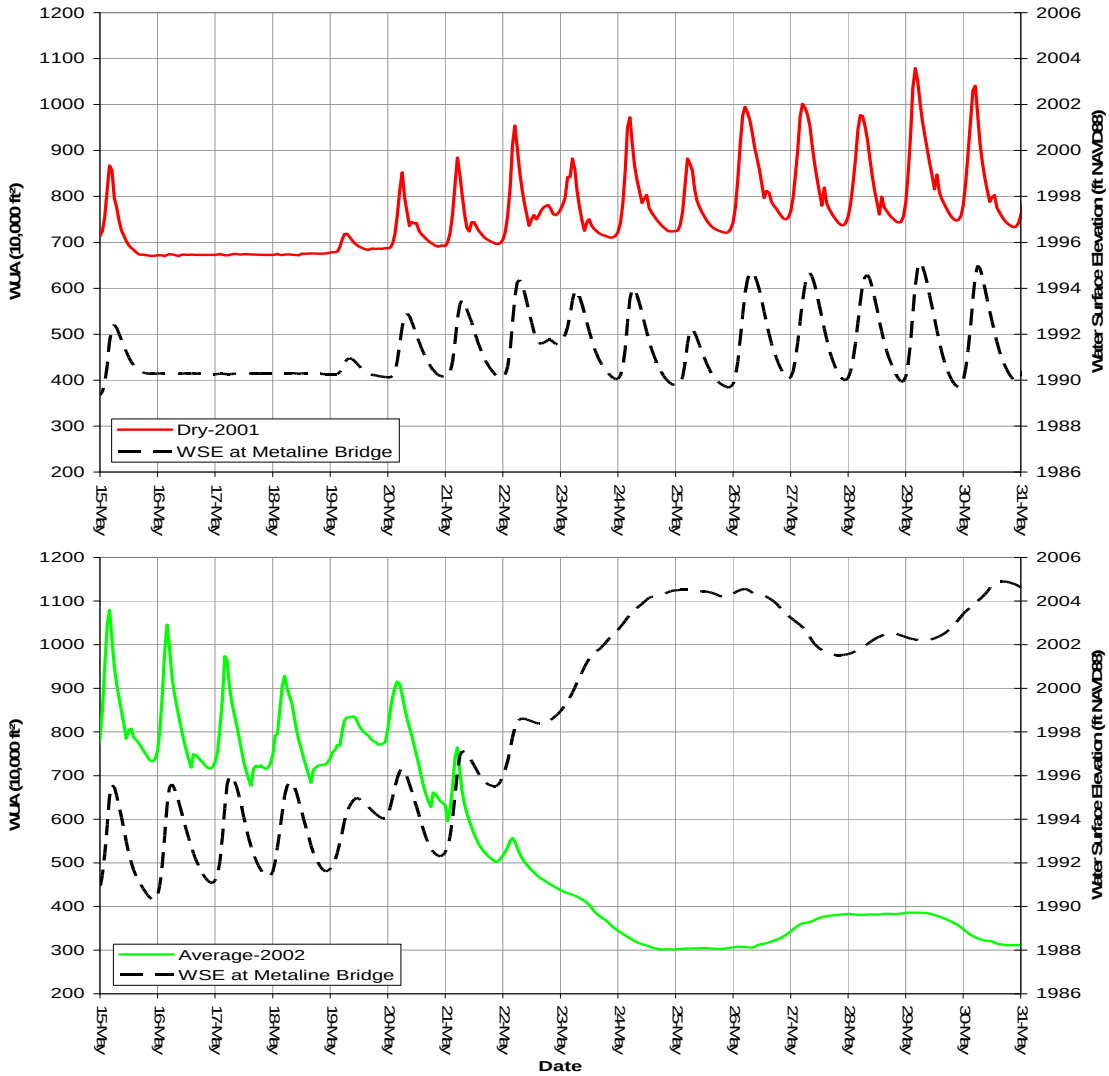



**Figure 5.7-7.** Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during May 15–31; WUA determined by the mainstem habitat model for dry and average years.

Note: Periphyton WUA for the wet year was held constant due to a bounding condition of 80,000 cfs; therefore no graph is presented.

Water surface elevations during the last two weeks of July were mostly below 1,995 feet NAVD 88 (1,991 feet NGVD 29) and resulted in high WUA estimates for periphyton during all three

hydrologic years (e.g., wet, dry, and average). Water surface elevations with maximums above 1,992 feet NAVD 88 (1,988 feet NGVD 29) during the dry year in the Upper Reservoir Reach had the highest WUA estimates in the last two weeks of July (Figure 5.7-8). When water surface elevations fell below 1,992 feet NAVD 88 (1,988 NGVD 29), periphyton WUA estimates began to decline. Similar to the response of macrophytes with water surface elevations continuously greater than 1,997 feet NAVD 88 (1,993 feet NGVD 29), wet year periphyton WUA estimates were lowest throughout the beginning of this two-week interval.

Periphyton WUA estimates for the Upper Reservoir reach in the last two weeks of September directly responded to water surface elevation fluctuation (Figure 5.7-9). Water surface elevations (wet and average hydrologic years) were consistently between 1,989 and 1,995 feet NAVD 88 (1,985 and 1,990 feet NGVD 29) during this two-week interval with periphyton habitat suitability responding directly to these changes. The lowest potential WUA estimates for periphyton occurred during all three years in which water surface elevations were at or below 1,990 feet NAVD 88 (1,986 feet NGVD 29). Ramping rates of less than 4 inches change per hour and low flows contributed to increased available habitat for periphyton during this time of year so fluctuations would not limit useable area other than dewatering of shoreline margins.

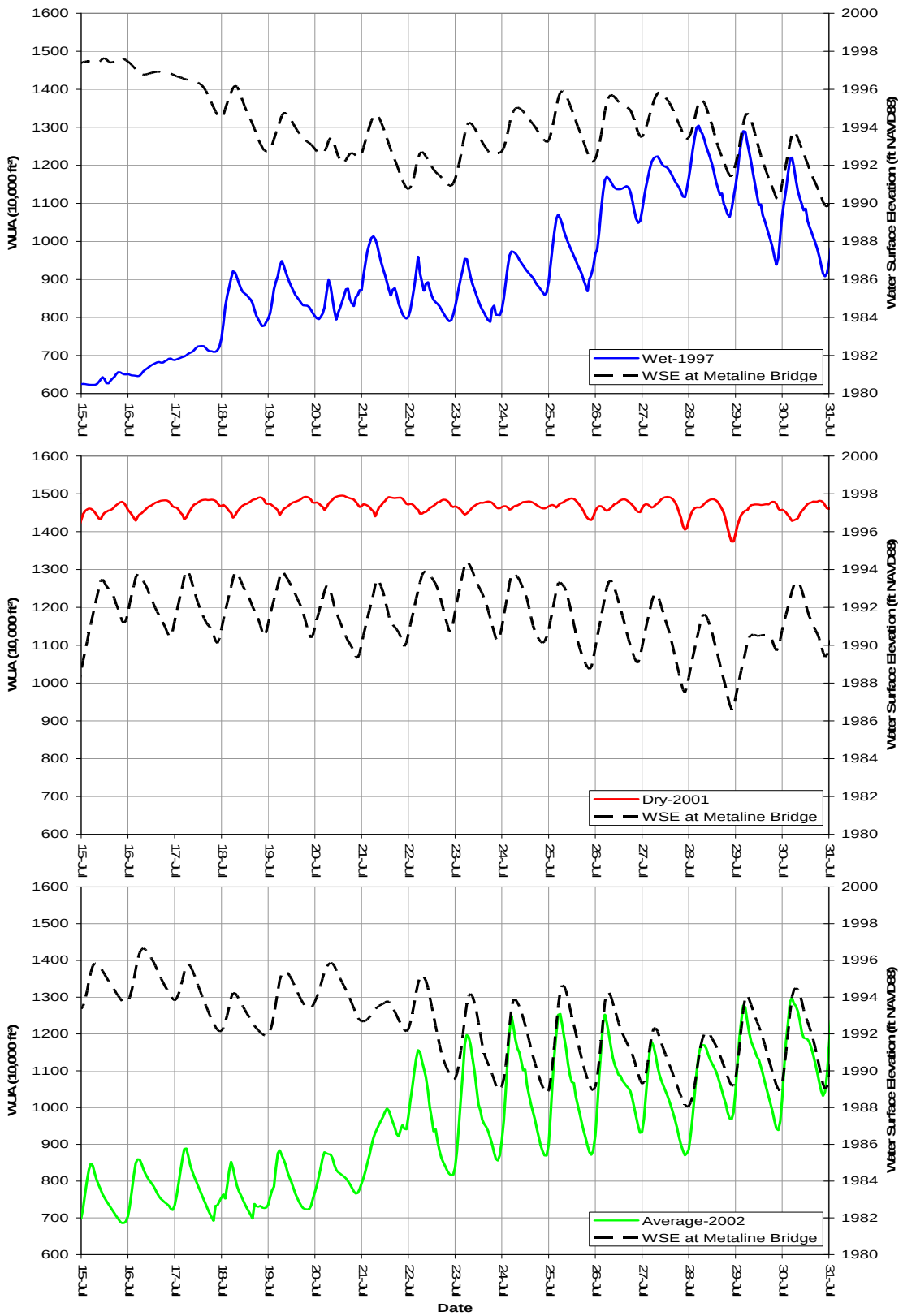



**Figure 5.7-8.** Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during July 15–31 for wet, dry, and average years.

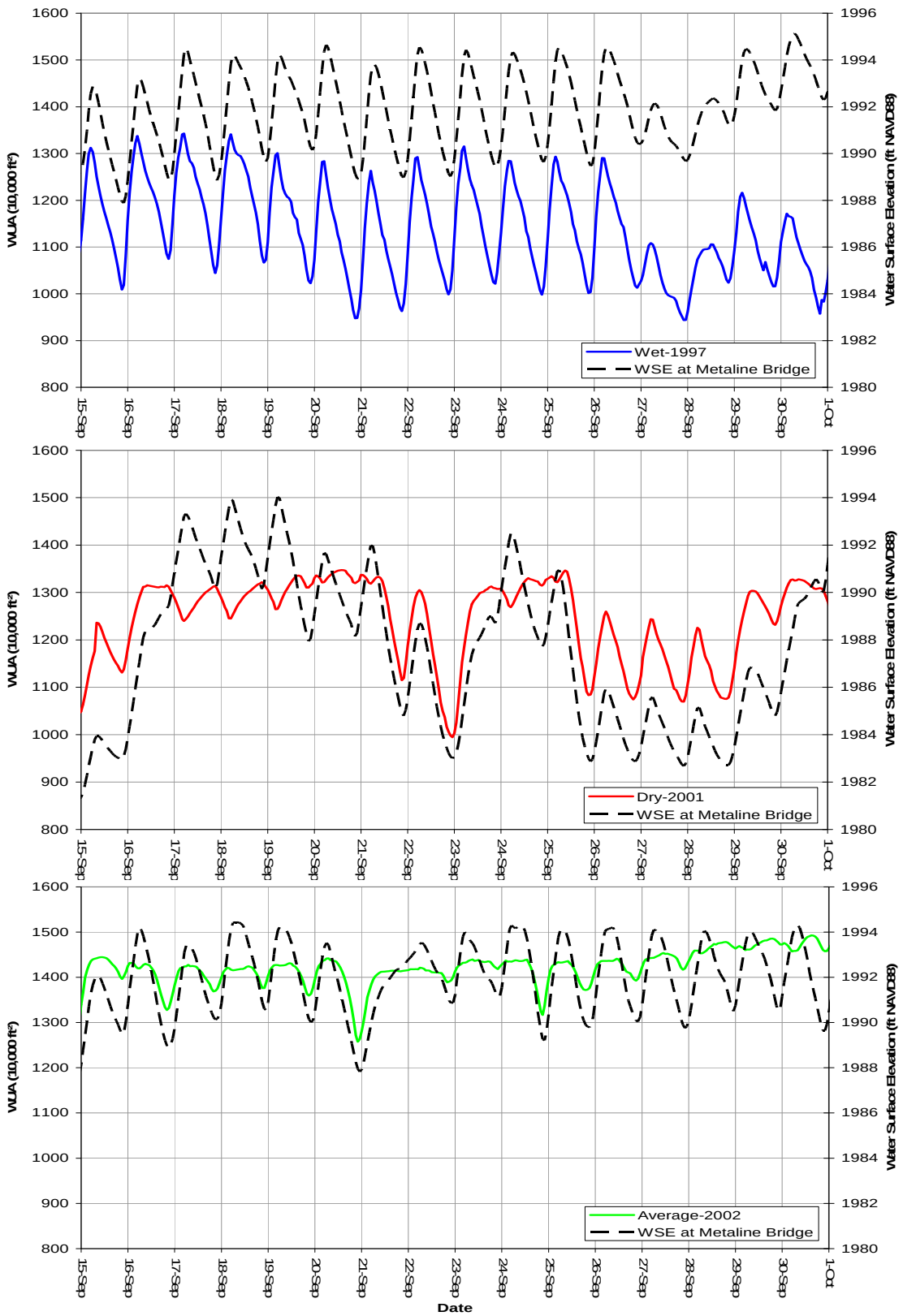



**Figure 5.7-9**. Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during September 15–31 for wet, dry, and average years.

### 5.7.4. Tailrace Reach

The Mainstem Aquatic Habitat Model results for periphyton WUA in the Tailrace Reach are shown in Figure 5.7-10 and summarized by season in Table 5.7-6. Overall, estimated periphyton WUA in the Tailrace Reach was substantially lower than the WUA determined for the Upper Reservoir Reach, similar to that determined for the Canyon Reach, and higher than that determined for the Forebay Reach. The maximum relative periphyton WUA in the Tailrace Reach (at any time) was determined by the model to be 410 (x 10,000 square feet), occurring in January of a dry hydrologic year (Table 5.7-6). The lowest relative periphyton WUA at any given time over the model simulation was determined to be 84 (x 10,000 square feet) and occurred in May of an average hydrologic year. On average, estimated periphyton WUA in the Tailrace Reach decreased in the spring during all hydrologic years, particularly during the dry year. There was also less variability through the year in estimated periphyton WUA in the Tailrace Reach as compared to the Upper Reservoir Reach (Figure 5.7-10) but more variability through the year compared to the Canyon and Forebay reaches. Most of the variation in periphyton WUA in the Tailrace Reach is due to extreme pool fluctuations and depth, similar to periphyton WUA in the Forebay and Canyon reaches. Velocity, however, is less stable in the Tailrace Reach than in the Forebay or Canyon reaches and therefore may influence the variation in periphyton WUA. Substrate in the Tailrace Reach, however, is fairly uniform throughout the reach and therefore does not contribute to the variation in periphyton WUA as seen in the Upper Reservoir Reach. Daily fluctuations in potential WUA for periphyton and the variance of these observations are not statistically different between months among wet, dry, or average hydrologic years.

Estimates for WUA in the Tailrace Reach were similar to the magnitude of WUA that could be colonized in the Canyon Reach, but represent more variation in the hourly time-steps, reminiscent of conditions in the Forebay Reach. A combination of factors identified from both the Canyon and Forebay reaches resulted in these WUA patterns. The higher variability between time-steps indicated that water surface elevation fluctuation was a primary factor that suppressed WUA estimates, as in results seen for the Forebay Reach. On average, the monthly estimated periphyton WUA decreased in the spring during all hydrologic years. However, the factor that may have diminished seasonal fluctuations in the Tailrace Reach was regularity in water elevations during spring runoff, created by high flows during this period in average and wet hydrologic years.

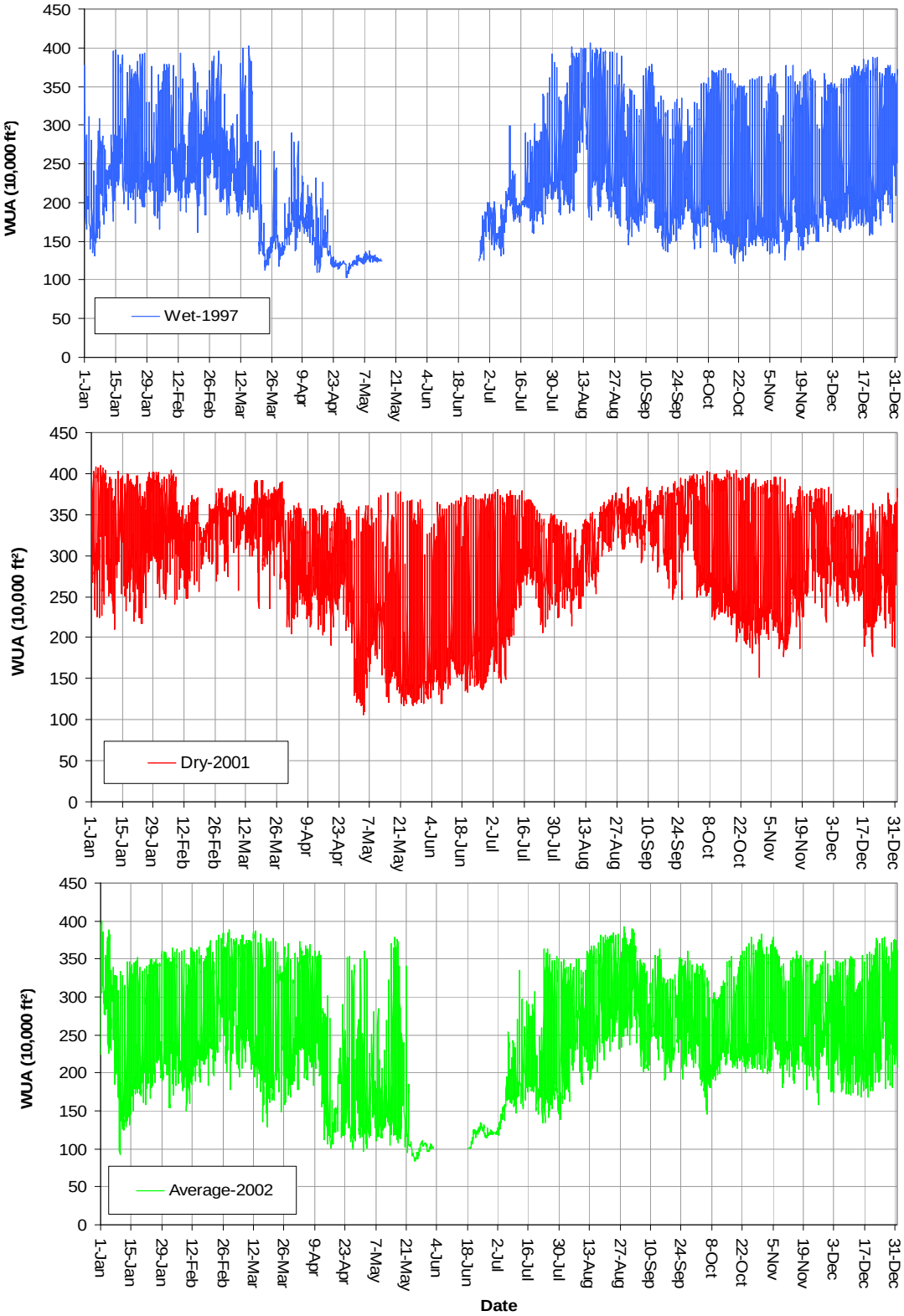



**Figure 5.7-10.** Habitat WUA for periphyton in the Tailrace Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.7-6.** Summary of monthly periphyton WUA (x 10,000 sq. ft.) in the Tailrace Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 249 | 397 | 132 | 60.3 | 327 | 410 | 210 | 52.5 | 250 | 400 | 92 | 73.1 |
| February | 269 | 393 | 162 | 51.7 | 335 | 404 | 241 | 32.4 | 266 | 389 | 150 | 64.3 |
| March | 213 | 402 | 113 | 66.7 | 335 | 392 | 213 | 32.8 | 263 | 387 | 129 | 70.8 |
| April | 156 | 289 | 104 | 36.0 | 286 | 367 | 129 | 49.6 | 207 | 372 | 100 | 76.4 |
| May | 126 | 138 | 117 | 3.4 | 214 | 377 | 105 | 83.4 | 151 | 378 | 84 | 67.3 |
| June | 155 | 189 | 125 | 21.4 | 224 | 375 | 120 | 84.3 | 117 | 134 | 99 | 9.4 |
| July | 207 | 392 | 131 | 45.2 | 285 | 381 | 144 | 60.7 | 197 | 362 | 118 | 57.7 |
| August | 277 | 406 | 169 | 69.8 | 312 | 381 | 214 | 37.4 | 283 | 392 | 162 | 57.5 |
| September | 229 | 379 | 136 | 62.5 | 341 | 399 | 246 | 33.8 | 277 | 390 | 191 | 47.2 |
| October | 225 | 374 | 121 | 79.1 | 288 | 404 | 151 | 66.1 | 258 | 382 | 146 | 53.9 |
| November | 225 | 378 | 126 | 74.0 | 290 | 396 | 177 | 63.1 | 265 | 378 | 159 | 54.3 |
| December | 253 | 388 | 157 | 73.7 | 288 | 381 | 177 | 46.0 | 265 | 379 | 168 | 60.3 |

## 5.8. BMI Habitat Development and Modeling Efforts

This section presents the results of the BMI habitat modeling effort in the mainstem of the Pend Oreille River including Boundary Reservoir and its tailrace. Results are presented by each of the four reaches (Forebay, Canyon, Upper Reservoir, and Tailrace) within the study area. The modeling effort establishes a baseline condition for identification of Project effects and for comparing operation scenarios. Operational scenarios will be evaluated in subsequent relicensing efforts. The final BMI HSI curves were used in the Mainstem Aquatic Habitat Model to estimate the WUA available for BMI in Boundary Reservoir. The following subsections provide a summary of the model results and discussion for BMI WUA by reach and for each model simulation. More detailed discussion of BMI production is provided in the Study 11 Final Report (SCL 2009c).

Modeling of WUA for BMI habitat potential was completed for historic Project operations during wet (1997), dry (2001), and average (2002) years. These years were selected as representative of wet, dry, and average conditions using factors like average annual flows (R2 Resource Consultants 2008). For reference, the flow hydrographs for the wet, dry, and average years are presented in Figures 5.0-1 through 5.0-3, respectively, and a comparison of the flow hydrographs across these three years are shown in Figure 5.0-4. WUA results presented in the following sections did not consider flows exceeding 80,000 cfs. Once flows exceeded this volume, the calculated WUA for a given species was not considered in the determination of the WUA. The plotted results do not show WUA values for flows in excess of 80,000 cfs. Likewise, the WUA values for flows in excess of 80,000 cfs were not included in the tabulated numerical results. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs, ensured the incorporation of all flows potentially influenced

by Project operations. When flows exceed 55,000 cfs, pool level fluctuations are typically dominated by inflow hydrology not Project operations as shown by the HRM.

Hourly time-step data describing WUA estimates were summarized with monthly summary statistics and with two-week summary statistics. These two-week summary statistics were reported for select reaches and more closely analyzed for Project operations effects on BMI in the Forebay and Upper Reservoir reaches.

### 5.8.1. Forebay Reach

The Mainstem Aquatic Habitat Model results for BMI WUA in the Forebay Reach are shown in Figure 5.8-1 and summarized by month in Table 5.8-1. Data absent during the wet and average years in Figure 5.8-1 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated BMI WUA was the lowest in the Forebay Reach compared to other reaches within Boundary Reservoir and much less variable throughout the year. The maximum relative BMI WUA in the Forebay Reach (at any time) was determined by the model to be 154 (x 10,000 square feet) and occurred during May of a wet hydrologic year (Table 5.8-1). The lowest relative BMI WUA at any given time over the model simulation was determined to be 75 (x 10,000 square feet) and occurred during May of a dry hydrologic year. On average, relative BMI WUA in the Forebay Reach was very similar throughout the seasons in wet and average hydrologic years with decreases observed during summer of a dry hydrologic year (Table 5.8-1).

The daily variation in BMI WUA seen in Figure 5.8-1 and summarized as standard deviations in Table 5.8-1 is due to the hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Other HSI parameters for BMI (velocity and substrate) have very little to no variability on an hourly timescale. Daily variation in BMI WUA in the Forebay Reach is not due to variability in velocity and substrate because these two environmental factors are relatively uniform throughout the reach. The daily pool fluctuations are expressed in the WUA as variations in the plotted data, but these are within the definable variation range and not significant on a monthly average when comparing wet, dry, or average hydrologic years.

There was some seasonal variation in WUA estimates for BMI in the Forebay Reach. This reach experienced the highest water surface elevation fluctuations among those within the Boundary Reservoir. Disturbance may have resulted in suboptimal habitable locations due to frequent dewatering. The variation in the hourly time-step WUA estimates was fairly small, but reflected the lower amount of relative habitat available for BMI colonization.

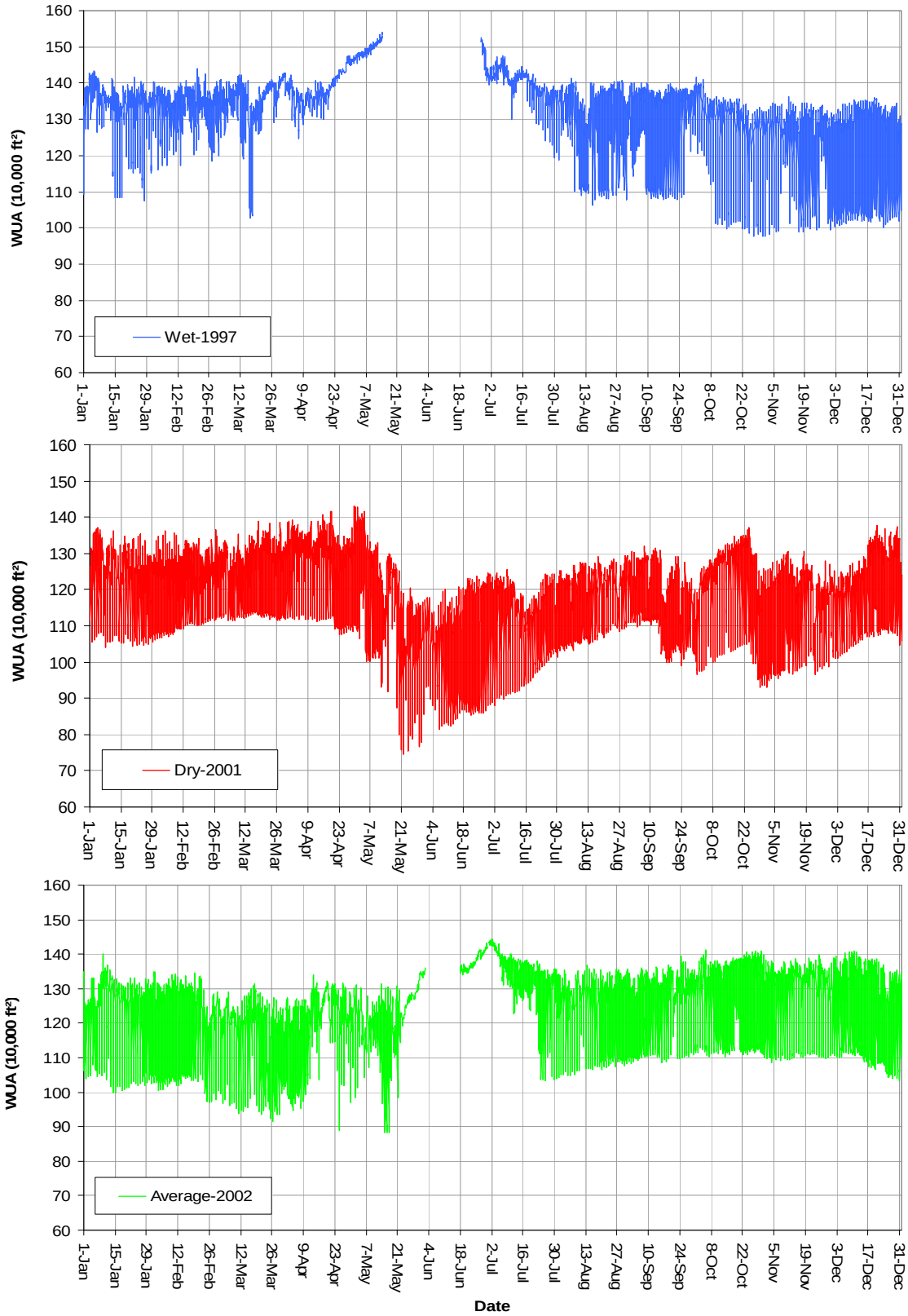



**Figure 5.8-1.** Habitat WUA for BMI in the Forebay Reach of Boundary Reservoir, determined by the Mainstem Aquatic Habitat Model, for wet, dry, and average years.

**Table 5.8-1.** Summary of monthly BMI WUA (x 10,000 sq. ft.) in the Forebay Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 133 | 143 | 107 | 7.2 | 121 | 137 | 104 | 9.9 | 122 | 140 | 100 | 10.7 |
| February | 133 | 144 | 116 | 5.3 | 121 | 137 | 107 | 8.0 | 121 | 135 | 97 | 10.9 |
| March | 135 | 143 | 103 | 5.9 | 124 | 139 | 111 | 8.2 | 116 | 131 | 91 | 10.6 |
| April | 138 | 147 | 125 | 4.4 | 126 | 143 | 108 | 9.5 | 120 | 134 | 89 | 8.8 |
| May | 149 | 154 | 146 | 1.9 | 114 | 143 | 75 | 14.6 | 122 | 135 | 88 | 8.0 |
| June | 146 | 153 | 141 | 4.0 | 108 | 125 | 81 | 11.4 | 138 | 144 | 133 | 2.5 |
| July | 139 | 147 | 119 | 4.9 | 111 | 125 | 88 | 10.0 | 133 | 144 | 103 | 8.1 |
| August | 131 | 141 | 106 | 8.9 | 118 | 129 | 103 | 7.9 | 124 | 137 | 104 | 9.8 |
| September | 131 | 140 | 108 | 9.0 | 117 | 132 | 99 | 8.7 | 126 | 139 | 108 | 9.0 |
| October | 126 | 142 | 98 | 11.1 | 121 | 137 | 93 | 10.9 | 130 | 141 | 110 | 9.9 |
| November | 124 | 136 | 98 | 10.1 | 116 | 131 | 93 | 10.2 | 128 | 140 | 109 | 9.7 |
| December | 123 | 136 | 100 | 11.2 | 121 | 138 | 101 | 9.6 | 126 | 141 | 103 | 10.6 |

Two-week averages and related statistics were reported for BMI WUA estimates and corresponding water surface elevations for three representative months and the hydrologic conditions in the Forebay Reach (Table 5.8-2). The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter timeframe (i.e., two weeks) was to determine how BMI WUA estimates in the Forebay Reach were responding to Project operations. These comparisons within a shorter timeframe were used to determine the influence of individual model variables on the WUA estimates in each season and hydrologic year.

**Table 5.8-2.** Summary of BMI WUA and water surface elevations at Boundary Dam for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| **BMI WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 107.7 | 130.0 | 74.6 | 13.1 | 123.3 | 134.9 | 88.3 | 8.5 |
| July | 136.7 | 144.4 | 119.3 | 5.0 | 111.3 | 125.3 | 93.4 | 9.0 | 129.6 | 138.4 | 103.3 | 8.8 |
| September | 130.8 | 139.8 | 107.7 | 9.4 | 114.1 | 129.1 | 98.8 | 8.6 | 126.3 | 139.5 | 108.7 | 8.9 |
| **Water Surface Elevation (feet NAVD 88) at Boundary Dam** | | | | | | | | | | | | |
| May | 1988.6 | 1992.9 | 1984.4 | 1.8 | 1981.8 | 1993.5 | 1963.2 | 7.3 | 1989.5 | 1994.2 | 1976.5 | 3.6 |
| July | 1990.0 | 1994.3 | 1983.3 | 2.2 | 1990.9 | 1994.1 | 1985.3 | 1.8 | 1988.8 | 1993.6 | 1982.1 | 2.8 |
| September | 1989.8 | 1993.8 | 1984.2 | 2.3 | 1986.6 | 1993.8 | 1977.1 | 3.9 | 1991.3 | 1994.0 | 1986.2 | 1.7 |

Note:
1 BMI WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

BMI WUA peak estimates in the Forebay Reach lagged behind peaks in water surface elevation fluctuations for both dry and average hydrologic years during May (Figure 5.8-2). Response time to water surface elevation fluctuations responded within one-half day of any maximum or minimum water surface elevation. The lowest water surface elevations between 1,964 and 1,977 feet NAVD 88 (1,960 and 1,973 feet NGVD 29) did not reduce the WUA estimates during the dry hydrologic year. However, some response was observed during the average year. Water surface elevations that were sustained above 1,990 feet NAVD 88 (1,986 feet NGVD 29) stabilized the BMI WUA estimates during the average hydrologic year at the highest level within this two-week period (Figure 5.8-2).

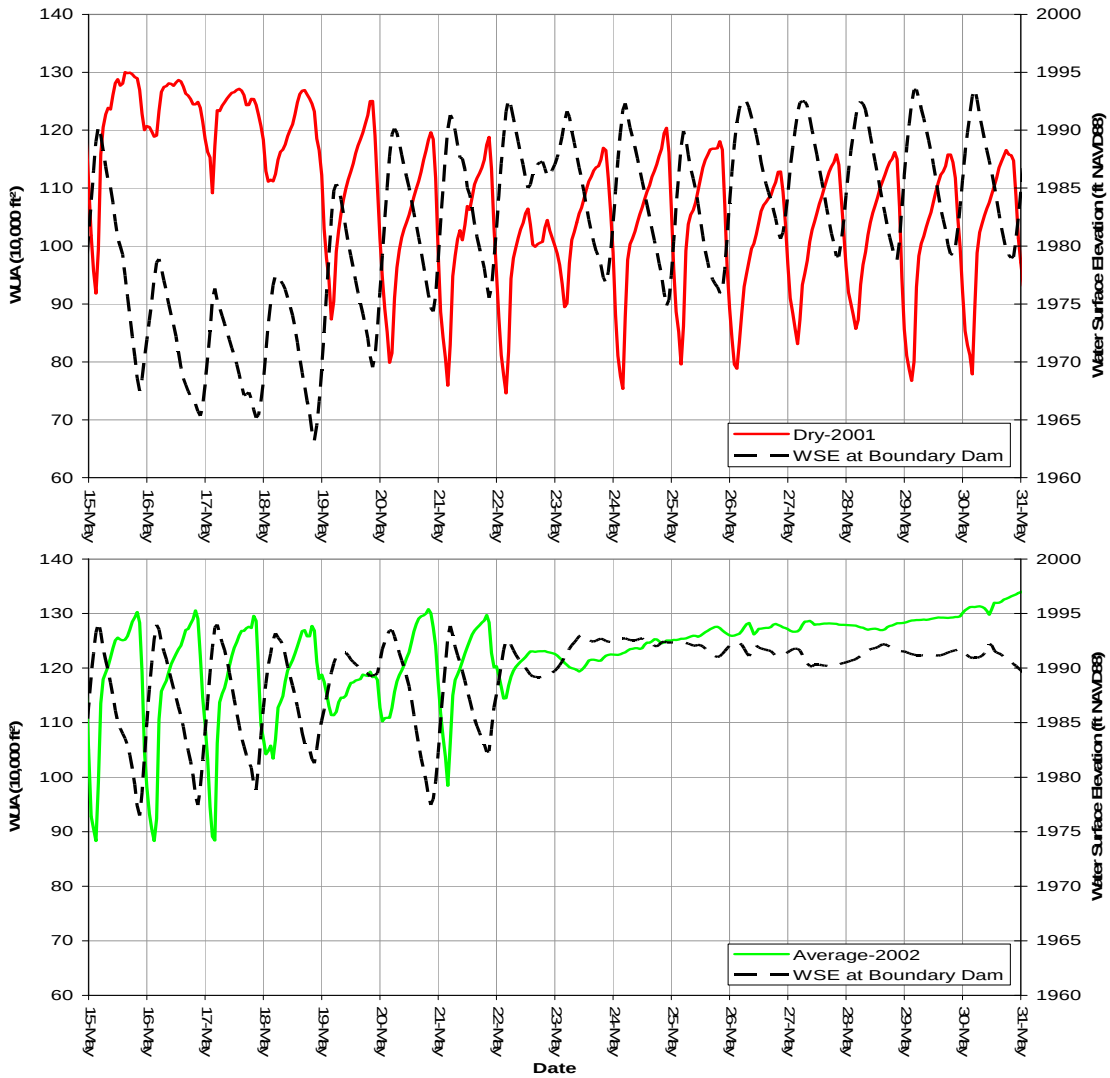



**Figure 5.8-2.** Habitat WUA for BMI in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during May 1531; WUA determined by the mainstem habitat model for dry and average years.

Note: BMI WUA for the wet year was held constant due to a bounding condition of 80,000 cfs; therefore, no graph is presented).

BMI WUA estimates during the two-week period at the end of July responded directly with water surface elevation fluctuations, but lagged in response by one-quarter to one-half of a day (Figure 5.8-3). Water surface elevations fluctuations below 1,985 feet NAVD 88 (1,981 feet NGVD 29) during the average year resulted in more frequent minimum WUA estimates within a two-day period (Figure 5.8-3). Although more stable and sustained potential WUA estimates were calculated when water surface elevation was at or above 1,990 feet NAVD 88 (1,986 feet NGVD 29) during wet and average years, lower WUA estimates were predicted during the dry hydrologic year at the same water surface elevations. The BMI peak potential WUA during this two-week interval shows that response is not immediate when water surface elevation begins to decline, but has a sustained peak potential for at least one-half day.

BMI WUA estimates varied directly with water surface elevation fluctuations during the last two weeks of September (Figure 5.8-4). There was a lag in response time by BMI to minimum or maximum water surface elevations of less than one-half of a day in the wet, dry, and average hydrologic years. The highest WUA estimates for BMI occurred during maximum water surface elevations (over 1,990 feet NAVD 88 [1,986 feet NGVD 29]) during the wet year in September indicating that dewatering of habitat in the Forebay Reach did not have an appreciable effect on WUA during this portion of the year.

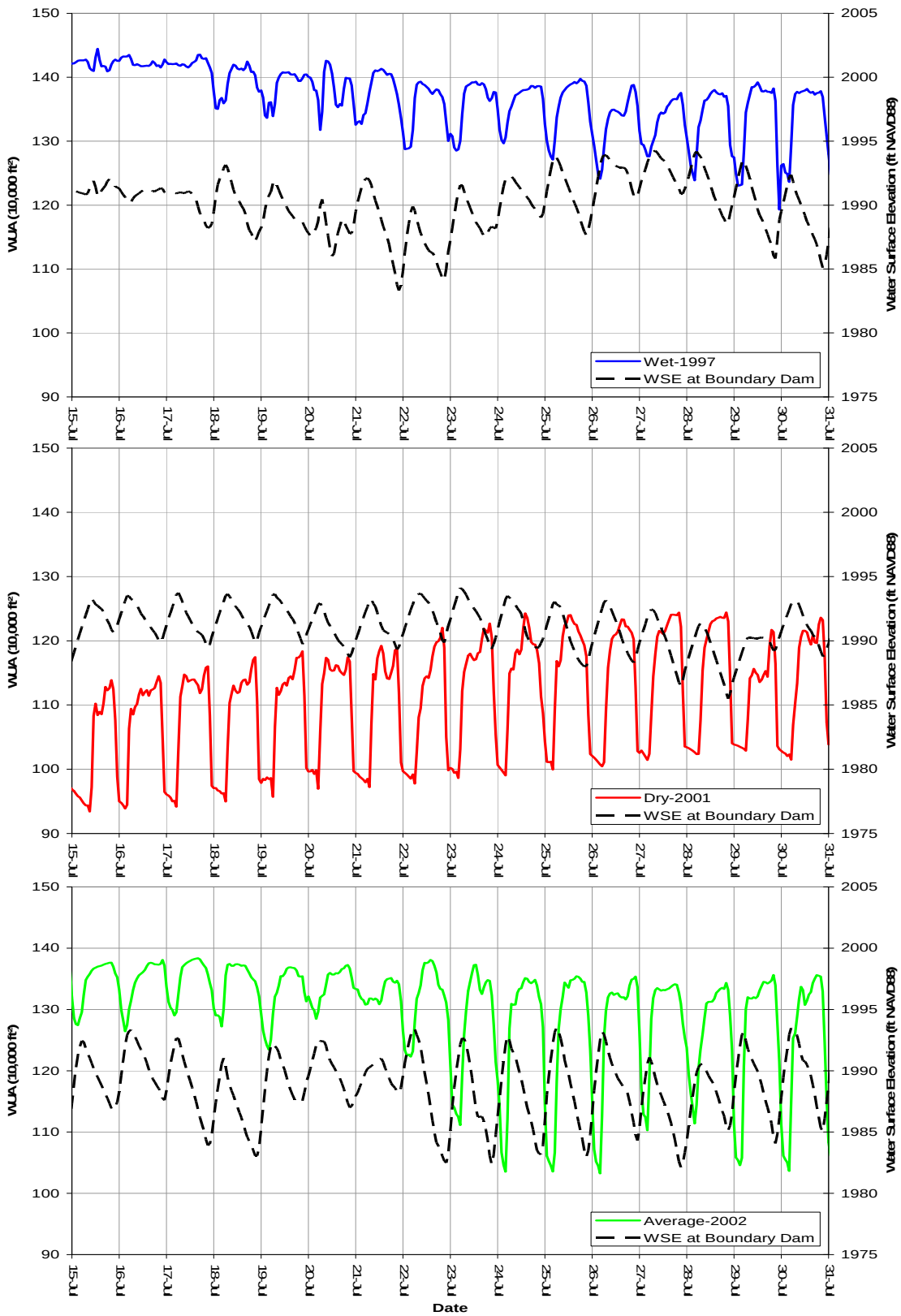



**Figure 5.8-3.** Habitat WUA for BMI in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during July 15th to 31st for wet, dry, and average years.

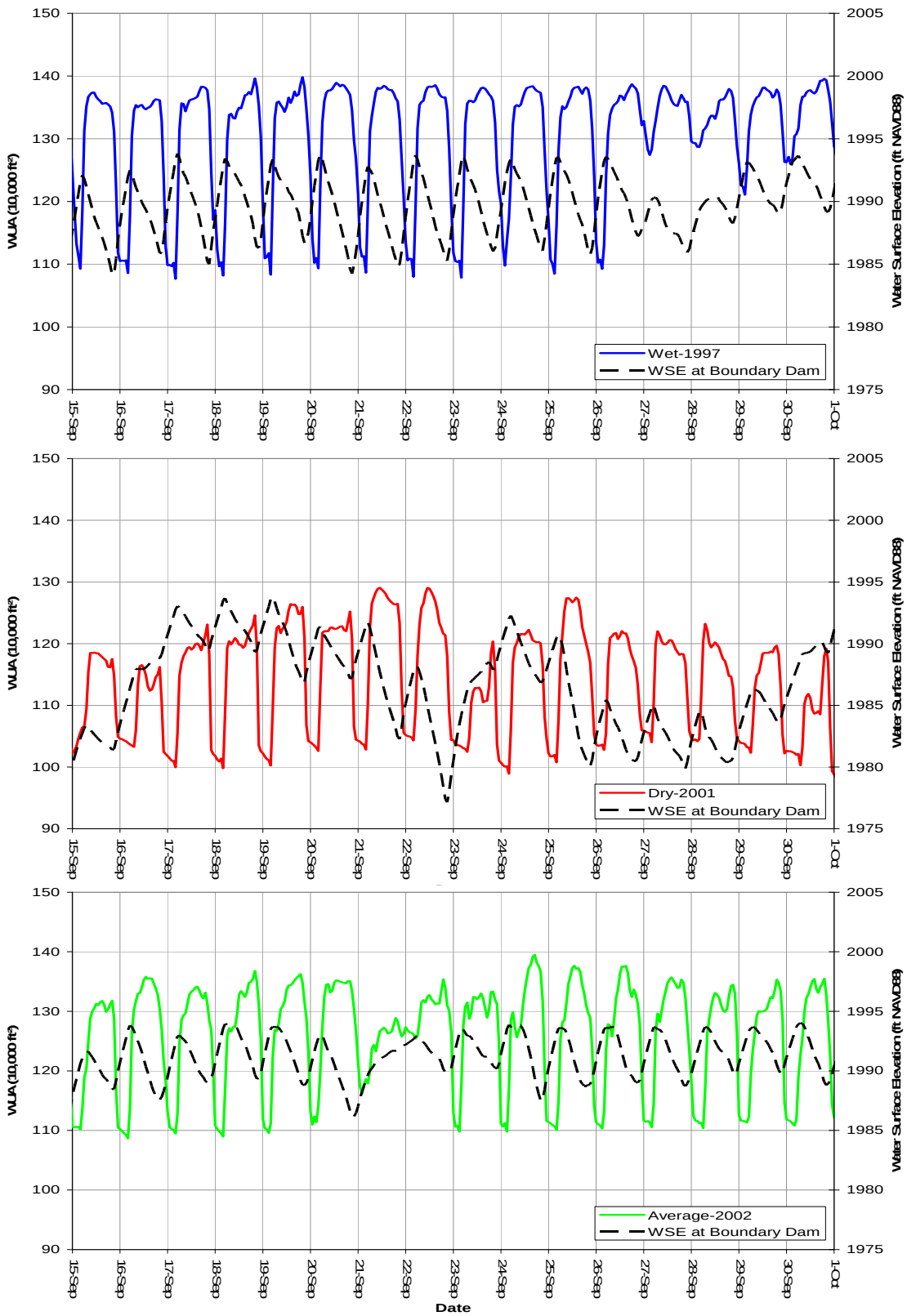



**Figure 5.8-4.** Habitat WUA for BMI in the Forebay Reach of Boundary Reservoir compared to water surface elevations at Boundary Dam during September 15–31 for wet, dry, and average years.

### 5.8.2. Canyon Reach

The Mainstem Aquatic Habitat Model results for BMI WUA in the Canyon Reach are shown in Figure 5.8-5 and summarized by month in Table 5.8-3. Data absent during the wet and average years in Figure 5.8-5 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, the potential BMI WUA in the Canyon Reach was higher than in the Forebay Reach but lower than in the Upper Reservoir Reach. The maximum potential BMI WUA in the Canyon Reach (at any time) was determined by the model to be 573 (x 10,000 square feet) and occurred during May of a dry hydrologic year (Table 5.8-3). The lowest potential BMI WUA at any given time was determined to be 291 (x 10,000 square feet) and also occurred during May of a dry hydologic year. There was also less variability throughout the year in potential BMI WUA in the Canyon Reach than in the Upper Reservoir Reach (Figure 5.8-5). On average, potential BMI WUA in the Canyon Reach was very similar throughout the seasons and over all three model simulations. Exceptions to this were the slightly higher average potential BMI WUA determined during the wet hydrologic year (Table 5.8-3).

Most of the daily variation in BMI WUA seen in Figure 5.8-5 and summarized as standard deviations in Table 5.8-3 is due to the hourly pool fluctuations influenced by Project operations. These pool fluctuations are represented in the Mainstem Aquatic Habitat Model by the depth, duration of dewatering, and duration of inundation HSI curves. Other HSI parameters for BMI (velocity and substrate) have very little to no variability on an hourly timescale. The Canyon Reach is considered a high pool fluctuation zone, which would explain some of the daily variation in BMI WUA. Daily variation in BMI WUA in the Canyon Reach is not due to variability in velocity and substrate because these two environmental factors are relatively uniform throughout the reach. The daily pool fluctuations are expressed on the WUA as variations in the plotted data, but these are within the definable variation range and not significant on a monthly average when comparing wet, dry, or average hydrologic years.

The Canyon Reach had the second highest WUA estimates among all reaches in and below (Tailrace Reach) Boundary Reservoir. Unlike estimations for periphyton WUA, depth did not appear to have as great an influence on suitability for colonization of BMI. WUA estimates for BMI in this reach were higher during all hydrologic years than those for periphyton, even though both of these biological groups were collected from the same locations and from the same substrates. Photoperiod does not influence BMI colonization as it does periphyton communities, except insofar as photoperiods increase periphyton that BMI can use as a food base. The low variability for WUA between each time-step was similar to that found in other reaches. WUA during the wet hydrologic year was very stable indicating that more water may result in more habitable area by BMI even though water surface elevation fluctuations were greater in this reach than in the Upper Reservoir Reach. These higher water surface elevation fluctuations in the Canyon Reach provided enough disturbances to BMI communities to depress overall WUA estimates and produce lower average scores than in the Upper Reservoir Reach.

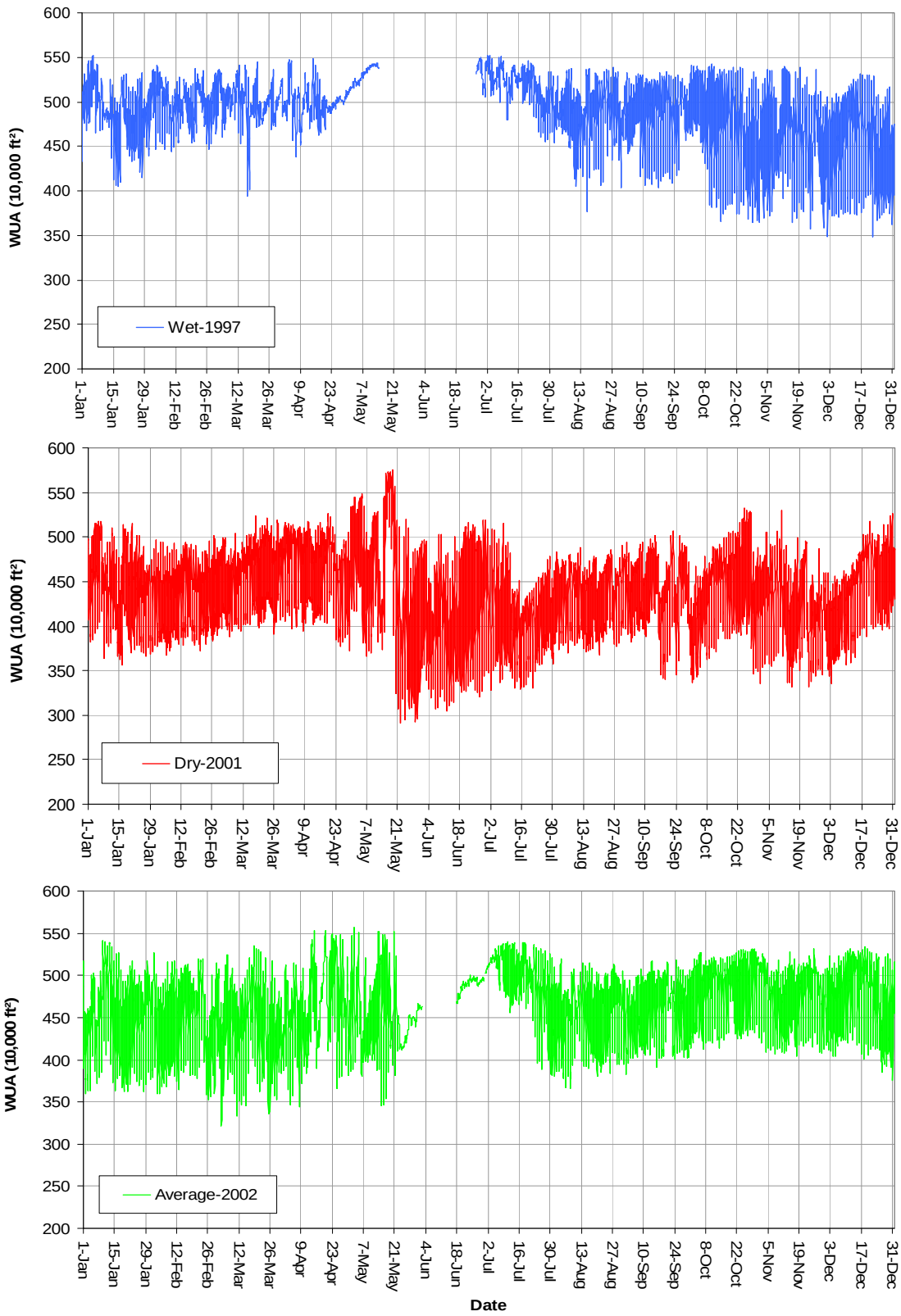



**Figure 5.8-5.** Habitat WUA for BMI in the Canyon Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.8-3.** Summary of monthly BMI WUA (x 10,000 sq. ft.) in the Canyon Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 493 | 552 | 404 | 26.1 | 447 | 518 | 356 | 38.9 | 456 | 541 | 359 | 42.6 |
| February | 498 | 541 | 444 | 20.6 | 441 | 501 | 368 | 33.5 | 454 | 527 | 352 | 40.5 |
| March | 501 | 545 | 394 | 20.6 | 463 | 524 | 388 | 34.3 | 446 | 535 | 322 | 44.8 |
| April | 499 | 549 | 438 | 17.8 | 470 | 535 | 372 | 36.1 | 465 | 554 | 344 | 45.0 |
| May | 530 | 543 | 512 | 9.5 | 455 | 575 | 291 | 69.1 | 452 | 556 | 345 | 40.7 |
| June | 534 | 549 | 508 | 12.1 | 419 | 519 | 305 | 53.1 | 487 | 503 | 459 | 11.1 |
| July | 519 | 552 | 456 | 19.9 | 415 | 516 | 328 | 41.3 | 500 | 539 | 382 | 29.9 |
| August | 490 | 539 | 377 | 29.7 | 437 | 490 | 368 | 32.2 | 458 | 520 | 365 | 35.0 |
| September | 491 | 533 | 404 | 28.9 | 444 | 506 | 340 | 36.4 | 467 | 518 | 382 | 31.8 |
| October | 481 | 542 | 365 | 43.8 | 447 | 532 | 336 | 42.5 | 489 | 531 | 413 | 30.9 |
| November | 464 | 540 | 357 | 40.3 | 428 | 530 | 331 | 40.3 | 478 | 531 | 405 | 31.3 |
| December | 457 | 532 | 348 | 41.0 | 448 | 526 | 335 | 40.0 | 477 | 534 | 376 | 35.0 |

### 5.8.3. Upper Reservoir Reach

The Mainstem Aquatic Habitat Model results for BMI WUA in the Upper Reservoir Reach are shown in Figure 5.8-6 and summarized by month in Table 5.8-4. Data absent during the wet and average years in Figure 5.8-6 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, estimated BMI WUA was substantially higher in the Upper Reservoir Reach compared to other reaches within Boundary Reservoir. The maximum relative BMI WUA in the Upper Reservoir Reach determined by the model was 2,681 (x 10,000 square feet) and occurred during July of a wet hydrologic year (Table 5.8-4). The lowest relative BMI WUA was determined to be 1,462 (x 10,000 square feet) and occurred in September of a dry hydrologic year. Throughout the year the relative BMI WUA was extremely stable (Figure 5.8-6), especially between August and December during wet and average years (Figure 5.8-6). On average, the highest relative BMI WUA was available during the wet and average hydroglogic years. However, the daily pool fluctuations as expressed on the WUA as variations in the plotted data, but these are within the definable variation range and not significant on a monthly average when comparing wet, dry, or average hydrologic years.

Estimates for WUA for BMI were relatively similar over the period of one year with little or no identifiable seasonal variation, even though there was significant daily variation in BMI WUA. BMI communities are generally classified into two seasonal types: winter and summer, depending on the time of year when early instar larvae appear. Preferences defined by the habitat suitability curves (depth, velocity, and substrate) remained the same for either community and were not influenced on a seasonal basis by the hydrologic year (wet, dry, and average) or within each of the hydrologic years (January through December). The lowest WUA estimates occurred during the dry hydrologic year for portions of September and October when water

surface elevations were generally lower. The relative WUA estimates for BMI reflected less available habitat under more stable water surface elevations and lower flow volumes during this time of the year. Variability of WUA estimates during the annual cycle for other hydrologic years reflects the sensitivity of BMI to water surface elevation fluctuation in the Upper Reservoir Reach. This portion of the reservoir had the lowest range of water surface elevation fluctuations and resembled pre-Project riverine conditions. This may explain, in part, the highest estimate for WUA among all reaches in and below the reservoir.

When comparing WUA estimates of BMI with periphyton, both had maximum WUA estimates during summer for the wet and average hydrologic years (Figure 5.8-6) in contrast with periphyton which had relatively stable WUA estimates before and after spring runoff during the hydrologic year (Figure 5.7-6). Interpretation of this contrast in response to water surface elevations that were below 1,990 feet NAVD 88 (1,986 feet NGVD 29) for extended periods of time preceding this interval indicates that inundation of habitat was short and that BMI WUA estimates would be diminished. Periphyton communities were able to colonize previously dewatered habitat more rapidly than BMI and that the BMI WUA estimates would increase once water surface elevations consistently remained above 1,990 feet NAVD 88 (1,986 feet NGVD 29). The longer inundation intervals (>25 days) were more influential in promoting identification of optimal habitat for BMI.

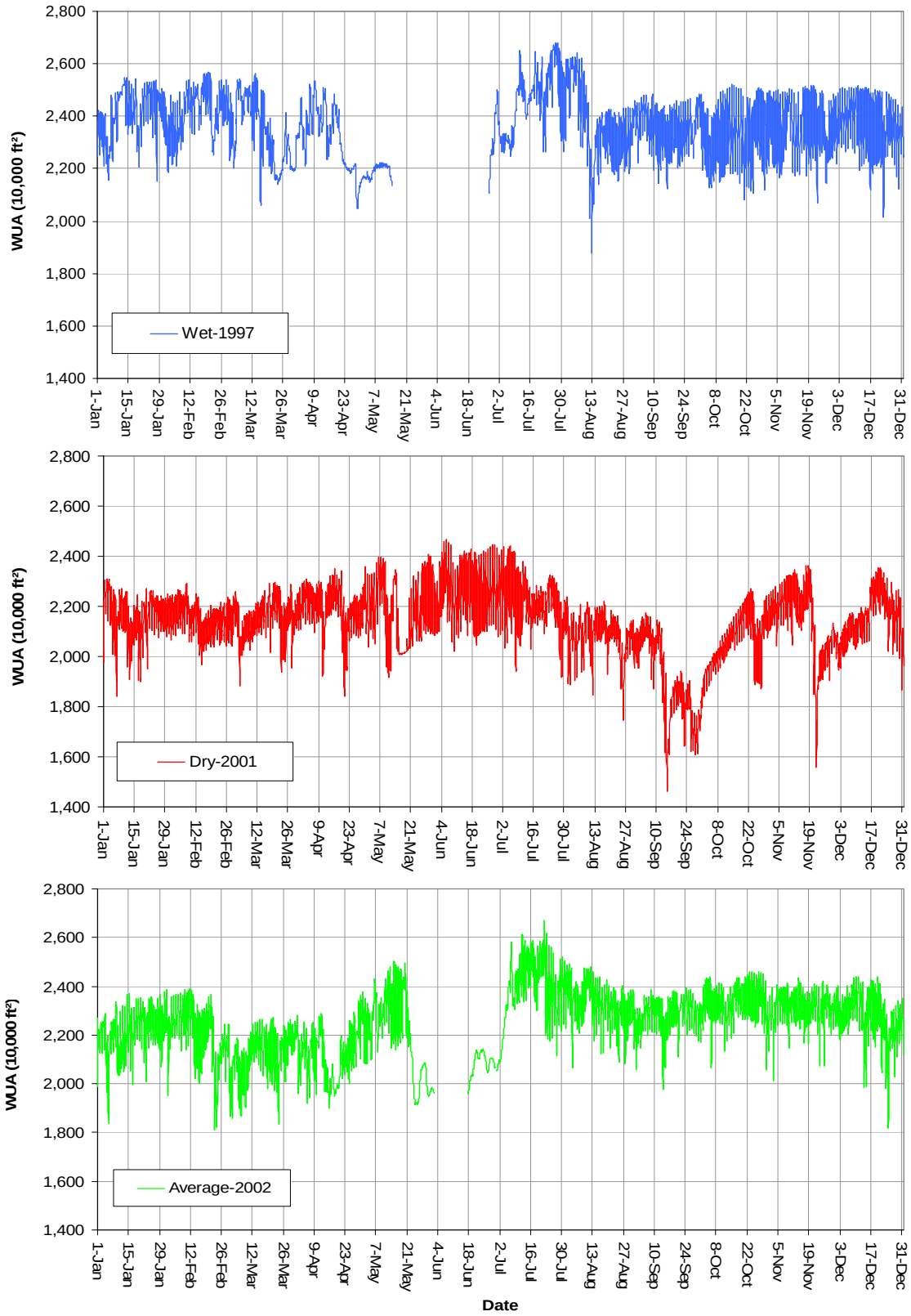



**Figure 5.8-6.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.8-4.** Summary of monthly BMI WUA (x 10,000 sq. ft.) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 2,407 | 2,548 | 2,153 | 90.0 | 2,160 | 2,309 | 1,841 | 84.4 | 2,213 | 2,376 | 1,838 | 90.4 |
| February | 2,414 | 2,569 | 2,186 | 85.8 | 2,150 | 2,290 | 1,967 | 57.1 | 2,208 | 2,389 | 1,810 | 114.7 |
| March | 2,333 | 2,562 | 2,059 | 121.4 | 2,157 | 2,296 | 1,881 | 70.5 | 2,113 | 2,271 | 1,833 | 98.0 |
| April | 2,318 | 2,535 | 2,047 | 116.3 | 2,195 | 2,357 | 1,840 | 86.8 | 2,111 | 2,362 | 1,899 | 103.0 |
| May | 2,190 | 2,222 | 2,133 | 23.1 | 2,168 | 2,408 | 1,917 | 123.2 | 2,203 | 2,503 | 1,914 | 158.8 |
| June | 2,292 | 2,460 | 2,107 | 97.8 | 2,255 | 2,465 | 2,022 | 109.6 | 2,077 | 2,141 | 1,960 | 50.9 |
| July | 2,457 | 2,681 | 2,246 | 116.0 | 2,221 | 2,442 | 1,912 | 93.2 | 2,389 | 2,669 | 2,057 | 136.0 |
| August | 2,365 | 2,643 | 1,879 | 145.7 | 2,083 | 2,222 | 1,747 | 78.8 | 2,329 | 2,490 | 2,064 | 83.1 |
| September | 2,359 | 2,485 | 2,122 | 76.3 | 1,898 | 2,174 | 1,462 | 168.3 | 2,281 | 2,393 | 1,977 | 67.5 |
| October | 2,322 | 2,520 | 2,082 | 110.1 | 2,065 | 2,270 | 1,795 | 101.2 | 2,332 | 2,459 | 2,056 | 73.6 |
| November | 2,359 | 2,519 | 2,069 | 100.6 | 2,142 | 2,363 | 1,557 | 143.3 | 2,311 | 2,434 | 2,015 | 65.8 |
| December | 2,370 | 2,517 | 2,014 | 95.9 | 2,155 | 2,356 | 1,868 | 94.1 | 2,274 | 2,440 | 1,817 | 101.4 |

Two-week averages and summary statistics were reported for BMI WUA estimates and corresponding water surface elevations for three representative months and the hydrologic conditions in the Upper Reservoir Reach (Table 5.8-5). The purpose of describing WUA estimates and water surface elevation fluctuations on a shorter timeframe (i.e., two weeks) was to determine how BMI WUA estimates in the Upper Reservoir Reach were responding to Project operations. These comparisons within a shorter timeframe were used to determine the influence of individual model variables on the WUA estimates in each season and hydrologic year.

**Table 5.8-5.** Summary of BMI WUA and water surface elevations at Metaline Bridge for the last two weeks (15th through end of month) for May, July, and September.

| Last Two Weeks of | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. | Mean | Max. | Min. | Stdev. |
| **BMI WUA (x 10,000 sq. ft.)** | | | | | | | | | | | | |
| May | N/A[1] | N/A | N/A | N/A | 2,139 | 2,408 | 2,007 | 113.5 | 2,143 | 2,503 | 1,914 | 176.3 |
| July | 2,510 | 2,681 | 2,263 | 99.7 | 2,197 | 2,325 | 1,894 | 74.1 | 2,424 | 2,669 | 2,114 | 117.5 |
| September | 2,354 | 2,485 | 2,122 | 75.3 | 1,780 | 1,943 | 1,465 | 94.3 | 2,296 | 2,393 | 2,111 | 56.4 |
| **Water Surface Elevation (feet NAVD 88) at Metaline Bridge** | | | | | | | | | | | | |
| May | 2012.6 | 2014.8 | 2007.1 | 2.4 | 1991.3 | 1995.1 | 1989.5 | 1.4 | 1999.0 | 2004.9 | 1990.3 | 4.8 |
| July | 1993.9 | 1997.7 | 1989.8 | 1.9 | 1991.4 | 1994.4 | 1986.3 | 1.6 | 1992.6 | 1996.7 | 1988.1 | 2.1 |
| September | 1991.9 | 1995.1 | 1987.9 | 1.7 | 1987.6 | 1994.0 | 1981.6 | 3.3 | 1992.0 | 1994.4 | 1987.8 | 1.5 |

Note:
1 BMI WUA held constant due to a bounding condition of 80,000 cfs in the Mainstem Aquatic Habitat Model.

BMI WUA estimates in the Upper Reservoir Reach during the last two weeks of May responded directly to water surface elevation fluctuations, but with a short lag time following the peak of a rising hydrograph (Figure 5.8-7). Water surface elevation fluctuations within the two-week interval in May during the dry hydrologic year ranged between 1,990 and 1,995 feet NAVD 88 (1,986 and 1,991 feet NGVD 29). During the average hydrolocig year, water surface elevations sustained at a level higher than 2,000 feet NAVD 88 (1,996 feet NGVD 29) in the Upper Reservoir Reach resulted in lower WUA estimates. Greater depth and higher mean channel velocity diminished usability of optimal habitat for BMI when water surface elevation was sustained at a higher level than 2,000 feet NAVD 88 (1,996 feet NGVD 29) in the Upper Reservoir Reach during May.

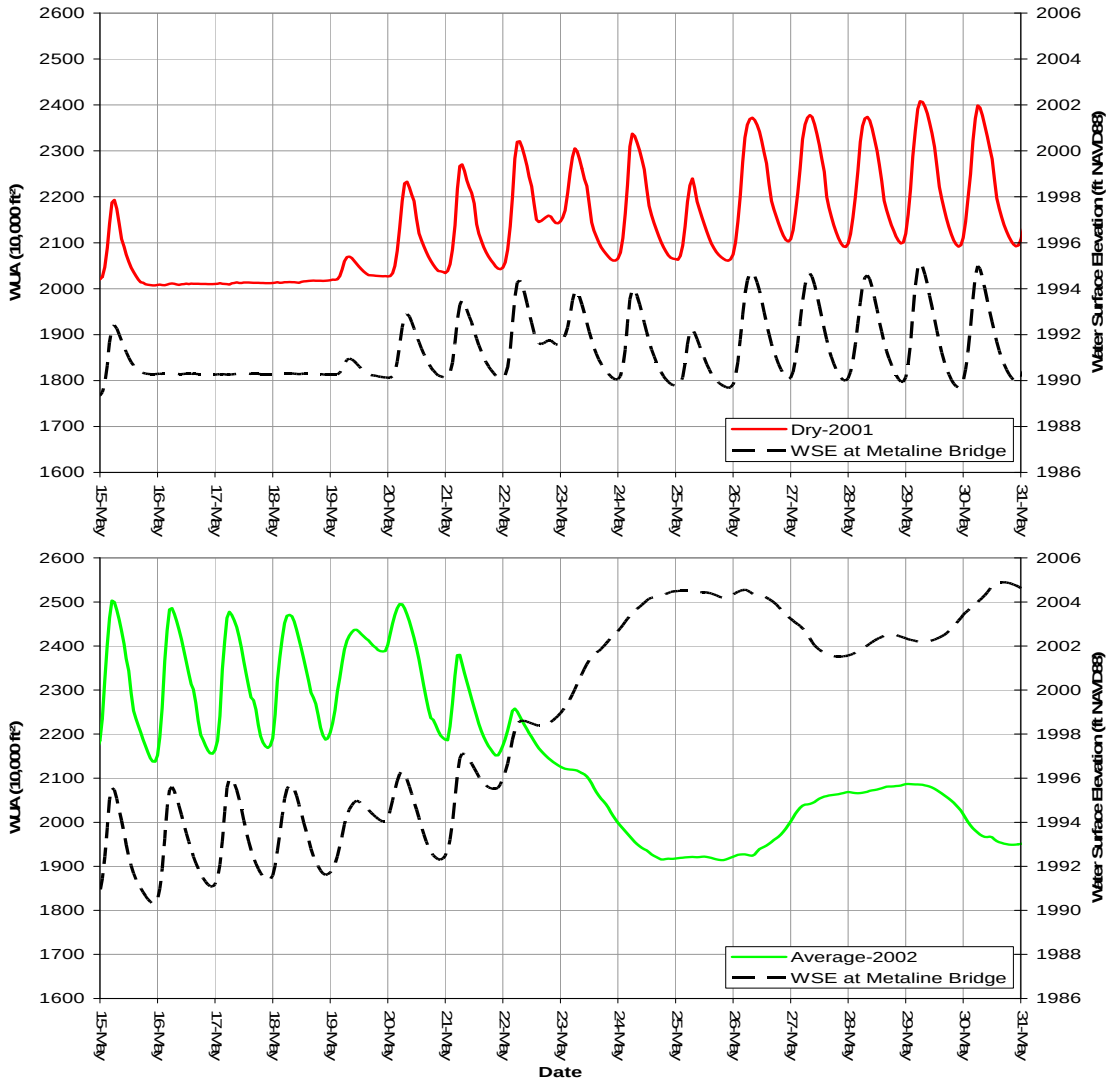



**Figure 5.8-7.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during May 15–31; WUA determined by the mainstem habitat model for dry and average years.

Note: BMI WUA for the wet year was held constant due to a bounding condition of 80,000 cfs; therefore no graph is presented.

BMI WUA estimates for the last two weeks in July had a response lag that was slightly behind the change in water surface elevation (Figure 5.8-8). The highest WUA estimates occurred during the last two weeks during the wet hydrologic year even though water surface elevation fluctuation was in the same range (e.g., between 1,990 and 1,995 feet NAVD 88 [1,986 and 1,991 feet NGVD 29]) as the dry and average hydrologic years. The difference between minimum and maximum water surface elevations was greatest during the average year and lowest during the dry year. By extension, BMI WUA estimate fluctuations in July during the dry year were smaller and less pronounced compared to the wet and average years. Factors limiting larger fluctuations in BMI WUA response were related to constant water surface elevation and lower ramping rates in the Upper Reservoir Reach.

BMI WUA estimates for the Upper Reservoir Reach during the last two weeks of September had a short lag time response (i.e., hours) to maximum water surface elevations (Figure 5.8-9). The highest WUA estimates for BMI occurred during the wet hydrologic year. Water surface elevations consistently between 1,990 and 1,995 feet NAVD 88 (1,986 and 1,991 feet NGVD 29) resulted in the highest WUA estimates for BMI in the Upper Reservoir Reach during September. The lowest WUA estimates coincided with the lowest water surface elevations during the dry year in the Upper Reservoir Reach. The larger pool fluctuations in this reach do not affect BMI WUA appreciably based on the large amount of habitat and relatively small losses compared to availability.

BMI biomass responds more slowly to changes in available habitat areas compared to periphyton due to frequent and short durations of de-watering. Periphyton colonize and reconstruct communities more quickly in new habitat and this explains the more immediate response of periphyton to pool fluctuation than occurs with BMI colonization. The consistent range in pool fluctuation in the Upper Reservoir Reach does not disrupt the relatively stable amount of WUA for BMI during all seasons. When contrasted with the Forebay Reach, the Upper Reservoir Reach does not experience the short-term disturbance from dewatering or the short-term inundation of critical habitat (i.e., two-week intervals) in the other reaches.

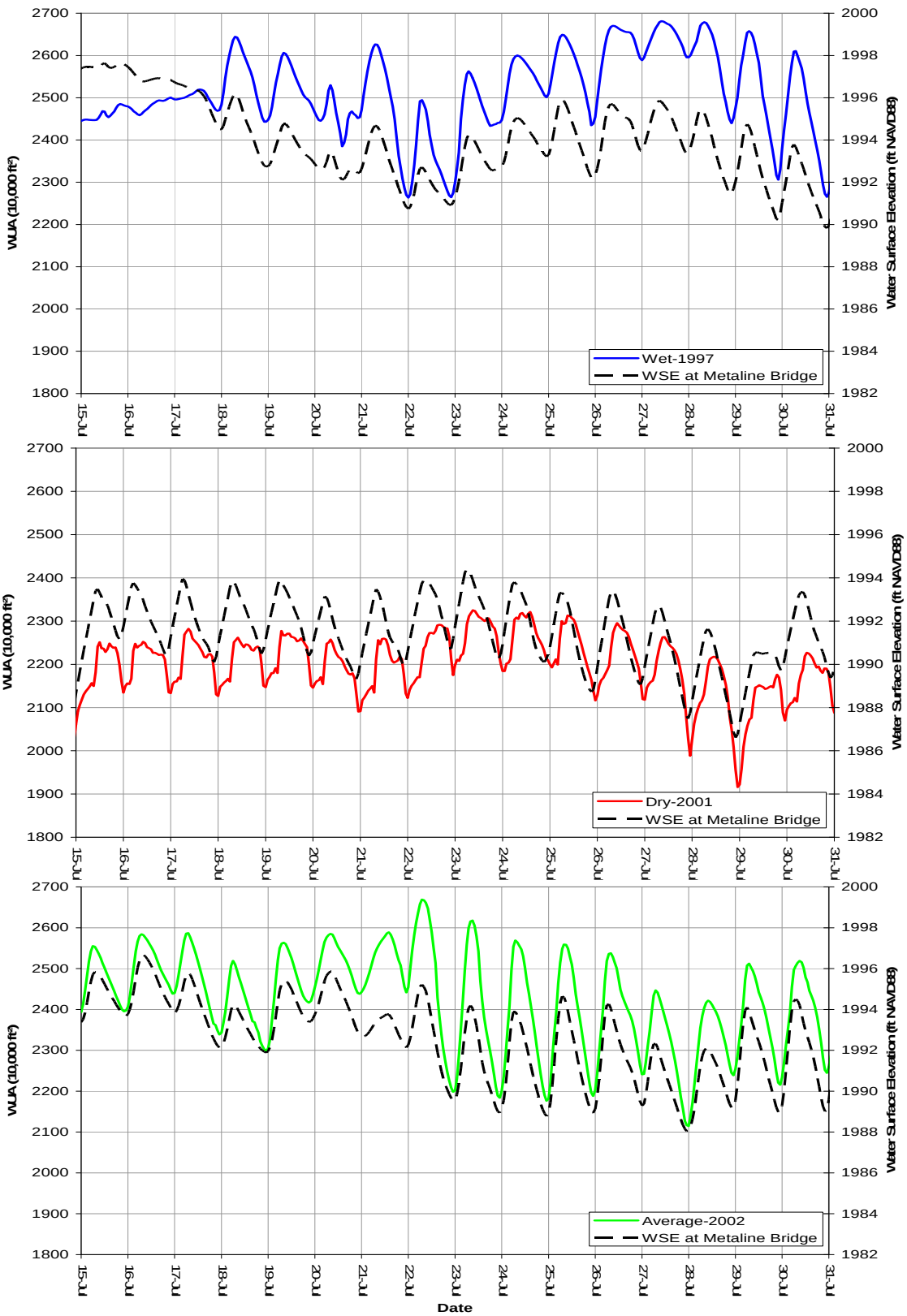



**Figure 5.8-8.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during July 15–31 for wet, dry, and average years.

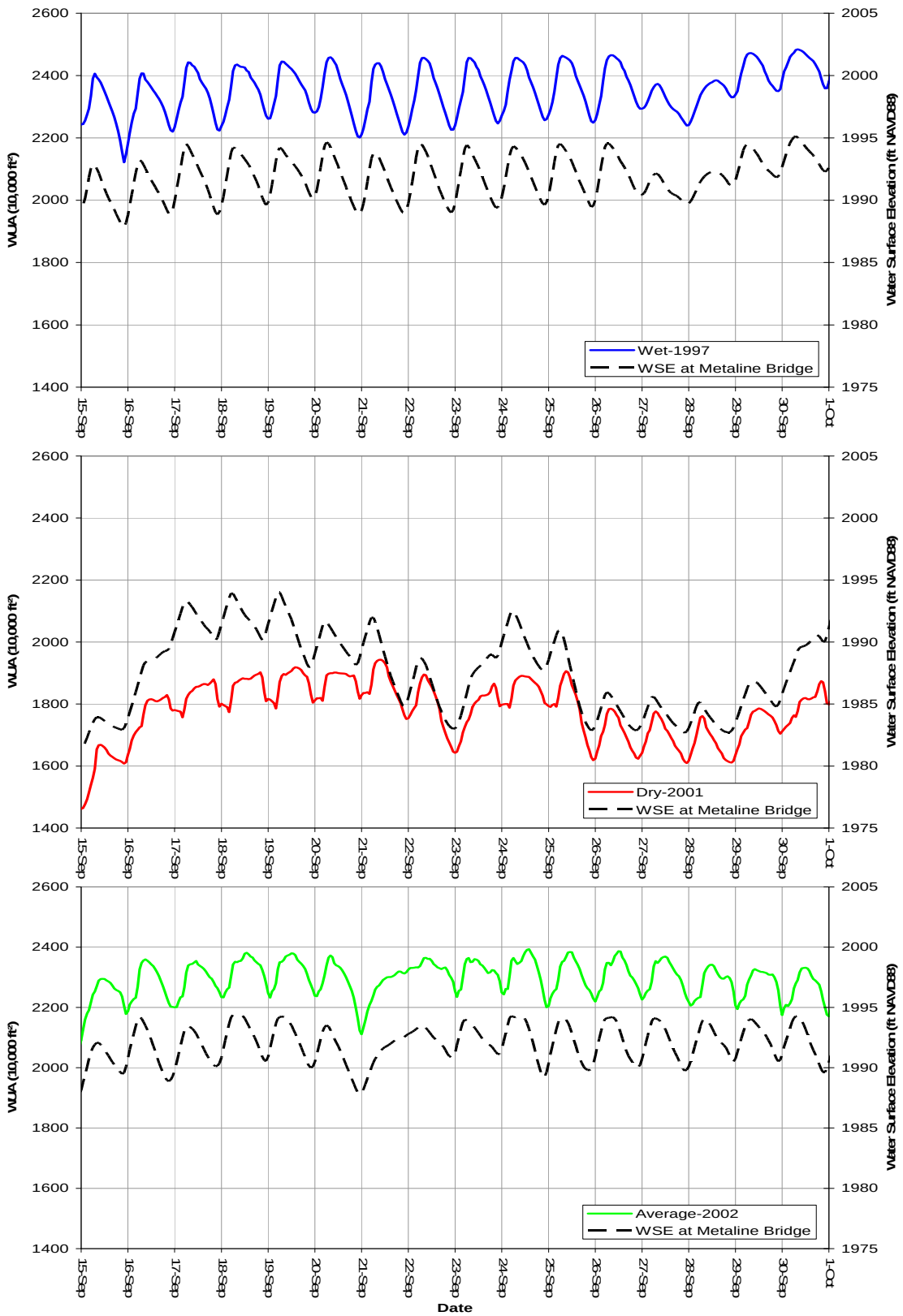



**Figure 5.8-9.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir compared to water surface elevations at Metaline Bridge during September 15–31 for wet, dry, and average years.

### 5.8.4. Tailrace Reach

The Mainstem Aquatic Habitat Model results for BMI WUA in the Tailrace Reach are shown in Figure 5.8-10 and summarized by month in Table 5.8-6. Data absent during the wet and average years in Figure 5.8-10 are due to exceedance of the 80,000 cfs bounding condition in the Mainstem Aquatic Habitat Model. Overall, the relative BMI WUA in the Tailrace Reach was significantly lower than that for the Upper Reservoir Reach, similar to that for the Canyon Reach, and higher than that for the Forebay Reach. The maximum relative BMI WUA in the Tailrace Reach (at any time) was determined by the model to be 359 (x 10,000 square feet) and occurred during July of a wet hydrologic year (Table 5.8-6). The lowest relative BMI WUA at any given time over the model simulation was determined to be 166 (x 10,000 square feet) and occurred during May of an average hydrologic year.

Variability in BMI WUA in the Tailrace Reach was slightly higher than that seen in the Forebay Reach and more similar to the Canyon Reach (Figure 5.8-10 and Table 5.8-6). Most of the variation in BMI WUA in the Tailrace Reach is due to extreme pool fluctuations and depth, similar to BMI WUA in the Forebay and Canyon reaches. Velocity, however, is more variable in the Tailrace Reach than the Forebay or Canyon reaches and therefore may influence the differences in BMI WUA. Substrate in the Tailrace Reach is fairly uniform throughout the reach and therefore does not contribute to the variation in BMI WUA as seen in the Upper Reservoir Reach. The daily pool fluctuations are expressed on the WUA as variations in the plotted data, but these are within the definable variation range and not significant on a monthly average when comparing wet, dry, or average hydrologic years.

The WUA estimates for BMI in the Tailrace Reach were lower than for the Forebay Reach, indicating a similar disturbance of BMI communities by dewatering that may explain part of the difference in BMI communities in the Upper Reservoir and Canyon reaches.

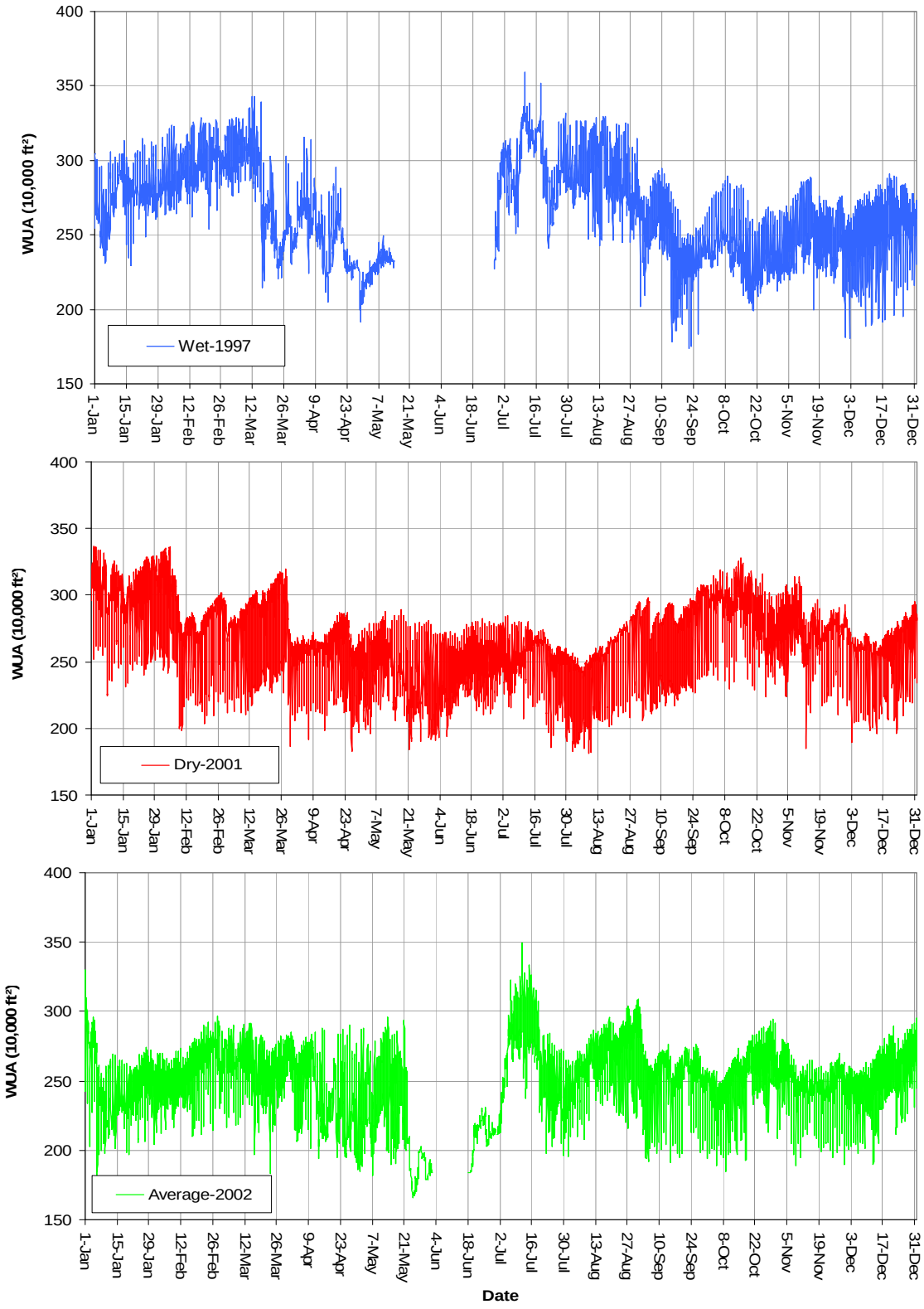



**Figure 5.8-10.** Habitat WUA for BMI in the Tailrace Reach of Boundary Reservoir determined by the Mainstem Aquatic Habitat Model for wet, dry, and average years.

**Table 5.8-6.** Summary of monthly BMI WUA (x 10,000 sq. ft.) in the Tailrace Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. | Mean | Max | Min | Stdev. |
| January | 279 | 315 | 230 | 16.5 | 295 | 337 | 224 | 25.3 | 242 | 310 | 179 | 21.9 |
| February | 296 | 329 | 254 | 14.5 | 273 | 336 | 198 | 31.5 | 252 | 296 | 210 | 17.8 |
| March | 278 | 343 | 214 | 30.2 | 273 | 319 | 186 | 30.0 | 254 | 292 | 183 | 17.2 |
| April | 248 | 315 | 191 | 23.2 | 252 | 287 | 183 | 21.1 | 243 | 290 | 186 | 24.6 |
| May | 230 | 250 | 214 | 6.4 | 239 | 289 | 184 | 23.2 | 219 | 296 | 166 | 31.7 |
| June | 266 | 305 | 227 | 24.8 | 238 | 282 | 191 | 18.8 | 207 | 231 | 182 | 14.1 |
| July | 299 | 359 | 241 | 21.5 | 248 | 285 | 186 | 18.5 | 261 | 349 | 196 | 30.0 |
| August | 288 | 329 | 202 | 20.1 | 246 | 295 | 181 | 27.2 | 262 | 309 | 196 | 20.4 |
| September | 242 | 294 | 174 | 21.2 | 268 | 308 | 205 | 28.2 | 250 | 303 | 191 | 20.7 |
| October | 240 | 290 | 199 | 17.8 | 283 | 328 | 224 | 20.4 | 248 | 294 | 185 | 20.8 |
| November | 244 | 289 | 182 | 16.9 | 268 | 314 | 185 | 20.0 | 244 | 280 | 189 | 17.2 |
| December | 248 | 291 | 181 | 18.5 | 256 | 295 | 189 | 21.1 | 249 | 295 | 190 | 18.5 |

## 5.9. Fish Habitat Development and Modeling Efforts

This section presents the results of the fish habitat modeling efforts for the mainstem of the Pend Oreille River encompassing Boundary Reservoir and its tailrace. These modeling efforts were conducted to assess how changes in streamflow or reservoir water surface elevation may influence the quantity and quality of habitat for fish. The calculated WUA and spawning widths are indices of fish habitat that were developed in this report to establish baseline conditions for historic Project operations during wet (1997), dry (2001), and average (2002) years. These years were selected as representative of wet, dry, and average conditions using factors like average annual flows (R2 Resource Consultants 2008). For reference, the flow hydrographs for the wet, dry, and average years were previously presented in Figures 5.0-1 through 5.0-3, respectively, and a comparison of the flow hydrographs across these three years was shown in Figure 5.0-4. The WUA and spawning indices will be later used in the LA to compare the effects of several operations scenarios on aquatic habitat. Section 5.9.1 includes the results of the WUA calculations for each of the four reaches (Forebay, Canyon, Upper Reservoir, and Tailrace) within the study area. Section 5.9.2 provides the results of the baseline modeling of the spawning widths at selected habitat transects within the study area. The interpretation of model results in Sections 5.9.1 and 5.9.2 is not intended to be comprehensive; rather, examples for specified species, life stages, hydrologic conditions, and reaches of the study area are presented and discussed to illustrate how the model output can be interpreted. Complete sets of WUA model output can be found in Attachments A and B to Appendix 9. Attachment C to Appendix 9 includes all figures of modeled PSI and ESI widths.

The derivation of modeling approach used to calculate WUA and PSI and ESI widths is discussed in detail in Section 4.9. The values of WUA are based on the fish HSCs for fry,

juvenile, and adult life stages. The HSCs are separated by two seasons, winter and summer. The winter period ran from November 1 through March 31; the summer period extended from April 1 through October 31. All of the fish species and life stage combinations have separate winter and summer curves except for fry mountain whitefish, which typically grow larger than the 55 mm fry length by November 1, so no winter curves were developed for fry mountain whitefish. The PSI and ESI widths were based on the HSCs for spawning adults. A detailed presentation of the development of the HSI curves and complete sets of model output are included in Appendix 9.

### 5.9.1. Fish Habitat – Weighted Useable Area

The results of the fish habitat modeling within the Boundary Reservoir and its tailrace were calculated for selected fish species and life stages. Final species and life stage selections, along with associated periodicity and HSI curves, were determined in coordination with the relicensing participants at meetings held on April 23 and August 27, 2008. A general discussion of the WUA output is provided below, followed by discussions in Sections 5.9.1.1 through 5.9.1.4 of WUA results for various life stages of selected species for the four study reaches (i.e., Forebay, Canyon, Upper Reservoir, and Tailrace reaches). Figures of the results of additional WUA analyses for all selected species and life stages can be found within Appendix 9, Attachments A and B. The fish species discussed below were selected based on their abundance observed during the 2007 and 2008 field activities, interest in the species as part of the recreational fisheries, native salmonids species, and interest identified by the relicensing participants. Monthly summaries for each species for each of the representative years are also provided in Appendix 9, Attachment A.

WUA results presented in the following sections did not consider flows exceeding 80,000 cfs. Once flows exceeded this threshold, the calculated WUA for a particular fish species and life stage was not included in either the plotted results or numerical values of the WUA. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs ensured the incorporation of all flows potentially influenced by Project operations.

The mean annual WUA values per foot of channel length within the Boundary Reservoir and its tailrace by fish species and life stage are presented in Table 5.9-1. Values of WUA presented in this table have been normalized by the total length of the study area, or approximately 20 miles.

**Table 5.9-1.** Mean annual WUA per foot of channel length for representative wet, dry, and average years, by fish species and life stage for the Project.

| Representative Hydrologic Year | Mean Annual WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Bull Trout (Juvenile)** | **Bull Trout (Adult)** | **Cutthroat Trout (Fry)[1]** | **Cutthroat Trout (Juvenile)** | **Cutthroat Trout (Adult)** | **Cyprinids & Forage Fish (Fry & Juvenile)[1]** | **Redband Trout (Fry)[1, 2]** | **Redband Trout (Juvenile)[2]** | **Redband Trout (Adults)[2]** | **Smallmouth Bass (Fry)[1]** | **Smallmouth Bass (Juvenile)** | **Smallmouth Bass (Adults)** | **Mountain Whitefish (Fry)[1]** | **Mountain Whitefish (Juvenile)** | **Mountain Whitefish (Adults)** |
| **Wet Year (1997)** | 76 | 245 | 19 | 50 | 295 | 45 | 18 | 51 | 303 | 23 | 83 | 219 | 17 | 38 | 208 |
| **Dry Year (2001)** | 96 | 285 | 24 | 62 | 347 | 57 | 24 | 64 | 361 | 33 | 113 | 273 | 23 | 43 | 209 |
| **Average Year (2002)** | 82 | 262 | 21 | 54 | 319 | 49 | 21 | 56 | 329 | 27 | 94 | 241 | 19 | 40 | 207 |

Notes:
1 WUA results for fry are reported for the period coinciding with the shoulder and peak season periodicity of the given species.
2 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

Table 5.9-1 shows that for 14 combinations of species and life stages there is a greater availability of potentially suitable habitat for the fish species identified within the table during the dry year followed secondly by the average year, and lastly the wet year. The WUA values for adult mountain whitefish, the lone exception, are rated highest during the dry year, followed by the wet year, then the average year. Using the average year as the basis for comparison, the difference between the fry and juvenile WUA values for each species when compared with the wet and dry years ranged from 10 to 30 percent. The magnitude of this variability can be primarily attributed to differences in hydrologic conditions between these years. The difference in adult WUA values ranged from 5 to 15 percent with the exception of adult mountain whitefish, which had less than 2 percent difference between the wet, dry, and average years.

In all cases for species with multiple life stages, the WUA increased with life stage. This was expected because fry and juvenile fish utilize shallower depths and lower velocities than adults. Because the Pend Oreille River is large, rearing and juvenile habitat was primarily limited to the shallow margins along the channel edges. Review of the magnitudes of WUA for a given life stage shows that the suitability of habitat approximately tripled as the life stage progressed from fry to juvenile. As the life stage progressed from juvenile to adult, the WUA for the bull trout and smallmouth bass approximately tripled; however, for the remaining species found throughout the study area (cutthroat trout and mountain whitefish) the area increased by approximately a factor of 6.

Not reflected in Table 5.9-1 is the difference in WUA on a seasonal basis. As noted earlier, the fish HSI curves are subdivided into two seasons, winter (November 1 to March 31) and summer (April 1 to October 31). Figure 5.9-1 is an example of the WUA calculations on an hourly basis for the entire average year for cutthroat trout in the Upper Reservoir Reach. This figure presents the WUA per linear foot of channel length on the y-axis. On the x-axis is the corresponding date for which the WUA was calculated. Additional graphs are presented in Appendix 9, Attachment A, and contain the WUA for a given life stage of a particular species of interest. It should be noted that the periods when WUA is not reported in Figure 5.9-1 coincide with either the periodicity of fry cutthroat limits when WUA is applicable or when flows are greater than 80,000 cfs. The periodicity of fry cutthroat extends from June 1 through April 30 as discussed in Appendix 3.

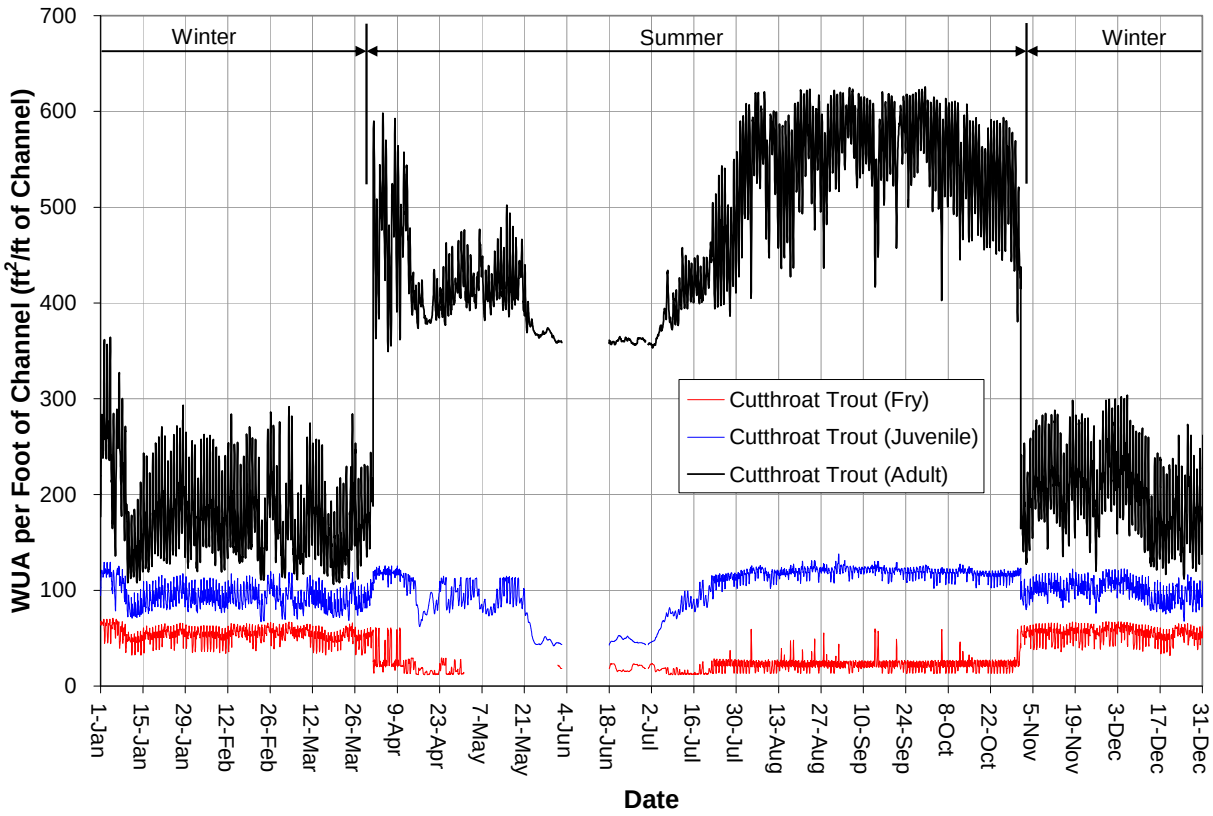



**Figure 5.9-1.** Example of fry, juvenile, and adult cutthroat trout WUA per foot of channel length in the Upper Reservoir Reach for hydrologic conditions representing an average year (2002).

The Figure 5.9-1 example also shows the operational influence on WUA. The general trend of calculated WUA is influenced by the overall hydrologic conditions and explains the general increase or decrease in the WUA for the Project when considered on a multi-week or monthly basis. Daily fluctuations in WUA were primarily produced by load-following, though the change in inflow can produce fluctuation in WUA. An example of the influence of hydrologic conditions is presented in Figure 5.9-1 from July through September. As flows receded from the

spring "freshet" in early July, the corresponding WUA began to increase from 400 square feet/foot of channel length to 575 square feet/foot of channel length. Daily fluctuations varying on average ±50 square feet/foot of channel length occurred during this time; however, the overall trend of the WUA for this period was increasing as inflows into Boundary Reservoir were decreasing. This was more pronounced in the WUA calculated for adult cutthroat trout, compared to fry and juvenile cutthroat trout.

Further review of Figure 5.9-1 highlights the difference between the two seasonal HSI curves for cutthroat trout. During the winter, the mean WUA for adult, juvenile, and fry cutthroat trout was 188, 96, and 53 square feet/foot of channel length, respectively. During the summer, the mean WUA for adult, juvenile, and fry cutthroat trout was 478, 100, and 21 square feet per foot of channel length, respectively. The difference between the winter and summer periods is based on HSI curves used for the specified periods presented in Appendix 9. For example, the HSI curves for adult cutthroat trout as shown in Appendix 9 reflect greater suitability of low mainstem velocities during the winter as compared to the summer. Based on HSI curves, cutthroat trout during the winter utilize a narrower range of depths (5 to 30 feet) than during the summer months (1.5 to 30 feet), also contributing to the decrease in WUA during the winter months.

Using adult mountain whitefish in the Upper Reservoir Reach as an example to illustrate the fluctuation in hourly WUA over the course of a year, Figure 5.9-2 shows the modeling results graphically for each of the three representative years. During the dry year in the winter season, the overall magnitude of WUA was greater than during the wet and average years. With the onset of the spring freshet beginning in early May, there was an increase in the dry year WUA as flows increased to approximately 30,000 cfs. Conversely, during the wet and average year, WUA decreased as flows increased past the threshold of 80,000 cfs, as represented by the trend toward lower values in WUA during the spring freshet period. The gap in values during this period corresponds to the period when the hourly WUA value was removed from consideration because flows were in excess of 80,000 cfs. Flows were in excess of 80,000 cfs during the wet and average years for 44 and 16 days, respectively. As flows receded after the spring "freshet" in early July, overall WUA values during the summer months were the highest during the wet year followed by the average year. The overall WUA values calculated during the dry year were the lowest during the summer months.

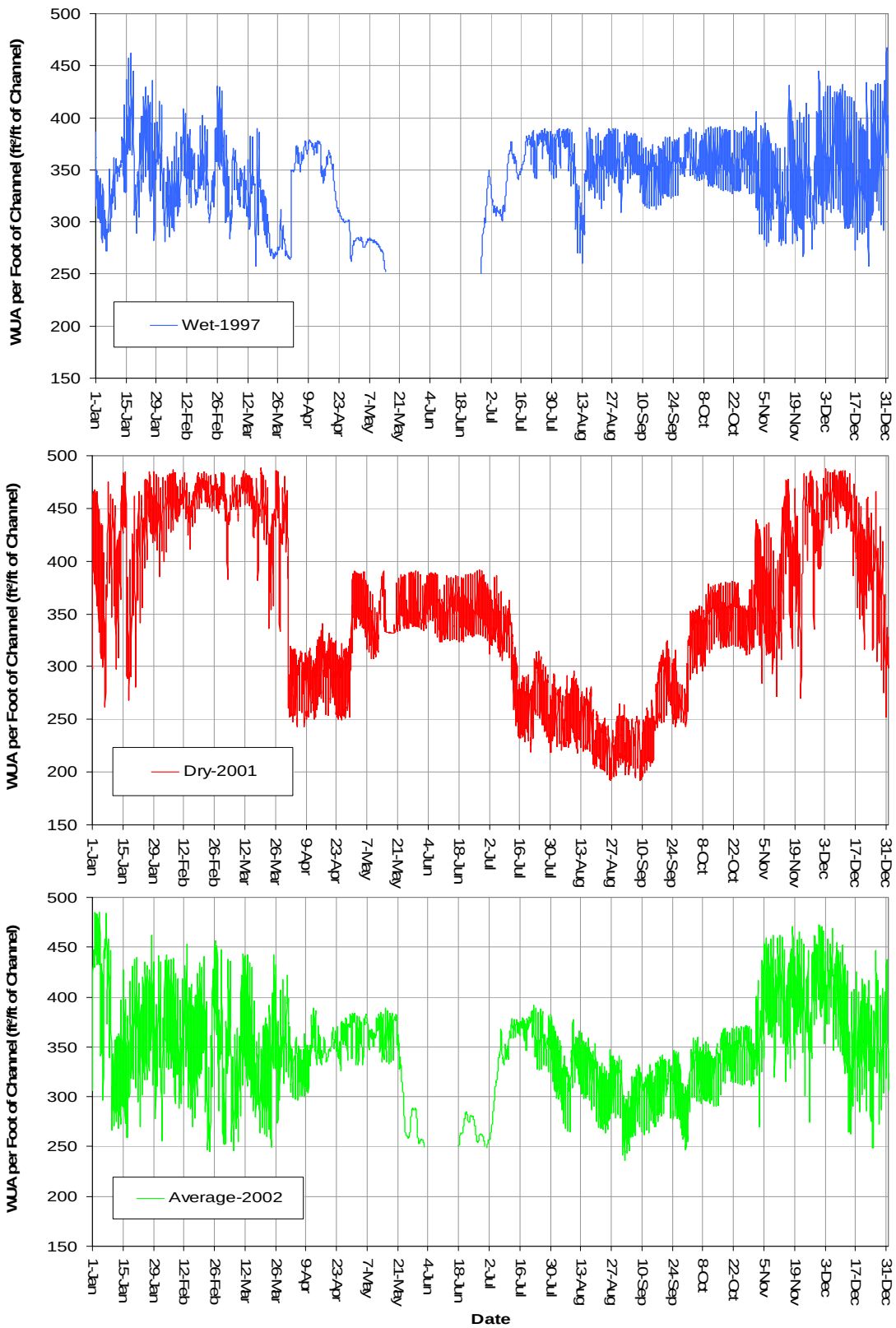



**Figure 5.9-2.** WUA for adult mountain whitefish in the Upper Reservoir Reach for the representative wet, dry, and average years.

Similar to the example presented in Figure 5.9-1 and Figure 5.9-2, the overall trends observed in WUA values across each of the fish species and life stages are related to hydrologic conditions. The fluctuations in hourly WUA values were primarily a result of load-following activities; however, changes in inflow can contribute to fluctuations in WUA values as well. The overall trends in WUA values over seasonal periods were more closely related to inflows than load following operations. An example of the differences in these patterns is presented in Figure 5.9-3 for the month of July during the three representative years. This series of plots shows the corresponding WUA values for adult mountain whitefish residing within the Upper Reservoir Reach. Also included on the plots are the water surface elevation and flow rate modeled during the month of July at the Metaline Falls Bridge (State Route 31).

During the wet year, flows modeled at Metaline Falls Bridge had receded from the peak during the Spring Freshet to approximately 45,000 cfs. Flow rates during July 1997 decreased from a high of 60,000 cfs in the beginning of the month to a low of approximately 20,000 at the end of the month. Corresponding water surface elevations during the wet year trended with flow at the bridge until approximately July 18, where inflow into Boundary Reservoir was near 30,000 cfs and load-following operations were increased. As flows approached the maximum capacity of the powerhouse (55,000 cfs), the ability of the Project to load-follow was reduced. A similar reduction in the Project's ability to fluctuate water surface elevations occurs as flows decrease below approximately 20,000 cfs because of the limited capacity of inflows to refill the reservoir. These hydrologic conditions influenced the overall trends in WUA values as described in the following paragraphs.

WUA for adult mountain whitefish during the beginning of July of the wet year shows minor daily fluctuations. There is a trend downward of WUA values as water surface elevations are increased above an elevation of 1,995 feet NAVD 88 (1,991 feet NGVD 29). As load-following operations are increased and water surface elevations fall below 1,995 feet NAVD 88 (1,991 feet NGVD 29), the daily fluctuation in WUA increases and somewhat mimics the pattern in water surface elevation. This is more noticeable from July 28 through August 1.

Flows modeled during the dry year (2001) at Metaline Falls Bridge varied between 28,000 and 4,000 cfs. Corresponding water surface elevations during the dry year fluctuated on a daily basis due to load-following operations from the Project, but overall trends in water surface elevation were related to inflow. WUA for adult mountain whitefish show a similar daily fluctuation. Over multiple days, the overall trend in WUA values shows an inverse relationship with water surface elevation.

During the average year (2002), flows were still receding from the "spring freshet" as of July 1 and decreased gradually throughout the month. Flows modeled at Metaline Falls Bridge ranged from a high of approximately 80,000 cfs to a low 7,000 cfs. Beginning on July 7 as flows decreased to approximately 40,000 cfs, load-following operations from the Project increased. The resulting WUA values for adult mountain whitefish show a daily fluctuation that does not vary greatly until July 22, after which the range of fluctuation in WUA increases. Prior to the resuming of load-following operations, the WUA values were increasing as flows decreased and these values were consistent with observations during the wet year.

During each of the three years evaluated, the overall trends in WUA values during July for mountain whitefish in the Upper Reservoir Reach were inversely related to water surface elevation. This response is likely due to changes toward less optimal depths and velocities.

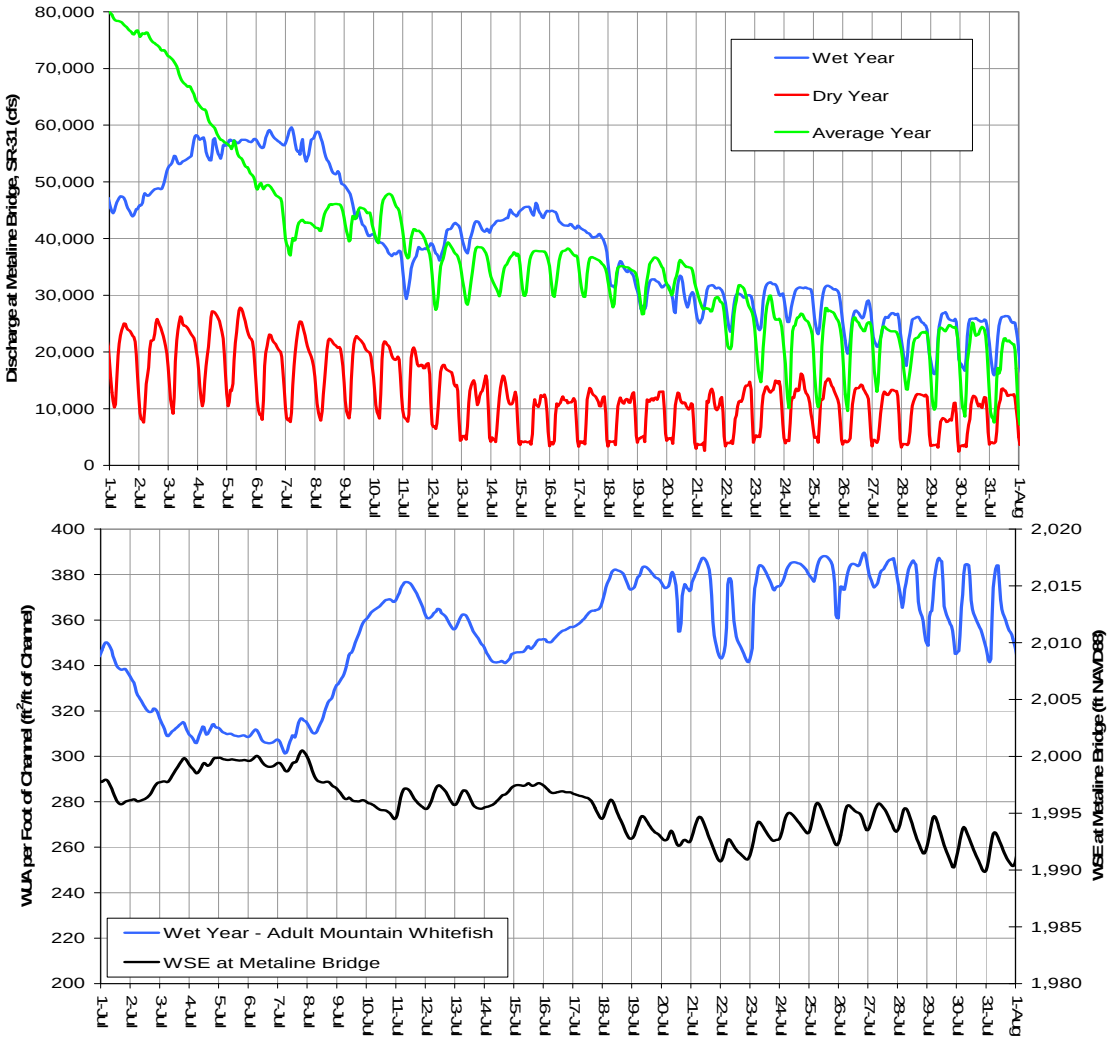



**Figure 5.9-3.** Example of hourly WUA values of adult mountain whitefish in the Upper Reservoir Reach of Boundary Reservoir and corresponding water surface elevation and discharge at Metaline Falls Bridge (SR 31) for the month of July during the representative wet, dry, and average years.

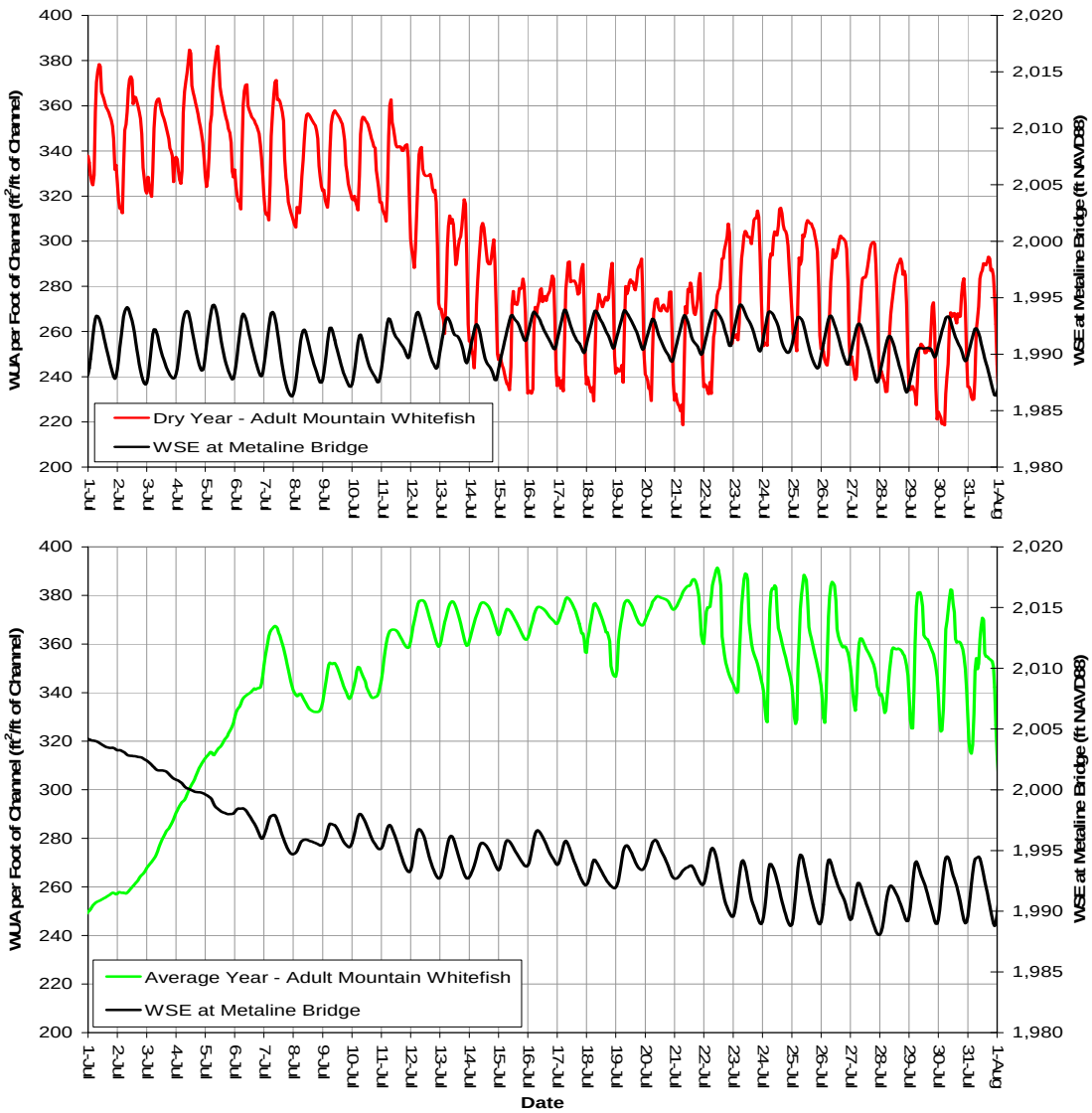



**Figure 5.9-3 (continued).** Example of hourly WUA values of adult mountain whitefish in the Upper Reservoir Reach of Boundary Reservoir and corresponding water surface elevation and discharge at Metaline Falls Bridge (SR-31) for the month of July during the representative wet, dry, and average years.

### *5.9.1.1. Forebay Reach*

The calculated monthly mean, maximum, and minimum WUA per linear foot of channel length for selected fish species in the Forebay Reach during representative years are presented in Table 5.9-2. A channel reach length of approximately 5,400 feet was used to calculate the results presented in Table 5.9-2. A mean wetted width for the Forebay Reach of 1,831 feet was based on a median pool of 1,989.8 feet NAVD 88 (1,985.8 feet NGVD 29) at Boundary Dam and a median flow rate of 19,500 cfs in the Pend Oreille River just downstream of Box Canyon Dam.

**Table 5.9-2.** Monthly mean, maximum, and minimum WUA in the Forebay Reach for selected species and life stages during representative years.

| Month | Event | WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Jan | Wet | 838 | 851 | 811 | 838 | 851 | 811 | 246 | 258 | 215 | -- | -- | -- | 155 | 161 | 140 | 63 | 75 | 52 |
| | Dry | 836 | 848 | 803 | 836 | 848 | 803 | 248 | 257 | 232 | -- | -- | -- | 154 | 159 | 135 | 66 | 71 | 41 |
| | Ave | 833 | 850 | 800 | 833 | 850 | 800 | 245 | 257 | 219 | -- | -- | -- | 152 | 161 | 135 | 64 | 71 | 34 |
| Feb | Wet | 836 | 849 | 813 | 836 | 849 | 813 | 246 | 257 | 226 | -- | -- | -- | 154 | 160 | 140 | 63 | 69 | 54 |
| | Dry | 842 | 849 | 831 | 842 | 849 | 831 | 253 | 257 | 244 | -- | -- | -- | 156 | 160 | 152 | 67 | 71 | 61 |
| | Ave | 832 | 848 | 797 | 832 | 848 | 797 | 245 | 256 | 228 | -- | -- | -- | 152 | 159 | 135 | 64 | 71 | 37 |
| Mar | Wet | 835 | 849 | 798 | 835 | 849 | 798 | 239 | 256 | 219 | -- | -- | -- | 154 | 160 | 135 | 60 | 71 | 35 |
| | Dry | 840 | 849 | 818 | 840 | 849 | 818 | 251 | 257 | 235 | -- | -- | -- | 155 | 160 | 144 | 67 | 71 | 60 |
| | Ave | 829 | 849 | 797 | 829 | 849 | 797 | 243 | 257 | 225 | -- | -- | -- | 150 | 160 | 135 | 62 | 71 | 35 |
| Apr | Wet | 741 | 831 | 609 | 781 | 830 | 720 | 182 | 195 | 153 | 9 | 11 | 3 | 36 | 45 | 26 | 15 | 25 | 11 |
| | Dry | 551 | 730 | 460 | 722 | 770 | 686 | 165 | 179 | 152 | 8 | 10 | 6 | 26 | 34 | 21 | 13 | 19 | 10 |
| | Ave | 650 | 778 | 463 | 743 | 799 | 687 | 169 | 188 | 142 | 8 | 11 | 1 | 30 | 39 | 21 | 15 | 25 | 8 |
| May | Wet | 817 | 839 | 799 | 819 | 837 | 807 | 193 | 197 | 190 | 10 | 11 | 7 | 43 | 47 | 40 | 15 | 16 | 12 |
| | Dry | 632 | 756 | 465 | 729 | 783 | 660 | 162 | 183 | 136 | 6 | 10 | 1 | 28 | 36 | 20 | 15 | 25 | 8 |
| | Ave | 725 | 836 | 469 | 774 | 834 | 680 | 178 | 196 | 141 | 8 | 11 | 1 | 35 | 46 | 21 | 15 | 25 | 8 |
| Jun | Wet | 788 | 828 | 739 | 801 | 829 | 776 | 187 | 195 | 177 | 8 | 10 | 6 | 39 | 45 | 35 | 14 | 21 | 11 |
| | Dry | 620 | 724 | 465 | 732 | 771 | 682 | 165 | 179 | 141 | 7 | 10 | 3 | 28 | 34 | 21 | 16 | 25 | 9 |
| | Ave | 816 | 830 | 799 | 818 | 831 | 806 | 192 | 195 | 189 | 8 | 10 | 7 | 43 | 46 | 40 | 14 | 18 | 12 |
| Jul | Wet | 706 | 812 | 515 | 768 | 815 | 710 | 178 | 192 | 162 | 8 | 11 | 6 | 33 | 42 | 25 | 14 | 21 | 10 |
| | Dry | 558 | 713 | 463 | 722 | 769 | 679 | 164 | 179 | 140 | 8 | 10 | 3 | 26 | 33 | 21 | 14 | 24 | 10 |
| | Ave | 692 | 826 | 467 | 762 | 826 | 697 | 176 | 194 | 154 | 8 | 11 | 5 | 33 | 45 | 23 | 15 | 23 | 10 |
| Aug | Wet | 611 | 709 | 466 | 737 | 769 | 689 | 169 | 179 | 154 | 8 | 10 | 6 | 29 | 34 | 22 | 14 | 19 | 10 |
| | Dry | 523 | 602 | 461 | 714 | 737 | 689 | 162 | 170 | 154 | 8 | 10 | 6 | 25 | 29 | 22 | 13 | 19 | 10 |

**Table 5.9-2, continued…**

| Month | Event | WUA (ft²/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| | Ave | 570 | 673 | 465 | 727 | 755 | 696 | 166 | 175 | 157 | 8 | 10 | 6 | 27 | 31 | 23 | 13 | 19 | 10 |
| Sept | Wet | 611 | 695 | 467 | 737 | 762 | 696 | 169 | 177 | 156 | 8 | 10 | 6 | 29 | 32 | 23 | 14 | 19 | 10 |
| | Dry | 524 | 641 | 447 | 708 | 742 | 662 | 159 | 171 | 135 | 7 | 10 | 2 | 25 | 30 | 19 | 14 | 24 | 9 |
| | Ave | 556 | 659 | 464 | 724 | 750 | 693 | 165 | 174 | 155 | 8 | 10 | 6 | 27 | 31 | 22 | 13 | 19 | 10 |
| Oct | Wet | 626 | 725 | 469 | 736 | 777 | 676 | 167 | 181 | 139 | -- | -- | -- | 29 | 35 | 20 | 16 | 26 | 9 |
| | Dry | 595 | 701 | 465 | 732 | 764 | 675 | 167 | 178 | 139 | -- | -- | -- | 28 | 33 | 20 | 14 | 24 | 9 |
| | Ave | 584 | 674 | 467 | 730 | 758 | 693 | 167 | 176 | 155 | -- | -- | -- | 28 | 32 | 22 | 13 | 19 | 10 |
| Nov. | Wet | 833 | 850 | 804 | 833 | 850 | 804 | 242 | 257 | 220 | -- | -- | -- | 152 | 161 | 135 | 62 | 71 | 42 |
| | Dry | 836 | 849 | 803 | 836 | 849 | 803 | 248 | 257 | 227 | -- | -- | -- | 154 | 160 | 135 | 65 | 71 | 41 |
| | Ave | 838 | 849 | 809 | 838 | 849 | 809 | 249 | 257 | 230 | -- | -- | -- | 155 | 160 | 137 | 65 | 71 | 53 |
| Dec. | Wet | 836 | 851 | 804 | 836 | 851 | 804 | 245 | 258 | 225 | -- | -- | -- | 153 | 161 | 135 | 64 | 76 | 42 |
| | Dry | 838 | 849 | 801 | 838 | 849 | 801 | 250 | 257 | 228 | -- | -- | -- | 155 | 160 | 135 | 66 | 71 | 37 |
| | Ave | 835 | 848 | 798 | 835 | 848 | 798 | 246 | 257 | 228 | -- | -- | -- | 153 | 160 | 135 | 64 | 71 | 37 |
| Annual | Wet | 750 | 851 | 466 | 795 | 851 | 676 | 207 | 258 | 139 | 8 | 11 | 3 | 89 | 161 | 20 | 37 | 76 | 9 |
| | Dry | 682 | 849 | 447 | 771 | 849 | 660 | 199 | 257 | 135 | 7 | 10 | 1 | 80 | 160 | 19 | 36 | 71 | 8 |
| | Ave | 725 | 850 | 463 | 785 | 850 | 680 | 204 | 257 | 141 | 8 | 11 | 1 | 83 | 161 | 21 | 36 | 71 | 8 |

Note:
1 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

WUA values normalized by reach length computed for the Forebay Reach were, in general, the smallest of any of the four modeled reaches. Table 5.9-2 shows that the WUA values for fry and, to a lesser extent, juveniles are relatively low within the Forebay Reach. Results for the adult life stage show that cutthroat trout had substantially greater values of WUA than smallmouth bass and mountain whitefish. This was due in part to the summer and winter season depth suitability for cutthroat trout; the curve maintains an optimum value of 1.0 through depths of 30 feet and does not fall below 0.5 until depths exceed the deepest areas of the Forebay Reach. The 1.0 value for cover when depths exceed 50 feet also played a role in the high WUA values for cutthroat trout in the Forebay Reach.

The hourly model calculations of WUA per foot of channel length in the Forebay Reach during the representative wet, dry, and average years are shown in Figure 5.9-4. A complete set of figures for all modeled species and life stages in the Forebay Reach is available in Figures A-1 through A-15 in Attachment A to Appendix 9. The minimum WUA of 447 square feet per foot of channel length was calculated on September 15, 2001 (historic dry year). Load-following operations during this week show a progressive decrease in Boundary forebay water surface elevations until September 14 (a Friday), after which time reservoir water surface elevations increased as the reservoir was refilled over the weekend. Corresponding WUA for adult cutthroat trout shows a diurnal pattern with the peak occurring midday during the period of greatest reservoir drawdown. Similarly, the minimum hourly WUA values on a daily basis correspond to periods of refilling. Changes in flow velocity and the preferences of adult cutthroat trout drive these patterns. Low flow velocities (between 0.25 and 1.5 fps during the summer season and less than 0.5 fps during the winter season) represent optimal to near optimal conditions for adult cutthroat trout. HSI values for velocity decline rapidly above 1.5 fps in the summer season and above 0.5 fps in the winter season. As the reservoir is refilled, flow velocities in the Forebay Reach are near zero and are weighted favorably; conversely, at midday, when the reservoir is being drawn down and flow velocities in the Forebay Reach are greatest, velocity HSI values are lowest. The observed patterns in WUA fluctuation on a daily basis are the result of the changing flow velocities.

All three plots in Figure 5.9-4 illustrate generally lower values of WUA per foot of channel for the summer season than the winter season. These trends are supported by the monthly values presented in Table 5.9-2. The months of August and September exhibit the smallest WUA values. Lower mainstem flow rates result in lower flow velocities in the Forebay Reach. Velocities less than 0.25 fps are rated only half as high in the summer season as the winter season. Consequently, for comparable mainstem flow velocities, the WUA values during the summer season are less than the values in the winter season. This seasonal pattern is consistent with the daily pattern noted in the previous paragraph.

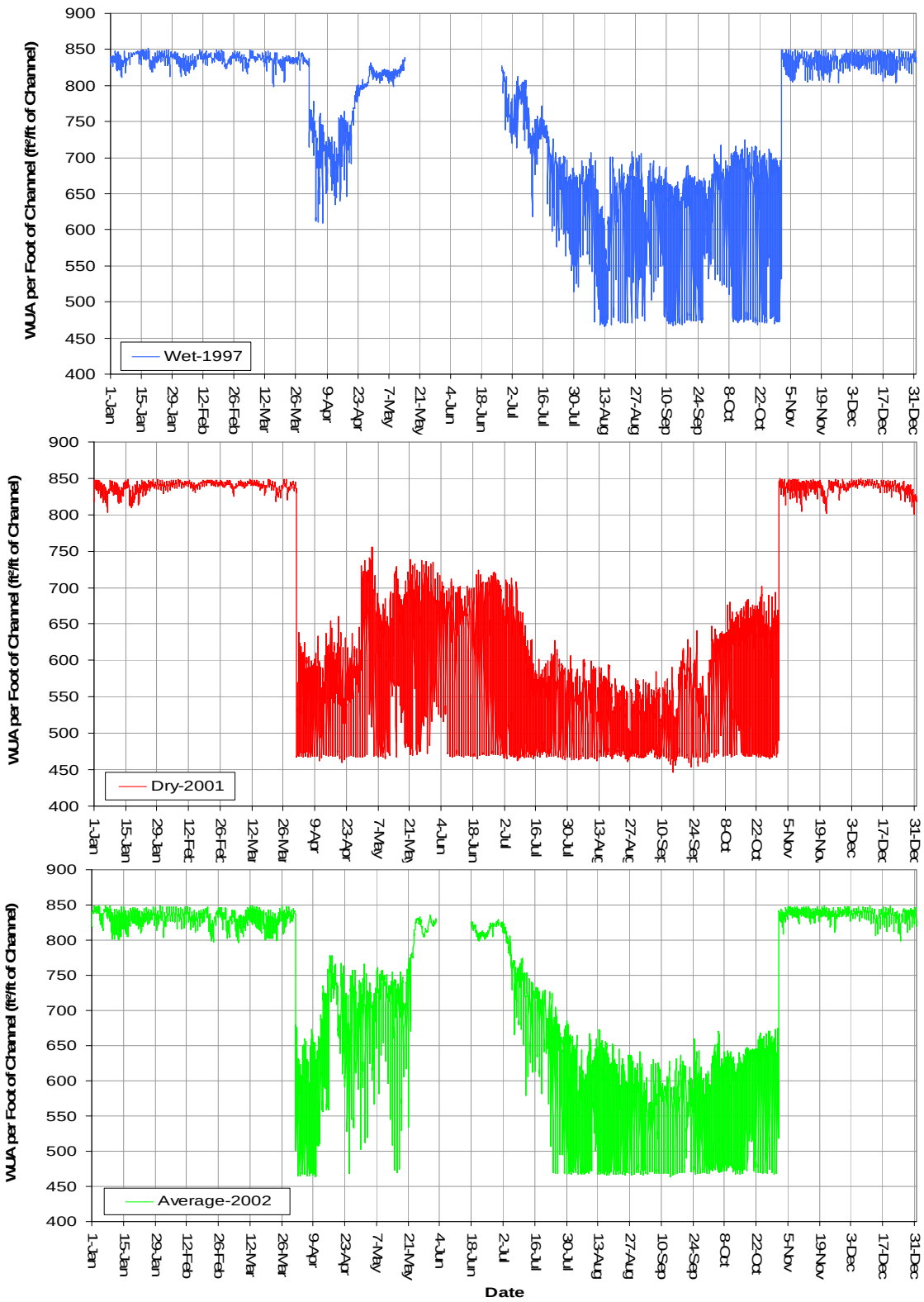



**Figure 5.9-4.** WUA for adult cutthroat trout in the Forebay Reach for the representative wet, dry, and average years.

Figure 5.9-5 presents the duration of adult cutthroat trout WUA per foot of channel on a seasonal basis within the Forebay Reach. The magnitude of hourly WUA values is shown along the y-axis and the corresponding duration of the season when particular values of WUA are equaled or exceeded is shown on the x-axis. Curves for the winter and summer seasons for fry, juvenile, and adult life stages are displayed on this figure. Curves for all modeled species and life stages in the Forebay Reach can be found in Figures B-1 through B-15 of Attachment B to Appendix 9. Hourly WUA values during the summer season had a higher degree of variability than during the winter season, as is also apparent in Figure 5.9-4. The minimum value of approximately 470 was exceeded only approximately 80 percent of the summer season during the dry year, whereas this values was exceeded approximately 92 percent of the summer in the average year and nearly 100 percent of the summer in the wet year.

Hourly WUA during the winter season for the three hydrologic years fluctuated less, and the minimum winter values in all three years are approximately equal to the maximum values during the summer season. Indicated by the nearly identical lines in Figure 5.9-5, there is little difference in the magnitude of WUA between the three representative years during the winter season.

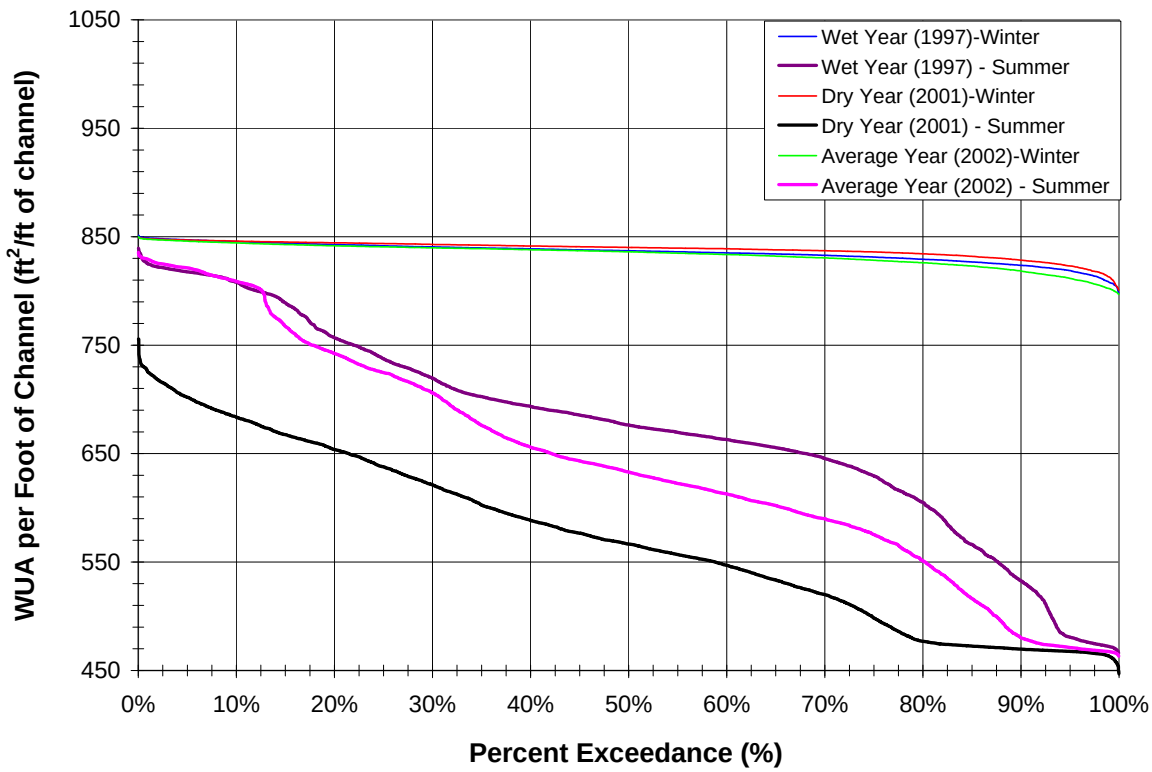



**Figure 5.9-5.** Frequency of exceedance of hourly WUA by winter and summer seasons for adult cutthroat trout in the Forebay Reach by the representative wet, dry, and average years.

#### 5.9.1.2. Canyon Reach

The monthly mean, maximum, and minimum hourly WUA per linear foot of channel length for the Canyon Reach for the representative hydrologic years are presented in Table 5.9-3. A channel reach length of approximately 44,200 feet was used to calculate the results presented in Table 5.9-3. A mean wetted width for the Canyon Reach of 538 feet was based on a median pool of 1,989.8 feet NAVD 88 (1,985.8 feet NGVD 29) at Boundary Dam and a median flow rate of 19,500 cfs in the Pend Oreille River just downstream of Box Canyon Dam.

Similar to the results found in the Forebay Reach, WUA values shown in Table 5.9-3 for adult cutthroat trout were higher than the values calculated for smallmouth bass and mountain whitefish. This is due to the dominance of deep water habitats in both of these reaches and the suitability of greater depths for the two trout species. As mentioned in discussion of the Forebay Reach, the HSI depth curve for cutthroat trout maintains an optimum value of 1.0 through depths of 30 feet and is above 0.5 for depths in Boundary Reservoir greater than 30 feet. The 1.0 value for cover when depths exceed 50 feet also played a role in the high HSI in the Canyon Reach. The calculated WUA values normalized by reach length in the Canyon Reach were approximately 10 to 20 percent greater than the values calculated in the Forebay Reach.

**Table 5.9-3.** Monthly mean, maximum, and minimum WUA in the Canyon Reach for selected species and life stages during representative years.

| Month | Event | WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Jan | Wet | 229 | 312 | 140 | 227 | 312 | 128 | 181 | 279 | 98 | -- | -- | -- | 144 | 150 | 127 | 37 | 52 | 23 |
| | Dry | 285 | 314 | 213 | 285 | 314 | 211 | 241 | 283 | 169 | -- | -- | -- | 147 | 153 | 145 | 42 | 54 | 24 |
| | Ave | 258 | 314 | 161 | 257 | 314 | 154 | 213 | 283 | 123 | -- | -- | -- | 146 | 151 | 140 | 39 | 54 | 17 |
| Feb | Wet | 233 | 305 | 168 | 231 | 305 | 161 | 184 | 260 | 127 | -- | -- | -- | 145 | 149 | 139 | 36 | 48 | 25 |
| | Dry | 304 | 314 | 241 | 304 | 314 | 240 | 266 | 284 | 193 | -- | -- | -- | 148 | 149 | 146 | 47 | 55 | 35 |
| | Ave | 259 | 312 | 189 | 258 | 312 | 186 | 214 | 280 | 150 | -- | -- | -- | 147 | 160 | 144 | 38 | 53 | 21 |
| Mar | Wet | 193 | 306 | 139 | 188 | 306 | 126 | 147 | 269 | 95 | -- | -- | -- | 139 | 156 | 123 | 33 | 50 | 18 |
| | Dry | 302 | 314 | 239 | 302 | 314 | 238 | 263 | 284 | 192 | -- | -- | -- | 148 | 149 | 146 | 46 | 54 | 31 |
| | Ave | 250 | 312 | 168 | 248 | 312 | 161 | 204 | 283 | 128 | -- | -- | -- | 147 | 161 | 140 | 36 | 53 | 19 |
| Apr | Wet | 292 | 319 | 243 | 300 | 323 | 260 | 148 | 159 | 132 | 10 | 11 | 6 | 79 | 93 | 63 | 13 | 14 | 11 |
| | Dry | 277 | 317 | 188 | 295 | 320 | 261 | 141 | 156 | 125 | 9 | 11 | 7 | 44 | 75 | 28 | 12 | 14 | 9 |
| | Ave | 295 | 318 | 224 | 302 | 322 | 271 | 146 | 159 | 130 | 9 | 11 | 6 | 70 | 105 | 32 | 12 | 14 | 7 |
| May | Wet | 254 | 266 | 236 | 271 | 281 | 254 | 136 | 141 | 129 | 11 | 11 | 9 | 85 | 86 | 84 | 14 | 14 | 12 |
| | Dry | 296 | 319 | 228 | 302 | 322 | 271 | 147 | 158 | 131 | 8 | 11 | 5 | 76 | 135 | 33 | 11 | 14 | 6 |
| | Ave | 284 | 319 | 224 | 293 | 323 | 242 | 144 | 159 | 120 | 9 | 11 | 6 | 80 | 109 | 40 | 12 | 14 | 7 |
| Jun | Wet | 259 | 296 | 222 | 273 | 304 | 240 | 135 | 150 | 119 | 9 | 10 | 8 | 86 | 93 | 80 | 12 | 14 | 11 |
| | Dry | 298 | 318 | 244 | 305 | 321 | 279 | 147 | 157 | 135 | 9 | 11 | 6 | 66 | 93 | 36 | 11 | 14 | 7 |
| | Ave | 239 | 252 | 220 | 256 | 268 | 238 | 128 | 133 | 118 | 9 | 10 | 9 | 86 | 88 | 84 | 12 | 14 | 11 |
| Jul | Wet | 297 | 319 | 237 | 304 | 323 | 255 | 149 | 159 | 124 | 10 | 11 | 7 | 75 | 93 | 47 | 12 | 14 | 10 |
| | Dry | 278 | 315 | 191 | 295 | 319 | 261 | 141 | 155 | 124 | 9 | 11 | 6 | 47 | 79 | 28 | 12 | 14 | 8 |
| | Ave | 292 | 318 | 221 | 300 | 322 | 240 | 146 | 159 | 117 | 9 | 11 | 7 | 73 | 89 | 34 | 12 | 14 | 9 |
| Aug | Wet | 301 | 320 | 206 | 308 | 323 | 268 | 149 | 159 | 127 | 10 | 11 | 8 | 58 | 77 | 31 | 12 | 14 | 9 |
| | Dry | 259 | 304 | 182 | 285 | 309 | 257 | 136 | 148 | 122 | 9 | 11 | 8 | 38 | 50 | 27 | 11 | 13 | 9 |

**Table 5.9-3, continued…**

| Month | Event | WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| | Ave | 286 | 315 | 203 | 300 | 318 | 265 | 144 | 155 | 127 | 9 | 11 | 8 | 48 | 67 | 30 | 12 | 14 | 9 |
| Sept | Wet | 301 | 317 | 239 | 308 | 321 | 276 | 149 | 157 | 133 | 10 | 11 | 8 | 58 | 73 | 34 | 12 | 14 | 9 |
| | Dry | 263 | 308 | 183 | 285 | 313 | 257 | 135 | 150 | 122 | 8 | 11 | 6 | 41 | 66 | 28 | 11 | 13 | 7 |
| | Ave | 282 | 312 | 199 | 297 | 315 | 263 | 142 | 153 | 126 | 9 | 11 | 8 | 44 | 61 | 29 | 12 | 14 | 9 |
| Oct | Wet | 301 | 320 | 250 | 307 | 324 | 283 | 148 | 159 | 137 | -- | -- | -- | 66 | 91 | 36 | 12 | 14 | 7 |
| | Dry | 295 | 317 | 218 | 305 | 321 | 270 | 147 | 157 | 130 | -- | -- | -- | 55 | 84 | 31 | 12 | 14 | 7 |
| | Ave | 293 | 316 | 221 | 304 | 320 | 270 | 146 | 156 | 130 | -- | -- | -- | 51 | 69 | 31 | 12 | 14 | 9 |
| Nov | Wet | 222 | 312 | 157 | 219 | 312 | 150 | 176 | 278 | 119 | -- | -- | -- | 145 | 150 | 139 | 35 | 52 | 21 |
| | Dry | 270 | 314 | 179 | 269 | 314 | 175 | 225 | 283 | 140 | -- | -- | -- | 147 | 155 | 143 | 41 | 54 | 22 |
| | Ave | 273 | 312 | 200 | 272 | 312 | 197 | 226 | 280 | 159 | -- | -- | -- | 147 | 149 | 145 | 41 | 52 | 25 |
| Dec | Wet | 243 | 313 | 172 | 241 | 313 | 166 | 198 | 281 | 133 | -- | -- | -- | 146 | 150 | 142 | 38 | 53 | 23 |
| | Dry | 288 | 314 | 198 | 287 | 314 | 196 | 242 | 283 | 159 | -- | -- | -- | 147 | 155 | 145 | 43 | 54 | 20 |
| | Ave | 263 | 312 | 185 | 262 | 312 | 181 | 217 | 280 | 145 | -- | -- | -- | 147 | 158 | 143 | 39 | 52 | 21 |
| Annual | Wet | 261 | 320 | 139 | 264 | 324 | 126 | 161 | 281 | 95 | 10 | 11 | 6 | 104 | 156 | 31 | 23 | 53 | 7 |
| | Dry | 285 | 319 | 179 | 293 | 322 | 175 | 186 | 284 | 122 | 9 | 11 | 5 | 92 | 155 | 27 | 25 | 55 | 6 |
| | Ave | 275 | 319 | 161 | 280 | 323 | 154 | 174 | 283 | 117 | 9 | 11 | 6 | 99 | 161 | 29 | 23 | 54 | 7 |

Note:

1 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

The hourly model calculations of WUA per foot of channel length in the Canyon Reach for adult cutthroat trout during the representative wet, dry, and average years are shown in Figure 5.9-6. A complete set of figures for all modeled species and life stages in the Canyon Reach is available in Figures A-16 through A-30 in Attachment A to Appendix 9. The minimum WUA of 139 square feet per foot of channel length was calculated on March 31, 1997 (historic wet year). Load-following operations during this week show a progressive decrease in Boundary forebay water surface elevations until September 14 (a Friday), after which time reservoir water surface elevations increased as the reservoir was refilled over the weekend. Corresponding WUA for adult cutthroat trout shows a diurnal pattern with the peak occurring midday during the period of greatest reservoir drawdown. Similarly, the minimum hourly WUA values on a daily basis correspond to periods of refilling.

As shown in Figure 5.9-6, during the wet and average years, the winter season exhibits lower WUA values than the summer season; values during the dry year are relatively consistent. These trends are supported by the monthly values presented in Table 5.9-2. Using the HSI curves in Appendix 9, for flow velocities in excess of 0.5 fps during the winter months the HSI values decline. The smaller magnitude year-round flows during the dry year reduce flow velocities in the Canyon Reach such that more favorable habitat conditions persist throughout the year.

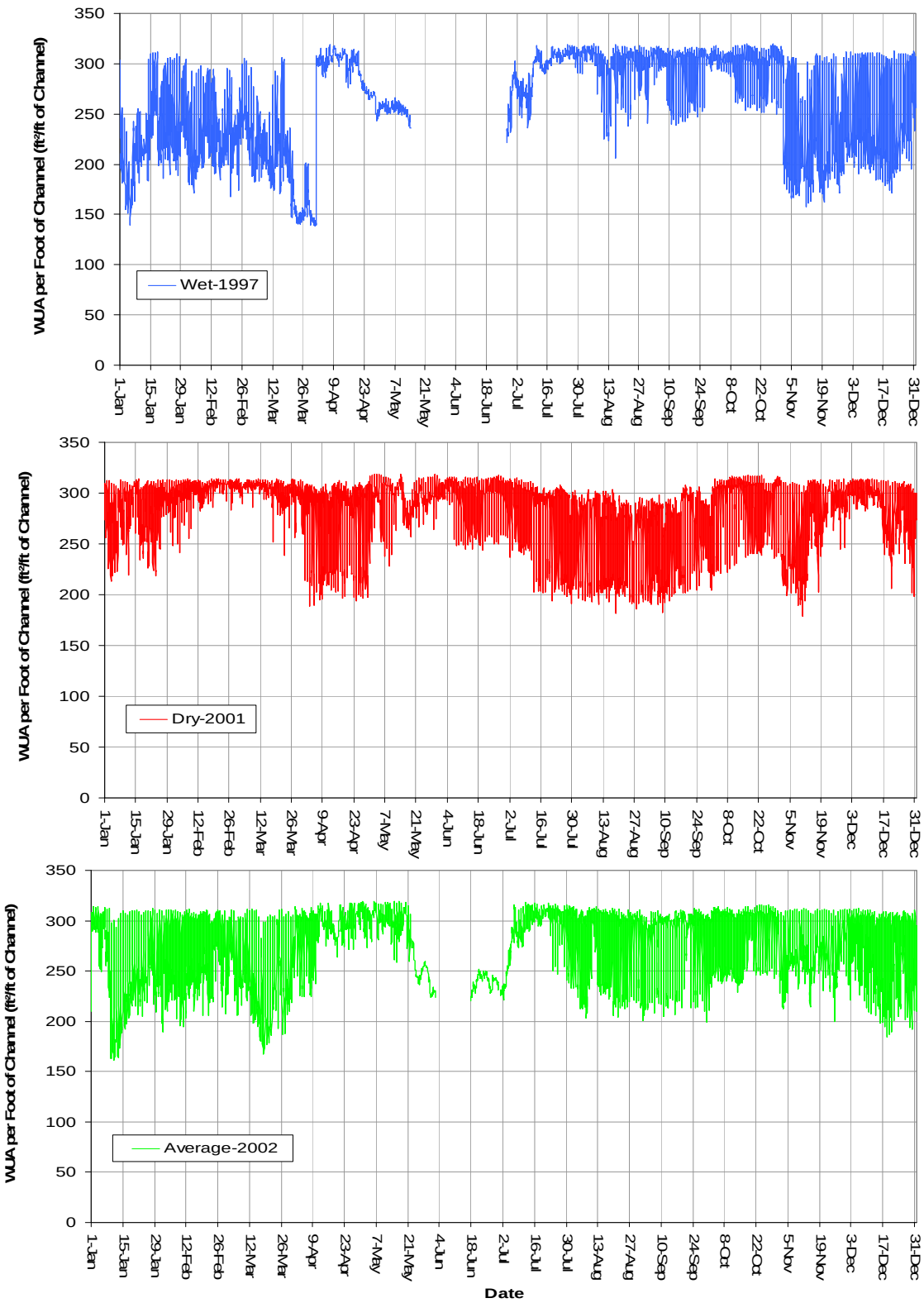



**Figure 5.9-6.** WUA for adult cutthroat trout in the Canyon Reach for the representative wet, dry, and average years.

The WUA duration curves shown in Figure 5.9-7 for cutthroat trout in the Canyon Reach support the discussion based on the hourly plots. The summer and winter curves for the dry year closely track each other whereas the summer and winter curves for the wet and average years diverge considerably with the difference in the wet year more pronounced than the average year. The apparent influence of higher flow velocities during the winter months can be easily seen by these curves. The similarity of the summer curves during all three years shows that values of WUA within approximately 50 square feet per foot of channel length of the seasonal maximums are exceed nearly 70 percent of the summer. There is no apparent threshold toward the minimum values as was present in the Forebay Reach.

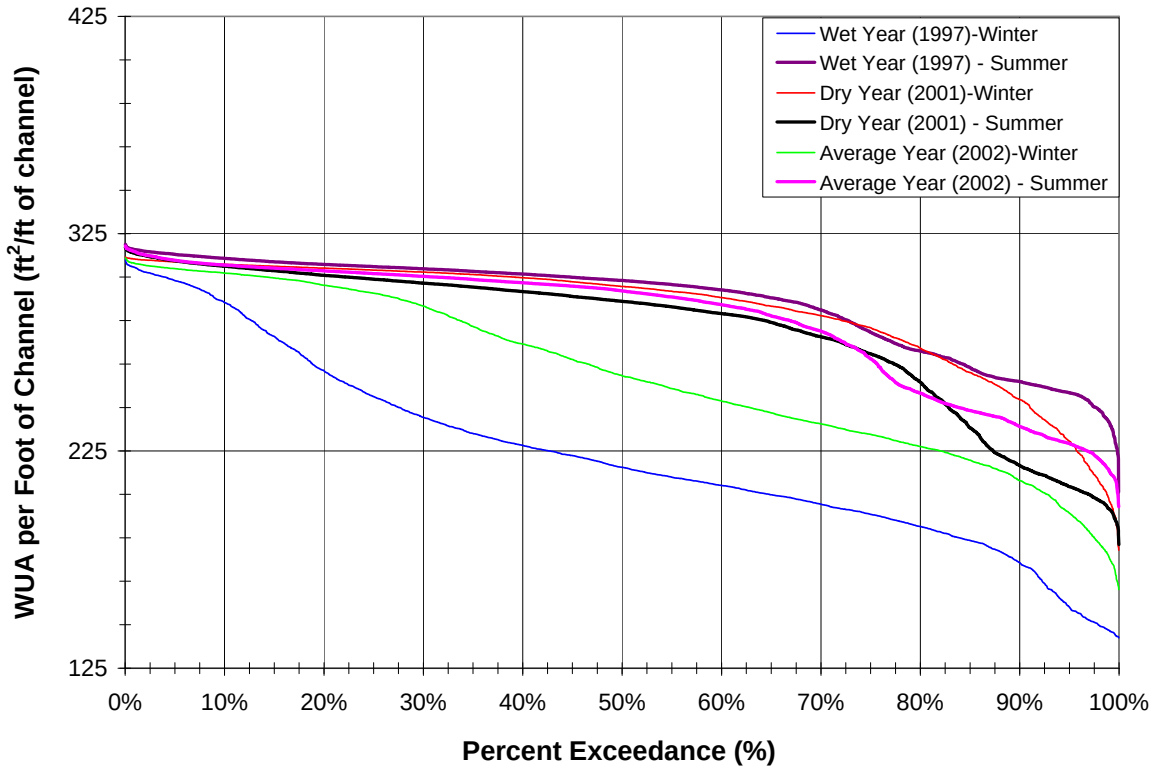



**Figure 5.9-7.** Frequency of exceedance of hourly WUA by winter and summer seasons for adult cutthroat trout in the Canyon Reach by the representative wet, dry, and average years.

### *5.9.1.3. Upper Reservoir Reach*

WUA values in the Upper Reservoir Reach were, in general, the greatest of the four modeled reaches during all representative hydrologic years. The monthly mean, maximum, and minimum hourly WUA values per linear foot of channel length for the Upper Reservoir Reach for the representative years are presented in Table 5.9-4. A channel reach length of approximately 38,500 feet was used to calculate the results presented in Table 5.9-4. A mean wetted width for the Upper Reservoir Reach of 1,020 feet was based on a median pool of 1,989.8 feet NAVD 88 (1,985.8 feet NGVD 29) at Boundary Dam and a median flow rate of 19,500 cfs in the Pend Oreille River just downstream of Box Canyon Dam.

Table 5.9-4 shows that adult mountain whitefish have greater WUA values than the adult life stage of cutthroat trout and smallmouth bass during the winter season, but this pattern is reversed in the summer season. The sensitivity of velocities greater than 0.5 fps for adult cutthroat trout and smallmouth bass is reflected by the decrease in WUA during the winter season. Likewise, lower velocities in the summer are recognized by the decrease in WUA for adult mountain whitefish. For mountain whitefish fry, the WUA values for the Upper Reservoir Reach were similar to the Forebay and Canyon reaches, but less than the Tailrace Reach. The Tailrace Reach had higher WUA values for fry due to the presence of gravel and cobble substrate throughout most of its shallower depths. Much of the shallow areas in the Upper Reservoir Reach comprise fines.

**Table 5.9-4.** Monthly mean, maximum, and minimum WUA in the Upper Reservoir Reach for selected species and life stages during representative years.

| Month | Event | WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Jan | Wet | 168 | 271 | 116 | 143 | 258 | 93 | 156 | 292 | 75 | -- | -- | -- | 351 | 462 | 272 | 114 | 169 | 84 |
| | Dry | 231 | 375 | 118 | 216 | 373 | 96 | 216 | 399 | 78 | -- | -- | -- | 409 | 485 | 262 | 149 | 200 | 93 |
| | Ave | 192 | 364 | 108 | 173 | 361 | 87 | 170 | 391 | 68 | -- | -- | -- | 370 | 485 | 259 | 132 | 191 | 95 |
| Feb | Wet | 163 | 233 | 118 | 138 | 214 | 97 | 143 | 236 | 82 | -- | -- | -- | 345 | 430 | 281 | 118 | 152 | 101 |
| | Dry | 341 | 449 | 190 | 338 | 449 | 172 | 343 | 479 | 159 | -- | -- | -- | 460 | 486 | 400 | 185 | 223 | 130 |
| | Ave | 180 | 286 | 111 | 157 | 274 | 89 | 152 | 295 | 71 | -- | -- | -- | 357 | 456 | 245 | 128 | 175 | 86 |
| Mar | Wet | 146 | 214 | 106 | 123 | 194 | 86 | 140 | 203 | 68 | -- | -- | -- | 310 | 389 | 258 | 98 | 144 | 68 |
| | Dry | 314 | 440 | 159 | 309 | 440 | 138 | 310 | 465 | 117 | -- | -- | -- | 448 | 488 | 334 | 177 | 221 | 124 |
| | Ave | 167 | 292 | 106 | 144 | 280 | 86 | 138 | 298 | 68 | -- | -- | -- | 340 | 447 | 246 | 123 | 182 | 91 |
| Apr | Wet | 401 | 459 | 367 | 446 | 509 | 397 | 415 | 479 | 349 | 20 | 38 | 14 | 341 | 379 | 262 | 29 | 59 | 23 |
| | Dry | 565 | 626 | 381 | 584 | 648 | 398 | 561 | 615 | 383 | 40 | 55 | 26 | 295 | 388 | 243 | 66 | 97 | 36 |
| | Ave | 435 | 598 | 349 | 477 | 627 | 380 | 454 | 598 | 351 | 33 | 53 | 17 | 348 | 389 | 297 | 53 | 96 | 24 |
| May | Wet | 370 | 375 | 365 | 404 | 409 | 395 | 360 | 366 | 344 | 15 | 15 | 14 | 279 | 286 | 252 | 27 | 28 | 23 |
| | Dry | 431 | 592 | 337 | 473 | 623 | 369 | 452 | 594 | 334 | 37 | 52 | 20 | 351 | 391 | 307 | 62 | 96 | 28 |
| | Ave | 404 | 502 | 358 | 447 | 549 | 387 | 417 | 524 | 343 | 23 | 42 | 14 | 336 | 389 | 253 | 36 | 71 | 23 |
| Jun | Wet | 372 | 398 | 359 | 410 | 444 | 387 | 375 | 412 | 341 | 17 | 19 | 14 | 301 | 345 | 250 | 25 | 29 | 23 |
| | Dry | 443 | 549 | 359 | 486 | 589 | 400 | 465 | 567 | 363 | 39 | 49 | 24 | 355 | 391 | 323 | 64 | 87 | 33 |
| | Ave | 360 | 365 | 356 | 391 | 400 | 384 | 352 | 364 | 340 | 15 | 15 | 14 | 267 | 285 | 249 | 26 | 29 | 23 |
| Jul | Wet | 422 | 546 | 360 | 468 | 587 | 398 | 443 | 563 | 371 | 24 | 42 | 16 | 354 | 390 | 301 | 36 | 71 | 24 |
| | Dry | 538 | 625 | 345 | 562 | 648 | 378 | 539 | 613 | 345 | 41 | 56 | 28 | 298 | 387 | 219 | 68 | 97 | 37 |
| | Ave | 423 | 590 | 353 | 467 | 621 | 382 | 442 | 595 | 341 | 26 | 47 | 14 | 348 | 391 | 250 | 41 | 80 | 22 |

**Table 5.9-4, continued…**

| Month | Event | WUA (ft²/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Aug | Wet | 495 | 617 | 402 | 534 | 641 | 430 | 516 | 610 | 414 | 36 | 56 | 20 | 355 | 390 | 260 | 58 | 96 | 29 |
| | Dry | 558 | 621 | 443 | 573 | 643 | 448 | 549 | 607 | 429 | 43 | 58 | 32 | 243 | 296 | 192 | 71 | 97 | 43 |
| | Ave | 552 | 623 | 405 | 578 | 646 | 439 | 558 | 613 | 416 | 39 | 54 | 26 | 323 | 377 | 263 | 64 | 95 | 36 |
| Sept | Wet | 494 | 582 | 402 | 535 | 615 | 443 | 517 | 588 | 413 | 37 | 50 | 23 | 358 | 387 | 312 | 60 | 84 | 32 |
| | Dry | 509 | 625 | 313 | 525 | 647 | 333 | 503 | 614 | 321 | 45 | 57 | 32 | 253 | 324 | 192 | 70 | 97 | 43 |
| | Ave | 573 | 626 | 417 | 593 | 647 | 439 | 571 | 614 | 418 | 39 | 55 | 29 | 303 | 347 | 236 | 64 | 96 | 40 |
| Oct | Wet | 451 | 556 | 373 | 495 | 594 | 416 | 475 | 567 | 383 | -- | -- | -- | 359 | 391 | 327 | 61 | 78 | 28 |
| | Dry | 510 | 621 | 341 | 546 | 644 | 376 | 527 | 611 | 341 | -- | -- | -- | 345 | 382 | 263 | 62 | 95 | 34 |
| | Ave | 534 | 615 | 381 | 565 | 641 | 418 | 546 | 608 | 388 | -- | -- | -- | 337 | 371 | 255 | 63 | 95 | 36 |
| Nov | Wet | 157 | 262 | 113 | 133 | 247 | 92 | 137 | 276 | 74 | -- | -- | -- | 335 | 445 | 267 | 114 | 161 | 98 |
| | Dry | 213 | 371 | 111 | 195 | 368 | 89 | 197 | 393 | 70 | -- | -- | -- | 393 | 485 | 270 | 139 | 197 | 87 |
| | Ave | 209 | 299 | 120 | 189 | 290 | 96 | 191 | 316 | 78 | -- | -- | -- | 397 | 473 | 270 | 139 | 181 | 101 |
| Dec | Wet | 176 | 299 | 112 | 152 | 289 | 89 | 156 | 320 | 71 | -- | -- | -- | 359 | 468 | 258 | 122 | 173 | 96 |
| | Dry | 245 | 397 | 114 | 232 | 396 | 92 | 236 | 426 | 74 | -- | -- | -- | 420 | 488 | 252 | 152 | 206 | 96 |
| | Ave | 192 | 304 | 112 | 170 | 295 | 91 | 168 | 323 | 74 | -- | -- | -- | 373 | 471 | 248 | 133 | 181 | 87 |
| Annual | Wet | 312 | 617 | 106 | 322 | 641 | 86 | 314 | 610 | 68 | 28 | 56 | 14 | 343 | 468 | 250 | 78 | 173 | 23 |
| | Dry | 408 | 626 | 111 | 420 | 648 | 89 | 408 | 615 | 70 | 41 | 58 | 20 | 355 | 488 | 192 | 105 | 223 | 28 |
| | Ave | 352 | 626 | 106 | 362 | 647 | 86 | 347 | 614 | 68 | 31 | 55 | 14 | 345 | 485 | 236 | 86 | 191 | 22 |

Note:
1 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

Figure 5.9-8 includes the hourly WUA per foot of channel during the three representative years for adult cutthroat trout in the Upper Reservoir Reach. The plots for the other species and life stages modeled in this reach are available in Figures A-31 through A-45 of Attachment A to Appendix 9. In all three representative years, the WUA values during the summer season are generally greater than the values in the winter season. The HSCs presented in Appendix 9 demonstrate that the greater suitability of aquatic and riparian vegetation, preference for shallower depth, and tolerance of greater flow velocity in the summer season contribute to the increased WUA values. The minimum WUA of 106 square feet per foot of channel length was calculated on March 15, 1997 (historic wet year) and during March 18, 2002 (historic average year). Both of these events occurred at times when daily load-following operations had ceased and the reservoir had begun to refill. The low water surface elevation in the Upper Reservoir Reach at these times reduced habitat area with suitable depths for adult cutthroat trout. Concurrently, the elevated flow velocities during the beginning of the refilling period were less than optimal. As the reservoir refilled, the rising water surface elevation increased depth, inundating additional habitat area. The influence of the backwater from the filling reservoir caused flow velocities to decrease. In conjunction, the WUA values increased from the minimum values. Additionally, the minimum values during the summer seasons exceeded or nearly exceeded the maximum values during the winter seasons. The minimum values during the winter seasons were approximately one-sixth of the maximum values during the summer season. As with the Canyon Reach, the sensitivity of adult cutthroat trout to flow velocities in excess of 0.5 fps during the winter months is the cause of the depressed winter season WUA values.

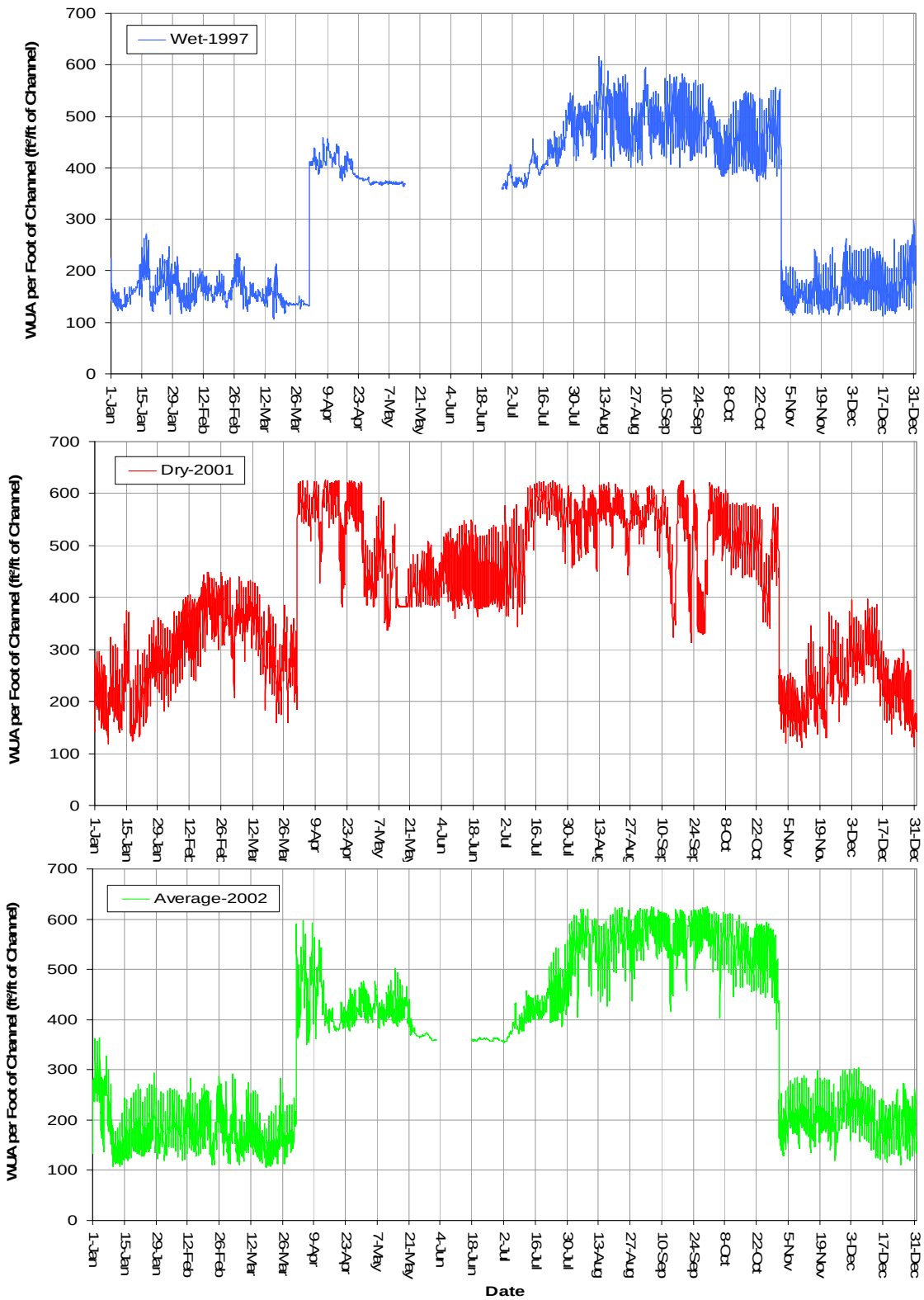



**Figure 5.9-8.** WUA for adult cutthroat trout in the Upper Reservoir Reach for the representative wet, dry, and average years.

The duration of WUA per foot of channel habitat calculated for adult cutthroat trout on a seasonal basis in the Upper Reservoir Reach is presented in Figure 5.9-9. This figure clearly shows that the winter seasons produce WUA values that are lower than the values in the summer months (wet and average years) and nearly always lower than the summer months in the dry year. The wet and average year winter months produce similar duration curves.

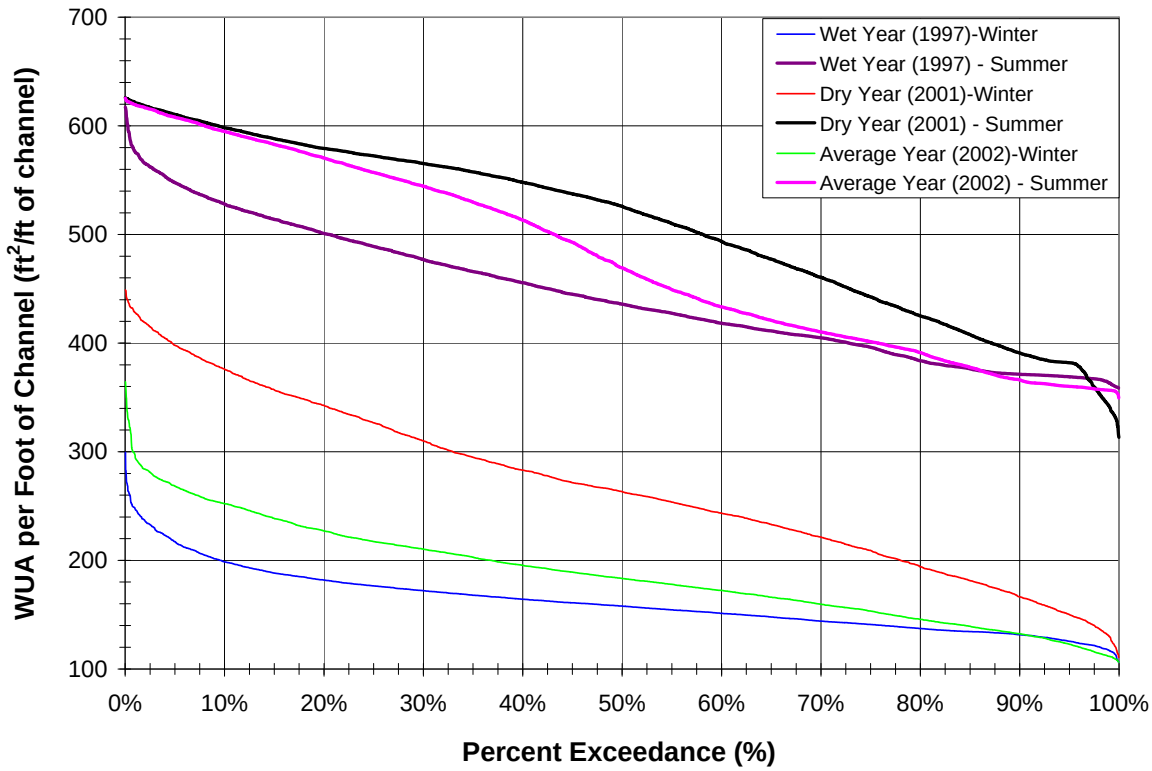



**Figure 5.9-9.** Frequency of exceedance of hourly WUA by winter and summer seasons for adult cutthroat trout in the Upper Reservoir Reach by the representative wet, dry, and average years.

### *5.9.1.4. Tailrace Reach*

The monthly mean, maximum, and minimum hourly WUA per linear foot of channel length for the Tailrace Reach on an annual basis is presented in Table 5.9-5. A channel reach length of approximately 15,600 feet was used to normalize the results presented in Table 5.9-5. WUA values computed for the Tailrace Reach were, in general, the second smallest of all the reaches. The dry year generally produced the highest WUA followed by the average year and lastly the wet year. A mean wetted width for the Tailrace Reach of 491 feet was based on a median pool of 1,732.3 feet NAVD 88 (1,728.3 feet NGVD 29) at Seven Mile Dam and a median flow rate of 22,600 cfs from Boundary Dam.

Table 5.9-5 shows that the minimum hourly calculated WUA values for the adult life stages of redband trout, cutthroat trout, and smallmouth bass during the winter season were less than during the summer period. Additionally, the maximum WUA for the adult life stages presented

in Table 5.9-5 was the greatest during the winter period. Adult cutthroat trout experienced a minimum WUA of 74 square feet per foot of channel length in the Tailrace Reach on March 16, 2002 (historic average year). This minimum occurred near dawn when power demands resulted in substantial outflows from the powerhouse and high flow velocity in the Tailrace Reach. High velocities in the winter season are unsuitable for adult cutthroat trout; the minimum WUA values reflect these conditions. In the evening when load-following operations are curtailed and outflows from the powerhouse cease, flow velocities in the Tailrace Reach decrease to near-optimal to optimal values for adult cutthroat trout. Higher spikes in WUA values were noted during these low outflow conditions.

**Table 5.9-5.** Monthly mean, maximum, and minimum hourly WUA for the Tailrace Reach for selective species and life stage for the wet, dry, and average years.

| Month | Event | WUA ($ft^2$/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Jan | Wet | 141 | 371 | 81 | 127 | 371 | 69 | 115 | 364 | 59 | -- | -- | -- | 225 | 329 | 160 | 38 | 131 | 24 |
| | Dry | 226 | 396 | 108 | 217 | 396 | 93 | 208 | 411 | 78 | -- | -- | -- | 277 | 332 | 190 | 62 | 133 | 29 |
| | Ave | 183 | 385 | 79 | 172 | 385 | 68 | 157 | 393 | 54 | -- | -- | -- | 241 | 330 | 152 | 54 | 133 | 23 |
| Feb | Wet | 145 | 260 | 90 | 130 | 254 | 77 | 119 | 238 | 67 | -- | -- | -- | 235 | 316 | 170 | 38 | 62 | 25 |
| | Dry | 263 | 395 | 111 | 256 | 395 | 95 | 247 | 412 | 79 | -- | -- | -- | 296 | 332 | 197 | 70 | 133 | 32 |
| | Ave | 194 | 392 | 90 | 183 | 392 | 76 | 171 | 404 | 62 | -- | -- | -- | 252 | 332 | 174 | 54 | 133 | 26 |
| Mar | Wet | 122 | 384 | 81 | 108 | 384 | 69 | 99 | 386 | 60 | -- | -- | -- | 206 | 330 | 157 | 32 | 107 | 24 |
| | Dry | 254 | 393 | 104 | 247 | 393 | 89 | 238 | 410 | 74 | -- | -- | -- | 294 | 332 | 195 | 68 | 132 | 30 |
| | Ave | 184 | 386 | 74 | 173 | 386 | 63 | 160 | 394 | 50 | -- | -- | -- | 244 | 332 | 144 | 52 | 131 | 21 |
| Apr | Wet | 197 | 305 | 150 | 218 | 323 | 164 | 147 | 219 | 114 | 14 | 21 | 11 | 192 | 241 | 145 | 13 | 19 | 10 |
| | Dry | 285 | 374 | 192 | 306 | 382 | 234 | 221 | 277 | 159 | 24 | 42 | 14 | 183 | 244 | 67 | 19 | 30 | 12 |
| | Ave | 237 | 379 | 148 | 258 | 385 | 165 | 179 | 278 | 115 | 18 | 41 | 12 | 200 | 248 | 68 | 16 | 30 | 11 |
| May | Wet | 164 | 174 | 156 | 180 | 192 | 170 | 122 | 129 | 118 | 11 | 12 | 11 | 154 | 165 | 147 | 11 | 12 | 10 |
| | Dry | 245 | 387 | 150 | 264 | 391 | 167 | 184 | 281 | 117 | 19 | 42 | 14 | 193 | 244 | 73 | 16 | 30 | 11 |
| | Ave | 202 | 355 | 144 | 221 | 365 | 162 | 151 | 266 | 112 | 16 | 41 | 11 | 187 | 247 | 81 | 14 | 28 | 10 |
| Jun | Wet | 182 | 213 | 155 | 201 | 237 | 169 | 135 | 158 | 117 | 13 | 15 | 10 | 175 | 206 | 147 | 12 | 14 | 10 |
| | Dry | 243 | 383 | 154 | 261 | 388 | 172 | 185 | 278 | 121 | 21 | 42 | 14 | 187 | 244 | 77 | 17 | 30 | 11 |
| | Ave | 165 | 178 | 157 | 180 | 197 | 171 | 123 | 132 | 118 | 11 | 12 | 10 | 155 | 171 | 147 | 11 | 12 | 10 |
| Jul | Wet | 226 | 364 | 165 | 248 | 371 | 184 | 167 | 273 | 125 | 16 | 28 | 11 | 206 | 245 | 157 | 14 | 21 | 11 |
| | Dry | 268 | 374 | 173 | 287 | 379 | 192 | 210 | 273 | 134 | 26 | 42 | 14 | 177 | 238 | 68 | 20 | 30 | 12 |
| | Ave | 210 | 333 | 147 | 230 | 348 | 163 | 160 | 250 | 114 | 17 | 41 | 11 | 194 | 246 | 70 | 15 | 29 | 10 |

**Table 5.9-5, continued…**

| Month | Event | WUA (ft²/ft of channel length) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adult Cutthroat | | | Adult Redband Trout[1] | | | Adult Smallmouth Bass | | | Fry Mountain Whitefish | | | Adult Mountain Whitefish | | | Cyprinids & Forage Fish (Fry & Juvenile) | | |
| | | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min | Mean | Max | Min |
| Aug | Wet | 280 | 389 | 187 | 299 | 394 | 208 | 209 | 279 | 145 | 19 | 40 | 14 | 204 | 249 | 73 | 16 | 28 | 11 |
| | Dry | 301 | 382 | 192 | 325 | 387 | 234 | 237 | 278 | 185 | 22 | 40 | 16 | 164 | 235 | 67 | 19 | 30 | 14 |
| | Ave | 290 | 384 | 205 | 312 | 389 | 226 | 220 | 278 | 158 | 19 | 38 | 14 | 190 | 244 | 71 | 17 | 28 | 12 |
| Sept | Wet | 256 | 375 | 165 | 275 | 382 | 182 | 196 | 273 | 131 | 21 | 46 | 14 | 199 | 245 | 65 | 17 | 36 | 12 |
| | Dry | 303 | 379 | 213 | 331 | 385 | 277 | 239 | 277 | 199 | 20 | 41 | 15 | 164 | 240 | 68 | 18 | 30 | 14 |
| | Ave | 282 | 379 | 195 | 303 | 385 | 215 | 219 | 276 | 173 | 23 | 43 | 15 | 187 | 238 | 66 | 19 | 33 | 13 |
| Oct | Wet | 258 | 388 | 170 | 276 | 393 | 191 | 193 | 280 | 131 | -- | -- | -- | 193 | 248 | 76 | 17 | 31 | 11 |
| | Dry | 281 | 378 | 183 | 302 | 385 | 203 | 211 | 276 | 146 | -- | -- | -- | 198 | 244 | 70 | 17 | 30 | 12 |
| | Ave | 281 | 386 | 181 | 302 | 391 | 201 | 213 | 279 | 147 | -- | -- | -- | 193 | 244 | 67 | 17 | 37 | 12 |
| Nov | Wet | 157 | 391 | 88 | 145 | 391 | 74 | 132 | 403 | 61 | -- | -- | -- | 225 | 331 | 162 | 43 | 127 | 25 |
| | Dry | 198 | 388 | 90 | 188 | 388 | 77 | 174 | 400 | 63 | -- | -- | -- | 255 | 332 | 166 | 56 | 135 | 26 |
| | Ave | 184 | 394 | 92 | 173 | 394 | 78 | 158 | 408 | 63 | -- | -- | -- | 246 | 332 | 176 | 55 | 137 | 28 |
| Dec | Wet | 178 | 388 | 95 | 167 | 388 | 81 | 153 | 399 | 67 | -- | -- | -- | 236 | 331 | 175 | 53 | 155 | 26 |
| | Dry | 201 | 396 | 110 | 192 | 396 | 95 | 178 | 413 | 84 | -- | -- | -- | 263 | 333 | 196 | 58 | 134 | 28 |
| | Ave | 201 | 396 | 96 | 191 | 396 | 82 | 180 | 412 | 67 | -- | -- | -- | 257 | 333 | 179 | 56 | 134 | 27 |
| Annual | Wet | 195 | 391 | 81 | 199 | 394 | 69 | 152 | 403 | 59 | 17 | 46 | 10 | 209 | 331 | 65 | 27 | 155 | 10 |
| | Dry | 255 | 396 | 90 | 265 | 396 | 77 | 211 | 413 | 63 | 22 | 42 | 14 | 220 | 333 | 67 | 37 | 135 | 11 |
| | Ave | 220 | 396 | 74 | 227 | 396 | 63 | 177 | 412 | 50 | 18 | 43 | 10 | 215 | 333 | 66 | 32 | 137 | 10 |

Note:

1 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

Hourly calculated WUA per foot of channel length in the Tailrace Reach for adult cutthroat trout during the representative wet, dry, and average years are shown in Figure 5.9-10. A complete set of figures for all modeled species and life stages in the Tailrace Reach is available in Figures A-46 through A-60 in Attachment A to Appendix 9. A trend similar to the ones observed in the other three reaches was noted in the Tailrace Reach. Higher WUA for adult cutthroat trout, redband trout, and smallmouth bass occurred during the summer months whereas lower values were calculated for mountain whitefish.

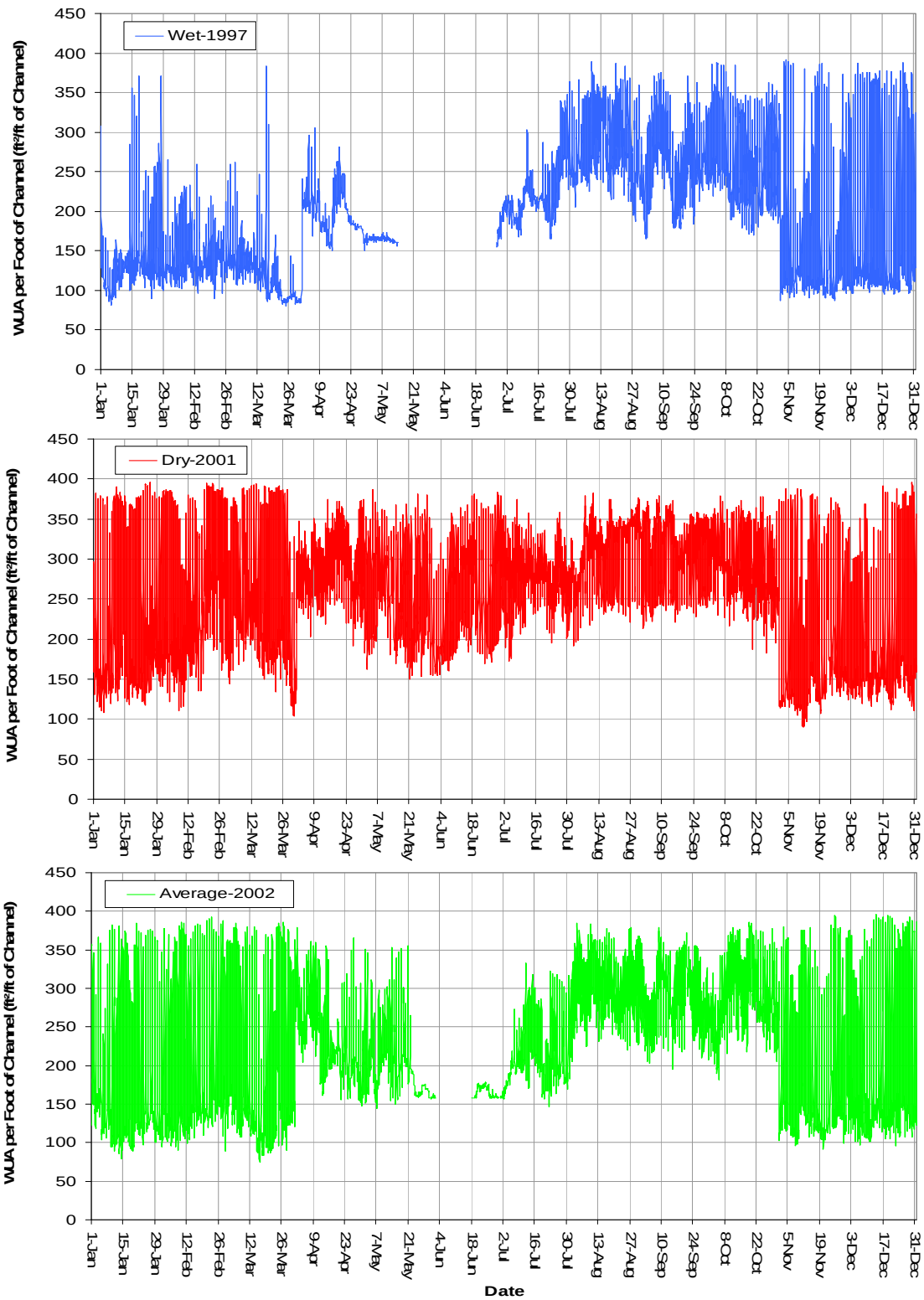



**Figure 5.9-10.** WUA for adult cutthroat trout in the Upper Reservoir Reach for the representative wet, dry, and average years.

The influence of seasonal suitability curves for velocity on adult cutthroat trout is evident in the variability of WUA shown in Figure 5.9-10. The calculated hourly WUA increased as a result of decreased velocities and depths coinciding with load-following operations ceasing around midnight. As load-following operations resume, the resulting WUA decreases to the minimum value for that day. During the winter periods, the lower velocities (associated with high WUA values) are more suitable than during summer periods; conversely, the higher velocities (associated with lower WUA values) are less suitable during the winter. Therefore, this range of WUA fluctuation is generally greater during the winter period than during the summer.

The WUA duration curves are shown in Figure 5.9-11 for adult cutthroat trout in the Tailrace Reach. The figure shows that the left side of the frequency curves for the winter period is much steeper than the right side for all three years. In contrast, the summer curves have a more uniform slope. In general, hourly WUA is greater than 170 square feet per foot of channel length 90 percent of the time during the summer period for the representative wet and average years. Hourly WUA during the summer months is greater than 210 square feet per foot of channel length 90 percent of the time during the dry year. This is in contrast to the winter period, when hourly WUA ranges from 90 to 130 square feet per foot of channel for 90 percent of the season. For both seasons, the dry year had the higher WUA values.

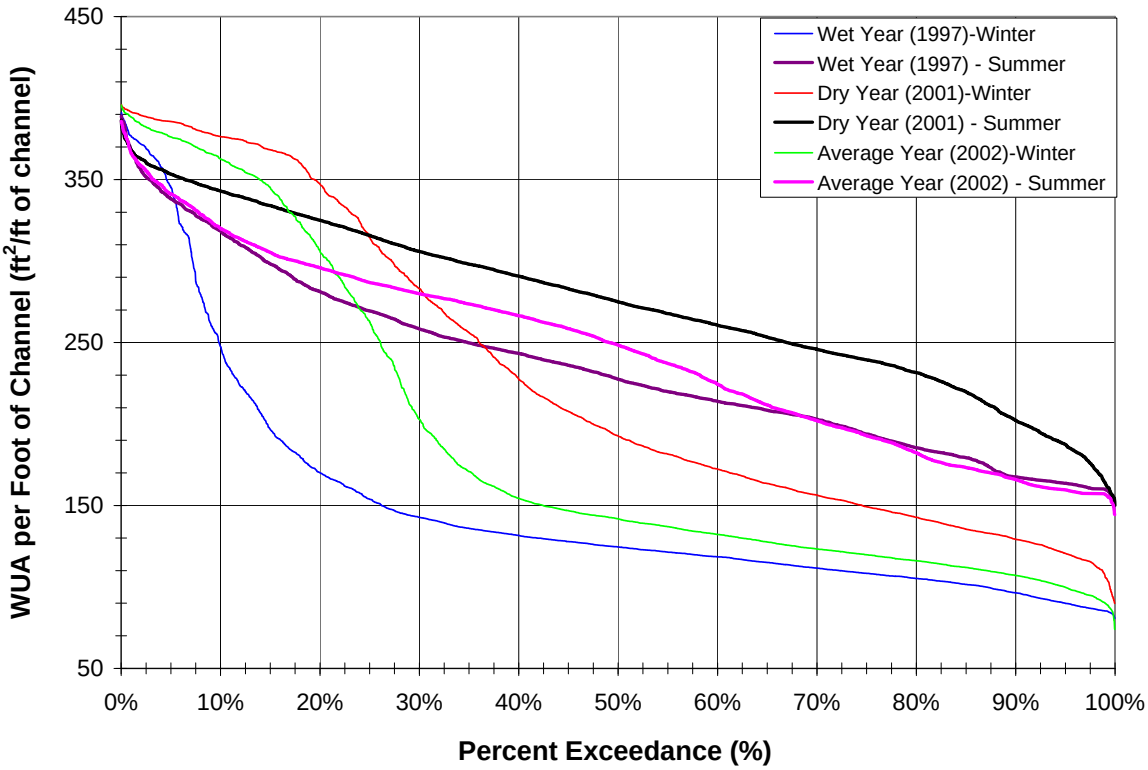



**Figure 5.9-11.** Frequency of exceedance of hourly WUA by winter and summer seasons for adult cutthroat trout in the Tailrace Reach for the representative wet, dry, and average years.

### 5.9.2. Fish Habitat – Potential and Effective Spawning Index

Indices of potential and effective spawning habitat were modeled at selected habitat transects for mountain whitefish and smallmouth bass. The habitat was represented using indices of calculated widths and the ratio of ESI width to PSI width. The PSI width was calculated as the distance along a transect at a specific point in time with suitable depth and substrate conditions for spawning. The ESI width considers inundation over the incubation period to identify only the portion of the PSI that can effectively support egg incubation. The ratio of the ESI width to the PSI width at a transect provides a measure of the influence of water surface elevation fluctuations on spawning and incubation habitat—ratios close to one indicate minimal influence whereas ratios close to zero indicate substantial influence. The transect-weighted, reach-averaged ESI width is an indicator of the modeled effective spawning habitat within a reach of the study area. Section 5.9.2.1 provides the results for mountain whitefish and Section 5.9.2.2 provides the results for smallmouth bass.

In addition to plotting the PSI and ESI widths over the spawning seasons, the outputs from the spawning model were summarized in tabular form to facilitate comparisons. Three types of tables were assembled for each fish species. One type presents the mean, maximum, and minimum daily ESI widths for the shoulder and peak seasons by habitat transect. The values in this table only reflect the spawning season, and do not include any values once the season ends—even when the incubation period extends past the end of the season. The daily values reflect hourly weighting factors applied to the hourly output; however, no seasonal weighting factors were applied. The second type of table presents the annual PSI and ESI widths at modeled habitat transect weighted by applying the seasonal factors to the mean values within each season. This table also includes a ratio of the ESI to the PSI width as an indicator of the influence of fluctuations in water surface elevation over the incubation period. Without fluctuations in the water surface elevation, the ratio would be one; a ratio of near zero indicates a substantial influence of fluctuations. The third table condenses the PSI or ESI widths for all modeled transects in a study reach into a single width value that is weighted by the PSI width at a transect relative to the total PSI width summed for all transects within the reach.

#### *5.9.2.1. Mountain Whitefish*

Attachment C to Appendix 9 includes figures of the daily PSI and ESI widths, hourly water surface elevations, and minimum water surface elevations over the incubation period. An example is provided in Figure 4.9-3. Table 5.9-6 presents the seasonal mean, maximum, and minimum ESI widths calculated from the daily-weighted values and Table 5.9-7 provides the annual-weighted PSI and ESI widths as well as the ESI to PSI ratio. Figure 5.9-12 illustrates the data in Table 5.9-7. Table 5.9-8 shows the calculated transect-weighted, reach-averaged ESI widths.

**Table 5.9-6.** Seasonal ESI widths calculated by spawning season for mountain whitefish during representative wet (1997), dry (2001), and average (2002) years.

| Transect | Season[1] | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. |
| U-05 | S1 | 539 | 580 | 500 | 419 | 500 | 382 | 499 | 552 | 427 |
| | Peak | 514 | 565 | 429 | 461 | 576 | 380 | 469 | 556 | 430 |
| | S2 | 520 | 586 | 462 | 504 | 593 | 424 | 488 | 584 | 446 |
| U-10 | S1 | 285 | 305 | 266 | 180 | 217 | 163 | 259 | 283 | 228 |
| | Peak | 291 | 373 | 252 | 232 | 296 | 162 | 247 | 284 | 230 |
| | S2 | 331 | 362 | 302 | 260 | 303 | 227 | 256 | 295 | 236 |
| U-11 | S1 | 355 | 383 | 327 | 231 | 285 | 206 | 319 | 360 | 267 |
| | Peak | 338 | 375 | 276 | 282 | 369 | 205 | 296 | 356 | 271 |
| | S2 | 342 | 387 | 298 | 314 | 377 | 266 | 309 | 377 | 279 |
| U-23 | S1 | 402 | 417 | 386 | 261 | 286 | 248 | 387 | 415 | 353 |
| | Peak | 393 | 420 | 348 | 337 | 392 | 245 | 344 | 381 | 320 |
| | S2 | 407 | 429 | 379 | 364 | 393 | 339 | 375 | 396 | 360 |
| U-24 | S1 | 355 | 380 | 331 | 348 | 393 | 325 | 364 | 404 | 338 |
| | Peak | 339 | 382 | 263 | 370 | 448 | 319 | 365 | 431 | 332 |
| | S2 | 348 | 385 | 306 | 372 | 433 | 343 | 379 | 436 | 351 |
| TR-15 | S1 | 54 | 58 | 50 | 56 | 64 | 46 | 57 | 66 | 47 |
| | Peak | 91 | 162 | 41 | 79 | 106 | 43 | 67 | 82 | 47 |
| | S2 | 75 | 91 | 54 | 75 | 93 | 59 | 61 | 77 | 46 |
| TR-16 | S1 | 64 | 68 | 58 | 65 | 74 | 54 | 67 | 78 | 55 |
| | Peak | 71 | 105 | 48 | 75 | 98 | 49 | 72 | 88 | 48 |
| | S2 | 63 | 79 | 45 | 75 | 94 | 61 | 71 | 82 | 55 |

Note:
1 S1 and S2 are shoulder spawning seasons (excluding incubation durations). S1: 10/15–10/31; Peak: 11/1–1/15; S2: 1/16–2/28.

**Table 5.9-7.** Annual PSI and ESI widths calculated for mountain whitefish during representative wet (1997), dry (2001), and average (2002) years.

| Transect | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] |
| U-05 | 534 | 509 | 0.95 | 567 | 472 | 0.83 | 566 | 477 | 0.84 |
| U-10 | 618 | 307 | 0.50 | 522 | 237 | 0.45 | 526 | 250 | 0.48 |
| U-11 | 566 | 335 | 0.59 | 516 | 289 | 0.56 | 518 | 301 | 0.58 |
| U-23 | 415 | 392 | 0.95 | 424 | 338 | 0.80 | 425 | 359 | 0.84 |
| U-24 | 346 | 334 | 0.97 | 390 | 372 | 0.95 | 383 | 367 | 0.96 |
| TR-15 | 355 | 88 | 0.25 | 303 | 78 | 0.26 | 309 | 65 | 0.21 |
| TR-16 | 564 | 69 | 0.12 | 462 | 74 | 0.16 | 477 | 71 | 0.15 |

Note:
1 Ratio is the ESI width divided by the PSI width.

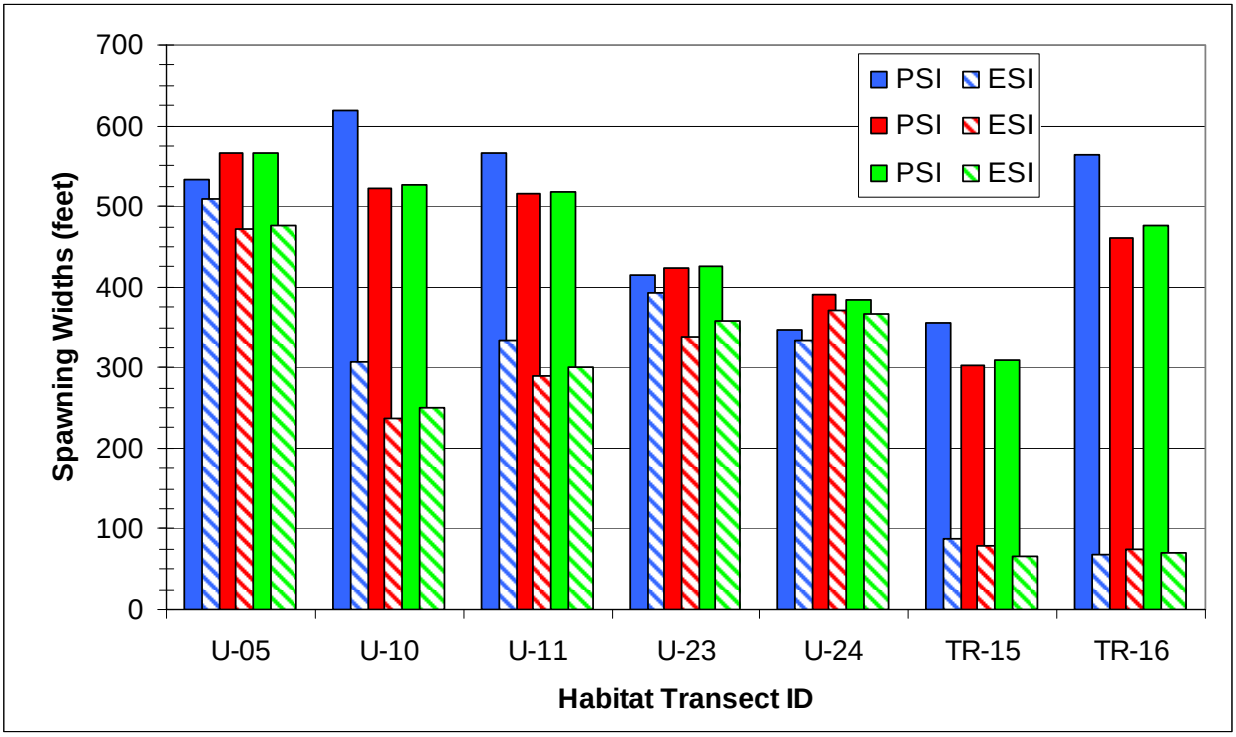



**Figure 5.9-12.** Annual PSI and ESI widths calculated for mountain whitefish at targeted habitat transects during representative wet (1997), dry (2001), and average (2002) years.

**Table 5.9-8.** Transect-weighted, reach-averaged PSI widths, ESI widths, and ESI to PSI ratios for mountain whitefish during representative wet, dry, and average years.

| Reach | Weighted Average Channel Width (feet) | Wet Year Widths (feet) | | | Dry Year Widths (feet) | | | Ave. Year Widths (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PSI | ESI | Ratio | PSI | ESI | Ratio | PSI | ESI | Ratio |
| Upper Reservoir | 1,020 | 516 | 375 | 0.73 | 493 | 343 | 0.70 | 493 | 352 | 0.71 |
| Tailrace | 491 | 483 | 76 | 0.16 | 399 | 75 | 0.19 | 411 | 68 | 0.17 |

Notes:
ESI – Effective Spawning Index
PSI – Potential Spawning Index

### *5.9.2.2. Smallmouth Bass*

Attachment C to Appendix 9 includes figures of the daily-weighted PSI and ESI widths, hourly water surface elevations, and minimum water surface elevations over the incubation period. An example is provided in Figure 4.9-3. Table 5.9-9 presents the seasonal mean, maximum, and

minimum ESI widths calculated from daily-weighted values and Table 5.9-10 provides the annual-weighted PSI and ESI widths as well as the ESI to PSI ratio. Figure 5.9-13 illustrates the data in Table 5.9-9. Table 5.9-11 shows the calculated transect-weighted, reach-averaged ESI widths.

**Table 5.9-9** Seasonal ESI widths calculated by spawning season for smallmouth bass during representative wet (1997), dry (2001), and average (2002) years.

| Transect | Season[1] | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. |
| C-06 | S1 | 62 | 85 | 38 | 0.0 | 0.0 | 0.0 | 43 | 83 | 0.0 |
| | Peak | 33 | 88 | 5.2 | 6.9 | 65 | 0.0 | 45 | 84 | 2.4 |
| | S2 | 20 | 51 | 6.8 | 41 | 47 | 36 | 4.7 | 13 | 1.9 |
| C-07 | S1 | 33 | 48 | 19 | 0.0 | 0.0 | 0.0 | 24 | 47 | 0.0 |
| | Peak | 25 | 50 | 7.6 | 4.0 | 34 | 0.0 | 29 | 47 | 6.4 |
| | S2 | 16 | 26 | 10 | 19 | 25 | 15 | 9.2 | 19 | 4.9 |
| U-05 | S1 | 0.4 | 1.3 | 0.0 | 27 | 31 | 24 | 8.7 | 23.3 | 1.9 |
| | Peak | 2.2 | 11 | 0.0 | 27 | 31 | 23 | 3.8 | 15.2 | 1.2 |
| | S2 | 17 | 26 | 4.8 | 26 | 31 | 23 | 22 | 30 | 11 |
| U-06 | S1 | 15 | 19 | 14 | 0.4 | 1.6 | 0.0 | 15 | 20 | 3.7 |
| | Peak | 6.2 | 16 | 1.0 | 0.0 | 0.0 | 0.0 | 7.3 | 20 | 0.0 |
| | S2 | 1.6 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| U-07 | S1 | 58 | 68 | 23 | 0.2 | 1.0 | 0.0 | 17 | 26 | 2.9 |
| | Peak | 17 | 60 | 1.2 | 0.0 | 0.0 | 0.0 | 8.1 | 20 | 0.0 |
| | S2 | 0.9 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| U-10 | S1 | 6.6 | 9.9 | 3.4 | 3.5 | 4.8 | 1.8 | 9.3 | 12 | 6.5 |
| | Peak | 3.3 | 10 | 0.5 | 2.1 | 2.3 | 1.8 | 4.1 | 10 | 1.0 |
| | S2 | 3.5 | 5.0 | 1.6 | 2.0 | 2.4 | 1.8 | 1.8 | 2.2 | 1.3 |
| U-16 | S1 | 2.0 | 4.4 | 1.2 | 40 | 48 | 29 | 26 | 47 | 8.7 |
| | Peak | 8.9 | 33 | 1.0 | 20 | 36 | 10 | 11 | 30 | 4.1 |
| | S2 | 28 | 48 | 4.1 | 8.1 | 9.8 | 6.1 | 16 | 37 | 6.6 |
| U-17 | S1 | 2.2 | 5.2 | 1.2 | 69 | 89 | 42 | 32 | 77 | 7.2 |
| | Peak | 11 | 47 | 0.5 | 48 | 58 | 40 | 12 | 41 | 4.3 |
| | S2 | 52 | 85 | 26 | 41 | 48 | 35 | 36 | 51 | 18 |
| U-21 | S1 | 11 | 15 | 9.4 | 38 | 61 | 15 | 46 | 86 | 16 |
| | Peak | 21 | 73 | 1.8 | 17 | 20 | 14 | 15 | 56 | 7.1 |
| | S2 | 36 | 59 | 8.8 | 14 | 16 | 12 | 13 | 17 | 6.0 |

Note:
1 S1 and S2 are shoulder spawning seasons (excluding incubation durations). S1: 5/15–5/31; Peak: 6/1–7/15; S2: 7/16–7/31.

**Table 5.9-10.** Annual PSI and ESI widths calculated for smallmouth bass during representative wet (1997), dry (2001), and average (2002) years.

| Transect | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] |
| C-06 | 82 | 35 | 0.43 | 54 | 11 | 0.20 | 78 | 38 | 0.49 |
| C-07 | 47 | 25 | 0.53 | 32 | 5.7 | 0.18 | 45 | 25 | 0.56 |
| U-05 | 4.3 | 4.1 | 0.95 | 27 | 27 | 1.00 | 7.3 | 7.3 | 1.00 |
| U-06 | 15 | 6.8 | 0.45 | 4.4 | 0.1 | 0.01 | 17 | 7.3 | 0.43 |
| U-07 | 42 | 21 | 0.49 | 5.2 | 0.0 | 0.01 | 20 | 8.3 | 0.42 |
| U-10 | 8.4 | 3.8 | 0.45 | 6.2 | 2.3 | 0.37 | 10 | 4.5 | 0.45 |
| U-16 | 16 | 11 | 0.66 | 43 | 21 | 0.50 | 22 | 14 | 0.63 |
| U-17 | 19 | 16.1 | 0.86 | 77 | 50 | 0.65 | 27 | 19 | 0.70 |
| U-21 | 33 | 22 | 0.66 | 53 | 20 | 0.37 | 39 | 19 | 0.50 |

Note:
1 Ratio is the ESI width divided by the PSI width.

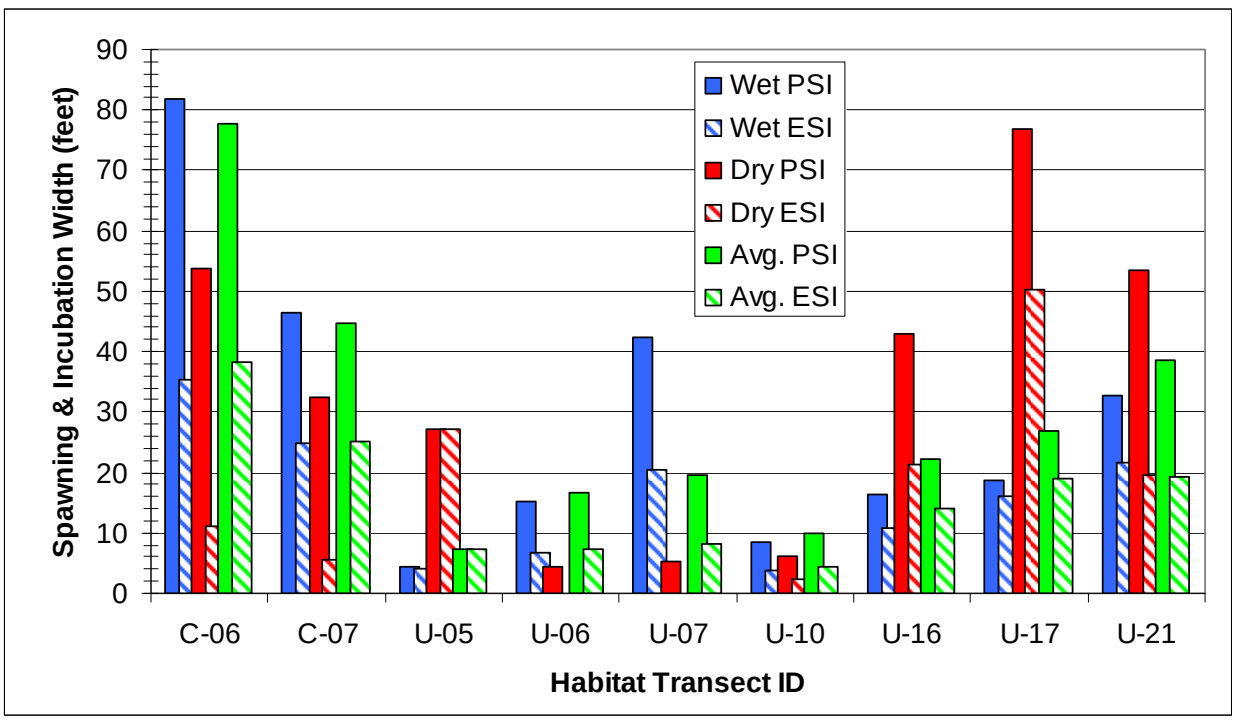



**Figure 5.9-13.** Annual PSI and ESI widths calculated for smallmouth bass at targeted habitat transects during representative wet (1997), dry (2001), and average (2002) years.

**Table 5.9-11.** Transect-weighted, reach-averaged PSI widths, ESI widths, and ESI to PSI ratios for smallmouth bass during representative wet, dry, and average years.

| Reach | Weighted Average Channel Width (feet) | Wet Year Widths (feet) | | | Dry Year Widths (feet) | | | Ave. Year Widths (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PSI | ESI | Ratio | PSI | ESI | Ratio | PSI | ESI | Ratio |
| Canyon[3] | 538[1] | 69 | 32 | 0.46 | 46 | 9.0 | 0.20 | 66 | 34 | 0.51 |
| Upper Reservoir | 1,020 | 28 | 16 | 0.57 | 53 | 30 | 0.57 | 25 | 14 | 0.56 |

Notes:
1 Average width of side channel to the west of Everett Island is approximately 306 feet.
ESI – Effective Spawning Index
PSI – Potential Spawning Index

### *5.9.2.3. General Discussion of Mountain Whitefish and Smallmouth Bass Spawning Index Widths*

The plots of model output provided in Attachment C to Appendix 9 as well as the tables and figures in the previous two sections are useful for illustrating common trends in the indices of potential and effective spawning habitats for mountain whitefish and smallmouth bass. Before examining these trends, it is helpful to consider the spawning preferences and incubation requirements of both mountain whitefish and smallmouth bass. Optimal spawning habitat for mountain whitefish occurs in depths between 1.5 and 10 feet, with substrate between medium gravel and small cobbles (e.g., approximately 0.5-inch to 6-inch diameter). Depths up to 30 feet were modeled as suitable for spawning. The 61-day incubation period means that spawning areas need to stay continuously inundated for 61 days after spawning for effective egg incubation. Optimal spawning habitat for smallmouth bass is found in depths between 2.0 and 5.0 feet, with medium gravel substrate (e.g., approximately 0.5-inch to 1.5-inch diameter). Depths up to 30 feet were modeled as suitable for spawning; however, the suitability in depths greater than 12 feet was very low (HSI value = 0.1). Comparing these conditions reveals that smallmouth bass have more restrictive spawning preferences than mountain whitefish.. This comparison is supported by comparing model output at common habitat transects such as U-05 and U-10. The ESI widths calculated during the representative years at these transects are approximately one to two orders of magnitude greater for mountain whitefish than for smallmouth bass.

The relationship between effective spawning habitat and reservoir water surface elevation depends on the position of potential spawning habitat in relation to the location of Metaline Falls. Upstream of Metaline Falls, the hydraulic control provided by the falls dampens the fluctuations in water surface elevation associated with Project operations; however, the water surface elevation fluctuations resulting from the rising and falling of the runoff hydrograph are more pronounced. Downstream of Metaline Falls, the backwater effect of Boundary Dam dampens the rising and falling of the runoff hydrograph; however, the Canyon and Forebay reaches are exposed to the full range of the daily fluctuations associated with Project operations. Excepting the smallmouth bass spawning habitat in the Canyon Reach, the figures in Attachment C of

Appendix 9 show for both fish species, across the three representative hydrologic years, the ESI widths generally vary inversely with water surface elevation. Lower water surface elevations concentrate wetted areas to the deeper portions of the varial zone, locations where substrate is typically gravel and cobble instead of sand and fines. Additionally, spawning at lower elevation increases the likelihood that the nest will remain inundated over the incubation period. Thus, the daily minimum water surface elevations appear to be the most influential in calculating the ESI widths because the spikes in ESI width correspond with the lowest water surface elevations. Given the fluctuations in water surface elevation resulting from Project operations, the spikes in ESI are no longer than a few days in duration, returning to lower widths when the water surface elevation increases. Downstream of Metaline Falls, the width of smallmouth bass spawning habitat in the Canyon Reach is directly influenced by reservoir water surface elevation. When Project operations during dry years lead to pronounced daily fluctuations in reservoir surface elevation and lower daily minimum water surface elevations than in wet and average years, the dewatering of spawning smallmouth bass habitats adjacent to Everett Island restricts effective spawning areas. However, during wet and average years, the magnitude of the flow in the Pend Oreille River between mid-May and the beginning of July reduces the magnitude of reservoir water surface elevation fluctuations resulting from Project operations and greater amounts of potential spawning habitat stay inundated over the incubation period. The magnitude of the annual ESI to PSI ratios compared across the representative years at these transects illustrates this observation—the dry year ratio is less than half of the wet and average year ratios.

The greatest PSI and ESI widths calculated for mountain whitefish in the Upper Reservoir Reach generally occur during the wet year, and the lowest widths were calculated in the dry year. The minimum water surface elevations over the incubation period during the wet and average years were higher than during the wet year, so greater amounts of spawning habitat were effective for egg incubation. Conversely, the PSI and ESI widths calculated for smallmouth bass in the Upper Reservoir Reach were greatest during the dry year, with the wet and average years having similar but lower values. The lack of major peak flows during the dry year meant that there was not a pronounced falling limb of the runoff hydrograph in the Upper Reservoir Reach that would continuously dewater potential spawning habitat as flow magnitude receded. Despite this difference between the optimal conditions for both species in the Upper Reservoir Reach, the ratios of ESI to PSI widths were generally similar when comparing across representative years for each species (the exception being smallmouth bass in the Canyon Reach, which was discussed in the previous paragraph). While the relative magnitudes of the PSI widths are greater for the mountain whitefish than for the smallmouth bass, the corresponding ESI widths are also greater. Figures 5.9-11 and 5.9-12 help to illustrate this comparison. The more specific velocity, substrate, and depth spawning preferences for smallmouth bass, coupled with the shorter incubation period, contribute to the relatively smaller ESI width values.

The PSI and ESI widths calculated for mountain whitefish in the Tailrace Reach were consistent across the three modeled years. The similarity of typical daily load-following operations in all three years resulted in the consistent patterns.

When considering the transect-weighted, reach-averaged ESI widths for the modeled reaches in the study area for mountain whitefish, the Upper Reservoir Reach stands out as the reach with the greatest ESI width during all three representative years. Despite similarity between the PSI

widths for mountain whitefish in the Upper Reservoir and Tailrace reaches, the ESI width modeled in the Upper Reservoir Reach was approximately five times greater than the ESI width modeled in the Tailrace Reach. This difference is attributed to fluctuations in water surface elevation that were two to three times greater in the Tailrace Reach, dewatering more of the potential spawning areas over the incubation period. For both species, the Upper Reservoir Reach exhibited the greatest ratios of ESI width to PSI width across representative years. This result is due to the reduced daily variability in reservoir water surface elevation in the Upper Reservoir Reach as compared to the fluctuations in the Canyon Reach and the Tailrace Reach.

At the habitat transects represented in the spawning models, for the three hydrologic years evaluated, the lack of optimally sized substrate at preferred spawning depths constrains the PSI width, and the dewatering of these areas over the incubation period limits the ESI width. Although changes to the substrate sizes within optimal depths could increase calculated PSI widths, the ESI widths may not increase if these areas are dewatered during the incubation periods.

# 6 CONCLUSIONS

Study 7 investigated the aquatic habitat associated with the mainstem of the Pend Oreille River from Box Canyon Dam downstream to the confluence with Red Bird Creek in Canada. Operation of the Project influences water surface elevations and flow rates throughout the study area. These influences can result in changes to physical habitat conditions associated with depth and velocity and also result in cyclic inundation and dewatering of the shallow water habitats. Because of the potential for Project operations to influence aquatic habitat conditions in the mainstem of the Pend Oreille River, Study 7 was conducted.

Study 7 primarily utilized indices to describe various components of the habitat. Indices can be generated for habitat components of interest to compare between operations scenarios. In this final report, the indices and other habitat analyses were generated for the historic operation conditions for representative wet, dry, and average hydrologic years selected from the period of 1987 through 2005. Future application of the models developed in Study 7, along with results of the Scenario Tool, will be utilized to evaluate mainstem aquatic habitat conditions under operations scenarios. The results of the habitat modeling for the operations scenarios will be compared against the results of a baseline scenario to determine the relative effects of the operation scenarios on mainstem aquatic habitat. This effort will be carried out in interactions with the relicensing participants during the Integrated Resource Analysis (IRA) process in 2009 and documented in the License Application (LA).

The indices modeled in Study 7 included fish stranding, fish trapping, fish weighted useable area (WUA), aquatic macrophyte WUA, periphyton WUA, benthic macroinvertebrate (BMI) WUA, and spawning indices. The spawning indices include the potential spawning index (PSI) and the effective spawning index (ESI). In addition to these indices, a Hydraulic Routing Model (HRM) was developed to determine hourly water surface elevations and flow rates throughout the study area. The hourly water surface elevations and flow rates were used to estimate depths and velocities across habitat transects using a calibrated Physical Habitat Simulation (PHABSIM) modeling procedure. The HRM was utilized to determine historic downramping rates

throughout the study area. The HRM also provided valuable insight into the response of the Pend Oreille River to Project operations, including the influence of the hydraulic control at Metaline Falls.

The conclusions presented in this section provide a summary of important aspects of the mainstem aquatic habitat conditions and Project effects for historic operations as represented by the wet, dry, and average years from the hydrologic record. Study 7 does not comprise the entire analysis of aquatic habitat conditions and Project effects for historic operations in the study area. The Study 7 analysis was conducted in conjunction with Study 8 (SCL 2009a), Study 9 (SCL 2009b), and Study 11 (SCL 2009c). Study 8 investigated the habitat on the major tributary deltas and the sediment transport processes on the deltas and in the mainstem. Study 8 made extensive use of the HRM developed in this study to model inundation and dewatering of the delta areas and in developing the mainstem sediment model. Study 9 was conducted to provide information on the distribution, relative abundance, and periodicity of different life stages for various fish species of interest in order to examine the potential effects of historic project operations on mainstem aquatic habitat conditions. Under Study 9, passive and active fish sampling was conducted in Boundary Reservoir, the Tailrace Reach, and selected tributaries to the reservoir. Both shallow water habitats (considered to be depths <10 feet in Study 9) and habitats with depths greater than 10 feet were sampled in the reservoir and tailrace using a variety of gear types. The correspondence between Study 9 findings and how they pertain to Study 7 are summarized in this section. Study 11 investigated primary and secondary production in the mainstem of the Pend Oreille River. Part of the analysis in Study 11 relied on application of the WUA indices developed in this study for submerged aquatic macrophytes, periphyton, and BMI. In addition to utilizing the physical parameters applied to the WUA determination for these biota, Study 11 used nutrient and biological elements to develop an index to evaluate production in Boundary Reservoir and its tailrace.

## 6.1. Background Information

The presence and distribution of shallow water habitats identified in Study 7 and the observed fish assemblages developed in Study 9 are important in understanding and interpreting the modeling results from Study 7.

### 6.1.1. Shallow Water Habitats

The Pend Oreille River and Boundary Reservoir within the study area have depths up to 300 feet. Though a wide range of depths are present, the shallow water habitats, in the 0- to 20-foot depth range, are potentially more productive than the deep water habitats. These shallow water habitats are critical to a variety of fish species during certain times of the year. This is reflected in the Habitat Suitability Index (HSI) curves that for adult fish generally start falling below their optimum values at depths greater than 20 to 30 feet. For younger life stages and spawning, the depth suitability drops off steeply before depths of 10 feet are reached. Results of the passive and active sampling and biotelemetry components of Study 9 also support the seasonal importance of shallow water habitat, especially for spawning and early rearing of most fish species. For macrophytes, periphyton, and BMI, the depth HSI curves start falling from their optimum values at 12, 11, and 22 feet, respectively.

The distribution of shallow water habitats within the three study reaches comprising Boundary Reservoir is presented in Table 6.1-1a. Similar information for the Tailrace Reach, the portion of the study area below Boundary Dam, is provided in Table 6.1-1b. The areas are divided into depths of 0 to 10 feet (shallow water habitat as identified in Study 9), 10 to 20 feet, and 0 to 20 feet (representing the sum of the previous two depth ranges). The areas are presented for three combinations of forebay elevations and hydrologic conditions (Boundary Inflow from Box Canyon). For discussion purposes, the median pool median flow condition is discussed, but similar trends hold true for the other two conditions.

- Over 86 percent of the shallow water habitat in Boundary Reservoir is in the Upper Reservoir Reach (median pool/median flow condition).
- The Forebay Reach has the least amount of shallow water habitat with about 4 percent of the total within Boundary Reservoir (median pool, median flow condition).
- The Tailrace Reach has about one-fifth the amount of shallow water habitat as the Upper Reservoir Reach (median pool/median flow condition).

**Table 6.1-1a.** Summary of shallow water habitat areas within Boundary Reservoir (Forebay, Canyon and Upper Reservoir reaches), in terms of average channel width, area, and by percentages.

| Reach | | | Depth 0 to 10 feet | | | Depth 10 to 20 feet | | | Depth 0 to 20 feet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length[1] (ft)** | **Weighted Average Channel Width[2] (ft)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** |
| **Low Pool/Low Flow Condition[3]** | | | | | | | | | | | |
| Forebay | 5,360 | 1,722 | 84 | 45 | 3 | 106 | 57 | 5 | 189 | 101 | 4 |
| Canyon | 44,156 | 474 | 28 | 124 | 9 | 34 | 149 | 13 | 62 | 272 | 11 |
| Upper Reservoir | 38,549 | 663 | 332 | 1,278 | 88 | 234 | 900 | 81 | 565 | 2,179 | 85 |
| Total Boundary Reservoir | 88,065 | 630 | 164 | 1,447 | 100 | 126 | 1,106 | 100 | 290 | 2,553 | 100 |
| **Median Pool/Median Flow Condition[4]** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 102 | 55 | 4 | 102 | 54 | 4 | 204 | 109 | 4 |
| Canyon | 44,156 | 538 | 42 | 184 | 12 | 27 | 118 | 8 | 68 | 302 | 10 |
| Upper Reservoir | 38,549 | 1,020 | 328 | 1,265 | 84 | 326 | 1,258 | 88 | 654 | 2,522 | 86 |
| Total Boundary Reservoir | 88,065 | 827 | 171 | 1,503 | 100 | 162 | 1,431 | 100 | 333 | 2,934 | 100 |
| **High Pool/High Flow Condition[5]** | | | | | | | | | | | |
| Forebay | 5,360 | 1,849 | 84 | 45 | 5 | 133 | 71 | 5 | 217 | 116 | 5 |
| Canyon | 44,156 | 553 | 37 | 166 | 20 | 33 | 145 | 10 | 70 | 311 | 13 |
| Upper Reservoir | 38,549 | 1,148 | 158 | 609 | 74 | 335 | 1,292 | 86 | 493 | 1,901 | 82 |
| Total Boundary Reservoir | 88,065 | 892 | 93 | 819 | 100 | 171 | 1,509 | 100 | 264 | 2,329 | 100 |

Notes:
1 Length based on distance used for weighting of habitat transects and may vary slightly from total length between reach limits.
2 Cross section weighted, reach-averaged channel width
3 Boundary forebay elevation = 1,974.00 NAVD 88 (1,969.97 NGVD 29), Boundary inflow = 10,700 cfs
4 Boundary forebay elevation = 1,989.77 NAVD 88 (1,985.74 NGVD 29), Boundary inflow = 19,500 cfs
5 Boundary forebay elevation = 1,994.00 NAVD 88 (1,989.97 NGVD 29), Boundary inflow = 55,000 cfs

**Table 6.1-1b.** Summary of shallow water habitat areas below Boundary Dam (Tailrace Reach), in terms of average channel width, area, and by percentages.

| Reach | | | Depth 0 to 10 feet | | | Depth 10 to 20 feet | | | Depth 0 to 20 feet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length[1] (ft)** | **Weighted Average Channel Width[2] (ft)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** | **Channel Width (ft)** | **Area (10,000 ft$^2$)** | **Percent Area (%)** |
| **Low Pool/Low Flow Condition[3]** | | | | | | | | | | | |
| Tailrace | 15,613 | 383 | 135 | 211 | 100 | 130 | 203 | 100 | 265 | 414 | 100 |
| **Median Pool/Median Flow Condition[4]** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 94 | 146 | 100 | 137 | 214 | 100 | 231 | 361 | 100 |
| **High Pool/High Flow Condition[5]** | | | | | | | | | | | |
| Tailrace | 15,613 | 544 | 72 | 113 | 100 | 113 | 176 | 100 | 185 | 289 | 100 |

Notes:
1 Length based on distance used for weighting of habitat transects and may vary slightly from total length between reach limits.
2 Cross section weighted, reach-averaged channel width
3 Seven Mile forebay elevation = 1,715.68 NAVD 88 (1,711.65 NGVD 29), Boundary outflow = 5,900 cfs
4 Seven Mile forebay elevation = 1,727.00 NAVD 88 (1,722.97 NGVD 29), Boundary outflow = 22,600 cfs
5 Seven Mile forebay elevation = 1,732.28 NAVD 88 (1,728.25 NGVD 29), Boundary outflow = 55,000 cfs

Water surface elevation fluctuations, such as those associated with Project operations and seasonal changes in inflow from upstream storage and hydropower projects affect shallow water habitats more than deep water habitats. Typical Boundary Project load following operations can occur between elevation 1,974 and 1,994 feet NAVD 88 (1,970 and 1,990 feet NGVD 29) during the fall, winter, and spring. Between Labor Day and Memorial Day, Project operations generally occur between 1,984 and 1,994 feet NAVD 88 (1,980 and 1,990 feet NGVD 29). The reduced range in the summer period is a result of voluntary restrictions on fluctuations in water surface elevations SCL implements to enhance recreational resource values. Since load-following operations occur within the range of elevations coinciding with the shallow water habitat, Project operations have the potential to influence the portion of the aquatic habitat with the highest potential productivity. However, the level of influence varies with location, time of year, and inflow. A large factor that can reduce the level of Project effects on the aquatic habitat in the Upper Reservoir Reach, the reach with the majority of the shallow water habitat, is the influence of Metaline Falls. Important aspects concerning water surface elevation fluctuations associated with Project operations are listed below:

- Water surface elevation fluctuations in the Forebay Reach are replicated up through the Canyon Reach to the base of the hydraulic control at Metaline Falls.
- Metaline Falls attenuates or dampens water surface elevation fluctuations for the areas upstream of Metaline Falls.
- Water surface elevation fluctuations in the Tailrace Reach result from a combination of changes in outflow from Boundary Dam during load following operations and changes in the Seven Mile Dam forebay elevation.
- When inflows exceed Project turbine capacity, approximately 55,000 cfs, forebay water surface elevations are held fairly constant and Project operational effects are minimal throughout the three reaches above Boundary Dam and in the Tailrace Reach.

The combination of the influence of Metaline Falls on reducing water surface elevation fluctuations in the Upper Reservoir Reach and the majority of the shallow water habitat occurring in the Upper Reservoir Reach are reflected in the habitat modeling results that distinguish this reach from the other reaches.

### 6.1.2. Observed Fish Assemblages

The physical characteristics of each of the reaches translate into differences in fish habitat and corresponding fish communities. The extensive shallow water, off channel, and riverine-like conditions in the Upper Reservoir Reach provide for a wide range of habitat conditions supportive of a diverse assemblage of fish. The Canyon and Forebay reaches are more reservoir-like, with depths that may exceed 200 feet and lower water velocities often with very steep topography along channel margins. The Tailrace Reach provides a mix of conditions, ranging from boulder-studded, riverine-like conditions with moderate velocities proximal to the Boundary Dam to more reservoir-like conditions farther downstream in Seven Mile Reservoir.

The fish assemblage of the Boundary Reservoir and tailrace includes a variety of non-native and native species. During the course of all sampling (monthly study sites and supplemental sample locations), nearly 90,000 fish representing at least 28 species and 9 families were observed or

captured. Overall study catch (catch at monthly study sites only) totaled 34,813 fish, with 21,389 fish captured in the mainstem of the Boundary reservoir and tailrace. Of the total mainstem reservoir study catch, 94 percent of the catch was in shallow water habitat less than 10 feet deep, while 6 percent of the catch was in water deeper than 10 feet. Dominant species by number captured in the mainstem during the 2007 and 2008 study in all gears were largescale sucker (44 percent), yellow perch (14 percent), smallmouth bass (11 percent), triploid rainbow trout (7 percent), northern pikeminnow (6 percent), pumpkin seed (5 percent), and peamouth (5 percent). Some native salmonids including bull trout, cutthroat trout, redband rainbow trout (tailrace), and mountain whitefish are present in very low abundance in the mainstem. The majority of the cutthroat trout and wild rainbow trout catch were encountered in the lower reaches of selected tributaries to the reservoir. Species catch composition varied among the Project reaches.

Catostomids (mostly largescale sucker) dominated the catch across all Project reaches and reached their highest relative abundance in the Forebay Reach. Cyprinids (primarily northern pikeminnow and peamouth) reached their highest relative abundance in the Upper Reservoir and Canyon reaches but were notably less common in the Forebay Reach and Tailrace Reach catches. Centrarchids (mostly smallmouth bass and pumpkinseed) comprised between 11 and 24 percent of the catch in each of the reaches, reaching their peak in relative abundance in the Canyon Reach. Percids (primarily yellow perch with a few walleye) accounted for between 12 and 19 percent of the catch across the three reservoir reaches, but were markedly lower in the Tailrace Reach (3 percent). Ictalurids and Esocids were captured primarily in the Upper Reservoir Reach. Both native and non-native salmonids reached their peak in mainstem relative abundance in the Upper Reservoir Reach followed by the Tailrace Reach.

Most salmonids captured or observed within mainstem habitats were either hatchery triploid rainbow trout or non-native species. Triploids comprised 76 percent of the total salmonid catch. Native salmonids, mountain whitefish, cutthroat trout, bull trout, and redband trout (in the tailrace only) comprised only 1.2 percent of the total reservoir and tailrace mainstem study catch. Mountain whitefish were the dominant native salmonid catch in the mainstem reservoir and tailrace reaches, with 179 fish representing 72 percent of the native salmonid catch. Gravid mountain whitefish females were captured at the mouth of Sullivan Creek, Boundary Tailrace, and in the upper one-half mile of the Upper Reservoir Reach, suggesting mainstem and possibly tributary spawning sites. Redband rainbow trout was the most commonly captured native salmonid in the tailrace. Forty-two wild rainbow trout that may have been native redband trout were included in the Tailrace Reach study catch, but no juvenile fish were captured. Only 25 cutthroat trout were captured in the mainstem tailrace and reservoir reaches. Most mainstem cutthroat trout were captured in the Tailrace and Upper Reservoir reaches. Most (540 of 565 specimens) of the total cutthroat trout study catch occurred in the lower reaches of selected tributaries. Both cutthroat trout and mountain whitefish (along with wild rainbow trout) were captured in downstream migrant traps in Sweet, Slate, and Sullivan creeks, especially in 2007 sampling, suggesting the tributaries may provide a source of native salmonids to the reservoir.

## 6.2. Conclusions by Reach

This section of the conclusions provides further discussion of the existing conditions and Project effects by reach. The four reaches and their locations by Project river mile (PRM) are given

below (these were described in Section 3, but the information is repeated here for the reader's convenience):

*Boundary Reservoir (Above Boundary Dam)*

- Forebay Reach—Boundary Dam to downstream end of Z Canyon to (PRM 17.0–18.0)
- Canyon Reach—Downstream end of Z Canyon to Metaline Falls to (PRM 18.0–26.8)
- Upper Reservoir Reach— Metaline Falls to Box Canyon Dam (PRM 26.8-34.5)

*Boundary Tailrace (Below Boundary Dam)*

- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

To facilitate the discussion, several tables are provided that summarize the various indices. Each table provides the average indices for the wet, dry, and average years for the four reaches. Table 6.2-1a and 6.2-1b provide a summary of the stranding and trapping indices (separate tables are provided for Boundary Reservoir and Boundary tailrace). Tables 6.2-2a and 6.2-2b provide the summary for selected species and life stages for the fish WUA. The average WUA indices for macrophytes, periphyton, and BMI are presented in Table 6.2-3a and 6.2-3b. The transect-weighted, reach-averaged PSI width, ESI widths, and ratios of ESI to PSI for applicable reaches are presented in Tables 6.2-4 for the three representative years. The fish species utilized for the effective spawning analysis were mountain whitefish and smallmouth bass. The transect-weighted, reach-averaged downramping rates for the representative average year are presented in Figure 6.2-1 for all four reaches.

Use of model indices does not imply that there is a positive linear relationship between WUA and fish abundance. Fish species abundance may be related to past and current habitat limitations for any life stage as well as other conditions such as water temperature and relatively low primary productivity that are not included in the habitat modeling. Hence, instantaneous estimates of habitat suitability may not necessarily be related to instantaneous population size. There are factors other than depth, velocity, and substrate determining the WUA that may limit fish populations. These other factors may include food availability, predator-prey interactions, "bottleneck effects" between winter and summer habitat, and macrohabitat conditions that are not considered in the computation of WUA, including turbidity, seasonal variability in water temperatures, and other environmental conditions that may limit the species in question. Results of the passive and active fish sampling are integrated into the following sections in order to provide comparisons among model results and observed fish communities under existing conditions. These comparisons are provided for context with regard to observed patterns of fish use and model indices used to describe habitat availability.

**Table 6.2-1a.** Summary of total annual stranding index and trapping index for Boundary Reservoir (Forebay, Canyon and Upper Reservoir reaches) for wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** |
| **Stranding Index (SI)** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 6.4 | 1,250 | 1 | 4.8 | 940 | 0.5 | 2 | 400 | 0.3 |
| Canyon | 44,156 | 538 | 4.4 | 7,075 | 7 | 2.3 | 3,668 | 2 | 1.7 | 2,700 | 2 |
| Upper Reservoir | 38,549 | 1,020 | 63 | 88,943 | 91 | 120 | 168,200 | 97 | 91 | 128,112 | 98 |
| Total Boundary Reservoir | 88,065 | 827 | 30 | 97,267 | 100 | 54 | 172,808 | 100 | 41 | 131,212 | 100 |
| **Trapping Index (TI)** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | n/a[2] | 1.1 | 0.1 | n/a[2] | 2.4 | 0.1 | n/a[2] | 1 | 0.1 |
| Canyon | 44,156 | 538 | n/a | 163 | 9 | n/a | 160 | 4 | n/a | 93 | 4 |
| Upper Reservoir | 38,549 | 1,020 | n/a | 1,616 | 91 | n/a | 3,916 | 96 | n/a | 2,478 | 96 |
| Total Boundary Reservoir | 88,065 | 827 | n/a | 1,780 | 100 | n/a | 4,079 | 100 | n/a | 2,572 | 100 |

Notes:

1 Cross section weighted, reach-averaged channel width based on a Boundary Forebay elevation of 1,989.77 feet NAVD 88 (1985.74 feet NGVD 29) and Boundary inflow of 19,500 cfs.

2 Weighted channel widths on a daily basis were not computed for the TI since trapping events can occur over several days and trapping occurs in discreet pools concentrated in specific areas along the channel.

**Table 6.2-1b.** Summary of total annual stranding index and trapping index Below Boundary Dam (Tailrace Reach) for wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** | **Average Daily Weighted Channel Width of Exposed Stranding Area (ft)** | **Annual Total Stranding or Trapping Area (10,000 ft$^2$)** | **Percent of Total Stranding or Trapping Area (%)** |
| **Stranding Index (SI)** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 4 | 2,473 | 100 | 4 | 2,490 | 100 | 5 | 2,600 | 100 |
| **Trapping Index (TI)** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | n/a[2] | 139 | 100 | n/a[2] | 213 | 100 | n/a[2] | 163 | 100 |

Notes:

1 Cross section weighted, reach-averaged channel width based on a Boundary Forebay elevation of 1,989.77 feet NAVD 88 (1985.74 feet NGVD 29) and Boundary inflow of 19,500 cfs.

2 Weighted channel widths on a daily basis were not computed for the TI because trapping events can occur over several days and trapping occurs in discrete pools concentrated in specific areas along the channel.

**Table 6.2-2a.** Summary of average hourly WUA indices for selected fish species and life stages for Boundary Reservoir (Forebay, Canyon, and Upper Reservoir reaches) wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** |
| **Adult Cutthroat Trout WUA** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 750 | 402 | 15 | 682 | 366 | 11 | 725 | 389 | 13 |
| Canyon | 44,156 | 538 | 261 | 1,153 | 42 | 285 | 1,257 | 39 | 275 | 1,212 | 41 |
| Upper Reservoir | 38,549 | 1,020 | 312 | 1,201 | 44 | 408 | 1,574 | 49 | 352 | 1,358 | 46 |
| Total Boundary Reservoir | 88,065 | 827 | 313 | 2,756 | 100 | 363 | 3,196 | 100 | 336 | 2,959 | 100 |
| **Adult Redband Trout WUA[2]** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 795 | 426 | 15 | 771 | 413 | 12 | 785 | 421 | 14 |
| Canyon | 44,156 | 538 | 264 | 1,165 | 41 | 293 | 1,295 | 39 | 280 | 1,238 | 41 |
| Upper Reservoir | 38,549 | 1,020 | 322 | 1,243 | 44 | 420 | 1,620 | 49 | 363 | 1,397 | 46 |
| Total Boundary Reservoir | 88,065 | 827 | 322 | 2,834 | 100 | 378 | 3,328 | 100 | 347 | 3,057 | 100 |
| **Adult Smallmouth Bass** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 207 | 111 | 5 | 199 | 107 | 4 | 204 | 109 | 5 |
| Canyon | 44,156 | 538 | 161 | 713 | 35 | 186 | 819 | 33 | 174 | 771 | 35 |
| Upper Reservoir | 38,549 | 1,020 | 314 | 1,209 | 59 | 408 | 1,575 | 63 | 347 | 1,339 | 60 |
| Total Boundary | 88,065 | 827 | 231 | 2,033 | 100 | 284 | 2,501 | 100 | 252 | 2,219 | 100 |

**Table 6.2-2a, continued…**

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** |
| **Fry Mountain Whitefish[3]** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 8.5 | 5 | 3 | 7.3 | 4 | 2 | 7.9 | 4 | 3 |
| Canyon | 44,156 | 538 | 9.7 | 43 | 28 | 8.7 | 39 | 19 | 9.3 | 41 | 25 |
| Upper Reservoir | 38,549 | 1,020 | 28 | 106 | 69 | 41 | 157 | 79 | 31 | 118 | 72 |
| Total Boundary | 88,065 | 827 | 17 | 154 | 100 | 23 | 200 | 100 | 19 | 164 | 100 |
| **Adult Mountain Whitefish** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 89 | 48 | 3 | 80 | 43 | 2 | 83 | 45 | 2 |
| Canyon | 44,156 | 538 | 104 | 460 | 25 | 92 | 405 | 22 | 99 | 438 | 24 |
| Upper Reservoir | 38,549 | 1,020 | 343 | 1,323 | 72 | 355 | 1,370 | 75 | 345 | 1,330 | 73 |
| Total Boundary | 88,065 | 827 | 208 | 1,831 | 100 | 206 | 1,818 | 100 | 206 | 1,813 | 100 |
| **Cyprinids and Forage Fish (Fry and Juvenile)** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 37 | 20 | 5 | 36 | 19 | 4 | 36 | 19 | 4 |
| Canyon | 44,156 | 538 | 23 | 103 | 24 | 25 | 109 | 20 | 23 | 104 | 23 |
| Upper Reservoir | 38,549 | 1,020 | 78 | 300 | 71 | 105 | 405 | 76 | 86 | 332 | 73 |
| Total Boundary | 88,065 | 827 | 48 | 423 | 100 | 61 | 534 | 100 | 52 | 454 | 100 |

Notes:

1 Cross section weighted, reach-averaged channel width based on a Boundary forebay elevation of 1,989.77 feet NAVD 88 (1985.74 feet NGVD 29) and Boundary inflow of 19,500 cfs.

2 Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

3 WUA results are reported from the period beginning on April 1 through September 30 and coincide with the shoulder and peak season periodicity of fry mountain whitefish.

**Table 6.2-2b.** Summary of average hourly WUA indices for selected fish species and life stages below Boundary Dam (Tailrace Reach) wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** |
| **Adult Cutthroat Trout WUA** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 195 | 304 | 100 | 255 | 399 | 100 | 220 | 344 | 100 |
| **Adult Redband Trout WUA** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 199 | 311 | 100 | 265 | 413 | 100 | 227 | 355 | 100 |
| **Adult Smallmouth Bass** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 152 | 237 | 100 | 211 | 329 | 100 | 177 | 276 | 100 |
| **Fry Mountain Whitefish[2]** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 17 | 26 | 100 | 22 | 34 | 100 | 18 | 28 | 100 |
| **Adult Mountain Whitefish** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 209 | 327 | 100 | 220 | 344 | 100 | 215 | 335 | 100 |
| **Cyprinids & Forage Fish (Fry & Juvenile)** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 27 | 42 | 100 | 37 | 57 | 100 | 32 | 51 | 100 |

Notes:

1 Cross section weighted, reach-averaged channel width based on a Seven Mile forebay elevation of 1,727.00 feet NAVD 88 (1,722.97 feet NGVD 29) and Boundary outflow of 22,600 cfs.

2 WUA results are reported from the period beginning on April 1 through September 30 and coincide with the shoulder and peak season periodicity of fry mountain whitefish.

**Table 6.2-3a.** Summary of average hourly WUA indices for macrophytes, periphyton, and BMI for Boundary Reservoir (Forebay, Canyon, and Upper Reservoir reaches) wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** |
| **Macrophyte WUA** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 92 | 49 | 5 | 90 | 48 | 4 | 91 | 49 | 5 |
| Canyon | 44,156 | 538 | 34 | 151 | 17 | 35 | 156 | 14 | 35 | 152 | 16 |
| Upper Reservoir | 38,549 | 1,020 | 185 | 712 | 78 | 228 | 878 | 81 | 198 | 765 | 79 |
| Total Boundary Reservoir | 88,065 | 827 | 104 | 912 | 100 | 123 | 1,082 | 100 | 110 | 967 | 100 |
| **Periphyton WUA** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 28 | 15 | 1 | 27 | 14 | 1 | 25 | 14 | 1 |
| Canyon | 44,156 | 538 | 66 | 292 | 23 | 67 | 294 | 18 | 66 | 289 | 21 |
| Upper Reservoir | 38,549 | 1,020 | 246 | 948 | 76 | 333 | 1,283 | 81 | 286 | 1,102 | 78 |
| Total Boundary Reservoir | 88,065 | 827 | 142 | 1,254 | 100 | 181 | 1,591 | 100 | 159 | 1,405 | 100 |
| **BMI WUA** | | | | | | | | | | | |
| Forebay | 5,360 | 1,831 | 247 | 132 | 4 | 220 | 118 | 4 | 233 | 125 | 4 |
| Canyon | 44,156 | 538 | 111 | 491 | 16 | 100 | 443 | 16 | 106 | 468 | 16 |
| Upper Reservoir | 38,549 | 1,020 | 613 | 2,362 | 79 | 555 | 2,138 | 79 | 582 | 2,245 | 79 |
| Total Boundary | 88,065 | 827 | 339 | 2,986 | 100 | 306 | 2,699 | 100 | 322 | 2,838 | 100 |

Note:

1 Cross section weighted, reach-averaged channel width based on a Boundary Forebay elevation of 1,989.77 feet NAVD 88 (1985.74 feet NGVD 29) and Boundary inflow of 19,500 cfs.

**Table 6.2-3b.** Summary of average hourly WUA indices for macrophytes, periphyton, and BMI below Boundary Dam (Tailrace Reach) wet, dry, and average years.

| Reach | | | Wet Year (1997) | | | Dry Year (2001) | | | Average Year (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Length (ft)** | **Weighted Average Channel Width[1] (ft)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** | **WUA as Channel Width (ft)** | **WUA as Area (10,000 ft$^2$)** | **Percent of Total WUA Area (%)** |
| **Macrophyte WUA** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 17 | 26 | 100 | 23 | 36 | 100 | 19 | 30 | 100 |
| **Periphyton WUA** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 144 | 225 | 100 | 188 | 294 | 100 | 153 | 239 | 100 |
| **BMI WUA** | | | | | | | | | | | |
| Tailrace | 15,613 | 491 | 169 | 265 | 100 | 168 | 262 | 100 | 158 | 246 | 100 |

Note:

1 Cross section weighted, reach-averaged channel width based on a Seven Mile forebay elevation of 1,727.00 feet NAVD 88 (1,722.97 feet NGVD 29) and Boundary outflow of 22,600 cfs.

**Table 6.2-4.** Transect-weighted, reach-averaged PSI widths, ESI widths, and ESI to PSI ratios for mountain whitefish and smallmouth bass during representative wet, dry, and average years.

| Reach | Weighted Average Channel Width (feet) | Wet Year Widths (feet) | | | Dry Year Widths (feet) | | | Ave. Year Widths (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PSI | ESI | Ratio | PSI | ESI | Ratio | PSI | ESI | Ratio |
| **Mountain whitefish** | | | | | | | | | | |
| Upper Reservoir | 1,020 | 516 | 375 | 0.73 | 493 | 343 | 0.70 | 493 | 352 | 0.71 |
| Tailrace | 491 | 483 | 76 | 0.16 | 399 | 75 | 0.19 | 411 | 68 | 0.17 |
| **Smallmouth bass** | | | | | | | | | | |
| Canyon[3] | 538[1] | 69 | 32 | 0.46 | 46 | 9.0 | 0.20 | 66 | 34 | 0.51 |
| Upper Reservoir | 1,020 | 28 | 16 | 0.57 | 53 | 30 | 0.57 | 25 | 14 | 0.56 |

Notes:
1 Average width of side channel to the west of Everett Island is approximately 306 feet
ESI – Effective Spawning Index
PSI – Potential Spawning Index

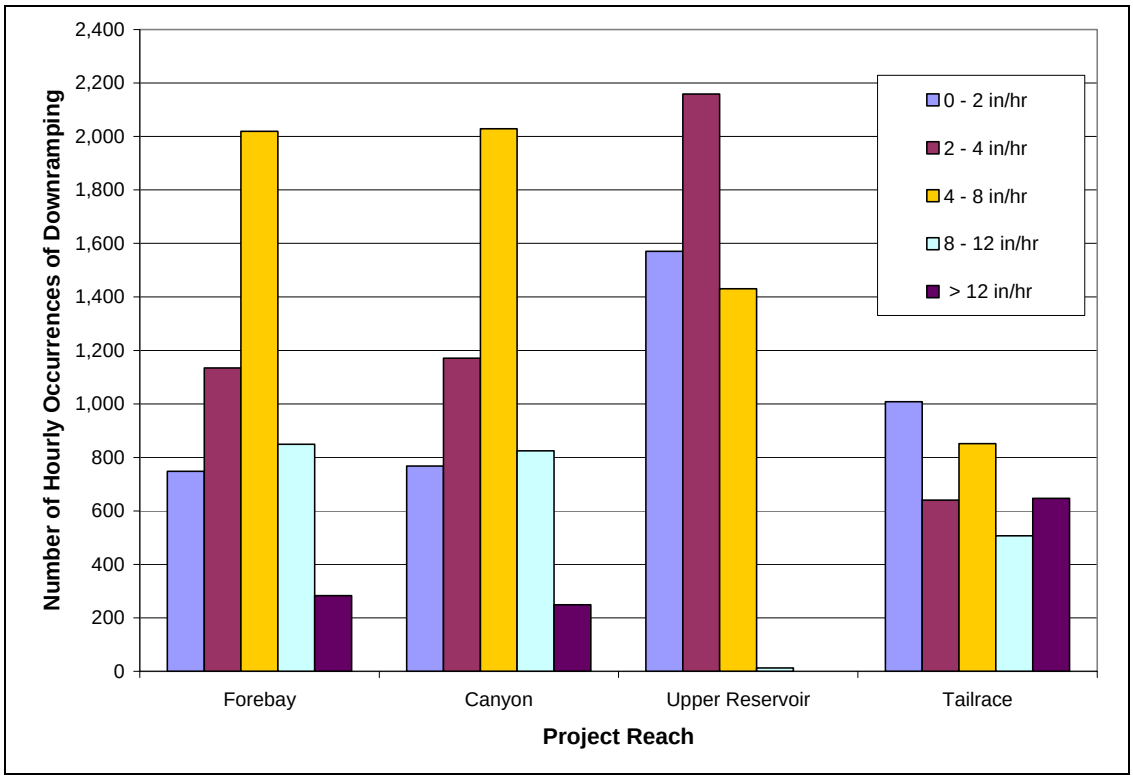



**Figure 6.2-1.** Annual transect-weighted, reach-averaged downramping rate distribution by Project reach for the representative average year (2002).

### 6.2.1. Forebay Reach

The Forebay Reach is the most reservoir-like of the four reaches. Depths can exceed 250 feet and the average wetted width is nearly 2,000 feet. Because of the large cross-sectional areas in the Forebay Reach, mean channel velocities are generally on the order of a few tenths of a foot per second or less except during high flow events. Therefore, the habitat in this reach is generally lacustrine in nature. Low water velocities and relatively little shallow water habitat as compared to other reaches in the Project area are more supportive of a species community dominated by suckers, yellow perch, stocked triploid rainbow trout, and northern pikeminnow.

Within the approximately 1 mile length of the Forebay Reach, the shallow water habitat in the 0 to 20 foot depth range at a median pool, median flow condition is 2,553 x $10^4$sq. ft. This represents 4 percent of the shallow water habitat in Boundary Reservoir. Viewing the shallow water habitat in terms of a width, the area of shallow water habitat is equivalent to an average width of 204 feet in the Forebay Reach. This is similar to the Tailrace Reach (231 feet) and represents more shallow water habitat on an average width basis than the Canyon Reach (68 feet) by a factor of 3. However, the Forebay Reach still has less shallow water habitat than the Upper Reservoir Reach (654 feet) by a factor of 3.

Figure 6.2-2 provides water surface profiles for the three reaches upstream of Boundary Dam at a flow of 40,000 cfs. There are six water surface profiles plotted, each associated with a different forebay elevation ranging from 1,994 to 1,954 feet NAVD 88 (1,950 to 1,990 feet NGVD 29). The plot at elevation 1,994 feet NAVD 88 (1,990 feet NGVD 29) represents the maximum or full pool condition. The elevation of 1,984 feet NAVD 88 (1,980 feet NGVD 29) is the typical minimum pool elevation during summer voluntary minimum pool restrictions. The elevation of 1,974 feet NAVD 88 (1,970 feet NGVD 29) represents the normal minimum pool. The elevation of 1,954 feet NAVD 88 (1,950 feet NGVD 29) is the lowest pool elevation under the current FERC license, but pool elevations typically only fall below the normal minimum pool during maintenance activities or other special conditions, such as studies associated with relicensing. Figure 6.2-2 shows that the water surface profiles are essentially flat throughout the Forebay Reach and reflect the lake-like nature of the Forebay Reach.

Because water surface elevations fall consistently throughout the Forebay Reach, the entire Forebay Reach experiences the same downramping rate. The information in Figure 6.2-2 shows that the highest percentage of the downramping rates for the Forebay Reach fall within the 4- to 8-inch per hour category for the average year (this also holds true for the wet and dry years).

The summary of the stranding index (SI) and the trapping index (TI) totals on an annual basis are provided in Table 6.2-1. Stranding and trapping indices were lowest in this reach and reflect the relatively small amount of shallow water habitat with gently sloping profiles and lack of large macrophyte beds. Additionally, low numbers of mountain whitefish, cutthroat trout, and smallmouth bass were found in shallow water habitats in the Forebay Reach, which reduces their vulnerability to trapping and stranding impacts associated with Project operations. Field studies indicate that trapping and stranding potential within the Forebay Reach is limited to the gently sloping, dense aquatic weed beds near the Forebay boat launch. Viewing the variability in the stranding index across the representative years, SI is the lowest in the average year by nearly a factor of 3 compared with the wet year. The wet year is about 15 percent higher than the dry

year. The TI is also lowest in the average year but within 10 percent of the value for the wet year and about 40 percent of the value for a dry year. Compared with TI values for the other reaches, the Forebay Reach has minimal potential for trapping. The annual magnitude of the TI can be greatly influenced by cyclic inundation of a few specific water surface elevations that expose trapping pools at lower elevations.

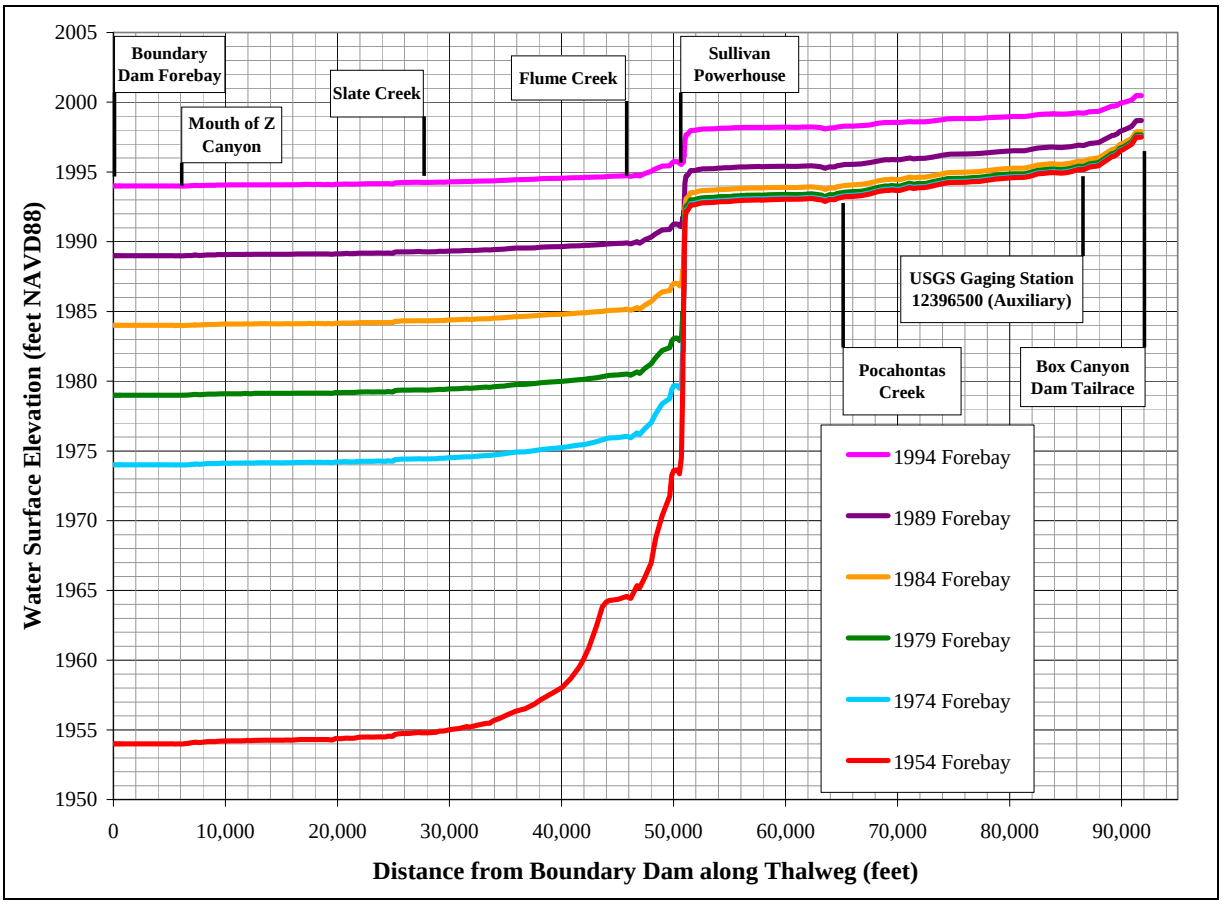



**Figure 6.2-2.** Boundary Reservoir HRM steady state water surface profiles for 40,000 cfs flow rate.

The fish WUA values are summarized in Tables 6.2-2a and 6.2-1b. The total WUA values for the three representative years do not vary greatly, though the wet year is always the highest and the dry year is always the lowest for all five species and life stages summarized in Table 6.2-2. The largest difference in WUA between years is for mountain whitefish fry and is about 15 percent greater for the wet year than the dry year (note: when comparing WUA values, the basis for comparison is the WUA values expressed as a width in feet).

Compared to other reaches, the Forebay Reach has the lowest WUA values for mountain whitefish fry and adult. The mountain whitefish fry values are similar to the Canyon Reach, which is due to the dominance of deep water in these reaches. Mountain whitefish catch rates reflected trends in the WUA values, as they represented nearly a fivefold decrease in catch rates as compared to the Upper Reservoir Reach. The adult cutthroat trout WUA values are the

highest in the Forebay Reach. This is due in part to the HSI depth curve, which maintains an optimum value of 1.0 through depths of 30 feet and does not fall below 0.5 until depths greater than those occurring in Boundary Reservoir. The 1.0 value for cover when depths exceed 50 feet also plays a role in the high HSI in the reservoir. The average width of the Forebay Reach is nearly 3 times that of the next widest reach, the Upper Reservoir Reach. Although WUA values for cutthroat trout are the highest in the Forebay Reach, cutthroat trout catch rates in the Forebay Reach were intermediate between the Upper Reservoir and Canyon. Only four cutthroat trout were captured during Study 9 sampling which suggests that cutthroat trout are not fully utilizing the available habitat or other factors are limiting their abundance and distribution. The WUA values for smallmouth bass are similar to those for the Canyon and Tailrace reaches, but about one-half to two-thirds the values for the Upper Reservoir Reach, depending on the hydrologic condition. Nevertheless, the smallmouth bass Forebay Reach catch rates were lowest among all the reaches under all Study 9 sampling methods.

Macrophyte WUA estimates were lowest in the Forebay Reach among the reaches in Boundary Reservoir. The variability for hourly time-step WUA estimates was uniform throughout each season of the year and among the three hydrologic years (Table 6.2-3a). Macrophyte habitat suitability in this reach was limited by poor substrate availability (e.g., gravel, cobble, and shale) and steeper bathymetry along the shoreline where depth optima were exceeded for establishment of macrophyte beds. The percentage of shallow water habitat optimal for macrophyte bed establishment was lowest under all pool flow conditions among the reservoir reaches (Table 6.1-1).

The low habitat availability of shallow water areas of the forebay for macrophytes is the primary limiting factor for establishment of beds when compared with other reaches (e.g., Upper Reservoir). The small area of distribution and growth of macrophytes in the Forebay Reach limits potential use by fish species. Fish populations may use macrophytes as cover from predators or as structure to prey upon other fish and BMI species. The larger BMI species, like dragonfly nymphs (Odonata), use macrophytes to capture prey (e.g., smaller BMI and zooplankton) by moving vertically in the water column. The absence of extensive macrophyte bed presence in the Forebay Reach reduces usable fish habitat and vertical structure for predatory BMI.

Periphyton WUA estimates were also lowest in the Forebay Reach among all Boundary Reservoir reaches. Substrate along the shoreline of the Forebay Reach presented suitable habitat for periphyton colonization and did not appear to be a limiting factor. However, WUA estimates for periphyton were lowest during the spring runoff period during the dry hydrologic year, whereas, estimates were higher during wet and average hydrologic years. The frequency of dewatering along the Forebay Reach shoreline may be one factor that presents the greatest disturbance during a dry hydrologic year when limited colonizeable habitat can be reduced further by pool elevation fluctuations.

A factor that temporarily increases potential WUA for periphyton in the Forebay Reach is expansion of accessible shoreline habitat for periphyton colonization that occurs during the wet and average hydrologic years. Inundation of additional shoreline habitat may be mediated by expansion of substrate accessibility, maintenance of optimal depth over a broader area of the

expanded habitat, and a reduction of effects from dewatering with the expanded habitat area. Depth and dewatering appear as controlling factors of WUA estimates for periphyton in other reaches; each having varying influence depending on the physical characteristics of the reach (e.g., channel width, average depth, and mean channel velocity).

WUA estimates for BMI were lowest in the Forebay Reach among all Boundary Reservoir reaches. This WUA pattern was the same as that estimated for periphyton and likely represented a loss in habitable substrate from operations during dry hydrologic years. Shallow water habitat was less than five percent of the total available for BMI colonization and was in contrast to greater than 86 percent available shallow water habitat found in the Upper Reservoir Reach (Table 6.1-1). Wet, dry, and average annual WUA estimates were almost identical indicating no seasonal differences optimizing for BMI habitat suitability. Even though the lowest WUA estimates for BMI were found in the Forebay Reach, more water during spring runoff or during wet and average years did not change the percentage of shallow water habitat or weighted useable areas for BMI in the Forebay (Table 6.2-3a).

BMI serve as an important food source for both juvenile and adult life stages of native salmonids as well as other species in the reservoir. Limitation of BMI biomass in the Forebay Reach is controlled by unavailability of shallow water habitat that is mediated by the steep bathymetry near the shoreline throughout most of this reach. This is the same physical setting as the Canyon Reach and, therefore, sampling results for BMI from the Canyon Reach location are applicable for describing conditions in the Forebay. Additionally, macrophyte beds that serve as vertical habitat for some BMI species have low suitability throughout the Forebay Reach and show low projected increases under any of the hydrologic conditions. BMI is influenced by other biological groups that serve as controls (e.g., food supply, macrophytes as physical habitat, and predation) equally with the physical characteristics used to predict potential WUA in the Forebay Reach. Limitations to the fish community imposed by BMI availability can be substantial and is underscored by importance of energy flow between trophic levels (see Study 11 [SCL 2009c] discussion on limiting factors to BMI production). The potential WUA estimates for BMI in the Forebay provide a good indication for the physical limitations.

Highlights of the discussion of aquatic habitat conditions in the Forebay Reach are summarized below.

- The Forebay Reach is reservoir-like, wide and deep, with low velocities, and a flat water surface across its 1-mile length.
- The Forebay Reach has the lowest area of shallow water habitat, though on an average width basis it is about equal to the Tailrace Reach.
- The SI and TI indicate there is little potential for fish stranding and fish trapping in the Forebay Reach, especially in comparison with the Upper Reservoir Reach.
- The fish WUAs vary by 15 percent or less between wet, dry, and average year, but the trend is consistent with the wet year having the highest and the dry year the lowest WUA.
- The fish WUA values for cutthroat trout adults are the highest in the Forebay Reach whereas the mountain whitefish fry and adult are the lowest in comparison with the other three reaches.

- Low catches of adult cutthroat trout (four) suggest that cutthroat trout are not fully utilizing the available habitat or that other factors are limiting their abundance and distribution in the Forebay Reach.
- The ESI analysis was not conducted for the Forebay Reach since potential spawning habitat for mountain whitefish and smallmouth bass is limited or non-existent in this reach.
- Water surface elevation fluctuations in the Forebay Reach (as well as the Canyon Reach) are greater than in the Upper Reservoir Reach, which increases the likelihood for dewatering of potential periphyton and BMI habitat. This reduction in potential habitat in these reaches further diminishes the limited amount of potentially colonizeable areas for macrophytes, periphyton, and BMI.
- Shallow water habitat is limited with steep-sided bathymetry in the Forebay Reach and limits the periphyton/BMI WUA estimates based on suboptimal depth and high frequency of dewatering conditions.
- Coarse substrate and lack of shallow water habitat along the shoreline limits macrophyte bed establishment in the Forebay Reach. The macrophyte beds serve as an important vertical structural habitat for BMI and BMI predators both as cover and food source habitat.

### 6.2.2. Canyon Reach

The Canyon Reach is generally reservoir-like, but because it is much narrower than the Forebay Reach, velocities are higher, especially near the upstream end of the reach. The bed profile of the Canyon Reach is the steepest and most varied of any of the four reaches and, as such, depths at a full pool range from over 250 feet at the downstream end of the reach to 60 feet at the upstream end of the reach. Although there may be an increased occurrence of higher velocities in the Canyon Reach as compared to Forebay Reach, because of the depth of water the Canyon Reach is still more representative of a reservoir-like environment. Species composition dominated by Catostomids, Cyprinids, Centrarchids, and Percids was observed and expected in an environment characterized by relatively slow water.

The Canyon Reach is much narrower than the Upper Reservoir Reach with an average width of 538 feet at the median pool, median flow condition. At the median flow of 19,500 cfs, velocities in the reach are generally less than 1 foot per second (fps) for pool elevations above 1,974 feet NAVD 88 (1,970 feet NGVD 29). With a flow of 40,000 cfs, the velocities are generally less than 2 fps for the same range of pool elevations.

The steep canyon walls in this reach limit the amount of shallow water habitat. Within the 8.8 mile length of the Canyon Reach, there are 302 x 10,000 square feet (average width of 68 feet) of shallow water habitat at the median pool, median flow condition. On an average width basis, the Canyon Reach has the lowest area of shallow water habitat within Boundary mainstem habitats. The average of 68 feet of width representing shallow water habitat is about one-third of the values for the Forebay and Tailrace reaches and about one-tenth of the Upper Reservoir Reach value.

The water surface profiles at 40,000 cfs provided in Figure 6.2-2 illustrate that the water surface is essentially flat, falling on the order of 1 foot in the lower 7.8 miles below Flume Creek. From Flume Creek to Metaline Falls, the slope steepens and in the last mile has a gradient ranging from 1 foot per mile to 4 feet per mile depending on the forebay elevation. The nearly flat water surface slope through most of the Canyon Reach results in its downramping rates being very similar to the Forebay Reach. The rate category with the highest occurrence is the 4- to 8-inch per hour range, followed by the 2- to 4-inch per hour range (Figure 6.2-1).

The Canyon Reach has the second highest SI and, depending on the hydrologic conditions, has the second or third highest TI (Table 6.2-1a). However, the TI and SI for the Canyon Reach should be kept in perspective by contrasting with the indices for the Upper Reservoir Reach. The SI for the Upper Reservoir Reach is 15 to 60 times greater than the Canyon Reach and the TI for the Upper Reservoir Reach is 10 to 25 times higher than the Canyon Reach. Field studies indicate that the significant stranding or trapping within the Canyon Reach is concentrated to one specific area, the side channel to the west of Everett Island. The side channel area contains several potential trapping pools that are exposed when reservoir levels fluctuate between elevation 1,984 feet and 1,977 feet NAVD 88 (1,980 and 1,973 feet NGVD 29, respectively). Surveys conducted in both 2007 and 2008 observed considerable trapping, although mortality was very low until the pools had been isolated for over 48 hours. Stranding observations were largely associated with the dense macrophyte beds that dewatered as water surface elevations receded below 1,984 feet NAVD 88 (1,980 feet NGVD 29). Such events require considerable decline in reservoir levels and do not typically occur during periods when the summer voluntary drawdown restrictions are in effect.

Species present in the shallow water habitat that may be trapped and/or stranded as a result of Project operations are predominantly non-target species such as larval Catostomids and Cyprinids although larval and juvenile smallmouth bass were observed in the varial zone in spring and summer months. Additionally, the two cutthroat trout that were captured in the shallow water habitat of the Canyon Reach were juvenile fish (less than 200 mm in length). Catostomids, Cyprinids (northern pikeminnow and tench), and Centrarchids (pumpkinseed with a few smallmouth and largemouth bass) dominated the trapping and stranding counts. No native or non-native salmonids were observed during the trapping and stranding surveys in the Canyon Reach. Smallmouth bass and northern pikeminnow may be the species most at risk to trapping and stranding events within the Canyon Reach. In terms of impact on these species as a whole, the Everett Island area represents a small fraction of the total gentling sloping, shallow littoral zones available in the reservoir.

The WUA indices for the species and life stages summarized in Table 6.2-2a show similar results for both fry and adult mountain whitefish for the Canyon Reach as were previously presented for the Forebay Reach. This is due to the dominance of deep water habitats in these reaches. The Canyon Reach values are slightly higher, ranging from 10 to 20 percent larger than the Forebay Reach. These two reaches have the lowest WUA values for mountain whitefish, though the fry WUA is only slightly higher for the Upper Reservoir Reach. The mountain whitefish WUA does not vary greatly for the three hydrologic conditions with a 10 percent range for adults and a 15 percent range for fry. Mountain whitefish Canyon Reach catch rates tracked relatively well with trends in the WUA values, as they represented approximately a 30 percent increase as compared

to the Forebay Reach, and were significantly lower than the Upper Reservoir Reach. A total of 14 mountain whitefish were captured in the Canyon Reach. However, no fry mountain whitefish were captured in the Canyon Reach, as the shallow, cobble and gravel substrates they prefer are limited by the very steep, bedrock and boulder dominated shorelines. Moreover, aside from limited habitat associated with the Flume Creek delta, the shorelines of the Canyon Reach provide little spawning habitat for mountain whitefish.

Adult cutthroat trout WUA values are lower for the Canyon Reach than the Forebay and Upper Reservoir reaches, but higher than the Tailrace Reach by 10 to 30 percent depending on the hydrologic condition. The differences are somewhat reflective of the differences in widths between these reaches. At a median pool median flow condition, the Forebay Reach is 3.4 times wider than the Canyon Reach, the Upper Reservoir Reach is nearly 2 times wider, and the Tailrace Reach is about 10 percent narrower. The variation in WUA for adult cutthroat trout between the hydrologic conditions is small, only varying by about 10 percent across the three representative years. As with the remainder of the reservoir, very few cutthroat trout were encountered in the Canyon Reach during the Study 9 surveys. Only 2 of the 25 cutthroat trout captured in the mainstem of the Project were encountered in the Canyon Reach, both were juvenile fish less than 200 mm in length within the shallow water habitat associated with steep shorelines.

The WUA values for smallmouth bass are similar for the Forebay, Canyon, and Tailrace reaches. However, the Canyon Reach smallmouth catch rates for boat electrofishing exceeded all other reaches, owing largely to the prevalence of yearling and adult fish captured during the summer months. In August, smallmouth bass (<35mm) began to appear in the catch. Both observations indicate that rearing and possibly spawning by smallmouth bass occur in the Canyon Reach. Several bass nests were located in the Everett Island side channel during 2008 bass nest surveys. Adult smallmouth bass were also captured in open water habitat at depths greater than 60 feet. The Canyon Reach affords smallmouth bass a variety of habitat conditions in the form of boulder, bedrock ledges, and attendant velocity shears. These features form important areas that smallmouth bass can conceal themselves in wait to ambush vulnerable prey, such as juvenile peamouth, northern pikeminnow, suckers, and yellow perch which are abundant in the reach. WUA values for adult smallmouth bass show larger variation across the hydrologic years in the Canyon Reach. The dry year has the highest WUA for adult smallmouth bass with the lowest corresponding to the wet year. Catch rates of smallmouth bass did not appear to support differences in WUA from wet versus dry years as catches for both 2007 (dry) and 2008 (wet) were highest from May through August and comparable between years.

The side channel at Everett Island was identified as a potential spawning location for smallmouth bass. Therefore the effective spawning analysis was performed on two transects for the side channels located at the island. The results in Table 6.2-4 indicate smallmouth bass ESI widths range between a high of 34 feet for the average year to a low of 9 feet for the dry year. This is similar to the range for the Upper Reservoir Reach where the ESI widths range from a high of 30 feet for the dry year to a low of 14 for the average feet. Spawning conditions in the Canyon Reach are similar during the average and wet years so the associated ESI widths are nearly equal; the ESI width is lowest in the dry year. The trend is reversed for the Upper Reservoir Reach where the highest ESI width occurs in the dry year and the lower widths are for the average and

wet years. This is due to the vastly different responses of the two reaches to high flows, which occur during the smallmouth bass spawning and incubation period. The Canyon Reach has the greatest water surface elevation fluctuations during the spawning and incubation period during the dry year. In comparison, the Upper Reservoir Reach has the highest water surface elevation fluctuations for the smallmouth bass spawning and incubation period during the wet and average years. This is due to the spring freshet creating high water surface elevations in the Upper Reservoir Reach that result in dewatering of the nests as runoff recedes. The highest ratios of ESI to PSI occur in the Upper Reservoir Reach, with all three years having values of either 0.56 or 0.57. In contrast, the ratios for the Canyon Reach range from 0.20 for the dry year to 0.51 for the average year. These ratios indicate that a larger percentage of the potential spawning width remains inundated throughout the incubation period in the Upper Reservoir Reach than in the Canyon Reach.

Macrophyte WUA estimates in the Canyon Reach were greater than the quantity of useable habitat estimated in the Forebay Reach. A decline in WUA estimates for macrophyte suitability was observed during the wet hydrologic year near the middle of the fall season (e.g., end of October) with fairly uniform predictions in WUA estimates during dry and average hydrologic years based on the hourly time-step. The small variation in WUA estimates for macrophytes indicated that dewatering of useable habitat was not a major factor during dry and average years, but that depth and substrate availability (e.g., fines and sand) may have been limiting to bed establishment in this reach. The margins of the Canyon Reach are dominated by rock faces along the shoreline which precludes aggregation of suitable substrate and habitable depth ranges. Pool elevation fluctuations in this reach do not appear as the primary limiting habitat factors for macrophyte bed establishment as in other reaches of the Boundary Reservoir.

The scarcity of macrophytes in the Canyon Reach affects potential use by fish species. Fish populations may use macrophytes as cover from predators or as structure to prey upon other fish and BMI species. The larger BMI species, like dragonfly nymphs (Odonata), use macrophytes to capture prey (e.g., smaller BMI and zooplankton) by moving vertically in the water column. The absence of extensive macrophyte bed presence in the Canyon Reach reduces some of the potential fish habitat and vertical structure for predatory BMI. This significantly reduces the overall productivity potential for all trophic levels within this reach.

Periphyton WUA estimates in the Canyon Reach were second highest within the Boundary Reservoir reaches and represented greater availability of habitable substrate in the Canyon Reach compared to the Forebay Reach. Periphyton colonize hard substrates that are not easily moved by current. The Canyon Reach is dominated by substrate sizes larger (e.g., cobble and bedrock) than sand and finer particle sizes and so has a predictably greater amount of habitat suitable for colonization. Higher WUA estimates were determined for the spring runoff period during the dry year. This is an indication that spring runoff during the lower flow hydrologic year had a smaller effect on reducing periphyton habitat than during the spring of the wet and average hydrologic years (Figure 5.7-5), likely an effect from differing mean channel velocities during each of the hydrologic years. The difference in peak potential WUA predictions for periphyton at different times of the year (i.e., dry in spring and wet in fall) results from increased inundation of shoreline areas in the Canyon Reach that provided optimal habitat conditions.

Periphyton is an important food base for grazing BMI and could be one of the factors influencing colonization of this important fish food resource. The timing for optimal physical conditions for periphyton colonization differs depending on water availability during seasons of the year. Other influences on production for periphyton in this reach are similar to those in the Forebay Reach and include a balance between phosphorus input and light availability (see Appendix 1 in Study 11 [SCL 2009c]). Water clarity during seasons of the year when average water surface elevations are higher (e.g., spring and dry year versus fall and wet year) may be key in determining the maximum production potential for periphyton in the reservoir.

The WUA estimates for BMI in the Canyon Reach were second highest as compared to other reaches in Boundary Reservoir. Habitat suitability for BMI is mediated by substrate availability, disturbance of the substrate particles small enough to be moved, and an adequate food base. Factors like depth and velocity are not as influential on BMI WUA values in this reach as they are on periphyton.

There were no distinct seasonal patterns based on potential WUA BMI habitat during any of the hydrologic years (Figure 5.8-5). The colonization of this potential habitat by BMI is important for use by fish. Fish species and life stages that depend on BMI as a food base will be affected by the timing when the greatest amount of BMI habitat occurs during the year (e.g., spring in the dry hydrologic year and fall in the wet hydrologic year). Production potential in the Canyon Reach was lowest during the wet and dry years regardless of optimal conditions based on physical characteristics (e.g., WUA estimates) (see Appendix 1 in Study 11 [SCL 2009c]).

Highlights of the discussion of aquatic habitat conditions in the Canyon Reach are summarized below.

- The Canyon Reach is similar to the Forebay Reach in that it is relatively low energy and mostly reservoir-like. The velocities and water surface gradient increase in the upper portion of the reach, with the largest increase for higher flow and lower pool conditions.
- The Canyon Reach has the lowest shallow water habitat area on a per foot of channel length basis. This is a result of the steep Canyon walls confining most of the reach.
- Based on the SI and TI values, the potential for fish stranding and fish trapping in the Canyon Reach is relatively small compared to the Upper Reservoir Reach. The closest of these indices is the TI for the wet year which is one tenth the value of the Upper Reservoir Reach.
- The variation across the representative hydrologic years in fish WUA for each combination of species and life stage varies from about 10 to 15 percent. In the Canyon Reach, there is not a high sensitivity in the WUA values summarized in relation to hydrologic condition.
- The WUA values for the summarized life stages and species in the Canyon Reach are generally toward the lower end of the range for the four reaches, though only the lowest for adult smallmouth bass in the dry and average years.
- Smallmouth bass ESI width was determined for both the Canyon and Upper Reservoir reaches, with the range of value both reaches being similar. However, the response of the ESI values to the conditions under the three representative hydrologic

years differed greatly between the two reaches. The highest values for the Upper Reservoir Reach occurred during the average year whereas the lowest values for the Upper Reservoir Reach occurred for the average and wet years.

- The ratios of the ESI to PSI, reflecting the relative success of spawning compared to the potential spawning area, are slightly higher (10 to 20 percent) for the wet and average year for the Upper Reservoir Reach compared to the Canyon Reach. However, the Upper Reservoir Reach ratio is nearly three times higher than the Canyon Reach for the dry year. There is a dramatic drop in the ratio in the Canyon Reach for the dry year due to the continuation of water surface elevation fluctuations from load-following during the spring freshet since Project inflows do not approach the 55,000 cfs powerhouse capacity during the dry year. Load-following has a greater influence in the Canyon Reach than the Upper Reservoir Reach because of the dampening influence of Metaline Falls on fluctuations upstream of the falls.
- Though the ESI to PSI ratios remain nearly constant across the wet, dry, and average years for the Upper Reservoir Reach, the ESI and PSI values are about one-half the dry year values in the wet and average years. This occurs since the higher spring freshet flows during the wet and average years move the inundated elevation zone corresponding to suitable spawning depths further up the sides of the channel. At these higher elevations, the width associated with suitable spawning substrate is less than the at the suitable spawning elevation zone associated with the dry year.
- Macrophyte habitat suitability is constrained by substrate and depth factors which are primarily a function of the channel morphology and not water surface elevation fluctuations.
- Substrate available for colonization is the same for both periphyton and BMI in the Canyon Reach; however, greater depths in the Canyon Reach and frequent dewatering have a greater effect by lowering the WUA potential for periphyton than for the BMI. BMI are able to colonize at greater depths than are periphyton; therefore, water level fluctuations influence a smaller portion of their potential habitat compared to periphyton.

### 6.2.3. Upper Reservoir Reach

The Upper Reservoir Reach has several unique aspects that are discussed in this section. It is the most riverine-like of all the reaches and at times experiences little influence from Project operations on hydraulic conditions and the resulting habitat indices. As shown in Figure 6.2-2, the Upper Reservoir Reach has a flat gradient of about 0.2 feet per mile or less for the first 3 miles above Metaline Falls (up to about Pocahontas Creek). In the next 4 miles, the gradient steepens on the order of a foot per mile, depending on Forebay elevation (steeper gradients are associated with lower forebay elevations). In the upper mile of the reach (below Box Canyon Dam), the water surface profile gradient noticeably increases to about 4 feet per mile.

The steeper gradient in the Upper Reservoir Reach is reflected in the hydraulics. The lowest mean channel velocities occur in the wide section adjacent to the town of Metaline where they range from about 0.5 to 1 fps at the median flow of 19,500 cfs depending on the forebay elevation. For the majority of the remainder of the reach, the velocities at the median flow vary between about 1 foot per second and 3 fps depending on the location and forebay elevation. In

the upstream mile of the reach, the steepest section, the velocities range between about 2 and 5 fps for the median flow depending on the location and forebay elevation. At 40,000 cfs, the mean channel velocities about double compared to the velocities at a median flow of 19,500 cfs, except in the steepest upstream mile where they increase by about 50 percent. The depths in the Upper Reservoir Reach are much less than in the Forebay and Canyon reaches. This is in part due to the higher velocities, but also due to the diminishing inundation of this reach, compared to the Forebay and Canyon reaches, from Boundary Dam. The depths can still be influenced by forebay elevations but generally range in the thalweg from about 10 feet to 50 feet for flows ranging from 6,000 cfs up to the approximate powerhouse capacity of 55,000 cfs. The influence of forebay elevations on water surface elevations in the Upper Reservoir Reach is discussed further in the next paragraph.

Review of Figure 6.2-2 illustrates another important aspect of the Upper Reservoir Reach, the influence of the hydraulic control at Metaline Falls on water surface elevations. The discussions for the Forebay and Canyon reaches indicated that the changes in water surface elevations essentially followed the changes that occur at Boundary Dam. This is not true for the Upper Reservoir Reach. At 40,000 cfs, under a forebay full pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29) , dropping the forebay elevation by 5 feet causes a 3-foot change in the water surface elevation immediately upstream of Metaline Falls and less than a 2-foot change immediately downstream of Box Canyon Dam.

Figure 6.2-3 presents the Project influence on water surface elevations compared to the condition with the forebay elevation at 1,954 feet NAVD 88 (1,950 feet NGVD 29) for the median inflow rate of 19,500 cfs. Reviewing the plots indicates that for forebay elevations of 1,974 and 1,979 feet NAVD 88 (1,970 and 1,975 feet NGVD 29) there is essentially no Project influence on water surface elevations upstream of Metaline Falls. For forebay elevation of 1,984 feet NAVD 88 (1,980 NGVD 29), there is about 1 foot of Project influence (increase in water surface elevation) immediately upstream of the falls. This level of influence continues upstream to near Box Canyon Dam. The influence does start to decrease in the last mile of the Upper Reservoir Reach as the channel gradient steepens. At a forebay elevation of 1,989 feet NAVD 88 (1,985 feet NGVD 29) and the median flow of 19,500 cfs, the Project influence is just under 5 feet immediately upstream of the falls and tapers to about 3 feet just below the point where the reach starts to steepen, about one mile downstream of Box Canyon. At a forebay full pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29), the Project influence on water surface elevations immediately upstream of Metaline Falls is about 10 feet, which tapers to about 8 feet 2 miles downstream of Box Canyon and to 6 feet at Box Canyon Dam. Based on this information, the influence of Metaline Falls is to reduce the change in water surface elevations related to Project operations upstream of the falls. The reduction t is the greatest at lower forebay elevations.

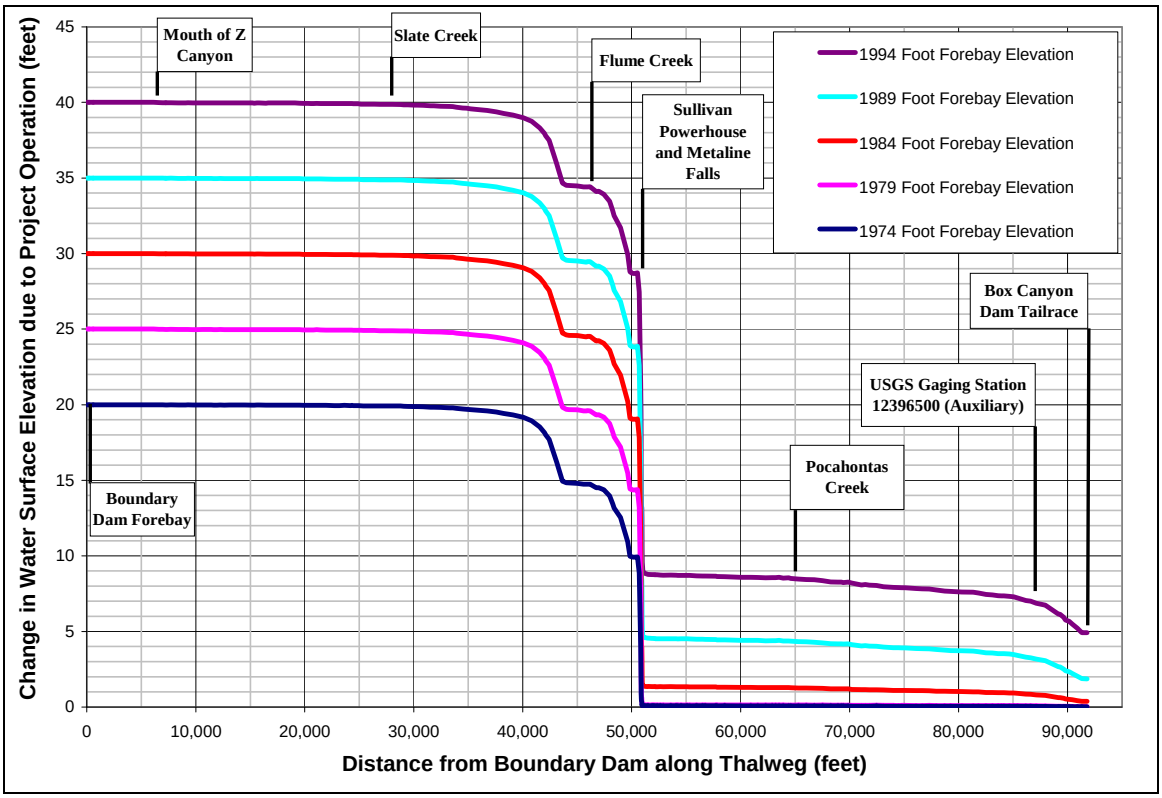



**Figure 6.2-3.** Upstream hydraulic influence of Project operations on water surface elevations for 19,500 cfs flow rate.

The dampening of the water surface elevation response in the Upper Reservoir Reach is reflected in the downramping rates in Figure 6.2-1. The most frequently occurring range of downramping rates in the Upper Reservoir Reach is the 2 to 4 inches per hour, in contrast to the Forebay and Canyon reaches with 4 to 8 inches per hour as the most frequent range. There are no occurrences of downramping rates in excess of 12 inches per hour in the Upper Reservoir Reach and the occurrences in the 8 to 12 inches per hour range are an order of magnitude less than in the Forebay and Canyon reaches.

Within the 7.7 miles of the Upper Reservoir Reach there are 2,522 x 10,000 square feet of shallow water habitat for the median pool, median flow condition. The average width of the shallow water habitat is 654 feet in a reach with an average wetted width of 1,020 feet at median pool and median flow conditions. The area represents over 86 percent of the shallow water habitat in Boundary Reservoir. The large area of shallow water habitat in the Upper Reservoir Reach is largely the result of the numerous low gradient bars within the channel and along its margins. With more riverine conditions and the vast majority of the shallow water habitat in Boundary Reservoir, the Upper Reservoir Reach boasts a more diverse species and life history assemblage than the other reaches.

The Upper Reservoir Reach is the most physically diverse reach within the Project area. Within this 7.7-mile reach, a variety of habitat conditions is provided by several islands, back channels,

and nearshore aquatic vegetation. Many of the off-channel areas away from the mainstem currents contain widespread and seasonally dense concentrations of submerged aquatic vegetation bordered by less dense emergent vegetation and flooded grasses in nearshore areas and flooded swales. These areas serve as both spawning and rearing areas for various fish species present in the reach. Nearshore areas within the more confined, steeper portions of the reach provide gravel and cobble bedded habitats, often in conjunction with swifter velocities that are more representative of riverine systems supportive of native salmonids. The shallow water zone is quite extensive under most flow conditions. The open water zone rarely exceeds 40 feet in depth, even at full pool.

Because of the potential for fish to spawn in the Upper Reservoir Reach, the effective spawning analysis was conducted for both mountain whitefish and smallmouth bass. The mountain whitefish ESI width values are similar for all three representative years, with the highest value of 375 feet for the wet year and the lowest value of 343 feet for the dry year. The small range is a result of the similar water level fluctuations during the potential spawning and incubation period for mountain whitefish, which occurs during the late fall and winter. These values are about five times higher than the ESI widths determined for mountain whitefish in the Tailrace Reach. The PSI values for mountain whitefish were only slightly higher, about 10 to 20 percent, in the Upper Reservoir Reach than the Tailrace Reach. Therefore, the relative success of mountain whitefish spawning and incubation, represented by the ratio of ESI to PSI, was modeled to be about four times higher in the Upper Reservoir Reach.

The smallmouth bass ESI widths exhibit a higher degree of variability than those calculated for mountain whitefish with a high of 30 feet for the dry year and a low of 14 feet for the wet year. The smallmouth bass spawning and incubation period typically carries into the spring freshet. The high values in the dry year reflect the lack of increased water surface elevations during the low runoff year. During the wet and average years, potential spawning nests are exposed when the high flows recede. Comparison of ESI and PSI values between the Upper Reservoir Reach and the Canyon Reach, the other reach for which smallmouth bass effective spawning was modeled, was presented in Section 6.2.2.

A variety of fish species are present in the Upper Reservoir Reach. Species composition of the reach consists mainly of Catostomids, Percids (yellow perch), Centrarchids (mainly smallmouth bass and pumpkinseed), and Cyprinids (mostly peamouth and northern pikeminnow). Native salmonids comprised less than 2 percent of the catch; however, the highest catch of both adult mountain whitefish (129) and cutthroat trout (8) were captured in the Upper Reservoir Reach.

Spawning of smallmouth bass as well as other Centrarchids has been documented in off-channel areas or on the downstream end of cobble bars in the Upper Reservoir Reach during the spring and summer months. Additionally, based on the capture of gravid females, Study 9 results suggest mountain whitefish may spawn in the upper one-half mile of the Upper Reservoir below Box Canyon Dam and in the vicinity of Sullivan Creek.

As a consequence of having the presence of low gradient bars as well as side channels, the Upper Reservoir Reach has about 93 percent of the total stranding area and 95 percent of the total trapping area in the study area. The Upper Reservoir Reach also has about 90 percent of

submerged aquatic macrophyte cover, which increases the potential for stranding and trapping. Due to the influence of Metaline Falls, the water surface elevation fluctuations are reduced in the Upper Reservoir Reach compared with the Forebay and Canyon reaches. Considering the predominance of macrophytes in the Upper Reservoir Reach, if only the area and macrophyte coverage were accounted for, the percentage of the stranding and trapping in the Upper Reservoir Reach would be even higher. The fact that the degree of pool fluctuation is lower in the Upper Reservoir Reach plays a role in reducing the relative potential for stranding and trapping in the Upper Reservoir Reach.

Because of the presence of large areas of shallow water habitat, several side channels with undulating bottom topography, and 98 percent of the Project submerged aquatic macrophyte cover; stranding and trapping indices are highest in this reach. Field studies conducted in 2007 and 2008 corroborate modeling results in that the Upper Reservoir Reach poses the greatest risk of trapping and stranding in the Project Area. During planned drawdown events directed specifically for study purposes, fry and yearling fish were stranded within the expansive, gently sloping, dense aquatic weed beds throughout the off-channel and side-channel areas. In addition, thousands of fry and yearling fish were observed trapped in several large, topographic swales within backwater and side-channel areas that were isolated during the drawdown events. The eventual fate of these trapped fish was largely dependent on the amount of time the pool stayed isolated from the mainstem reservoir. The longer the isolation, the greater the risk of fish mortality due to eventual pool desiccation or because of water temperatures eventually reach lethal levels during extremely hot summer periods. However, these potential impacts were often naturally mitigated by apparent groundwater or bank storage seepage in several locations, which served to maintain tolerable water depths and temperatures until the reservoir mainstem was reconnected.

Species present in the shallow water zone that may be trapped and/or stranded as a result of Project operations were predominantly non-target species such as larval Catostomids and Cyprinids. Catostomids, Cyprinids (northern pikeminnow and tench), and Centrarchids (pumpkinseed with a few smallmouth and largemouth bass) dominated the trapping and stranding counts as well as the shallow water zone study catch. However, the results of Study 9 indicate that shallow water zone sampling in the Upper Reservoir Reach revealed higher catch rates of a variety of salmonid species (as compared to salmonid catch rates in other reaches). No native or non-native salmonids were observed during the trapping and stranding surveys in the Upper Reservoir Reach. Very few salmonids and no native salmonids were captured within the shoreline backpack electrofishing sites, which include sampled areas most at risk to stranding and trapping. Smallmouth bass are a sport fish species, frequently pursued by Project anglers, most at risk to trapping and stranding events within the Upper Reservoir Reach, as they were commonly encountered during shoreline backpack electrofishing, boat electrofishing, and fyke net sampling activities targeting the 0- to 10-foot depths of the shallow water zone. Presence of fish in areas prone to trapping and stranding during the winter months were low. Very few fish were observed in the shallow shoreline areas during February through May, although this is when salmonids reached their peak catch rate. Two juvenile wild rainbow trout and one brook trout were captured along cobble dominated bottoms during February across a total of 3,000 feet of shoreline backpack electrofishing.

The SI values in the Upper Reservoir Reach follow a consistent trend in relationship to the hydrologic conditions. Both indices are highest for the dry year, next highest for the average year, and lowest for the wet year. This trend was not followed as consistently in the other reaches. The Upper Reach follows this trend because of the influence of Metaline Falls on reservoir fluctuations. The dampening effect of the falls increases as the flows increase. As a result, the wetter the year the smaller the fluctuations are in the Upper Reservoir Reach. In the lower reaches, the flow levels change the potential for load following. If there is not sufficient volume of inflow, load following cannot continue as long. In very low flow years, the load-following may be reduced. However, in very high flow years, the period of load-following can be reduced by flows exceeding plant capacity.

Fish WUA values for the Upper Reservoir Reach generally reflect the increased presence of shallow water habitat. For all of the adult species presented in Table 6.2-2, the WUA values (expressed as area) in the Upper Reservoir Reach are higher than in any of the other three reaches for all hydrologic conditions. In the case of adult cutthroat trout, the Upper Reservoir Reach WUA values are only slightly higher than those for the Canyon Reach.

Adult mountain whitefish catch rates corresponded to the trends in WUA indices, as they were highest in the Upper Reservoir in both the shallow and open water habitats. And although the Upper Reservoir mountain whitefish fry WUA values are similar to the Forebay and Canyon reaches, catch rates of young-of-the-year were much higher than any other mainstem reach. Mountain whitefish catch rates in the Upper Reservoir Reach may be due to several factors, including the fact that the primary suitable spawning habitat in terms of mainstem areas as well as tributary delta and tributary channel habitat occurs in the Upper Reservoir Reach. In addition, the Upper Reservoir Reach provides extensive moderately sloping, cobble and gravel armored substrates with moderate velocities that provide riverine like conditions to which the species is adapted.

Smallmouth bass WUA values were also highest in the Upper Reservoir Reach and are supported by consistent catches of smallmouth bass as well as other Centrarchid species such as pumpkinseed, largemouth bass, and black crappie that have generally similar habitat preferences. Although smallmouth bass catch rates were higher in the Canyon and Tailrace reaches, the species was commonly encountered in the Upper Reservoir Reach, especially during May through July when the water temperatures are favorable for spawning activity.

WUA values for adult cutthroat trout were second to only the Forebay Reach; however, a total of only eight cutthroat trout were captured in the Upper Reservoir Reach. Similar to the Canyon Reach, the Upper Reservoir Reach has tributaries that appear to provide a source of cutthroat trout production to the reach. Juvenile cutthroat trout were captured moving downstream via fyke nets in Sweet and Sand creeks during July and August of 2007. It is also likely that cutthroat trout, and probably mountain whitefish as well, are recruited from Box Canyon Reservoir. However, similar to the Canyon Reach, few native trout were observed in mainstem Upper Reservoir Reach habitats. Adult cutthroat trout do not appear to be utilizing the available habitat in the Upper Reservoir Reach. This could be due to high summer water temperatures, predation on cutthroat trout, or other factors discussed earlier for cutthroat WUA in the Canyon Reach.

One trend that is consistent across the adult life stages is that the highest WUA occurs for the dry year and the lowest for the wet year. For mountain whitefish fry, the WUA for the Upper Reservoir Reach are similar to the Forebay and Canyon reaches, but less than the Tailrace Reach. The Tailrace Reach has higher WUA for fry due to the presence of gravel and cobble substrate throughout most of the shallower depths. While there are several areas of gravel and cobble dominated shorelines, the majority of the shallowest areas in the Upper Reservoir Reach comprise fines.

The relatively shallow nature of the Upper Reservoir Reach and the availability of suitable substrate for established macrophyte beds are substantially greater than in any of the other reaches. Consequently, macrophyte WUA estimates were greatest in the Upper Reservoir Reach among all reaches of Boundary Reservoir. Habitable area for macrophytes was highest during the dry hydrologic year (Table 6.2-3a) in this reach with an average areal coverage that was fifteen percent lower than during the wet season. The estimate for shallow water habitat less than 20 feet deep is approximately equal during all hydrologic years (e.g., wet, dry, and average) (Table 6.1-1a). Hourly occurrences of downramping rates greater than 12 inches per hour in this reach are relatively few compared to frequency of occurrences greater than twelve inches per hour in the Forebay and Canyon reaches (Figure 6.2-1). Any differences in WUA estimates between hourly time-steps or seasons are due to inundation of new habitat suitable for macrophyte establishment. The margins of the river channel in this reach have low bank angles and low-elevation floodplain areas dominated by fine sediments (e.g., sand and silt) that are deposited during wet hydrologic years and spring runoff.

Pool elevation fluctuations from power generation are the lowest in this reach and similar during all hydrologic years. The dewatering factor has a smaller influence on potential WUA estimates in the Upper Reservoir Reach as surface water fluctuations are generally smaller as compared to other reaches. Both native and non-native macrophyte species colonize the Upper Reservoir Reach and have differing tolerances to environmental extremes characteristic of the natural and reservoir setting. The presence of macrophytes provide important habitat for many fish and BMI species. Macrophytes are found in only thirteen percent of the total area in the reservoir with most of the beds found in the Upper Reservoir Reach. Part of the reason for higher production potentials for BMI and fish (including life stages) includes vertical habitat provided by macrophytes that are in addition to the soft substrate preference.

WUA estimates for periphyton were highest in the Upper Reservoir Reach, but with results more closely related between wet and average years than during the dry year. Lower annual WUA averages for periphyton were determined during the spring runoff period for wet and dry hydrologic years. During the wet hydrologic year, 33 percent less usable habitat area was determined for periphyton even though shallow habitat less than 20 feet deep was constant throughout all hydrologic years. Changes in factors like velocity during wet and average hydrologic years indicates factors other than water volume (i.e., flow) in this reach may be responsible for promoting optimal habitat for periphyton colonization.

The dry year had sustained intervals of stable potential WUA estimates for periphyton before and after the spring runoff (high flow) period. The wet and average years with the highest levels of

potential WUA occurred during the summer indicating that additional surface water elevation in this reach is beneficial for expanding available periphyton habitat. Periphyton serves as a food base for BMI grazers, but peak potential WUA estimates for periphyton coincided with one peak in potential WUA BMI estimates during late summer in the wet year.

The physical setting of the Upper Reservoir Reach is a more favorable location for growth of periphyton in comparison to the other reaches. Part of the reason for actual success in production of periphyton in this reach is that controlling factors like light availability and shallower depths promote production that is greater than measured from other locations in the reservoir (see Appendix 1 in Study 11 [SCL 2009c]).

BMI annual average WUA estimates were almost identical for each hydrologic year (e.g., wet, dry, and average) in the Upper Reservoir Reach (Table 6.2-3). Pool elevation fluctuations were lower in this reach with downramping rate frequency almost always lower than 8 to 12 inches per hour (Figure 6.2-1). Surface water elevation appears to promote greater and sustained potential WUA estimates as indicated by a peak during the wet and average years at the end of spring runoff (Figure 5.8-6). A slightly lower, but stable WUA estimate occurs during the dry year with few differences between seasons. The lowest WUA estimates occurred during the highest flows during spring runoff in wet and average years and at the end of the summer during the dry year. These patterns indicate a benefit to WUA increases when higher flows occur; however, there is an identifiable threshold for high flows that diminishes the value of the inundated channel for colonization by BMI.

Highlights of the discussion of aquatic habitat conditions in the Upper Reservoir Reach are summarized below.

- The hydraulic control at Metaline Falls results in dampening of the water surface elevation fluctuations in the Upper Reservoir Reach. In general, the influence of Metaline Falls on dampening Upper Reservoir Reach water surface elevation fluctuations is greatest at low the forebay water surface elevations and diminishes at higher forebay water surface elevations.
- The greatest quantity of shallow water habitat availability occurs in the Upper Reservoir Reach; shallow water habitat contains the largest combination of suitability factors that promote high WUA estimates for macrophytes, periphyton, and BMI.
- The Upper Reservoir Reach is the most riverine-like of all the reaches.
- The Upper Reservoir Reach has over 86 percent of the shallow water habitat in the Boundary Reservoir.
- Based on the SI and TI values, the potentials for fish stranding and fish trapping in the Upper Reservoir Reach are much higher than the other three reaches combined and account for about 95 percent of the stranding potential and about 90 percent of the trapping potential, depending on the hydrologic condition. This is consistent with the much higher presence of low gradient bars, side channels, and macrophytes in this reach.
- Both stranding and trapping potentials are greatest for the dry year and lowest for the wet year in the Upper Reservoir Reach.

- During the trapping surveys and stranding surveys conducted in 2008, the vast majority of the fish observed were Catostomids and Cyprinids (80 to over 90 percent) with the next most common observations being Centrarchids (about 10 percent or less). The only other taxa constituting more than one percent of the stranding and trapping observations was Percids at about 5 percent.
- The ESI values for both mountain whitefish are highest in the Upper Reservoir Reach by a factor of four compared to the Tailrace Reach.
- The ESI values for smallmouth bass fall within a similar range for both the Upper Reservoir and the Canyon reaches, but the values are distributed differently between the representative hydrologic years. The lowest smallmouth bass ESI values for the Upper Reservoir Reach occur during the wet and average years, whereas these years produce the lowest values for the Canyon Reach.
- In the Upper Reservoir Reach, the ESI values for smallmouth bass are negatively influenced by high runoff in the wet and average years. In contrast, the mountain whitefish ESI values are lowest in the dry year, though only slightly lower than the wet and average years.
- The WUA values for the adult life stages are relatively high in the Upper Reservoir Reach with two out of the three summarized species having the highest average annual adult WUA in the Upper Reservoir Reach and the third species having the second highest.
- Dewatering of habitable areas for periphyton and BMI occurs less frequently in the Upper Reservoir Reach, and low mean channel velocities present a greater area of optimal habitat.

### 6.2.4. Tailrace Reach

The 3.1-mile-long Tailrace Reach is situated below Boundary Dam. The first mile of the reach is in the U.S. The reservoir behind Seven Mile Dam in Canada can inundate the entire reach to the base of Boundary Dam, depending on its forebay elevation. This creates complex hydraulic conditions in the Tailrace Reach because the water surface elevations can vary with the changes in outflow from Boundary Dam and the changes in forebay elevation at Seven Mile Dam. This makes it difficult to identify or isolate effects from Boundary Dam operations in the Tailrace Reach because the influence of a given Boundary Dam operation depends on the forebay elevation being held at Seven Mile Dam. In evaluating operations scenarios, the task of identifying relative Project effects will be easier, because comparison can be made to the indices representing the baseline condition.

The Tailrace Reach can exhibit both reservoir-like and riverine-like conditions depending on the outflow from Boundary Dam and the forebay elevation of Seven Mile Dam. (It is important to note that for Study 9 passive and active sampling activities, the Tailrace Reach was defined as Boundary Dam to the U.S.-Canada border, which is PRM 17.0 to PRM 16.0. Therefore, the species composition described below is only representative of species captured in the 1-mile section directly downstream of Boundary Dam although the Tailrace Reach for the purposes of Study 7 is defined as PRM 17.0 to PRM 13.9.). Species composition in the Tailrace Reach is dominated by suckers, smallmouth bass, triploid rainbow trout, and northern pikeminnow.

Several large gravid walleye were also captured in the tailrace in April. A total of 80 native salmonids (2 percent of the total tailrace catch, including redband rainbow trout, cutthroat trout, mountain whitefish, and one bull trout) were encountered during the standard monthly sampling in the tailrace.

Figure 6.2-4 illustrates the influence of Project outflow on the water surface elevations in the Tailrace Reach. The condition depicted in the figure has the Seven Mile forebay set at the median pool elevation of 1,727 feet NAVD 88 (1,723 feet NGVD 29). The outflow is set at the median Project inflow rate of 19,500 cfs. The figure shows the increase in water surface elevation caused by release of flows higher than 19,500 cfs and the decrease in water surface elevation by the release of flows lower than 19,500 cfs during Project operations. Releasing a flow of 55,000 cfs causes a 9-foot increase in the water surface elevation at Boundary Dam (all comparisons are to a release of 19,500 cfs). The increase falls to less than 0.5 foot by the downstream end of the habitat modeling study reach at Red Bird Creek. For a release of 35,000 cfs, there is a 4-foot increase in water surface elevation at Boundary Dam, which drops to about 1 foot 2 miles downstream of the dam and near zero at Red Bird Creek. Conversely, a reduction in the release to 5,000 cfs results in lowering the water surface elevation at the base of Boundary Dam by about 4 feet, but less than 0.5 foot 2 miles downstream.

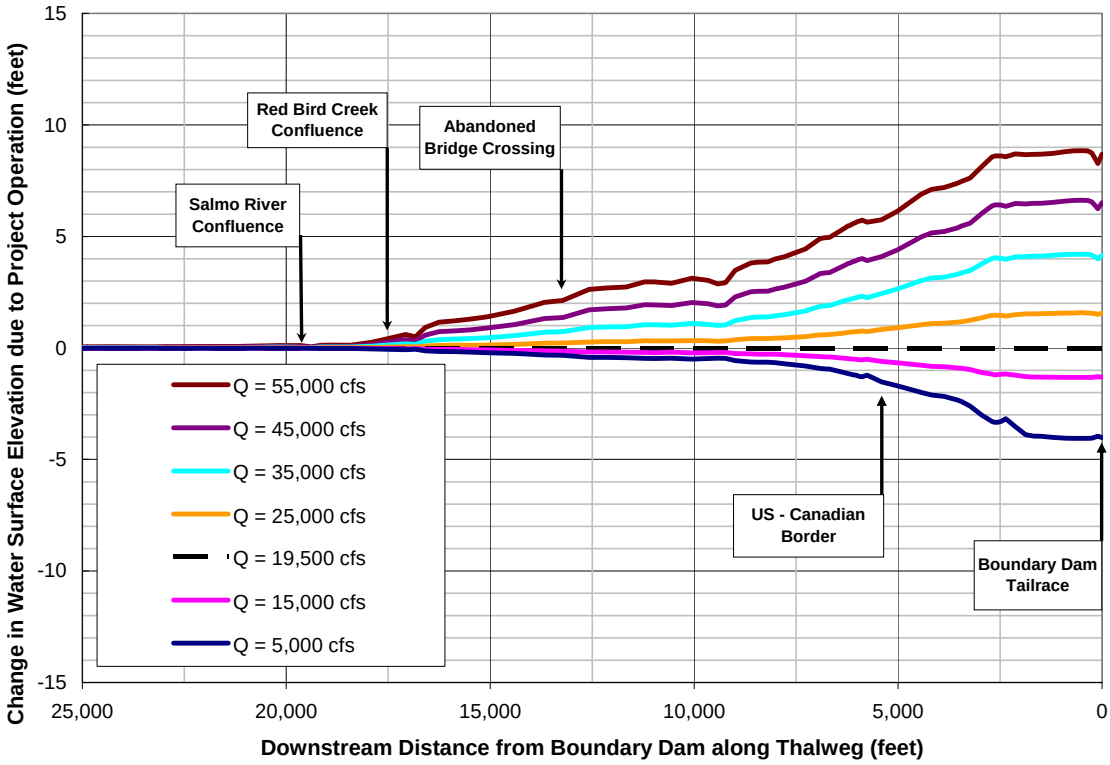



**Figure 6.2-4.** Downstream hydraulic influence of Project operations on water surface elevations relative to conditions associated with 1,727 feet NAVD 88 (1,723 feet NGVD 29) Seven Mile Dam forebay elevation and 19,500 cfs Project inflow.

Figure 6.2-1 shows that the distribution of downramping rates below Boundary Dam in the Tailrace Reach is significantly different from rates upstream of the dam. Below the dam, the most frequent downramping rate is the 0 to 2 inches per hour, which is indicative of slow changes in water surface elevation. However, the Tailrace Reach has over double the occurrences of the highest downramping rate, greater than 12 inches per hour. This is primarily the result of the relatively low storage volume in the Tailrace Reach compared to Boundary Reservoir during periods when the Seven Mile Forebay is drawn down. If future operations under the Waneta Dam upgrade result in higher Seven Mile Dam forebay elevations, the downramping rates in the Tailrace Reach may be reduced.

Within the Tailrace Reach there are nearly 83 acres of shallow water habitat at the median pool median flow condition. This represents about 11 percent of the total shallow water habitat in the study area. On a per mile of channel basis, the Tailrace Reach has the second highest occurrence of shallow water habitat at 26.7 acres per mile. This is about one-third of the per mile shallow water habitat in the Upper Reservoir Reach. It is slightly higher than the 25.1 acres per mile in the Forebay Reach and over three times higher than the 7.9 acres per mile in the steep walled Canyon Reach.

The SI values for the Tailrace Reach (Table 6.2-1) are the second lowest of all the reaches with only the Forebay Reach having lower values. The SI values in the Upper Reservoir Reach are 60 to 80 times greater, depending on the hydrologic condition. Field studies observed no trapping and stranding of any fish species occurring within the Tailrace Reach. Most nearshore areas are moderately sloping and comprised of large cobble and boulder, with minimal dense aquatic weed growth. The trapping and stranding surveys were limited to the area between the U.S.-Canada border and the Boundary Dam. Suckers are the primary species that appeared to have the most potential risk for trapping and stranding. Many young-of-the-year and fingerlings were observed in the Tailrace Reach in July and August. Although mountain whitefish, redband rainbow trout, or cutthroat trout fry have not been observed, early life stages of this species may also be potentially impacted during summer months if fry inhabit the Tailrace Reach. The shoreline areas provide abundant cobble bottom lined channels that would afford suitable rearing for the species, especially during periods of cooler water temperatures. However, similar to the reservoir reaches, water temperatures during summer months typically exceed salmonid thermal preferences and often reach intolerable levels by August (see Section 6.3 below).

The effective spawning analysis for mountain whitefish was conducted in the Tailrace Reach. The results were one-fifth the values for the Upper Reservoir Reach, ranging from a high of 76 feet for the wet year to a low of 68 feet for the average year. In contrast, the lowest mountain whitefish ESI for the Upper Reservoir Reach was 343 feet in the dry year.

The TI values for the Tailrace Reach are similar to the Canyon Reach. The Canyon Reach has higher values in the wet year by a factor of 2, but the Tailrace Reach has higher values for the average and dry years. In contrast, the TI values in the Upper Reservoir Reach are about 20 times larger than those in the Tailrace Reach. The similarity in SI and TI values between the Tailrace Reach and the Canyon Reach is indicative of the similar amounts of shallow water habitats. However, the differences between the individual years is a result of the varying influence on water surface elevation fluctuations that the hydrologic conditions have above

Boundary Dam compared to below Boundary Dam. In viewing the Tailrace Reach SI and TI values for the three representative years, the highest values are in the dry year, next highest in the average year, and the lowest in the wet year. This is similar to the Upper Reservoir Reach.

WUA values for adult mountain whitefish in the Tailrace Reach are the second highest of all reaches. This is supported by observations of adult mountain whitefish in the Tailrace Reach including observations in the late fall and early winter when their presence is likely related to spawning. Over the course of the study, mountain whitefish catch rates in the Tailrace Reach were second only to the Upper Reservoir Reach. The Tailrace Reach has the highest WUA values of all four reaches for mountain whitefish fry. The values are about double those for the reaches upstream of Boundary Dam. This is primarily due to the wider distribution of gravel and cobble substrates in the shallow channel margins throughout the Tailrace Reach compared with conditions upstream of Boundary Dam. Although no mountain whitefish fry were captured during passive and active sampling, it is likely that some spawning is occurring. Several gravid females were captured in November and December 2007. Because passive and active sampling did not occur throughout the entire 3.1-mile-long Study 7 Tailrace Reach and was restricted to the upper 1 mile of this reach for the purposes of Study 9, mountain whitefish fry may be present in the downstream portions of the Study 7 Tailrace Reach.

For adult cutthroat trout, the Tailrace Reach WUA values are similar to those in the Canyon Reach and lower than that of the Forebay Reach. However, catch rates of cutthroat trout were greatest in the Tailrace Reach as compared to the other reaches. Upper Reservoir cutthroat trout catch rates ranked second among the reaches. The riverine-like conditions of the passive and active sampling sites in both the Tailrace and Upper Reservoir reaches may in part account for the discrepancy between the WUA indices and observed relative abundance. The redband trout WUA values in the Tailrace Reach are very similar to the cutthroat trout values.

Likewise, the Tailrace WUA values for adult smallmouth bass are similar to those in the Canyon Reach and lower than that of the Forebay Reach. Smallmouth bass composed approximately 15 percent of the Tailrace Catch and were most prevalent during the spring and summer months. Smallmouth bass shallow water zone catch rates in the Tailrace and Canyon reaches were higher than other reaches during 2007, whereas the Canyon and the Forebay reaches led smallmouth bass catch rates during 2008.

There were no mapped macrophyte beds in the Tailrace Reach. Some factors serve to reduce the presence of any macrophyte beds in this reach and represent severe disturbance to macrophyte bed establishment and maintenance. The macrophyte WUA estimates were much lower in this reach than in any of the other Project reaches (Table 6.2-3). Similar quantities of shallow water habitat were available in the Tailrace Reach as in the Canyon Reach; however, the WUA estimates for each of the hydrologic years were lowest among all reaches in the reservoir (Table 6.1-1). The Tailrace Reach had the highest frequency of water surface elevation fluctuations >12 inches per hour and presented the potential for high water velocities and frequent dewatering of optimal habitat (Figure 6.2-1). In addition to high water velocities, very few areas of this reach had optimal habitat for macrophyte bed establishment, which is reflected in the high variance for WUA estimates (Figure 5.6-4). Macrophytes establish and sustain beds in soft substrate and are susceptible to uprooting from high water velocities. The level of physical disturbance in the

Tailrace Reach, including the high level of water level fluctuations, lack of fine substrate due to bed armoring, and high mean velocities, diminished the potential for macrophyte beds to establish and maintain a presence.

Periphyton WUA estimates were similar among three hydrologic years (e.g., wet, dry, and average) in the Tailrace Reach. Substrate sizes were larger (i.e., gravel and cobble) in this reach and were optimal for colonization of periphyton, but other factors like dewatering disturbance and high water velocities may have precluded higher predicted percentages of useable shallow water habitat (Table 6.1-1). The predicted WUA for the Tailrace Reach was similar to the area predicted for optimal colonization in the Canyon Reach (Table 6.2-3). The annual average WUA estimates for the Tailrace Reach were similar among the three hydrologic years (e.g., wet, dry, and average) and represented one-quarter the size of areas habitable by periphyton in the Upper Reservoir Reach. The highest ramping rate interval occurred most frequently in this reach and likely reduced the area where a combination of the suitability factors occurred for periphyton.

Habitat disturbance resulting from frequent and high water level fluctuations influences multiple variables that predict potential WUA estimates (e.g., depth, velocity, and duration of dewatering). Although regrowth of periphyton colonies is rapid, the changes associated with surface water fluctuation patterns controls many of the variables that predict increased potential for colonization.

The BMI WUA estimates were identical among all three hydrologic years in the Tailrace Reach (Table 6.2-3). The percentage of habitable shallow water habitat is low under all pool flow conditions in the Tailrace Reach and approximately one-fifth that of the Upper Reservoir Reach (Table 6.1-1). The Tailrace Reach is characterized by uniform WUA estimates throughout the year (Figure 5.8-4). The BMI and periphyton communities colonize the same substrates and require the same optimal categories (e.g., gravel and cobble). The same disturbance factors suppressing periphyton growth (e.g., frequent dewatering and high water velocity) are the likely the reason for poor BMI habitat suitability in this reach.

Potential WUA estimates for BMI are low for the Tailrace Reach, in part, resulting from the high level of disturbance from fluctuating flows. The food base for grazing BMI is substantially diminished and the physical factors promoting preferred habitat are low resulting in the low potential WUA estimates. The absence of macrophyte beds for substrate and cover, reduced food base through low availability of periphyton production, and high physical disturbance resulted in low potential for BMI colonization.

Highlights of the discussion of aquatic habitat conditions in the Tailrace Reach are summarized below.

- The evaluation of Project effects on conditions in the Tailrace Reach is complicated by the high level of variability in the forebay elevation of Seven Mile Dam. This factor makes it difficult to identify effects due to changes in Boundary outflow versus changes in Seven Mile forebay elevations. The difficulty will be lessened when scenarios are being evaluated, because the change or operation effect will be based on a comparison with the baseline conditions.

- If the Waneta Dam upgrade results in the Seven Mile Dam forebay elevation being operated at a higher level, this may reduce water surface elevation fluctuations and downramping rates in the Tailrace Reach (studies are currently underway investigating the expansion of the Waneta Project capacity).
- The Tailrace Reach stranding and trapping response for the wet hydrologic year was influenced by reduced water surface elevation fluctuations in Seven Mile Reservoir for the lengthy periods when flows exceeded the approximately 30,000 cfs existing capacity of the Waneta Project. For periods in excess of the 30,000 cfs capacity, the Seven Mile Reservoir remains at a more consistent high pool elevation.
- Project operations at a median Seven Mile pool elevation and median Project inflow rate (outflow from Box Canyon) result in a 10-foot increase in water surface elevation at Boundary Dam, which is reduced to less than 0.5 foot at Red Bird Creek. When releases from Boundary Dam are dropped to 5,000 cfs level, the water surface elevation at Boundary Dam is dropped by about 4 feet compared to what it would be if 19,500 cfs were being released.
- Calculated mountain whitefish ESI values for the Tailrace Reach were about one-fifth of those determined for the Upper Reservoir Reach. This is partially due to the high level of water surface elevation fluctuations in Tailrace Reach compared to the Upper Reservoir Reach.
- The potential for fish stranding and trapping in the Tailrace Reach, based on the SI and TI values, is minimal compared to the Upper Reservoir Reach.
- The WUA values in the Tailrace Reach exhibit a wide range of response compared with the other three reaches, sometimes being the highest and other times being the lowest.
- Soft substrates and low water velocities necessary for macrophyte bed establishment were non-existent in the Tailrace reach and resulted in the lowest estimates for suitable habitat.
- Optimal substrate sizes and depths were present in the Tailrace Reach, but water surface elevation level fluctuations result in frequent dewatering of the useable areas for both periphyton and BMI colonization.
- WUA estimates under all hydrologic years resulted in similarly low habitat area estimates for both periphyton and BMI.

## 6.3. Consideration of Other Factors

The WUA indices used in this analysis provide indicators of habitat change with different flow scenarios. The indices are not intended to directly quantify or predict the abundance of target species. For the Project aquatic habitat studies, HSC (i.e., depth, velocity, and substrate/cover) and HSI (i.e., light availability, duration of inundation, and dewatering) models were integrated to compute WUA indices for analyzing the effects of alternate operational scenarios (to be performed for the IRA and LA). The main focus was exploring relative change in WUA in relation to manipulation of flows.

There is considerable uncertainty over whether fish abundance would actually change with shifts in the WUA. It is recognized that other factors may affect fish abundance and productivity. In

the case of the Project, the annual temperature regime likely exerts considerable influence on the distribution and abundance of native salmonids. During summer months, the water temperature of the Pend Oreille River upstream of Boundary Dam (i.e., Boundary Reservoir) may be at the upper threshold for trout (the typical range of the high temperatures in Boundary Reservoir is from 23° to 25°C). Bull trout are the most sensitive to temperature and will suffer direct mortality when exposed for extended periods (e.g. a week or more) to temperatures in the range of about 21 to 22°C (Ecology 2002). Cutthroat trout are more tolerant with marked mortality occurring when temperatures are in the range of 21 to 24°C for similar periods (Ecology 2002). The adverse effects of elevated water temperature for salmonids range from simple reduction of optimum growth to immediate mortality. In natural systems where salmonids survive year-round, they may encounter conditions where temperatures have some adverse effects on some lifestages. In general, however, where salmonids thrive, they would rarely encounter levels that would be considered lethal for several hours or several days of exposure. Salmonids that are found in systems with adverse warm-water conditions are known to detect and use areas of lower temperature (e.g., thermal refugia), when available, to reduce adverse temperature effects (Sutton et al. 2007; Ebersole et al. 2001). During peak temperature summer months, native salmonids may congregate in cold-water refugia such as the mouths of tributary streams to avoid potentially lethal temperatures. During this period, other areas that contain suitable habitat in terms of depth, velocity, and substrate take on less importance due to unsuitable water temperatures.

The existence of many predator species, such as northern pike, walleye, smallmouth and largemouth bass, and northern pikeminnow may also influence the abundance of native salmonids. Walleye and northern pike have apparently recently colonized the Project, as neither species were captured during intensive sampling conducted during 2000 (McClellan and O'Connor 2001). Moreover, adult and subadult northern pike were only infrequently observed during 2007 sampling; no fry and yearlings were observed in the trapping and stranding surveys conducted that year. Yet, during 2008 surveys, northern pike were commonly encountered in mainstem surveys. Because soft-rayed fish, such as native salmonids, are a preferred prey item for northern pike (Coble 1973), the availability of salmonid WUA in mainstem reaches may be secondary to considerations of water temperature and species interactions.

# 7 VARIANCES FROM FERC-APPROVED STUDY PLAN AND MODIFICATIONS

This section presents and discusses variances from the FERC-approved RSP (SCL 2007a) and modifications. Variances address changes in FERC-approved study plans and changes in the approved study schedules presented in the RSP. Modifications are additions or refinements to the study effort to address study needs that were identified while conducting the study by either the study team or the relicensing participants. For both types of changes, this section presents a brief discussion of why the deviations were made and how the relicensing participants were involved in the process.

## 7.1. Variances

A significant variance that affects all modeling components of Study 7 involves performing operations scenarios. This Final Report presented development of the mainstem aquatic habitat

models and the results of applying the various models to the historic hydrologic record for representative wet, dry and average years. This study evaluated existing Project effects on the aquatic environment associated with the major tributary delta habitats within the study area. The RSP indicated that operations scenarios would be evaluated in the Final Report; however, this will occur in 2009 as part of the IRA. This is a variance from the study plan schedule as outlined in the RSP.

The IRA process will synthesize the results of individual study results across resource areas to characterize Project-related resource impacts and evaluate potential operations-related protection, mitigation, and enhancement (PME) measures. The results of Study 7: Mainstem Habitats, Study 8, and Study 11 will be integrated with the results of other resource studies such as wildlife, recreational resources, and water quality. The IRA process will also identify potential effects of operations scenarios on SCL's interests as a public power provider.

The IRA process has been discussed with the relicensing participants throughout the relicensing proceeding and was a main topic of the December 3, 2008, relicensing meeting. Additional meetings were held in January and February 2009 and coordination with the relicensing participants will continue through spring and early summer 2009. The results of the IRA effort will be documented in the LA to be filed in September 2009.

### 7.1.1. Transect and GIS Based Habitat Descriptors

The variances from methods outlined in the RSP (SCL 2007a) for development of transect and GIS information supporting the development of the mainstem aquatic habitat models involved tasks associated with the habitat transects. The tasks associated with transect development were described under the Tasks 1 though 4 of the Physical Habitat Model Development section of the Study 7 RSP (SCL 2007a).

Transect Selection: Transects for the Mainstem Aquatic Habitat Model were to be selected based on channel typing and major habitat features, and then each transect was to be given an appropriate weighting within the model. This general approach is commonly used in aquatic habitat modeling studies where longer sections of river are to be represented by more detailed data within habitat-type subsamples. For example, all "riffle" habitat in a river (as defined by habitat mapping) is represented by transects placed in a subset of riffles, which are then expanded by length-weighting to the total percentage of riffle.

When the proposed methodology for transect selection began to be implemented, however, two problems became apparent. First, much of the Boundary Reservoir is permanently inundated, and standard riverine habitat characteristics (e.g., riffle, run, low gradient bars, backwater sloughs, etc.) could not be readily determined. Using alternative mapping approaches, such as categories of deep-wide or deep-narrow aquatic habitat, appeared arbitrary and would require considerable "lumping" of many areas of the river without a clear rationale for doing so. Second, the hydraulic response of a transect closer to the dam may be considerably different from those of a transect of the same habitat type further from the dam.

The solution to these problems was to divide the Pend Oreille River between Box Canyon Dam and the U.S.-Canada border into geomorphically similar segments based on aerial photographs

and detailed bathymetric data. Transects were then selected within these segments and assigned weights based on the length of the segments. Therefore, this portion of the study area is represented by transects without the need to determine that one area of the river is "similar" to another that may be quite distant.

The revised approach was presented to relicensing participants using a similar number of transects in Task 1 of the proposed methodology for Physical Habitat Model Development (page 29 of the RSP [SCL 2007a]), and was approved following discussions and minor revisions in transect placement at the April 4, 2007, Fish and Aquatics Workgroup meeting. Task 1, Channel Typing of the Habitat Mapping study, was not performed for the portion of the study area from Box Canyon Dam to the U.S.-Canada border.

The Canadian portion of the Tailrace Reach transects was initially selected based on channel morphology using the detailed aerial photographs and topographic maps, but without the benefit of the detailed bathymetry available in the other reaches. In order to compensate for the absence of the detailed bathymetric data and evaluate whether the selected transects adequately represented the available habitat, reconnaissance-level mesoscale habitat mapping was completed prior to the planned, late summer 2007, installation of the transects (relicensing participant approval at the July 24, 2007, Fish and Aquatics Workgroup meeting). The stream was divided into run, broken water (i.e., riffle), and flat-water habitats with eddies. The transect locations were compared with the habitat typing, enabling a final determination about transect placement. The results are presented in Section 5.1.1.

Relicensing Participant Site Visit: The relicensing participant site visit to review the proposed location of the mainstem habitat transects was not conducted. However, a thorough coordination effort was conducted with the relicensing participants to achieve agreement on the transect locations. Proposed transect locations were reviewed and discussed with relicensing participants and some modifications were made to transect number and location prior to reaching consensus in the roundtable meeting environment on April 16, 2007, and at the Fish and Aquatics Workgroup meetings on April 24, June 7, and July 24, 2007. The availability of high quality current aerial photographs and available interim bathymetry and topography allowed the selection and approval of mainstem transects in this environment. A follow-up site visit to confirm/modify habitat transect selections was offered by SCL, but no relicensing participants indicated a need, so the trip was not implemented. During subsequent site visits, none of the relicensing participants expressed concerns with the proposed transect locations.

Substrate Characteristics: Within the Canyon and Forebay reaches, substrate was characterized to a depth of 50 feet below the low pool elevation using an underwater video camera. The RSP (SCL 2007a) indicates the use of acoustic backscatter to characterize channel substrate at depths greater than 40 feet. At the July 24, 2007, Fish and Aquatics Workgroup meeting, substrate coding was discussed with the relicensing participants, and it was agreed that in the reservoir-like areas, that the substrate below the depth of 50 feet would not be characterized by observation. It was agreed that substrate be set to a suitability value of 1.0 for fish habitat modeling in deep water cells where water depth exceeds 50 feet, thus eliminating substrate as a habitat factor and the need to characterize it at depths greater than 50 feet in the Canyon and Forebay reaches.

Velocity and Depth Measurements: Portions of the Canyon and Forebay reaches have depths well in excess of 50 feet and in some locations greater than 200 feet. Through discussion with the relicensing participants at the April 24, 2007, Fish and Aquatics Workgroup meeting, it was agreed that the velocity measurements would only be performed to a depth of 50 feet below the surface in the Canyon and Forebay reaches. During the same discussions, it was agreed to change the pool elevation condition and discharge requirements for the reaches from what is outlined in the RSP (page 30). The results are summarized in Table 4.3.5 of Section 4.3.4. In general, the modifications resulted in dropping the medium and low pool velocity and depth measurements in the reaches with reservoir-like conditions (Canadian portion of Tailrace Reach, Forebay Reach, and Canyon Reach), conducting the high, medium, and low flow velocity and depth measurement in the more riverine-like reaches (U.S. portion of the Tailrace Reach and the Upper Reservoir Reach) at low pool elevations, and performing a fourth set of measurements in the more riverine-like reaches at high flow and high pool.

### 7.1.2. Hydraulic Routing Model

There were no variances from the FERC-approved RSP (SCL 2007a) for the Hydraulic Routing Model component of Study 7. (Note: In March 2008 it was proposed that collection of the water surface elevation data used to calibrate the HRM would be terminated in June 2008 prior to the third quarter of 2008. However, data collected through July 2008 were used to calibrate the HRM for high flow conditions. Therefore, there is not a variance with the RSP in terms of the HRM water surface elevation data collection. Water surface elevation data will be collected through the winter of 2009, though no further calibration of the HRM will be performed.)

### 7.1.3. Fish Periodicity

There were no variances from the FERC-approved RSP (SCL 2007a) for the Fish Periodicity component of Study 7.

### 7.1.4. Stranding and Trapping

There were no variances from the FERC-approved RSP (SCL 2007a) for the Stranding and Trapping component of Study 7.

### 7.1.5. Downramping Analysis

There were no variances from the FERC-approved RSP (SCL 2007a) for the Downramping Analysis component of Study 7.

### 7.1.6. Macrophyte HSI and Habitat Modeling

There was one variance from the FERC-approved RSP (SCL 2007a) for the Macrophyte HSI and Habitat Modeling component of Study 7. Only the Box Canyon tailrace was surveyed for aquatic macrophytes and not the Box Canyon forebay. The RSP called for either the forebay or the tailrace to be surveyed. However, during the survey no aquatic macrophytes were found in the Box Canyon tailrace. This information was shared with relicensing participants at the April

23, 2008, Fish and Aquatics Workgroup meeting. The relicensing participants concurred that it would not be necessary to survey the macrophytes in the Box Canyon forebay to assist in constructing the HSI curves, because the scientific literature and assumptions based on observations made in Box Canyon Reservoir during the 1980s and early 1990s would sufficiently account for minimum pool fluctuation impact on aquatic macrophytes.

### 7.1.7. Periphyton HSI and Habitat Modeling

The Periphyton HSI and Habitat Model development study component was conducted in accordance with the FERC-approved RSP (SCL 2007a) with a minor variance. Based on the RSP, all hard substrate samples (shoreline and vertical face sites) were to be retrieved 8 weeks following deployment. This was the scheduled followed for the spring, summer, and fall periphyton hard substrate samples. The winter periphyton hard substrate samples however, were retrieved 14 weeks after deployment to due reservoir ice cover and inaccessibility. This variance was presented to the relicensing participants during the March 17, 2008, workgroup meeting.

There was a small variance in the number of samples deployed during the 2008 comparison study. As part of the comparison study, two sets of baskets were originally proposed to be deployed for exposure periods of 4 and 8 weeks along the shoreline in Boundary Reservoir. The first set of sampling baskets was deployed on schedule for an 8 week exposure period. However, increases in reservoir flows by early May 2008 were too high for the second deployment (4-week exposure) to occur. Flow levels higher than those safe for sample collection precluded further colonization studies past early May 2008 and resulted in the characterization of periphyton for a 4-week exposure time instead of an 8-week exposure time. The first set of sampling baskets was retrieved in early May 2008 due to projected flows for June 2008 that presented unsafe site conditions for retrieval of basket sets. The variance in exposure time during the comparison study was presented to July 17, 2008, Fish and Aquatics Workgroup meeting and the workgroup members understood the limitations due to flow conditions.

### 7.1.8. Benthic Macroinvertebrate HSI and Habitat Modeling

The Benthic Macroinvertebrate HSI and Habitat Modeling Component of Study 7 was conducted in accordance with the FERC-approved RSP (SCL 2007a), with a few minor variances. Due to the dynamic nature of field work and the inability to foresee all conditions that may be encountered, a few minor variances were implemented to adjust for conditions encountered during study implementation.

One minor variance involved sampling for soft substrate in the Upper Boundary Reservoir, which was affected by velocity conditions at the sample site. Velocity conditions at the 40-foot depth prevented the collection of a viable soft sediment sample either because the soft sediment had been washed away, or because the sediment was washed out of the petit ponar during retrieval. Repeated sampling in the area of the sample site did not produce a viable sample. Rather than change the location of the sample (which would have changed the physical habitat data analysis point), the 40-foot depth sample was not collected at this location in September. Although all samples are considered valuable, initial literature review suggested that while BMI may be found at 40 feet and deeper, the most suitable habitat is found at shallower depths (refer to Section 5.4.4). As such, the removal of one of the 40-foot depth seasonal samples would not

greatly affect the ability to evaluate macroinvertebrates in a system of moderate pool fluctuation, such as the upper Boundary Reservoir. The other data points from the other 40-foot-depth samples were used to extrapolate the biomass for the September sample. Relicensing participants were notified of this variance at the October 17, 2007, Fish and Aquatics Workgroup meeting.

Another minor variance concerned the retrieval of all hard substrate samples (shoreline and vertical face sites) 8 weeks following deployment. This was the scheduled followed for the spring, summer, and fall BMI hard substrate samples. The winter BMI hard substrate samples however, were retrieved 14 weeks after deployment to due to reservoir ice cover and inaccessibility. This variance was presented to the relicensing participants during the March 17, 2008, Fish and Aquatics Workgroup meeting.

The final minor variance was in the number of samples deployed during the 2008 comparison study. As part of the comparison study two sets of baskets were originally proposed to be deployed along the shoreline in Boundary Reservoir for exposure periods of 4 and 8 weeks. The first set of sampling baskets was deployed on schedule for an 8-week exposure period. However, increases in reservoir flows by early May 2008 were too high for the second deployment (4-week period) to occur. Flow levels higher than those safe for sample collection would preclude further colonization studies past early May 2008 and resulted in the characterization of BMI colonization for a 4-week instead of 8-week exposure time. The first set of sampling baskets was retrieved in early May 2008 due to projected flows for June 2008 that presented unsafe site conditions for retrieval of basket sets. The variance in exposure time during the comparison study was presented to the Fish and Aquatics Workgroup members on July 17, 2008.

### 7.1.9. Fish HSI and Habitat Modeling

There was one variance to the FERC-approved Study plan for the Fish HSI and Modeling component of the study in 2007 and three additional variances in 2008. These variances were all presented to and approved by the relicensing participants and are discussed below.

#### *7.1.9.1. 2007 Variances*

Only one variance occurred in 2007 from the FERC-approved RSP (SCL 2007a), which was to modify one of the fish species to be used for the mainstem model analysis. The RSP identified redside shiner as the species to be used in the habitat model to represent forage species habitat use and this was changed. This species was chosen because of its small size, presumed common occurrence within the reservoir, and reasonable characteristics as a forage base for larger predatory fish. However, early sampling in the reservoir found few of this species present. Also literature information on habitat use by this species, suitable for developing literature-based curves, was limited. In the April 24, 2007, Fish and Aquatics Workgroup meeting, SCL proposed to use a guilding approach to develop a generic forage fish HSC/HSI curve rather than select a representative species. During the June 7, 2007, Fish and Aquatics Workgroup meeting, relicensing participants agreed to use a generic forage fish HSC/HSI curve to be based upon site-specific data and existing literature curves for juvenile northern pikeminnow, redside shiner, peamouth, and other cyprinids. Fish that are about 10 cm in length or smaller were targeted as

those suitable as forage fish. Using small cyprinids as the target taxa, initial HSI curves were developed using literature information from other cyprinid taxa.

#### *7.1.9.2. 2008 Variances*

All modifications were presented and approved by the relicensing participants at the Fish and Aquatic Workgroup meeting held on March 25 and the FERC Initial Study Report meeting held on March 26, 2008. Modifications involved three main areas, the elimination of velocity measurements during biotelemetry mobile tracking, the cessation of HSI data collection by electrofishing after February 2008 and removal of several combinations of fish species and life stages from the HSI and modeling effort. The following provides a description of the accepted modifications to the Fish HSI and Modeling study component.

Biotelemetry Velocity Data for HSI: The collection of velocity data as part of the biotelemetry HSI methodology was eliminated. The velocity measurement data taken during the HSI data collection efforts were not of sufficient quality for HSI development. Due to limited accuracy (±33 feet) associated with fish locations identified by radio telemetry, the likelihood that fish were in a much different velocity (e.g., near the bottom) in deep and fast water areas, and difficulty in getting stationary positions to measure velocity during tracking, water velocity data recorded at these locations were not suitable for HSC curve development. Depth measurements however, did supply useful information for HSI curve development.

HSI Data Collection by Electrofishing: The collection of HSI data by electrofishing was terminated after February 2008. The RSP schedule showed HSI data collection continuing through the second quarter of 2008; however, in coordination with the relicensing participants, the collection of HSI data by boat electrofishing was terminated after February 2008. Fish distribution and abundance sampling (primarily electrofishing) was considered to be a secondary method of HSI data collection in the RSP. As discussed in the results, very few data points (depth, velocity, and substrate) were collected for most of the target species and life stages through September 2007. Less than four HSI data points were collected for any native salmonid (e.g., bull trout, cutthroat trout, wild rainbow trout, or mountain whitefish). Moderate to large literature databases were available from which to build curves for these species and life stages, as shown in Appendix 9. Some useful data were collected for rearing stages of smallmouth bass and forage species, but these numbers remained insufficient for developing new HSI curves. Also, boat electrofishing was restricted to sampling nearshore habitats with water depths of 1 to 7 feet, which in this deep reservoir system is a small portion of the total habitat. Therefore, there were limitations regarding the usefulness of electrofishing HSI data, even if more data points had been collected. Spawning stages of any fish species were not observed during any HSI data collection.

Elimination of HSI Development and Modeling for Four Life Stages/Species: The development of HSI curves and associated modeling analysis were eliminated for four life history stage curves for the mainstem habitat model (spawning and fry stages for bull trout and westslope cutthroat trout). Available current and historical data did not indicate that either bull trout or westslope cutthroat trout are present within the mainstream as spawning or fry stages. Adults are rarely present (no bull trout were captured in the reservoir and only nine cutthroat trout were captured in 2007). Additionally, no samples were obtained of either species as fry stages in the reservoir.

The implication is that spawning by either of these species is not occurring and is highly unlikely to occur in the reservoir. While some juvenile cutthroat trout were observed moving downstream toward the reservoir in tributaries during mid- to late summer, many of these fish were larger than fry stage (about 5 to 6 cm) and none of the fry-size cutthroat trout were ever captured in the reservoir. Considering the potential impact of existing Project effects on the life stages of these species in the mainstem reservoir habitat is not justified because of their absence of use.

## 7.2. Modifications

In general, modifications are additions or refinements that address needs that have been identified during the study by either the study team or the relicensing participants. This section lists the efforts conducted in 2007 and 2008 that were in addition to or a refinement of efforts outlined in the RSP (SCL 2007a).

### 7.2.1. Transect- and GIS-Based Habitat Descriptors

The only modification to the Transect- and GIS-Based Habitat Descriptors was the addition of a second macrophyte mapping effort in 2008. To support the stranding and trapping analysis, macrophyte coverage in pools and slopes required characterized at a higher level of resolution than in the 2007 macrophyte mapping effort. During the stranding and trapping surveys in 2007, it was documented that aquatic macrophyte growth plays a significant role in stranding and trapping rates. The macrophyte mapping was used in the stranding and trapping model for defining macrophyte coverage for stranding areas and trapping pools by overlaying the macrophyte mapping on the GIS maps of the stranding and trapping locations. The additional macrophyte mapping effort was conducted in August 2008 and is provided in Appendix 1b. This modification was presented to the relicensing participants and approved at the March 25, 2008, Fish and Aquatics Workgroup meeting.

### 7.2.2. Hydraulic Routing Model

There were no modifications to the HRM component of Study 7.

### 7.2.3. Fish Periodicity

There were no modifications to the Fish Periodicity component of Study 7.

### 7.2.4. Stranding and Trapping

There were a several modifications to the field work originally planned in the 2007 season and for the 2008 field sampling season. Changes in 2007 were primarily directed at obtaining stranding and trapping information from more areas, but collecting less detailed site-specific fish information data. Modifications for 2008 were intended to obtain winter stranding and trapping information and directing studies more specifically at refining the provisional stranding and trapping model factor value.

#### 7.2.4.1. 2007 Modifications

Minor changes from the methods outline were implemented during 2007. For example, the methods outline suggested using the hydraulic routing model to prioritize potential stranding and trapping sites identified during the initial reconnaissance survey. By integrating the results from the reconnaissance survey with bathymetry and water elevation model predictions, it would be possible to identify the elevations at which stranding and trapping sites would dewater and/or isolate. The summer 2007 field studies were delayed because the hydraulic routing model and bathymetry were not complete. Therefore, it was not possible to identify the flows and reservoir water elevations related to specific site dewatering and/or isolation. Location of isolated pools and dewatered stranding areas were documented on aerial photos and partially complete bathymetric maps during surveys in 2007. An extra field survey was conducted in September 2007. Results of the 2007 stranding and trapping data collection effort were presented to the Fish and Aquatics Workgroup at the February 28, 2008, including the dates surveys were conducted and the type of information collected. At the March 25, 2008, Fish and Aquatics Workgroup meeting and the March 26, 2008, FERC Initial Study Report meeting, the completed 2007 and proposed 2008 stranding and trapping field data collection efforts were presented and the workgroup agreed on the overall field data collection effort (see Section 7.2.4.2).

One other modification from the methods outline was that deep mud at several identified regions limited the collection of habitat data. Also, field conditions and time constraints led to a shift in priorities from fish observations to habitat data collection to allow as many sites as possible to be surveyed during drawdown events. Relicensing participants were kept informed of the 2007 data collection effort including a site visit on August 14, 2007, during which stranding and trapping regions were visited during a drawdown event. During this site visit, the relicensing participants observed the challenging field conditions.

#### 7.2.4.2. 2008 Modifications

All modifications to the stranding and trapping effort were presented and approved by the relicensing participants at the Fish and Aquatic Workgroup meeting held on March 25 and the FERC Initial Study Report meeting held on March 26, 2008. Based on the results from the 2007 stranding and trapping surveys in Boundary Reservoir, two study modifications were made to the 2008 stranding and trapping surveys. The 2008 stranding and trapping survey schedule was modified to support analysis of the seasonal differences in stranding and trapping rates and to aid in the determination of factor values for the stranding and trapping model development. The schedule modifications increased the number of stranding and trapping survey conducted in 2008. The second modification involved monitoring the rate at which pools and side channels drain during flow reduction.

<u>Seasonal Differences in Stranding and Trapping</u>: The survey schedule was modified for 2008 to address seasonal differences in stranding and trapping, and to address the effects of stranding and trapping during emergence of mountain whitefish and other salmonids, a more intensive study program was scheduled in late winter and early spring of 2008. To address stranding and trapping during winter and early spring, surveys were planned in the months of February and March. During the spring and summer months, monthly surveys were scheduled following reductions in Boundary forebay water surface elevations. The survey crews were unable to

perform the effort in February due to extensive ice on the reservoir. Surveys were conducted in March and April, but no emerging mountain whitefish were found. Due to the high runoff, conditions were not appropriate for performing standing and trapping surveys in June.

Monitoring of Pool Draining During Drawdown: Transducers were installed at 20 locations to monitor the rate at which water surface elevations drop in pool and side channel habitats after being disconnected from the mainstem flow. The dewatering rates were monitored during normal daily flow fluctuations and during the extended drawdowns performed in July and August of 2008.

### 7.2.5. Downramping Analysis

There were no modifications to the Downramping Analysis component of Study 7.

### 7.2.6. Macrophyte HSI and Modeling

There were no modifications to the Macrophyte HSI and Modeling study component. Additional mapping of macrophyte beds was conducted in August 2008 to support the Stranding and Trapping Study component. This effort was discussed under Section 7.2.1.

### 7.2.7. Periphyton HSI and Habitat Modeling

Additional sampling was conducted in 2008 to compare the periphyton found in the artificial substrate samplers with periphyton on natural hard substrate at shoreline sites in two reservoir locations. This study evaluated any differences in periphyton chlorophyll *a* that may result from altered conditions (i.e., reduced velocity) caused by the artificial sampling baskets. Results from this additional study were used in the calibration of HSI curves and to test the hypothesis that the influence of velocity on periphyton growth was adequately described based on initial results from collection with artificial substrate. Artificial baskets and existing periphyton community conditions were characterized simultaneously at the two shoreline site in Boundary Reservoir to define the difference in maximum accumulation of periphyton biomass as well as relative colonization time.

Statistical comparisons of depth and substrate types were conducted using parametric analysis of variance (ANOVA) evaluation methods. Each data set generated for chlorophyll *a* was transformed as needed to meet the normal distribution requirements for parametric statistical tests. Statistical results addressed the potential for differential biological response at locations in the Canyon and Metaline reaches of Boundary Reservoir. These results determined whether HSI curves should be developed for each of these two zones in the reservoir or if the response from periphyton communities to depth was consistent throughout the reservoir. Because this test used an environmental variable consistently used throughout the study area (i.e., depth), the statistical test evaluated a zone effect (i.e., Canyon vs. Metaline).

A set of graphical presentations was developed for each of the analyses to determine the direction of the response in each of the artificial vs. natural substrates to depth intervals. These results evaluated the level of colonization on the substrates (e.g., chlorophyll *a* accumulated during deployment) and the strength of biological signal to the depth gradient on each of the

artificial vs. natural substrates. Results from this evaluation were used to determine how well the use of previous artificial substrate results reflected natural substrate responses.

The additional 2008 comparison study between artificial and natural substrate was proposed to RPs initially at the February 28, 2008, Fish and Aquatics Workgroup meeting in Spokane, Washington. Relicensing participants tentatively agreed to the additional study at this meeting and gave further approval at the March 25, 2008, Fish and Aquatics Workgroup meeting.

### 7.2.8. Benthic Macroinvertebrate HSI

Additional sampling was conducted for 2008 to compare the effects of using artificial substrate baskets on BMI community structure and biomass. The artificial samplers may have created a protected environment over that of natural rock substrate that potentially altered the BMI community structure in favor of those species that prefer slower water velocities. Altered velocity conditions may have also artificially increased the biomass due to increased production of periphyton. The additional field study included sampling using both artificial samplers and native substrate at the shoreline sites in two locations in Boundary Reservoir.

Biological samples describing properties of BMI can be highly variable depending on their response to multiple environmental gradients. Properties of this variability in the biological response (e.g., dry biomass estimates) were evaluated using ANOVA and testing for influences from artificial vs. natural substrates and from depth of deployment. BMI biomass was estimated with *Hydra* sp. and without *Hydra* sp. for each of the substrate collection devices and at both depths. Previous collection of biological information analyzed the effect of inclusion and exclusion of *Hydra* sp. on interpretation of response to environmental gradients. Each of the ANOVA models used BMI data sets that included *Hydra* sp. and excluded *Hydra* sp. and examined the consistency of response between the two data sets and the biotic response to changes in substrate sampling method and depth.

The comparison between results from artificial versus natural substrate was evaluated by direct comparison of BMI response (with and without *Hydra* sp.) under each depth, velocity, and substrate scenario. These comparisons looked at whether the biological response was parallel between artificial and natural substrates along each environmental gradient or if it varied. If the response was not parallel, then other factors were identified and examined to learn if they have a greater influence on BMI community than does inundation and dewatering. These comparisons were useful for determining how to adjust and use results from the 2007 sampling effort by identifying if responses to environmental gradients were in the same direction and magnitude or if they varied along each environmental gradient.

The additional 2008 comparison study between artificial and natural substrate was proposed to relicensing participants initially at the February 28, 2008, Fish and Aquatics Workgroup meeting in Spokane, Washington. Relicensing participants tentatively agreed to the additional study at this meeting and gave further approval at the March 25, 2008, Fish and Aquatics Workgroup meeting.

### 7.2.9. Fish HSI and Habitat Modeling

There were no modifications to the Fish HSI and Habitat Modeling component of Study 7.

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# Appendix 1: Transects and GIS-based Habitat Descriptors

Appendix 1a. Habitat Transect Measurements and Calibration Final Report

Appendix 1b. Macrophyte Mapping Final Report

Appendix 1c. Stranding and Trapping GIS Mapping and Physical Characteristics Final Report

Appendix 1a. Habitat Transect Measurements and Calibration Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 1a*

## *Habitat Transect Measurements and Calibration*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
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**March 2009**

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# Study 7 Appendix 1a
# Habitat Transect Measurements and Calibration
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

This report presents the results of the mainstem habitat transect measurement and calibration effort. The transects are the primary habitat descriptor for the modeling of the weighted useable area (WUA) associated with macrophytes, periphyton and benthic macroinvertebrates (BMI). The habitat transects provide the geometric representation of the Pend Oreille River habitat as well as substrate and cover conditions. When combined with the hourly water surface elevations (WSEs) generated by the Hydraulic Routing Model (HRM) and the hydraulic calculation routines based on the Physical Habitat Simulation (PHABSIM) (Milhous et al. 1984), the transects supply the column velocity and depth information along the transects used to determine WUA from the Habitat Suitability Indices (HSIs).

A significant variable backwater effect from Metaline Falls and Boundary Dam is evident throughout the range of forebay elevations including low pool. This backwater effect precluded both development of individual transect stage-discharge relationships and use of the velocity regression method. In other words, the stage and the velocities for any given discharge are not solely a function of the channel cross-section shape and the discharge. They are also dependent on the elevation of the Boundary Dam forebay (or Seven Mile Dam in the case of the Tailrace Reach) dictated by Project operations, somewhat analogous to a tidal river where the tidal stage can have as much influence on depths and velocities as river flow. Because individual transect stage-discharge relationships could not be developed using least-squares analysis of the transect field data, the HRM was developed for the Boundary and Seven Mile reservoirs to model hydraulic conditions. The HRM is used to simulate the water surface elevation at the various transects for any given set of Forebay elevation and Project inflow conditions. In the portions of the study area with the most riverine-like conditions, four sets of transect measurements were collected and calibrated. In the portions of the Study Area that were most-reservoir like, only one set of transect measurements were made.

## 2 OBJECTIVES

The goal of the mainstem habitat measurements and calibration effort was to provide the channel geometry, cover and substrate conditions, and hydraulic information to support modeling of the WUA for the biota of interest to Study 7, Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009). The biota of interest include macrophytes, periphyton, BMI and a combination of nearly 30 fish species and associated life stages. Specific tasks or objectives to accomplish the goals of this effort included:

- Select representative habitat transects
- Characterize substrate and vegetation along habitat transects

- Perform velocity and depth measurements along habitat transects for selected combinations of flow and pool conditions
- Develop cross-sectional profiles (depth and velocity)
- Calibrate transect channel roughness (Manning's n-values)
- Integration of habitat transects into the hydraulic model

## 3 STUDY AREA

The study area for the habitat transect measurements and calibration effort coincided with the detailed study area for Study 7 Final Report (SCL 2009). It included all of Boundary Reservoir and portions of the Pend Oreille River mainstem downstream of Boundary Dam that could potentially be affected by operations scenarios and extends to the confluence with Red Bird Creek.

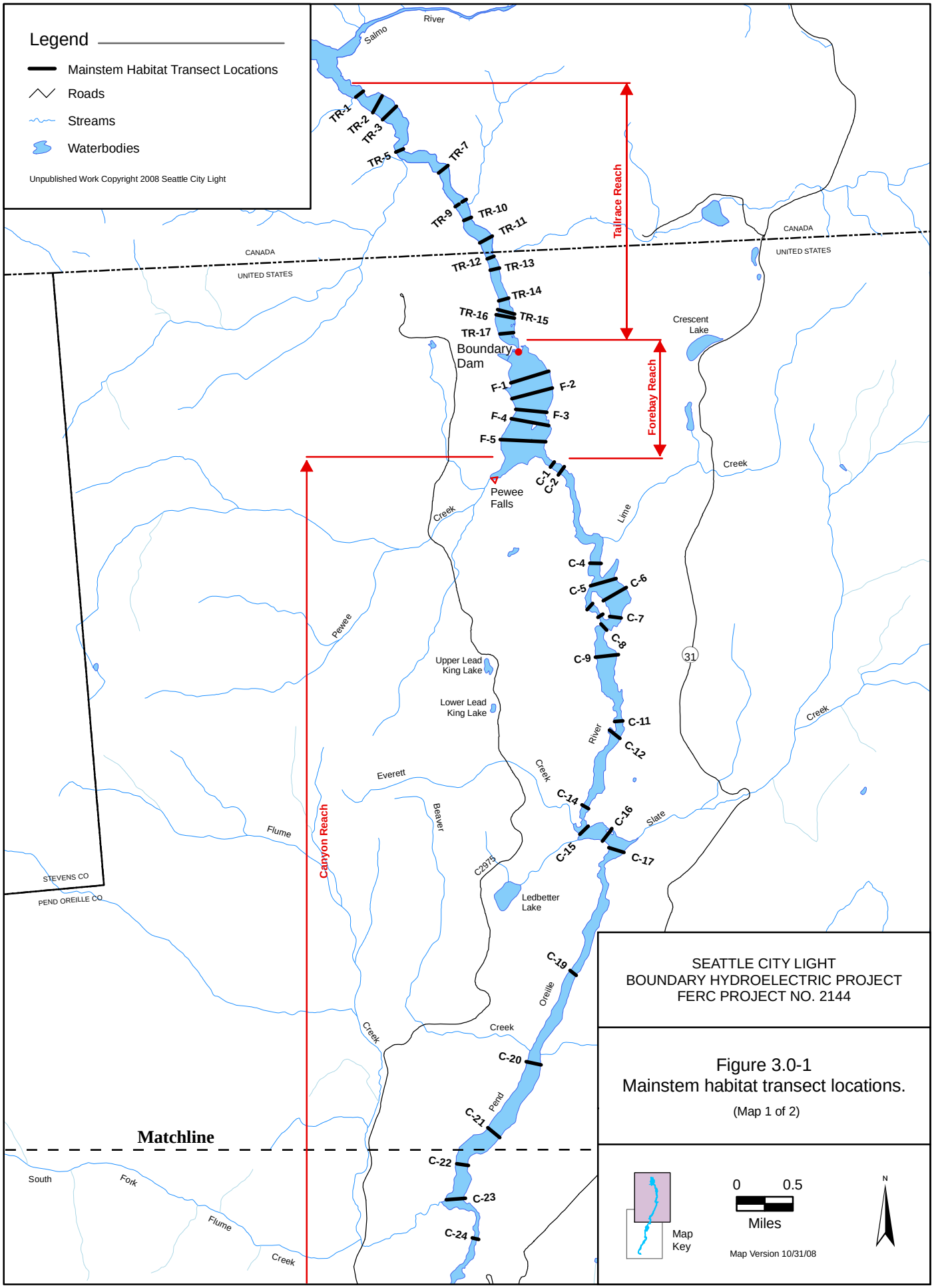
The study area was divided into the following four reaches:

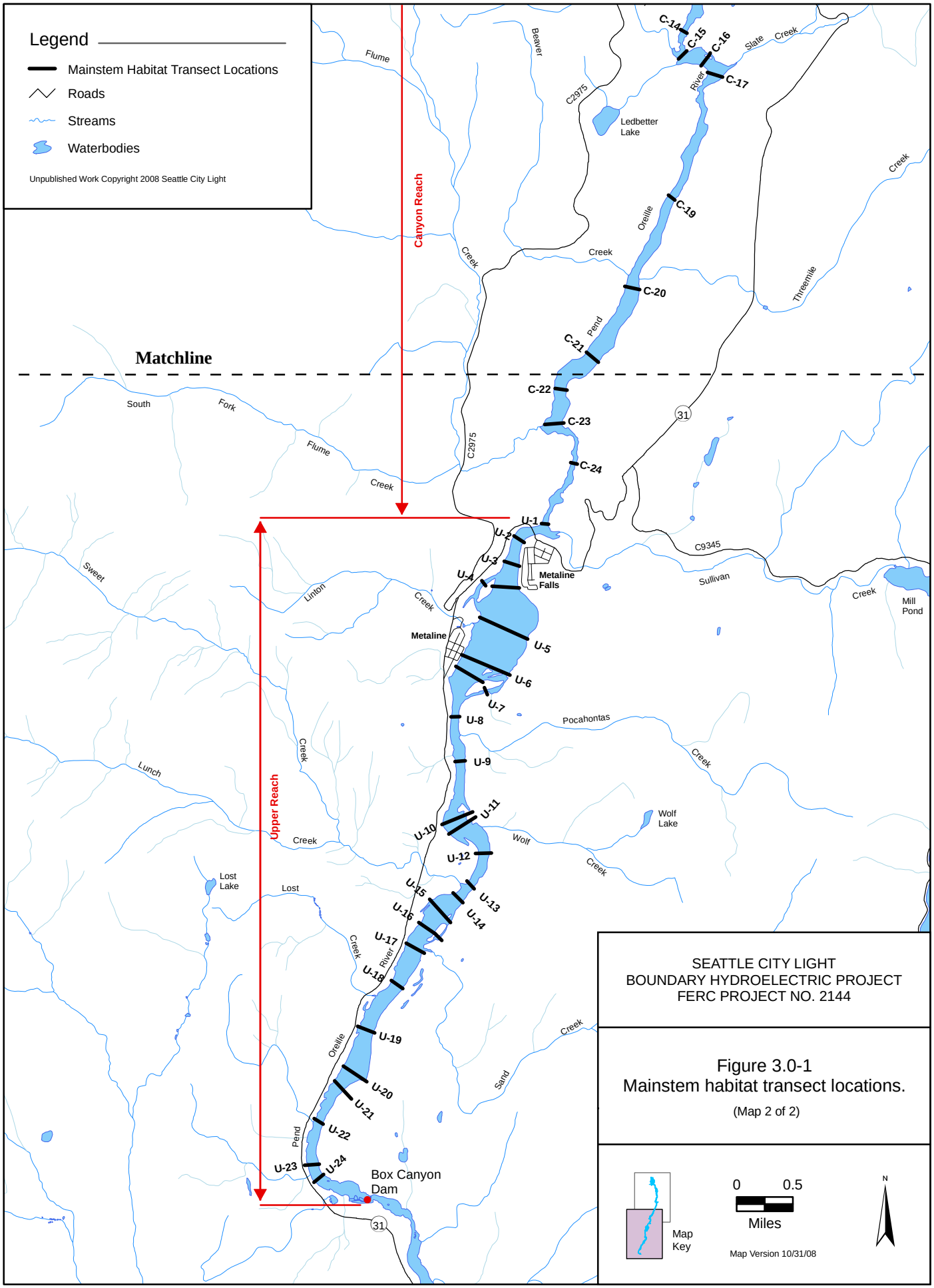
- Upper Reservoir Reach—Box Canyon Dam to Metaline Falls (Project river mile [PRM] 34.5–26.8)
- Canyon Reach—Metaline Falls to downstream end of Z Canyon (PRM 26.8–18.0)
- Forebay Reach—Downstream end of Z Canyon to Boundary Dam (PRM 18.0–17.0)
- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

A total of 63 habitat transects were surveyed and have been incorporated into the mainstream habitat aquatic modeling effort. These transects are distributed as follows:

- Forebay Reach—5 transects
- Canyon Reach—20 transects
- Upper Reservoir Reach—24 transects
- Tailrace Reach—14 transects

The locations of the reaches and the habitat transects are provided on Figure 3.0-1.


Legend
Mainstem Habitat Transect Locations
Roads
Streams
Waterbodies
Unpublished Work Copyright 2008 Seattle City Light
Salmo
River
TR-1
TR-2
TR-3
TR-5
TR-7
TR-9
TR-10
TR-11
TR-12
TR-13
TR-14
TR-16
TR-15
TR-17
Tailrace Reach
CANADA
UNITED STATES
Boundary Dam
Crescent Lake
F-1
F-2
F-4
F-3
F-5
Forebay Reach
C-1
C-2
Pewee Falls
Creek
Lime
C-4
C-5
C-6
C-7
C-8
C-9
Pewee
Upper Lead King Lake
Lower Lead King Lake
31
C-11
C-12
River
Everett
Creek
C-14
C-16
Slate
C-15
C-17
Beaver
Flume
Canyon Reach
C2975
STEVENS CO
PEND OREILLE CO
Ledbetter Lake
C-19
Oreille
Creek
C-20
Pend
C-21
Matchline
C-22
C-23
C-24
South
Fork
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 3.0-1
Mainstem habitat transect locations.
(Map 1 of 2)
Map Key
0
0.5
Miles
Map Version 10/31/08
N




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 3.0-1
Mainstem habitat transect locations.

(Map 2 of 2)

Map Key

0 0.5
Miles

Map Version 10/31/08

N

# 4 METHODS

This section presents the methods used to select habitat transects, perform field data collection, and calibrate the mainstem habitat transects. The steps in this process include: transect selection, substrate and aquatic vegetation characterization, velocity and depth measurements, development of cross-sectional profiles, and calibration of N-values and integration of the mainstem habitat transects into the HRM.

## 4.1. Transect Selection

In coordination with relicensing participants, transects in the mainstem Pend Oreille River were selected to describe physical habitat conditions based on channel morphology and major habitat features. Habitat transects were also placed in consideration of other distinct habitat features, such as localized areas of fish trapping, stranding, and localized spawning that may not have been adequately described by transects used to describe predominant habitat features. Each transect in each reach was selected to represent a segment of similar habitat. In this manner, each reach is entirely represented by the selected transects. Transects were located near some of the water surface elevation recorders (see the main report Section 4.2) to assist in calibrating the flow routing model to mainstem habitat transects.

Initially, each reach was divided into segments according to stream width on topographic maps. These segments were overlaid on reservoir bathymetry contours and aerial photographs. Additional segments were added to reflect variations in the water depth and additional features on the aerial photographs. Within each segment, a transect was placed in a position that best represented the entire segment. Each transect in each reach was selected to represent a segment of similar habitat. In this manner, each reach is entirely represented by the selected transects. Field inspection of the preliminary transect placement in the reaches upstream of Boundary Dam occurred prior to final submittal to the relicensing participants at the April 24, 2007, Fish and Aquatics Workgroup meeting.

At the April 24, 2007, Fish and Aquatics Workgroup meeting, the number and locations of the transects upstream of the Boundary Dam were approved, noting that a reduction in the number of Canyon Reach transects was possible due to the general homogeneity of habitat in that reach. Rationale for eliminating five transects in the Canyon Reach was presented and accepted at the June 7, 2007, Fish and Aquatics Workgroup meeting resulting in a final total of 20 transects in the Canyon Reach. Also at this meeting, the locations of the six U.S. Tailrace Reach transects were approved.

No detailed bathymetry was available for the Canadian Tailrace Reach prior to the transect selection process. In order to verify that the transect locations accurately represented the available habitat in the absence of detailed bathymetry data; reconnaissance-level mesoscale habitat mapping was completed prior to finalization. The locations of the selected transects were compared to the habitat mapping, resulting in the positioning of the eight transects downstream of the U.S.-Canada border. The number and locations of the Canadian Tailrace transects were approved at the July 24, 2007, Fish and Aquatics workgroup meeting.

Through the process just described, proposed transect locations were reviewed and discussed with relicensing participants and some modifications were made to transect number and location prior to reaching consensus in the roundtable meeting environment. The availability of high quality current aerial photographs and the detailed bathymetry and topography allowed the selection and approval of mainstem transects in this environment. A follow-up site visit to confirm/modify habitat transect selections was offered by SCL, but no relicensing participants indicated desire or need, so the trip was not implemented. During subsequent site visits, none of the relicensing participants expressed concerns with the proposed transect locations.

Several factors within this complex study area required departure from the normal methods of transect selection:

- The depth and width of the reservoir prevents important aspects (e.g., bottom topography) of the study reaches from being observed through traditional field habitat mapping methods.
- The variability of water surface elevation fluctuations precludes observation of the different pool stages during habitat mapping.
- The variability of water surface elevation fluctuations adds a complexity to the study area best addressed by representing entire reaches with transects, rather than subsampling the available habitat.

The traditional method of habitat mapping involves traveling upstream and demarcating appropriate mesohabitat types. The appropriate subsample quantity of mesohabitat types, based on representation, is determined and a random selection is made for transect placement. Due to the depth of the reservoir and availability of high quality bathymetry data, as well as aerial photography, initial characterization of the study area was better accomplished through inspection of that data. The large scale of the reservoir enabled sections of generally homogenous cross section to be selected. Rather than stratify each reach into mesohabitat types, each segment was represented by one transect, thus representing entire reaches. This avoided the complexity and errors associated with using a subsample of transects to represent habitat in other parts of the reservoir, which have different responses to the variability of water surface elevation fluctuations. The segments were short enough to allow for a coherent response to the flow changes to be represented by one transect. In the PHABSIM, each transect was weighted in the proportion of the segment length that it represents to the entire reach length.

## 4.2. Substrate and Aquatic Vegetation Characterization

Substrate and aquatic vegetation were mapped and characterized along habitat transects to a depth of 50 feet below the low pool water surface. An underwater video camera was used to characterize and map substrate and macrophytes in water too deep to observe from the surface. Although data collected from this effort compliments the river-wide aquatic vegetation mapping, the two study components were executed independently. The approach used during the riverwide aquatic vegetation mapping is presented in Section 4.1.2.1 of the Study 7 Final Report (SCL 2009).

Codes and associated descriptors for substrate and cover were developed in consultation with relicensing participants and approved at the July 24, 2007, Fish and Aquatics Workgroup

meeting. This effort included a set of additional codes and associated descriptors in the case that aquatic vegetation was identified as the cover type. The aquatic vegetation codes included primary codes for vegetation type and subcodes for density. A primary consideration for both descriptions and coding was compatibility with instream flow study guidelines from the Washington State Department of Fish and Wildlife (WDFW) and Washington Department of Ecology (Ecology) (WDFW and Ecology 2004). Codes for cover types associated with aquatic habitat are provided in Table 4.2-1 and codes for substrate types associated with aquatic habitat in Table 4.2-2.

**Table 4.2-1.** Codes for cover types.

| Code | Description |
|---|---|
| 1 | Undercut bank |
| 2 | Overhanging vegetation (within 3 feet of surface) |
| 3 | Rootwads |
| 4 | Log jams or brush piles |
| 5 | Individual logs |
| 6 | Aquatic vegetation[1] |
| 7 | Short (<1 ft) terrestrial grass |
| 8 | Tall (>3 ft) dense grass |
| 9 | Vegetation beyond the bank-full waters edge |

Note:
1 Additional description of aquatic vegetation to be provided on separate coding sheet when present.

**Table 4.2-2.** Codes for substrate types.

| Code | Description |
|---|---|
| 1[1] | Silt, clay, or organics |
| 2 | Sand |
| 3 | Small gravel (0.25–1.25 cm) |
| 4 | Medium gravel (1.25–3.75 cm) |
| 5 | Large gravel (3.75–7.5 cm) |
| 6 | Small cobble (7.5–15 cm) |
| 7 | Large cobble (15–30 cm) |
| 8 | Boulder (>30 cm) |
| 9 | Bedrock |

Note:
1 The full substrate code includes the code number for the dominant particle size (in terms of surface area covered), the subdominant particle size, and the percentage of the dominant (e.g., a 27.6 = sand dominant [at 60 percent] with large cobble subdominant).

The importance of substrate composition for rearing life stages of most non-benthic fish is frequently debated, with much evidence to suggest that the primary function of substrate for non-spawning fish is as cover from predators or high velocities. In the deep water areas of Boundary

Reservoir, substrate composition is not expected to play a significant role in determining the habitat suitability for rearing fish, either for feeding, resting, or for cover. Given this assumption, and the infeasibility of assessing substrate composition in deep-water areas, the substrate type for fish habitat modeling in deep water was set to a suitability value of 1.0. The initial cover and substrate codes collected were condensed during the development of fish HSI and prior to application in the hydraulic model. Fish HSI values were developed for the spawning life stages of whitefish and smallmouth bass using the dominant-only substrate type. Cover HSI were used to model habitat for the rearing life stages of all target fish species by combining the nine original cover codes into six categories:

- 1—no cover
- 2—riparian vegetation (field codes 2, 7, 8, and 9)
- 3—large woody debris (field codes 3, 4, and 5)
- 4—aquatic vegetation (field code 6)
- 5—substrate (using substrate codes 5–9)
- 6—deep water

Undercut banks (original code 1) were infrequent in the Project area and not used. The substrate and cover codes were condensed to form the single attribute allowed in the PHABSIM based WUA model. The condensed codes are tabulated in Table 4.2-3. In the HSI, each single combined code has a discrete suitability value.

To support the objectives of the macrophyte mapping effort (see Section 4.1.2 and Appendix 1.1b of Study 7 Final Report [SCL 2009]) and the overall habitat model when aquatic plants were observed along a transect (Code 6 from Table 4.2-1), additional descriptive and density data were recorded (Tables 4.2-4 and 4.2-5). These subcodes represent the relative number of plant stems observed per square yard defined by a visual estimate. The density subcodes were recorded to the right of the decimal point placed after the primary aquatic vegetation code. For example, the code for wetland emergent aquatic vegetation of moderate density is 1.2.

**Table 4.2-3.** Condensed single attribute substrate and cover codes.

| Substrate | Cover | Combined | | Substrate | Cover | Combined |
|---|---|---|---|---|---|---|
| 1 | 1 | 1.1 | | 5 | 4 | 5.4 |
| 1 | 2 | 1.2 | | 6 | 1 | 6.1 |
| 1 | 3 | 1.3 | | 6 | 2 | 6.2 |
| 1 | 4 | 1.4 | | 6 | 3 | 6.3 |
| 2 | 1 | 2.1 | | 6 | 4 | 6.4 |
| 2 | 2 | 2.2 | | 7 | 1 | 7.1 |
| 2 | 3 | 2.3 | | 7 | 2 | 7.2 |
| 2 | 4 | 2.4 | | 7 | 3 | 7.3 |
| 3 | 1 | 3.1 | | 7 | 4 | 7.4 |
| 3 | 2 | 3.2 | | 8 | 1 | 8.1 |
| 3 | 3 | 3.3 | | 8 | 2 | 8.2 |
| 3 | 4 | 3.4 | | 8 | 3 | 8.3 |
| 4 | 1 | 4.1 | | 8 | 4 | 8.4 |
| 4 | 2 | 4.2 | | 9 | 1 | 9.1 |
| 4 | 3 | 4.3 | | 9 | 2 | 9.2 |
| 4 | 4 | 4.4 | | 9 | 3 | 9.3 |
| 5 | 1 | 5.1 | | 9 | 4 | 9.4 |
| 5 | 2 | 5.2 | | Deep | Deep | 0.6 |
| 5 | 3 | 5.3 | | | | |

Note:
The cover codes tabulated represent the field cover codes as follows:
1 – no cover
2 – riparian vegetation (field codes 2, 7, 8, and 9)
3 – large woody debris (field codes 3, 4, and 5)
4 – aquatic vegetation (field code 6)
An additional code, 0.6, represents deep water.

**Table 4.2-4.** Codes for aquatic vegetation.

| Code | Description |
|---|---|
| 1 | Wetland emergent aquatic vegetation (i.e., reed canary grass), note if possible identification of dominant plants such as reed canary grass should be recorded |
| 2 | Emergent aquatic vegetation (i.e., lilies, bull rush) |
| 3 | Submersed aquatic vegetation (i.e., Eurasian watermilfoil [EWM])[1] |

Note:
1 In the case of submersed aquatic vegetation, the "edge" of aquatic weed bed must be one of the points recorded in the transect.

**Table 4.2-5.** Subcodes for vegetation density.

| Code | Description[1,2] |
|---|---|
| 1 | Low when 1 to 2 vertical stems cover per square yard (meter) |
| 2 | Moderate at 3 to 6 stems cover per square yard |
| 3 | High at 7 or more stems cover per square yard |

Notes:

1 In the case of *Elodea canadensis* (common Elodea) the relative plant density should be related to area of sediment visible from viewer because of that plant's growth characteristic. Therefore, low density would be less than 25 percent sediment coverage (75 percent of sediment surface visible), moderate at 25 to 75 percent sediment coverage, and high at 75 to 100 percent sediment coverage.

2 If the plants have canopied and have extensive growths on the water surface, as is often the case for EWM, that area shall be classified as saturated.

## 4.3. Velocity and Depth Measurements

Consultation with relicensing participants resulted in modifications to target river flows, pool water surface elevations, and number of velocity patterns from those identified in the Revised Study Plan (RSP). Velocities, water surface elevations, and transect bottom profiles were measured for a target stable high river flow at full pool elevation (approximately elevation 1,992 feet NAVD 88 [1,988 feet NGVD 29[1]]) at all transects upstream of Boundary Dam, and again for a target stable high flow, middle flow, and low flow at low pool elevation (less than approximately 1,984 feet NAVD 88 [1,980 feet NGVD 29]) on transects in the Upper Reservoir Reach above Metaline Falls. Similarly, all transects in the Tailrace Reach were measured for high flow, high pool (Seven Mile Reservoir) conditions. Additional measurements were made for high, middle, and low flow with low pool conditions for the Tailrace Reach transects on the U.S. side of the border (Table 4.3-1). The target flows for hydraulic routing model calibration were as follows:

- High flows (i.e., above 40,000 cfs).
- Mid-range flows (i.e., approximately 20,000 cfs).
- Low flows (i.e., below approximately 10,000 cfs).

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

**Table 4.3-1.** Target flows for water velocity and water surface elevation measurements to be used to model mainstem aquatic habitats in the Pend Oreille River upstream and downstream of the Boundary Dam.

| Reach | Range of Project River Miles | Length of Reach (miles) | No. of Transects | Target Flow for Velocity and Water Surface Measurements [1,2] |
|---|---|---|---|---|
| **Upper Reservoir**<br>Box Canyon Dam to Metaline Falls | 34.5 to 26.8 | 7.7 | 24 | High pool: 40,000 cfs<br>Low pool: 40,000 cfs<br>20,000 cfs<br>10,000 cfs |
| **Canyon**<br>Metaline Falls to Canyon mouth | 26.8 to 18.0 | 8.8 | 20 | High pool: 40,000 cfs |
| **Forebay**<br>Canyon mouth to Boundary Dam | 18.0 to 17.0 | 1.0 | 5 | High pool: 40,000 cfs |
| **Tailrace**<br>Boundary Dam to U.S./Canadian Border | 17.0 to 16.0 | 1.0 | 6 | High pool: 40,000 cfs<br>Low pool: 40,000 cfs<br>20,000 cfs<br>10,000 cfs |
| U.S./Canadian Border to Red Bird Creek | 16 to 13.9 | 2.1 | 8 | High pool: 40,000 cfs |
| **Totals** | | **20.6** | **63** | |

Notes:
1 Water velocities were not measured at depths greater than 50 feet.
2 In addition to the measurements described in the table, 14 transects in the Canyon and Upper Reservoir reaches that support heavy, late summer macrophyte growth were measured at a high pool/high flow condition (~41,000 cfs) in early May 2007 prior to macrophyte emergence.

Field data collection and data recording generally followed the guidelines established in the Instream Flow Guidance (IFG) field techniques manuals (Trihey and Wegner 1981; Milhous et al. 1984; Bovee 1997). Staff also conducted additional quality control checks that have been used on previous applications of the simulation models.

### 4.3.1. Velocity and Bottom Profile Measurements

Techniques for measuring discharge have evolved in recent years with the advent of the acoustic Doppler current profile (ADCP). The U.S. Geologic Survey (USGS) has been using ADCPs to conduct the streamflow measurements since 1985. Plainly stated, ADCPs use sound energy to measure water velocity and depth and thereby compute streamflow. The use of ADCPs has increased steadily, with manned boats used extensively on large rivers.

Velocity acquisition was made with a TRDI Instruments 1200 kHz Rio Grande ADCP. The ADCP can gather both depth and velocity information in user-defined steps across a transect to a depth of approximately 50 feet. The ADCP unit was attached to a vessel mount and operated by a laptop onboard a 17-foot jet boat. Because the ADCP can measure accurately only to a depth of approximately 1 foot, edge cell measurements were obtained by wading. Velocity

measurements beyond the range of the ADCP (depths greater than 50 feet) were not taken. This occurred in the transects within the Canyon and Forebay reaches.

A sub-meter accurate Global Positioning System (GPS) with Differential Global Positioning System (DGPS) subscription-based corrections (Trimble Pathfinder Pro XRS submeter GPS with OmniSTAR correction) was used to position and track the ADCP concurrent with the velocity measurements. A narrow beam (Airmar $6^0$ 235 kHz digital depth transducer) depth sounder was used for depth soundings concurrent with the ADCP and GPS. All measurements were recorded daily to the laptop hard drive and copied to a USB flash drive.

For those sections of a transect that could not be readily measured using the ADCP such as shallow areas (<1 foot), edge cells near the shore, and areas with heavy vegetation growth, staff used mechanical or electromagnetic meters attached to top-set rods. Mechanical velocity meters were vertical-axis, rotating-cup Scientific Instruments Price AA and pygmy-type meters. These meters are accurate where flow is turbulent, shifts in direction occur, and where air is entrained in the water column. Marsh-McBirney electronic meters were used in areas of dense aquatic vegetation. Mean column velocity was determined by a single measurement at six-tenths of the water depth in depths less than 2.5 feet, and at two-tenths and eight-tenths measurement for depths between 2.5 feet and 4.0 feet. All three points were measured where depths exceeded 4.0 feet, or where the velocity distribution in the water column was abnormal and one or two points were not adequate to derive an accurate mean column water velocity.

### 4.3.2. Quality Control

Considerable effort was applied to maintaining strict quality control throughout all aspects of field data collection. To ensure the quality of field data for the Boundary Project instream flow study, the following procedures and protocols were used:

- Staff gages were established and continually monitored throughout the course of collecting data at each study site. Significant changes in gage readings were recorded, and if necessary, additional water surface elevation data were taken.
- An independent benchmark was established for each set of transects. The benchmark was an immovable tree, boulder, or other naturally occurring object that would not be subject to tampering, vandalism, or movement. Upon establishment of headpin and tailpin elevations, a level loop was shot to check the auto-level for measurement accuracy. Allowable error tolerances on level loops were set at 0.02 foot. This tolerance was also applicable to both headpin and tailpin measurements except where extenuating circumstances (e.g., pins under sloped banks, shots through dense foliage, etc.) explained discrepancies and the accompanying headpin or tailpin was free of excessive error. Independent benchmarks were established on both sides of the river where required by extreme stream width.
- Water surface elevations were measured on both banks on each transect. If possible, on more complex and uneven transects such as riffles or pocket waters, water surface elevations were measured at a number of locations across a transect. An attempt was made to measure water surface elevations at each calibration flow at the same location (station on tape) across each transect.

- Pin elevations and water surface elevations were calculated during field measurements and compared to previous measurements. Changes in stage since the previous flow measurement were calculated. Patterns of stage change were compared between transects and determined if consistent with adjacent changes. If any discrepancies were discovered, potential sources of error were explored and noted.
- All calculations were completed in the field (given adequate time and daylight). Calculated discharges were compared between transects at the same flow. If an excessive amount of discharge (greater than 10 percent of the streamflow) was noted for an individual transect cell, additional adjacent stations were established to more precisely define the velocity distribution patterns at that portion of the transect.
- The ADCP compass was calibrated daily to ensure the proper application of magnetic correction.
- The ADCP output was examined in real-time as the unit was deployed. If necessary, multiple passes were made to ensure discharge calculations were reasonable and that good bottom profile and velocity patterns were obtained.
- High-quality current velocity meters were used for areas where velocity measurements could not be acquired by the ADCP, in edge cells, or in depths less than 1 foot. Price AA meters were used in fast, deep waters, and mini-meters were used in shallow, slower waters as recommended in the U.S. Geological Survey techniques manual (Rantz 1982). All mechanical meters were inspected daily. Pivot pins were replaced if significant wear was noted, pin clearances were adjusted, and the meters were spin tested. Meters were continually monitored during the daily course of data collection to ensure that they were functioning properly. Marsh-McBirney electronic meters were used in areas of dense aquatic vegetation.
- Photographs were taken of all transects from downstream, across, and upstream of the calibration flows. An attempt was made to shoot each photograph from the same location at each of the three levels of flow. These photographs provide a valuable record of the streamflow conditions (including velocity and depth), water surface elevations, and channel configurations that can be used for confirmation during the hydraulic routing model calibration.

## 4.4. Development of Cross-Sectional Profiles

Procedures for developing depth and velocity profiles for each habitat transect are presented in this section. The ADCP data required processing after collection to develop the depths and velocities associated with the cell widths assigned to each transect. In the case of the cross sections with depths in excess of 50 feet, the velocity was only measured to 50 feet and required extrapolation to develop velocities in the portion of the section deeper than 50 feet. The procedure to extrapolate the deep water portion of the cross-sectional velocity profiles is also presented.

### 4.4.1. Processing of ADCP Transect Data for Depth and Velocity

ADCP transect data were collected and post-processed using TRDI WinRiver software. The ASCII output from WinRiver was input into TRPA utility software in order to reduce the extensive ADCP data into cell depths and mean column velocities as well as to overlay

sequential measurements of the same transect. Initially, the high pool, high flow transect data were input into the utility software, and the beginning data point set to the field measured distance from the right bank (looking downstream) headpin. The stationing was selected with a maximum of 300 ADCP measured cells per channel and a minimum cell width of 4 feet. Subsequent ADCP data files (low pool; high, middle, and low flow) were imported and the bottom profiles aligned with the original high pool, high flow profile. Depths were converted to elevations using the water surface elevation surveyed in relation to a temporary benchmark during each ADCP measurement. The true elevations of the temporary benchmarks were determined through RTK GPS surveys. All data within each cell were averaged to output the elevation and mean column velocity. The ADCP elevation and velocity data were then imported into a spreadsheet and all manually measured cells (i.e., edge cells, shallow cells, areas of heavy macrophyte growth) were added.

### 4.4.2. Extrapolation of Mean Column Velocities

For transects that had cell depths greater than 50 feet, it was necessary to develop a method to estimate the mean column velocity for cells of the transect with depths greater than 50 feet. As discussed and agreed to by relicensing participants at the April 24, 2007 Fish and Aquatics Workgroup meeting, ADCP equipment was set to measure velocities to a maximum depth of approximately 50 feet below the water surface. This was sufficient to obtain measurement of the entire transect for all 24 of the Upper Reservoir Reach transects. However, velocities for the full depth were not measured in the 5 Forebay Reach transects and the 20 Canyon Reach transects, and were also not measured in 4 of the 14 Tailrace Reach transects (TR-1, TR-5, TR-7 and TR-9). For these 29 transects (20 Canyon, 5 Forebay, and 4 Tailrace) in which the velocity measurements do not extend to the full transect depth in all columns, a procedure for estimating the mean column velocity for the entire depth of each column over 50 feet deep was developed and agreed upon by the relicensing participants through the coordination conducted in April and May 2008.

The procedure was applied to each transect that exceeded 50 feet in depth and where velocities were not measured in the portion of the water column below 50 feet. The total flow in the transect was estimated by applying the HRM. A partial transect flow was calculated using the data acquired using an ADCP for portions of the transect less than 50 feet deep. The difference between the HRM estimated total flow and the flow measured by the ADCP was used to calculate the flow for the portion of each column of the transect where it was too deep to measure velocities. The total discharge in each column was determined by adding the measured and unmeasured discharges. The mean velocity in each column was calculated by dividing the total discharge in the column by its depth and width. The details of the procedure are presented below.

The procedure to extrapolate the velocities to include the unmeasured zone at depths greater than 50 feet relies on applying the 1/6 power law to represent the vertical velocity distribution in each water column. The 1/6 power law for velocity distribution states (Chen 1991):

$$u = a(y)^{(1/6)} \qquad \text{(EQ 1)}$$

Where u is the velocity at a depth y, y is the depth above the bottom of the channel bed, and a is a coefficient. This equation was integrated to obtain the total discharge in a column resulting in:

$$q = a(6/7)(w)(Y)^{(7/6)} \quad \text{(EQ 2)}$$

Where q is the discharge in the column with width w and Y is the total depth.

Similarly, an estimate of the discharge in the unmeasured zone was obtained by integrating up from the channel bed to the top of the unmeasured zone (50 feet below the water surface). The expression is then:

$$q_{um} = a(6/7)(w)(y_{um})^{(7/6)} \quad \text{(EQ 3)}$$

Where $q_{um}$ is the discharge in the unmeasured portion of the column greater than 50 feet below the surface and $y_{um}$ is the depth of the unmeasured zone from the bed to 50 feet below the water surface.

The ratio of the estimated unmeasured discharge in each column to the estimated measured discharge in each column was calculated as:

$$q_{um}/q_m = a(6/7)(w)(y_{um})^{(7/6)} / [a(6/7)(w)(Y)^{(7/6)} - a(6/7)(w)(y_{um})^{(7/6)}] \quad \text{(EQ 4)}$$

Where $q_m$ is the estimated discharge from the 1/6 power law in the measured zone for the column. The coefficient a is not known but is a constant within each column. Recognizing this, equation 4 reduces to:

$$q_{um}/q_m = (y_{um})^{(7/6)} / [(Y)^{(7/6)} - (y_{um})^{(7/6)}] \quad \text{(EQ 5)}$$

The ratios for each column in the transect are computed from equation 5 and used to estimate the unmeasured zone discharge by multiplying each actual measured portion of the column discharge by this ratio.

$$q_{um} = (q_{ADCP})\{(y_{um})^{(7/6)} / [(Y)^{(7/6)} - (y_{um})^{(7/6)}]\} \quad \text{(EQ 6)}$$

where $q_{ADCP}$ is the actual discharge measured in the upper 50 feet of the column by the ADCP. (The variable $q_{ADCP}$ represents the discharge in a given width of the transect associated with the column being represented and not the total discharge in the entire transect.) The estimates of unmeasured zone discharges in each column were summed to provide an estimate of the total unmeasured zone discharge, $Q_{um}$, for the entire transect. The actual total unmeasured zone discharge for the transect was calculated by subtracting the total discharge measured in the upper 50 feet of the transect from the total transect discharge determined in the HRM. The ratio to adjust the initial estimate of the unmeasured zone column discharges is then calculated as:

$$R_{adj} = (Q_{HRM} – Q_{ADCP})/Q_{um} \quad \text{(EQ 7)}$$

in which $R_{adj}$ is the ratio used to adjust the estimate of unmeasured discharges, $Q_{HRM}$ is the discharge from the HRM assumed to equal the actual total discharge in the transect at the time of the measurement, $Q_{ADCP}$ is the total discharge in the transect in the upper 50 feet measured by the ADCP, and $Q_{um}$ is the estimate of total unmeasured discharge in all columns. Each estimate of the column discharge was adjusted by multiplying by $R_{adj}$ to obtain the adjusted column discharge. The resulting column discharges were summed to equal the actual total discharge derived from the HRM. The adjusted column velocities were determined by dividing the adjusted column discharges by their respective column depths and widths.

## 4.5. Transect N-Value Calibration

Manning's N values for each measured vertical at each measured calibration flow were calculated with the RHABSIM (Payne 1994) software version of USGS hydraulic and habitat program PHABSIM. The required data input for each transect to calculate the N-values were: elevation profile, water surface elevation, given discharge, and mean column velocities measured at each vertical. RHABSIM calculates an N-value for each vertical of each transect for each calibration stage/discharge set. For the transects in the Reservoir Reach and Tailrace Reach, four sets of N-values were calculated, one each for the measured stage/discharge calibration sets of: high pool/high flow; low pool/high flow; low pool/medium flow; and low pool/low flow. The calibration N-value for a vertical is assumed to be constant throughout the range of modeled flows, but is adjusted by a velocity adjustment factor (VAF) that compensates for an effective change in N with discharge and stage.

In the Boundary study area, variable backwaters from Boundary Dam and Seven Mile Reservoir (in the Tailrace Reach) precluded the development of stage/discharge relationships throughout the range of flows and water surface elevations. Each calibration stage/discharge N-value was thus applied to a discrete portion of the water surface elevations modeled within the range of those modeled. Each N-value set was used to simulate only velocities at lower stages than those measured, except for the high pool, high flow N-values that were also used to simulate upwards to the highest modeled WSEs (see Section 4.6.3 for further discussion of this method).

Simulating velocities for higher flow and higher WSEs requires additional calibration of N-values. Only the high pool, high flow N-values were used to simulate velocities at greater WSEs and flows than measured. For this calibration set, particular attention was given to very large positive and negative N-values, oscillation between positive and negative N-values, very small positive and negative N-values, and edge effects.

Very large N-values, both positive and negative, suppress water velocity unreasonably when modeling higher discharges. These N-values occurred in verticals with very low measured velocities, especially in deeper water. They were changed to the most reasonable adjacent N-value.

Oscillation between positive and negative N-values occurred in groups of verticals with near zero velocities and in areas of surge flow. When velocities are simulated upwards, this creates unreasonable variation between positive and negative velocities. The N-values in these groups of verticals were changed to either all positive or all negative, which generated more reasonable velocity patterns with little discernable effect on calculated discharge.

Very small N-values create velocity spikes when discharges are simulated at higher flows. Small N-values can occur in both deep and shallow water due to hydraulic influence from an instream object or channel constriction. These N-values were changed to match reasonable adjacent N-values.

The N-value closest to the water's edge is projected up the bank when flows are modeled upwards. Edge effects created by partially submerged instream objects can create slow and/or negative velocities immediately adjacent to the margins. The resulting negative or unrealistically high N-values, when flows are projected upwards, suppress the edge velocities and concentrate the flow in the center of the transect. These N-values were calibrated by changing to the nearest reasonable thalweg-adjacent N-value. Compensating for edge effects was the most common type of calibration.

## 4.6. Integration with Hydraulic Routing Model

The mainstem habitat modeling utilizes the results of the hourly water surface elevations and discharges at each transect location from the HRM to calculate cells depths and velocities. Several steps were necessary to integrate the HRM and the habitat transect. The first step was integrating the habitat transect into the cross-sectional geometry of the HRM. The next step was to check the calibration of the water surface elevations produced by the HRM against the water surface elevations surveyed during the transect measurements. The final step was developing a protocol for applying the multiple sets of N-values developed for the Upper Reservoir Reach and the U.S. portion of the Tailrace Reach.

### 4.6.1. Incorporate Habitat Transect in HRM Cross Sections

Cross-sectional geometry collected during the ADCP transect data collection effort was incorporated into the HRM. The ADCP-collected transect geometry replaced the DTM-derived cross-section geometry at the habitat transect locations. Those cross sections in HRM that were not co-located with a habitat transect remained as DTM-derived cross sections.

To incorporate the habitat transects into the HRM, for each habitat transect, the left and right end points were geospatially located within ArcGIS using the GPS coordinates determined in the field survey of the end points and overlaid onto the DTM. The portion of the DTM-derived cross section between these two end points was removed from the hydraulic routing model and replaced with the ADCP-derived geometry.

### 4.6.2. Check HRM Calibration at Habitat Transects

The HRM underwent extensive calibration and verification using a series of 15-minute water surface elevations recorded at locations throughout the Study Area. More than 1.5 years of data were used to calibrate and verify the accuracy of the HRM. Details of the HRM calibration and verification process are presented in Appendix 2 and Section 4.2 and 5.2 of the main body of the report. To check the ability of the HRM at the habitat transect locations, the surveyed water surface elevations taken during the habitat transect measurements were compared against water surface elevations held constant by the HRM for the time period corresponding to the transect

surveys. For the Upper Reservoir Reach and U.S. portion of the Study Area, four elevations were available for checking HRM-generated water surface elevations. For the Forebay, Canyon, and Canadian portion of the Tailrace Reach, one water surface was available for each transect.

### 4.6.3. Velocity Pattern Selection for Aquatic Habitat Modeling

For the 20 Canyon, 5 Forebay and 8 Canadian Tailrace transects, only one set of velocity measurements was performed: high pool/high flow. These transects are located in areas in which conditions are typically more reservoir-like than riverine. The one set of velocity measurements are used for simulating velocity distributions for all conditions at these transects. In all cases, the measurements were taken at high pool and high flow conditions so that for the majority of the time, the pattern is applied to lower WSE and discharge conditions than the one measured for the transect.

For the 24 Upper Reservoir Reach transects and the 6 U.S. portions of the Tailrace Reach transects, four velocity patterns were measured. Therefore, developing a procedure to determine the conditions to apply each pattern was necessary. To develop the procedure, the plotted velocity patterns were reviewed. Attachment A (Figures A-1 through A-63) provides plots of all measured velocity patterns at the 63 habitat transects.

Reviewing the velocity patterns, Transect U-05(Figure A-30) represents the most complex situation encountered. Both U-05 and U-04 (Figure A-29) transects are located in the wide portion of the Pend Oreille River adjacent to the town of Metaline. The flow shifts from one side of the channel to the other depending on the river stage. At high WSE, the flow takes a straight path along the left bank (looking downstream). However, at lower water surface elevations, bar features deflect the flow into a deep thalweg that meanders over to the right bank and then back to the center of the channel. In this situation of an upstream obstruction redirecting flow, the use of WSE to select the velocity pattern is consistent with the physical conditions that result in the dramatic shift in the velocity pattern and will produce the best results. The velocity pattern for U-24 is also influenced by an upstream flow obstruction (Figure A-49).

Another condition that causes complex velocity pattern behavior is constriction. It was noted that many cross sections experience concentration of flow near the center, or deeper, portion of the channel, and the velocity does not drop as significantly as would be expected in this part of the channel. Examples of this type of behavior are evident in transects U-03 (Figure A-28), U-23 (Figure A-48), TR-15 (Figure A-61) and TR-16 (Figure A-62). As with the influence of a flow obstruction for the U-04 and U-05 example, the occurrence of concentration of flow in the center of the channel is closely related to the WSE; therefore, the use of WSE to select the appropriate velocity pattern is consistent with the physical processes driving the velocity pattern.

The majority of the remaining transects exhibit more uniform changes in velocity patterns similar to sections U-02 (Figure A-27) and U-09 (Figure A-34). The use of WSE to select the appropriate velocity pattern works well for these conditions.

The review of the velocity patterns was presented to relicensing participants through the coordination conducted in April and May 2008. The relicensing participants tentatively agreed that the proposed procedure of using WSE to select the velocity pattern to utilize for a specific

flow condition (combination water surface elevation and discharge) was the best procedure to follow. After a presentation of additional information at an August 7, 2008 meeting in Olympia with representatives from the state of Washington, it was agreed that in cases where four velocity patterns were measured at a transect, the water surface elevation would be used to select the appropriate velocity pattern. Using the water surface elevation as the basis for selecting the velocity pattern, the following protocol to use in determining which pattern to apply for a specific condition in the habitat model were agreed upon:

- *High Pool/High Flow*: This velocity pattern is to be used for all modeled water surface elevations greater than the elevation at which the velocity pattern was measured, and for all water surface elevations down to the elevation of the low pool high flow pattern.
- *Low Pool/High Flow*: This velocity is to be used for all modeled water surface elevations between the elevation at which the low pool high flow and the low pool medium flow measurements were taken.
- *Low Pool/Medium Flow*: This velocity is to be used for all modeled water surface elevations between the elevation at which the low pool medium flow and the low pool low flow measurements were taken.
- *Low Pool/High Flow*: This velocity is to be used for all modeled water surface elevations below the elevation at which the low pool low flow measurement was taken.

# 5 RESULTS

The following sections provide the results from the effort to develop the habitat transect information to support the various mainstem habitat modeling efforts.

## 5.1. Transect Selection

Through the methods presented in Section 4.1, the location of 63 habitat transects were identified. The location of these transects was previously presented in Figure 3.0-1. A summary of the number of transects by reaches includes the following:

- Forebay Reach—5 transects
- Canyon Reach—20 transects
- Upper Reservoir Reach—24 transects
- Tailrace Reach—14 transects

As discussed in the Methods, each transect was selected with the purpose of representing the habitat in the Pend Oreille River for a specific distance immediately upstream and downstream of its location. Based on the information used to perform the transect selection, the distance each transect represents was determined. This distance and the weighting factor to be applied to the distances between transects are provided in Tables 5.1-1 through 5.1-4. These weighting factors are applied in the mainstem modeling effort when reached averaged, transect weighted values of various habitat indices, and other indicators of factors influencing habitat such as downramping rates are determined.

**Table 5.1-1.** Distances between Forebay Reach habitat transects and distance-based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) (feet) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| -- | 1,245[1] | -- | N/A | -- |
| F-1 | 772 | 265 | 0.343 | 1,510 |
| F-2 | 822 | 285 | 0.347 | 792 |
| F-3 | 516 | 260 | 0.504 | 797 |
| F-4 | 945 | 482 | 0.510 | 738 |
| F-5 | 1,920[2] | 1,060 | 0.552 | 1,523 |

Notes:
1 1,245 feet is distance downstream to Boundary Dam.
2 1,920 feet is upstream habitat distance to Canyon Reach transect C-1.
N/A – not applicable

**Table 5.1-2.** Distances between Canyon Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) (feet) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| -- | 1,920[1] | -- | N/A | -- |
| C-1 | 516 | 249 | 0.483 | 1,109 |
| C-2 | 5,045 | 3,031 | 0.601 | 3,298 |
| C-4 | 977 | 635 | 0.650 | 2,649 |
| C-5 | 780 | 183 | 0.235 | 525 |
| C-6 | 1,143 | 584 | 0.511 | 1,181 |
| C-7 | 629 | 457 | 0.727 | 1,016 |
| C-8 | 1,388 | 928 | 0.669 | 1,100 |
| C-9 | 3,132 | 2,100 | 0.670 | 2,560 |
| C-11 | 663 | 494 | 0.745 | 1,526 |
| C-12 | 3,739 | 3,117 | 0.834 | 3,286 |
| C-14 | 1,095 | 596 | 0.544 | 1,218 |
| C-15 | 1,063 | 741 | 0.697 | 1,240 |
| C-16 | 815 | 363 | 0.445 | 685 |
| C-17 | 6,119 | 2,347 | 0.384 | 2,799 |
| C-19 | 4,667 | 1,524 | 0.327 | 5,296 |
| C-20 | 3,707 | 1,948 | 0.525 | 5,091 |
| C-21 | 2,145 | 1,725 | 0.804 | 3,484 |
| C-22 | 1,661 | 1,101 | 0.663 | 1,521 |
| C-23 | 2,500 | 891 | 0.356 | 1,451 |
| C-24 | 1,512[2] | 1,512 | 1.000 | 3,121 |

Notes:

1 1,920 feet is distance from C-1 downstream to Forebay Reach transect F-5 of which 860 feet are associated with habitat for transect C-1.

2 Upstream extent of habitat associated with C-24 is approximately PRM 26.6 (D/S end of Metaline Falls pool)

N/A – not applicable

**Table 5.1-3.** Distances between Upper Reservoir Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) (feet) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| -- | 607[1] | -- | N/A | -- |
| U-1 | 1,471 | 109 | 0.074 | 716 |
| U-2 | 1,174 | 717 | 0.611 | 2,079 |
| U-3 | 1,207 | 738 | 0.611 | 1,195 |
| U-4 | 1,818 | 902 | 0.496 | 1,371 |
| U-5 | 1,970 | 781 | 0.396 | 1,697 |
| U-6 | 703 | 326 | 0.464 | 1,515 |
| U-7 | 2,172 | 1,170 | 0.539 | 1,547 |
| U-8 | 2,142 | 1,131 | 0.528 | 2,133 |
| U-9 | 2,760 | 1,470 | 0.533 | 2,481 |
| U-10 | 377 | 177 | 0.469 | 1,467 |
| U-11 | 1,865 | 1,082 | 0.580 | 1,282 |
| U-12 | 1,651 | 758 | 0.459 | 1,541 |
| U-13 | 909 | 328 | 0.361 | 1,221 |
| U-14 | 1,049 | 664 | 0.633 | 1,245 |
| U-15 | 1,038 | 398 | 0.383 | 783 |
| U-16 | 1,084 | 542 | 0.500 | 1,182 |
| U-17 | 1,877 | 1,326 | 0.706 | 1,868 |
| U-18 | 2,560 | 932 | 0.364 | 1,483 |
| U-19 | 2,079 | 1,330 | 0.640 | 2,958 |
| U-20 | 911 | 272 | 0.299 | 1,021 |
| U-21 | 1,921 | 780 | 0.406 | 1,419 |
| U-22 | 2,050 | 1,059 | 0.517 | 2,200 |
| U-23 | 670 | 282 | 0.421 | 1,273 |
| U-24 | 2,484[2] | 409 | 1.000 | 2,872 |

Notes:
1 607 feet is the habitat distance downstream of U-1 and corresponds to PRM 26.8 at top of Metaline Falls.
2 2,484 feet is upstream extent of habitat associated with U-24 to approximately PRM 34.5 (Box Canyon Dam tailrace).
N/A – not applicable

**Table 5.1-4.** Distances between Tailrace Reach habitat transects and distance based weighting factors, transects listed from downstream (D/S) to upstream (U/S).

| Transect ID | Distance to Upstream Transect (feet) | Upstream Distance that Applies to Transect (feet) | Proportion of Upstream Distance that Applies to Transect (Weighting Factor) (feet) | Total Distance (U/S and D/S) that Applies to Transect (feet) |
|---|---|---|---|---|
| -- | 447[1] | -- | N/A | -- |
| TR-1 | 928 | 374 | 0.403 | 821 |
| TR-2 | 729 | 280 | 0.384 | 834 |
| TR-3 | 2,194 | 525 | 0.239 | 974 |
| TR-5 | 2,439 | 1,397 | 0.573 | 3,066 |
| TR-7 | 1,868 | 1,252 | 0.670 | 2,294 |
| TR-9 | 836 | 315 | 0.377 | 931 |
| TR-10 | 1,259 | 591 | 0.469 | 1,112 |
| TR-11 | 843 | 630 | 0.747 | 1,298 |
| TR-12 | 591 | 314 | 0.531 | 527 |
| TR-13 | 1,483 | 650 | 0.438 | 927 |
| TR-14 | 559 | 306 | 0.547 | 1,139 |
| TR-15 | 238 | 86 | 0.361 | 339 |
| TR-16 | 790 | 194 | 0.246 | 346 |
| TR-17 | 409[2] | 409 | 1.000 | 1,005 |

Notes:
1 447 feet is distance from TR-1 downstream to Red Bird Creek.
2 409 feet is upstream habitat distance and does not extend to Boundary Dam, which is an additional 792 feet.
N/A – not applicable

## 5.2. Substrate and Aquatic Vegetation Characterization

Section 4.2 presented the development of the codes for describing substrate and cover conditions. The substrate and habitat conditions were determined during the low pool/low flow transect measurement efforts conducted for each of the reaches. For the Forebay, Canyon and Upper Reservoir reaches, the substrate and cover coding for the habitat transects was performed in September 2007. The tailrace reach substrate and cover coding was performed during the March 2008 habitat transect measurements. Table 5.2-1 provides an example of the combined substrate and cover code applied to the Upper Reservoir Reach transect U-8.

**Table 5.2-1.** Example habitat transect showing horizontal distance, elevation and combined substrate and cover code, Upper Reservoir Reach transect U-8.

| Horiz. Offset (ft) | Elevation (ft NAVD 88) | Substrate/ Cover Code (S.C) | Horiz. Offset (ft) | Elevation (ft NAVD 88) | Substrate/ Cover Code (S.C) | Horiz. Offset (ft) | Elevation (ft NAVD 88) | Substrate/ Cover Code (S.C) |
|---|---|---|---|---|---|---|---|---|
| -4 | 2,001.56 | 1.2 | 140 | 1,962.10 | 5.1 | 292 | 1,965.00 | 9.1 |
| 0 | 1,997.64 | 1.2 | 144 | 1,961.46 | 5.1 | 296 | 1,967.33 | 9.1 |
| 2 | 1,996.94 | 6.2 | 148 | 1,960.73 | 5.1 | 300 | 1,969.20 | 9.1 |
| 4 | 1,995.99 | 6.2 | 152 | 1,960.13 | 5.1 | 304 | 1,970.27 | 9.1 |
| 6 | 1,995.19 | 6.2 | 156 | 1,959.55 | 5.1 | 308 | 1,970.79 | 9.1 |
| 8 | 1,994.54 | 6.2 | 160 | 1,959.25 | 5.1 | 312 | 1,971.31 | 9.1 |
| 12 | 1,993.01 | 6.1 | 164 | 1,958.48 | 5.1 | 316 | 1,973.18 | 9.1 |
| 16 | 1,992.33 | 6.1 | 168 | 1,957.87 | 5.1 | 320 | 1,974.59 | 9.1 |
| 20 | 1,991.36 | 2.1 | 172 | 1,957.23 | 5.1 | 324 | 1,976.18 | 9.1 |
| 24 | 1,990.28 | 2.1 | 176 | 1,956.40 | 5.1 | 328 | 1,975.77 | 9.1 |
| 28 | 1,989.26 | 2.1 | 180 | 1,955.63 | 5.1 | 332 | 1,975.58 | 5.1 |
| 32 | 1,988.08 | 2.1 | 184 | 1,954.89 | 6.1 | 336 | 1,975.38 | 5.1 |
| 36 | 1,985.44 | 2.4 | 188 | 1,953.84 | 6.1 | 340 | 1,975.65 | 5.1 |
| 40 | 1,984.77 | 2.4 | 192 | 1,952.88 | 6.1 | 344 | 1,976.34 | 5.1 |
| 44 | 1,983.89 | 2.1 | 196 | 1,951.97 | 6.1 | 348 | 1,977.04 | 7.1 |
| 48 | 1,981.60 | 7.1 | 200 | 1,951.17 | 6.1 | 352 | 1,978.22 | 9.1 |
| 52 | 1,978.23 | 7.1 | 204 | 1,949.84 | 6.1 | 356 | 1,979.31 | 6.1 |
| 56 | 1,977.84 | 7.1 | 208 | 1,948.79 | 6.1 | 360 | 1,980.50 | 6.1 |
| 60 | 1,976.76 | 7.1 | 212 | 1,948.19 | 6.1 | 364 | 1,981.73 | 6.1 |
| 64 | 1,975.88 | 7.1 | 216 | 1,947.17 | 6.1 | 368 | 1,982.44 | 6.1 |
| 68 | 1,974.78 | 7.1 | 220 | 1,946.50 | 6.1 | 372 | 1,984.12 | 6.1 |
| 72 | 1,973.50 | 7.1 | 224 | 1,945.81 | 2.1 | 376 | 1,985.58 | 6.1 |
| 76 | 1,972.32 | 7.1 | 228 | 1,945.32 | 2.1 | 380 | 1,987.61 | 6.1 |
| 80 | 1,971.27 | 6.1 | 232 | 1,944.01 | 2.1 | 384 | 1,987.07 | 6.1 |
| 84 | 1,970.08 | 6.1 | 236 | 1,943.37 | 2.1 | 388 | 1,988.73 | 6.1 |
| 88 | 1,969.29 | 6.1 | 240 | 1,942.68 | 2.1 | 392 | 1,990.53 | 6.1 |
| 92 | 1,968.39 | 6.1 | 244 | 1,941.83 | 2.1 | 396 | 1,993.24 | 6.1 |
| 96 | 1,967.85 | 6.1 | 248 | 1,941.12 | 3.1 | 398 | 1,995.49 | 6.1 |
| 100 | 1,967.44 | 6.1 | 252 | 1,940.37 | 5.1 | 400 | 1,996.39 | 6.1 |
| 104 | 1,967.02 | 5.1 | 256 | 1,939.79 | 5.1 | 402 | 1,997.09 | 6.1 |
| 108 | 1,966.43 | 5.1 | 260 | 1,939.46 | 5.1 | 404 | 1,997.69 | 6.1 |
| 112 | 1,965.77 | 5.1 | 264 | 1,940.85 | 5.1 | 406 | 1,999.00 | 6.1 |
| 116 | 1,965.36 | 5.1 | 268 | 1,941.13 | 5.1 | 408 | 1,999.44 | 6.1 |
| 120 | 1,964.94 | 5.1 | 272 | 1,943.44 | 5.1 | 410 | 2,000.03 | 6.1 |
| 124 | 1,964.50 | 5.1 | 276 | 1,946.68 | 9.1 | 412 | 2,000.55 | 6.1 |
| 128 | 1,964.01 | 5.1 | 280 | 1,952.65 | 9.1 | 415 | 2,002.72 | 6.1 |
| 132 | 1,963.45 | 5.1 | 284 | 1,957.25 | 9.1 | | | |
| 136 | 1,962.78 | 5.1 | 288 | 1,961.98 | 9.1 | | | |

## 5.3. Velocity and Depth Measurements

Velocity and depth measurements for all 63 habitat transects were performed May 2007 and April 2008. Measurements of transects in the reaches upstream of Boundary Reservoir were completed by August 2007. The measurements of the habitat transects below Boundary Reservoir, the Tailrace Reach, were completed in April 2008. A summary of the dates and flow ranges for each set of transect measurements taken in the four reaches is provided in Table 5.3-1.

**Table 5.3-1.** Actual flow ranges at time of data collection for water velocity and water surface elevation measurements to be used to model mainstem aquatic habitats in the Pend Oreille River upstream and downstream of the Boundary Dam.

| Reach (transects) | Actual Flow for Velocity and Water Surface Measurements [1,2] |
|---|---|
| **Upper Reservoir (24)**<br>Box Canyon Dam to Metaline Falls | High pool/high flow: 43,000 – 53,000 cfs (May 24 - 26 2007)<br><br>Low pool/high flow: 34,000 – 39,000 cfs (May 30-31, 2007)<br>Low pool/med. flow: 17,000 – 22,000 cfs (July 11-12, 2007)<br>Low pool/low flow: 7,500 – 9,700 cfs (August 22-23, 2007) |
| **Canyon (20)**<br>Metaline Falls to Canyon mouth | High pool/high flow: 35,000 – 43,000 cfs (May 26-28, 2007) |
| **Forebay (5)**<br>Canyon mouth to Boundary Dam | High pool/high flow: 39,000 – 43,000 cfs (May 27, 2007) |
| **Tailrace (14)**<br>Boundary Dam to U.S.-Canada Border (6) | High pool/high flow: 43,000 – 45,000 cfs (April 22, 2008)<br><br>Low pool/high flow: 37,000 – 39,000 cfs (March 10, 2008)<br>Low pool/med. flow : 21,000 – 23,000 cfs (March 7, 2008)<br>Low pool/low flow: 11,000 – 12,000 cfs (March 9, 2008) |
| U.S.-Canada Border to Redbird Creek (8) | High pool/high flow: 39,000 – 47,000 cfs (April 23-24, 2008) |

Notes:

1 Water velocities were not measured at depths greater than 50 feet.

2 In addition to the measurements described in the table, 14 transects in the Canyon and Upper Reservoir reaches that support heavy, late summer macrophyte growth were measured at a high pool and high flow condition (~41,000 cfs) in early May 2007 prior to macrophyte emergence.

## 5.4. Development of Cross-Sectional Profiles

The results of the processing of the ADCP measurements and the extrapolating of the mean column velocities are presented in this section.

### 5.4.1. Processing of ADCP Transect Data for Depth and Velocity

The processing of the ADCP measurements to develop depths and mean column velocities was performed using the methods described in Section 4.4.1. Tables A-1 through A-63 of Attachment A provide plots of the resulting velocity distributions for all 63 transects. In cases

where multiple sets of measurements were taken, the resulting velocity patterns are provided on a single plot for comparison purposes. In the case of sections where mean column velocities were extrapolated, these velocities have been substituted for the measured velocities because, in these cases, the measured velocities do not represent the entire depth.

### 5.4.2. Extrapolation of Mean Column Velocities

Extrapolation of mean column velocities in the unmeasured, deep water portions of the habitat transects were performed using the procedure outlined in Section 4.4.2. Graphs showing a comparison of the measured and adjusted column velocities are shown for all transects in Attachment B. The figures also include an overlay of the transect bed profile. Two example figures are included in this section to illustrate cases where the extrapolated mean column velocities were greater than the measured velocities, and another example figure where they were less. The Forebay Reach transect F-1 is presented in Figure 5.4-1 and represents velocity adjustments in the case when application of the mean column velocities from the ADCP measurements result in overestimating the total discharge in the transect. As shown in Figure 5.4-1, this requires a downward adjustment in the measured velocities. The application of the mean column velocities measured by the ADCP for the C-4 transect, Figure 5.4-2, results in an underestimation of the total discharge in the transect determined from the HRM. In this case, the measured velocities require an upward adjustment.

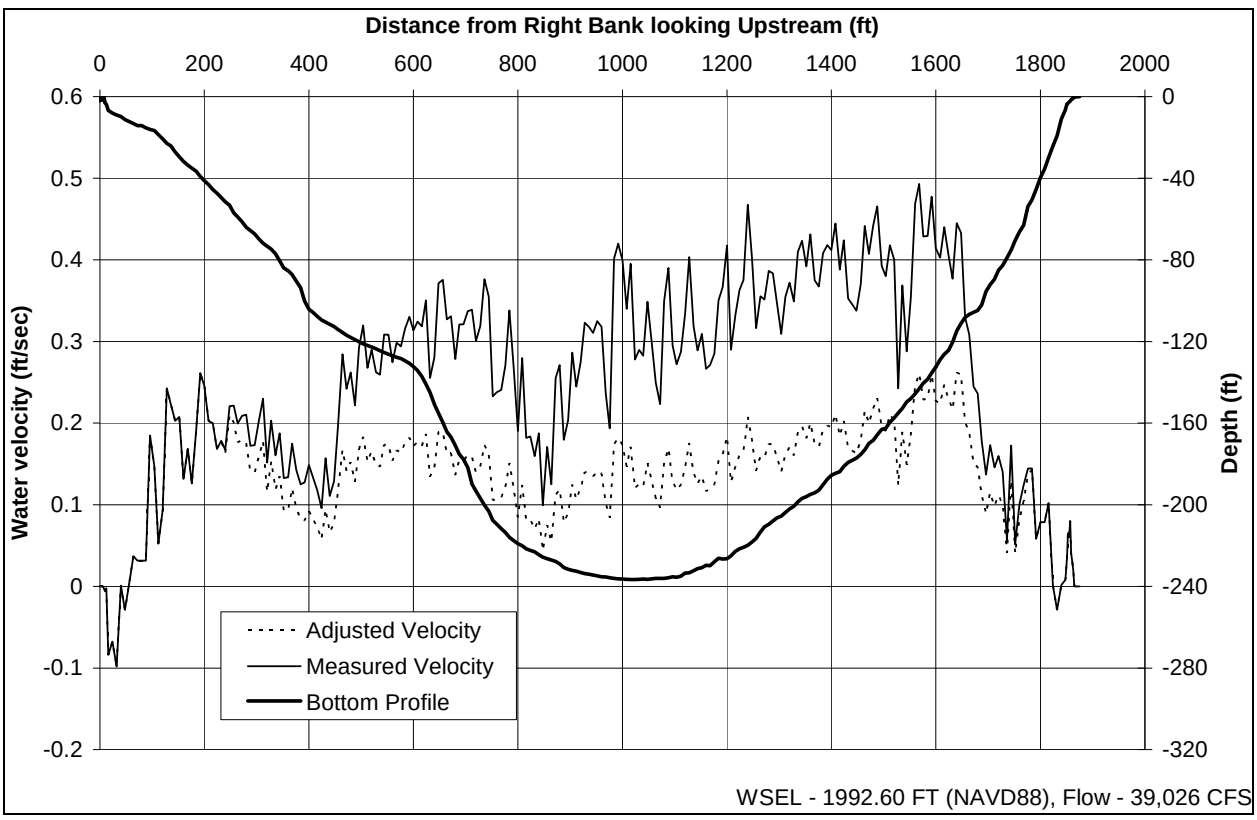



**Figure 5.4-1.** Example of mean column velocity adjustments for habitat transects where ADCP measurement overestimated mean column velocities, Forebay Reach transect F-1.

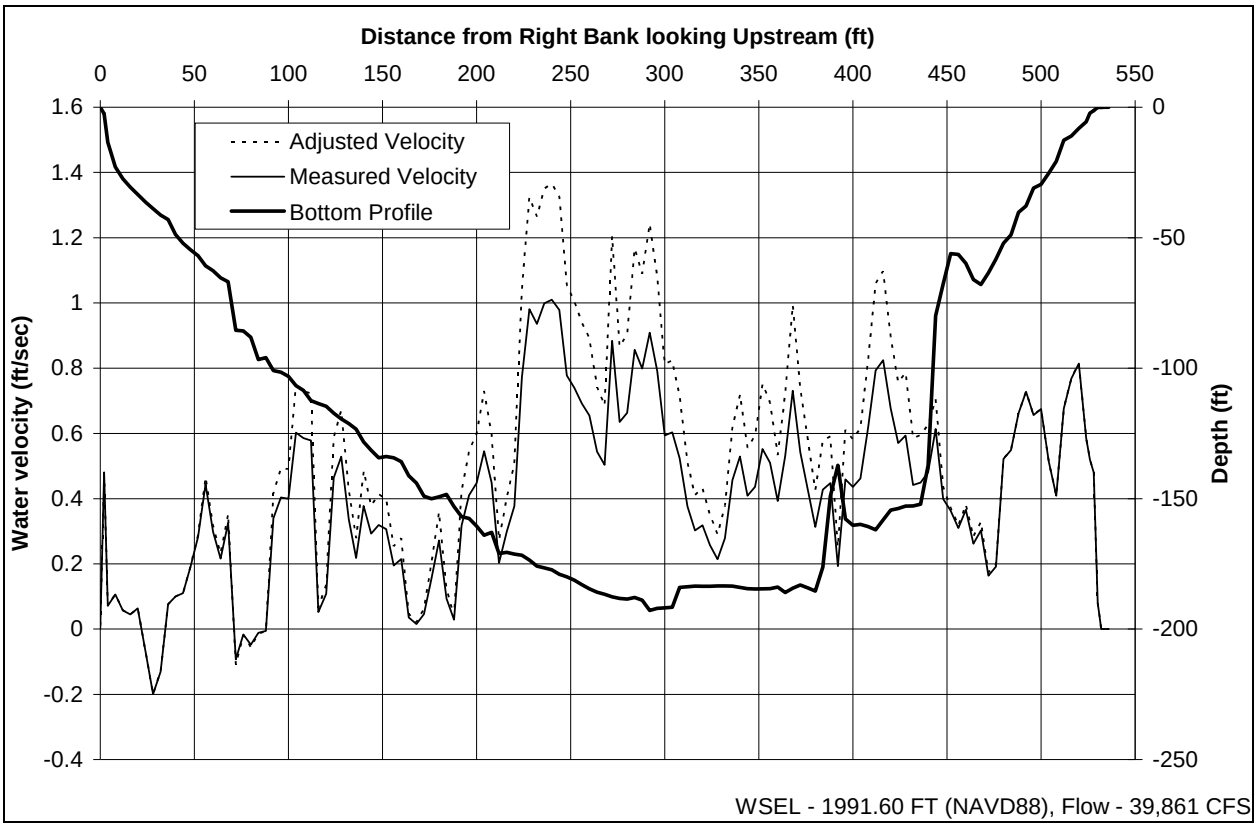



**Figure 5.4-2.** Example of mean column velocity adjustments for habitat transects where ADCP measurement underestimated mean column velocities, Canyon Reach Transect C-4.

## 5.5. Transect N-Value Calibration

The object of calibrating the N-values is to simulate reasonable velocities over the range of modeled flows and WSEs. Simulating velocities lower than those measured generally produces accurate results, and little to no calibration is necessary for those N-values. At lower flows, all velocities are reduced to achieve the lower simulated flow with a few exceptions (e.g., the channel can become constricted at lower WSEs, or submerged obstructions upstream of the transect can influence flow patterns at lower WSEs). Transects U-05 and U-24 (Figures A-5 and A-49) demonstrate the effect of upstream obstructions on flow allocation at a cross section. In both cases, upstream obstructions cause the flow at lower WSEs to be redistributed across the transect. No calibration of N-values can account for this; however, in these two situations, using N-values from multiple calibration sets for discreet ranges of WSEs models the aberrations accurately. Increased velocities resulting from a constricted channel at lower WSEs were observed at many transects in the Upper Reservoir Reach and Tailrace Reach. In many instances, the high pool, high flow velocities were less than the low pool, high flow velocities even though the high pool, high flow discharge was greater than the low pool, low flow discharge. Again, using N-values from multiple calibration sets for discrete ranges of WSEs simulated the aberrations with a high degree of accuracy and minimal calibration was necessary.

Simulating velocities for higher flow and higher WSEs requires additional calibration of N-values. Only the high pool, high flow N-values were used to simulate velocities at greater WSEs and flows than measured. For this calibration set, particular attention was given to very large positive and negative N-values, oscillation between positive and negative N-values, very small positive and negative N-values, and edge effects.

Table 5.5-1 lists the calibration modification techniques applied to each of the 63 cross sections for the various pool and flow conditions. As this table shows, the vast majority of the modifications were applied to the high pool high flow condition. Attachment C provides the calibration notes for each transect. The notes identify the specific transect locations to which the calibration modifications were applied. Further description of the types of calibration modifications are provided below.

- Type 1 – Reduced N-value: Very large N-values, both positive and negative, suppress water velocity unreasonably when modeling higher discharges. These N-values occurred in verticals with very low measured velocities, especially in deeper water. They were changed to the most reasonable adjacent N-value.

- Type 2 – Changed sign of N-value: Oscillation between positive and negative N-values occurred in groups of verticals with near zero velocities and in areas of surge flow. When velocities are simulated upwards, this creates unreasonable variation between positive and negative velocities. The N-values in these groups of verticals were changed to either all positive or all negative, which generated more reasonable velocity patterns with little discernable effect on calculated discharge.

- Type 3 – Increased N-value: Very small N-values create velocity spikes when discharges are simulated at higher flows. Small N-values can occur in both deep and shallow water as a result of hydraulic influence from an instream object or channel constriction. These N-values were changed to match reasonable adjacent N-values.

- Type 4 – Adjusted N-value for edge effects: The N-value closest to the water's edge is projected up the bank when flows are modeled upwards. Edge effects created by partially submerged instream objects can create slow and/or negative velocities immediately adjacent to the margins. The resulting negative or unrealistically high N-values, when flows are projected upwards, suppress the edge velocities and concentrate the flow in the center of the transect. These N-values were calibrated by changing to the nearest reasonable thalweg-adjacent N-value. Compensating for edge effects was the most common type of calibration.

**Table 5.5-1.** Types of calibration applied to each transect for each stage/discharge calibration set.

| Transect Number | Number of Points in Transect | Calibration Types Applied to Each Transect and Stage/Discharge Set | | | |
|---|---|---|---|---|---|
| | | High Pool/ High Flow | Low Pool/ High Flow | Low Pool/ Medium Flow | Low Pool/ Low Flow |
| F-1 | 254 | 0 | N/A | N/A | N/A |
| F-2 | 259 | 0 | N/A | N/A | N/A |
| F-3 | 199 | 0 | N/A | N/A | N/A |
| F-4 | 239 | 0 | N/A | N/A | N/A |
| F-5 | 282 | 0 | N/A | N/A | N/A |
| C-1 | 80 | 0 | N/A | N/A | N/A |
| C-2 | 140 | 0 | N/A | N/A | N/A |
| C-4 | 140 | 0 | N/A | N/A | N/A |
| C-5 | 227 | 0 | N/A | N/A | N/A |
| C-6 | 396 | 0 | N/A | N/A | N/A |
| C-7 | 285 | 0 | N/A | N/A | N/A |
| C-8 | 111 | 4 (1) | N/A | N/A | N/A |
| C-9 | 291 | 0 | N/A | N/A | N/A |
| C-11 | 100 | 0 | N/A | N/A | N/A |
| C-12 | 184 | 0 | N/A | N/A | N/A |
| C-14 | 90 | 0 | N/A | N/A | N/A |
| C-15 | 142 | 0 | N/A | N/A | N/A |
| C-16 | 198 | 0 | N/A | N/A | N/A |
| C-17 | 192 | 0 | N/A | N/A | N/A |
| C-19 | 105 | 0 | N/A | N/A | N/A |
| C-20 | 108 | 0 | N/A | N/A | N/A |
| C-21 | 192 | 0 | N/A | N/A | N/A |
| C-22 | 156 | 0 | N/A | N/A | N/A |
| C-23 | 242 | 0 | N/A | N/A | N/A |
| C-24 | 91 | 4 (2) | N/A | N/A | N/A |
| U-1 | 98 | 4 (1) | 0 | 0 | 0 |
| U-2 | 165 | 4 (2) | 0 | 0 | 0 |
| U-3 | 207 | 2 (1) | 0 | 0 | 0 |
| U-4 | 399 | 4 (2) | 0 | 3 (1) | 0 |
| U-5 | 296 | 4 (6) | 0 | 0 | 4 (1) |
| U-6 | 295 | 4 (2) | 0 | 0 | 4 (6) |
| U-7 | 337 | 4 (4) | 0 | 0 | 0 |
| U-8 | 119 | 2 (1), 4 (1) | 0 | 0 | 0 |
| U-9 | 149 | 2 (1), 4 (1) | 0 | 0 | 0 |
| U-10 | 289 | 4 (2) | 0 | 0 | 0 |
| U-11 | 292 | 4 (2) | 0 | 0 | 0 |
| U-12 | 232 | 0 | 0 | 0 | 0 |
| U-13 | 151 | 4 (2) | 0 | 0 | 0 |
| U-14 | 195 | 4 (8) | 0 | 0 | 0 |

**Table 5.5-1, continued…**

| Transect Number | Number of Points in Transect | Calibration Types Applied to Each Transect and Stage/Discharge Set | | | |
|---|---|---|---|---|---|
| | | High Pool/ High Flow | Low Pool/ High Flow | Low Pool/ Medium Flow | Low Pool/ Low Flow |
| U-15 | 270 | 0 | 0 | 0 | 0 |
| U-16 | 403 | 4 (2) | 0 | 0 | 0 |
| U-17 | 279 | 4 (2) | 0 | 0 | 3 (1) |
| U-18 | 224 | 4 (3) | 0 | 0 | 0 |
| U-19 | 241 | 4 (22) | 0 | 0 | 0 |
| U-20 | 286 | 2 (1) | 0 | 0 | 0 |
| U-21 | 268 | 4 (3) | 0 | 0 | 0 |
| U-22 | 161 | 4 (6) | 0 | 0 | 0 |
| U-23 | 194 | 4 (2) | 0 | 0 | 0 |
| U-24 | 171 | 4 (2) | 0 | 0 | 0 |
| TR-1 | 162 | 4 (1) | N/A | N/A | N/A |
| TR-2 | 258 | 0 | N/A | N/A | N/A |
| TR-3 | 255 | 4 (1) | N/A | N/A | N/A |
| TR-5 | 119 | 4 (1) | N/A | N/A | N/A |
| TR-7 | 161 | 0 | N/A | N/A | N/A |
| TR-9 | 172 | 4 (3) | N/A | N/A | N/A |
| TR-10 | 119 | 4 (2) | N/A | N/A | N/A |
| TR-11 | 190 | 4 (1) | N/A | N/A | N/A |
| TR-12 | 124 | 4 (1) | 0 | 0 | 0 |
| TR-13 | 151 | 4 (1) | 0 | 0 | 0 |
| TR-14 | 153 | 2 (2), 4 (1) | 0 | 0 | 0 |
| TR-15 | 269 | 4 (1) | 0 | 0 | 0 |
| TR-16 | 256 | 4 (5) | 0 | 0 | 0 |
| TR-17 | 203 | 4 (1) | 0 | 0 | 0 |

Notes:
0 – none
1 – N-value reduced
2 – Sign of N-value changed
3 – N-value increased
4 – N-value adjusted for edge effect.
Values in parentheses "(1)" are number of instances the modification was performed.
N/A – not applicable

## 5.6. Integration with Hydraulic Routing Model

The results of the integration of the mainstem habitat transects is presented in this section. These results include the comparison of the HRM modeled water surface elevations against those surveyed during the transect measurements and the water surface elevation ranges to apply each habitat transect velocity pattern.

### 5.6.1. Check HRM Calibration at Habitat Transects

As previously indicated in the introduction, the HRM is used to simulate the flow and water surface elevation at the habitat transect, and the use of stage-discharge relationships cannot be applied to determine the water surface elevation associated with a specific discharge. Therefore, the accuracy of the prediction of transect elevations cannot be evaluated by comparison with the associated stage-discharge relationship. However, the water surface elevations that result from the HRM predictions for the conditions at the time of each flow measurement can be compared with actual measurements of those conditions to evaluate the performance of the HRM in predicting transect water surface elevations.

Tables D-1 through D-4 in Attachment D list the measured water surface elevation, HRM modeled water surface elevation, and the difference in the two water surface elevations for all 63 habitat transects. This represents a total of 153 measurements with 30 transects having 4 measurements each and 33 transects having 1 measurement each. Statistics on the difference between the measured and modeled water surface elevations were developed. The results are as follows:

| | |
|---|---|
| Mean difference: | 0.25 foot |
| Median difference: | 0.21 foot |
| Root mean square: | 0.31 foot |
| Minimum difference: | 0.00 foot |
| Maximum difference: | 0.76 foot |

These statistics compare well with results from the calibration of the HRM to the water surface elevations recorded by the pressure transducers and USGS gages used to perform an overall calibration of the HRM over a range of flows. The overall calibration of the HRM produced a root mean square difference of approximately 0.30 foot or less for all locations and maximum difference of approximately 0.75 foot for the Reservoir model (Upper Reservoir, Canyon and Forebay reaches) and 1.5 feet for the Tailrace model (Tailrace Reach).

### 5.6.2. Application of Velocity Patterns Based on Water Surface Elevations

Using the agreed upon procedure of applying velocity patterns based on elevations (Section 4.6.3), the controlling elevations for application of each velocity pattern were determined. Tables 5.6-1 through 5.6-2 provide summaries of the water surface elevations used to determine the velocity pattern to apply to transects where multiple velocity patterns exist.

These tables apply only to the 24 Upper Reservoir Reach transects and the 6 U.S. portion of the Tailrace Reach transects—the only transects with multiple velocity measurements. The range of WSEs at a transect that each of the velocity patterns are applied to during habitat modeling are listed in the tables. The elevation ranges follow the same general selection procedure for all transects. The high pool/high flow condition is used to simulate velocities for all observations above the WSEs and for measurements below the WSE for the low pool/high flow condition. The low pool/high flow condition is used to model velocity patterns from the WSE associated with its measurement down to the WSE associated with the low pool/medium flow measurement. In turn, the low pool/medium flow velocity pattern is used to model down to the WSE for the

low pool/low flow measurement. The low pool/low flow pattern is applied to all WSEs equal to or less than its corresponding measured water surface elevation. Following this scheme, velocity patterns will be modeled downward, except for WSEs exceeding the high pool condition which require modeling upward from the high pool/high flow condition.

**Table 5.6-1.** Upper Reservoir Reach velocity patterns and elevation ranges to apply patterns.

| Transect Number | Velocity Patterns and Elevation Ranges (ft NAVD 88) for Application of Each Pattern | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High Pool/ High Flow | | Low Pool/ High Flow | | Low Pool/ Medium Flow | | Low Pool/ Low Flow | |
| | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) |
| U-1 | N/A | 1,991.75 | 1,991.75 | 1,988.22 | 1,988.22 | 1,984.78 | 1,984.78 | N/A |
| U-2 | N/A | 1,992.22 | 1,992.22 | 1,988.51 | 1,988.51 | 1,985.01 | 1,985.01 | N/A |
| U-3 | N/A | 1,992.12 | 1,992.12 | 1,988.33 | 1,988.33 | 1,984.64 | 1,984.64 | N/A |
| U-4 | N/A | 1,992.20 | 1,992.20 | 1,988.22 | 1,988.22 | 1,984.49 | 1,984.49 | N/A |
| U-5 | N/A | 1,992.69 | 1,992.69 | 1,987.98 | 1,987.98 | 1,984.46 | 1,984.46 | N/A |
| U-6 | N/A | 1,992.64 | 1,992.64 | 1,988.82 | 1,988.82 | 1,984.26 | 1,984.26 | N/A |
| U-7 | N/A | 1,992.46 | 1,992.46 | 1,987.75 | 1,987.75 | 1,984.09 | 1,984.09 | N/A |
| U-8 | N/A | 1,992.34 | 1,992.34 | 1,987.92 | 1,987.92 | 1,983.94 | 1,983.94 | N/A |
| U-9 | N/A | 1,992.38 | 1,992.38 | 1,987.69 | 1,987.69 | 1,983.78 | 1,983.78 | N/A |
| U-10 | N/A | 1,992.86 | 1,992.86 | 1,988.01 | 1,988.01 | 1,983.99 | 1,983.99 | N/A |
| U-11 | N/A | 1,992.83 | 1,992.83 | 1,987.97 | 1,987.97 | 1,983.96 | 1,983.96 | N/A |
| U-12 | N/A | 1,992.78 | 1,992.78 | 1,987.95 | 1,987.95 | 1,983.73 | 1,983.73 | N/A |
| U-13 | N/A | 1,992.88 | 1,992.88 | 1,997.99 | 1,997.99 | 1,983.67 | 1,983.67 | N/A |
| U-14 | N/A | 1,993.12 | 1,993.12 | 1,988.08 | 1,988.08 | 1,983.64 | 1,983.64 | N/A |
| U-15 | N/A | 1,993.15 | 1,993.15 | 1,988.07 | 1,988.07 | 1,983.50 | 1,983.50 | N/A |
| U-16 | N/A | 1,993.05 | 1,993.05 | 1,989.17 | 1,989.17 | 1,984.06 | 1,984.06 | N/A |
| U-17 | N/A | 1,992.99 | 1,992.99 | 1,989.03 | 1,989.03 | 1,984.24 | 1,984.24 | N/A |
| U-18 | N/A | 1,993.05 | 1,993.05 | 1,988.75 | 1,988.75 | 1,984.30 | 1,984.30 | N/A |
| U-19 | N/A | 1,993.39 | 1,993.39 | 1,988.58 | 1,988.58 | 1,984.22 | 1,984.22 | N/A |
| U-20 | N/A | 1,993.51 | 1,993.51 | 1,988.61 | 1,988.61 | 1,984.33 | 1,984.33 | N/A |
| U-21 | N/A | 1,993.68 | 1,993.68 | 1,988.55 | 1,988.55 | 1,984.45 | 1,984.45 | N/A |
| U-22 | N/A | 1,993.91 | 1,993.91 | 1,988.80 | 1,988.80 | 1,984.63 | 1,984.63 | N/A |
| U-23 | N/A | 1,994.75 | 1,994.75 | 1,989.56 | 1,989.56 | 1,985.22 | 1,985.22 | N/A |
| U-24 | N/A | 1,995.03 | 1,995.03 | 1,989.94 | 1,989.94 | 1,985.75 | 1,985.75 | N/A |

Note:
N/A – not applicable

**Table 5.6-2.** Tailrace Reach velocity patterns and elevation ranges to apply patterns.

| Transect Number | Velocity Patterns and Elevation Ranges (ft NAVD 88) for Application of Each Pattern | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | High Pool/ High Flow | | Low Pool/ High Flow | | Low Pool/ Medium Flow | | Low Pool/ Low Flow | |
| | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) | Upper Limit (≤ Elev) | Lower Limit (> Elev) |
| T-12 | N/A | 1,731.12 | 1,731.12 | 1,727.97 | 1,727.97 | 1,726.74 | 1,726.74 | N/A |
| T-13 | N/A | 1,731.83 | 1,731.83 | 1,728.51 | 1,728.51 | 1,726.99 | 1,726.99 | N/A |
| T-14 | N/A | 1,733.61 | 1,733.61 | 1,729.80 | 1,729.80 | 1,727.50 | 1,727.50 | N/A |
| T-15 | N/A | 1,733.91 | 1,733.91 | 1,730.05 | 1,730.05 | 1,727.67 | 1,727.67 | N/A |
| T-16 | N/A | 1,734.79 | 1,734.79 | 1,730.54 | 1,730.54 | 1,727.86 | 1,727.86 | N/A |
| T-17 | N/A | 1,734.95 | 1,734.95 | 1,731.41 | 1,731.41 | 1,728.27 | 1,728.27 | N/A |

Note:
N/A – not applicable

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# Attachment A: Calibrated Velocity Patterns for All Measured Flow Conditions

This attachment contains the following figures:

Figure A-1. Velocity profiles for Boundary Reservoir Forebay Reach, transect F-01.
Figure A-2. Velocity profiles for Boundary Reservoir Forebay Reach, transect F-02.
Figure A-3. Velocity profiles for Boundary Reservoir Forebay Reach, transect F-03.
Figure A-4. Velocity profiles for Boundary Reservoir Forebay Reach, transect F-04.
Figure A-5. Velocity profiles for Boundary Reservoir Forebay Reach, transect F-05.
Figure A-6. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-01.
Figure A-7. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-02.
Figure A-8. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-04.
Figure A-9. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-05.
Figure A-10. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-06.
Figure A-11. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-07.
Figure A-12. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-08.
Figure A-13. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-09.
Figure A-14. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-11.
Figure A-15. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-12.
Figure A-16. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-14.
Figure A-17. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-15.
Figure A-18. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-16.
Figure A-19. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-17.
Figure A-20. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-19.
Figure A-21. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-20.
Figure A-22. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-21.
Figure A-23. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-22.
Figure A-24. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-23.
Figure A-25. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-24.
Figure A-26. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U- 01.
Figure A-27. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-02.
Figure A-28. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-03.
Figure A-29. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-04.
Figure A-30. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-05.
Figure A-31. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-06.
Figure A-32. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-07.
Figure A-33. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-08.
Figure A-34. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-09.
Figure A-35. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-10.
Figure A-36. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-11.
Figure A-37. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-12.
Figure A-38. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-13.
Figure A-39. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-14.
Figure A-40. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-15.
Figure A-41. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-16.
Figure A-42. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-17.
Figure A-43. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-18.
Figure A-44. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-19.

Figure A-45. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-20.
Figure A-46. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-21.
Figure A-47. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-22.
Figure A-48. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-23.
Figure A-49. Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-24.
Figure A-50. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-01.
Figure A-51. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-02.
Figure A-52. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-03.
Figure A-53. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-05.
Figure A-54. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-07.
Figure A-55. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-09.
Figure A-56. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-10.
Figure A-57. Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-11.
Figure A-58. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-12.
Figure A-59. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-13.
Figure A-60. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-14.
Figure A-61. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-15.
Figure A-62. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-16.
Figure A-63. Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-17.

The legend below applies to the figures in this attachment.

**LEGEND**

**Vel1 = high pool/high flow**
**Vel2 = low pool/high flow**
**Vel3 = low pool/medium flow**
**Vel4 = low pool/low flow**

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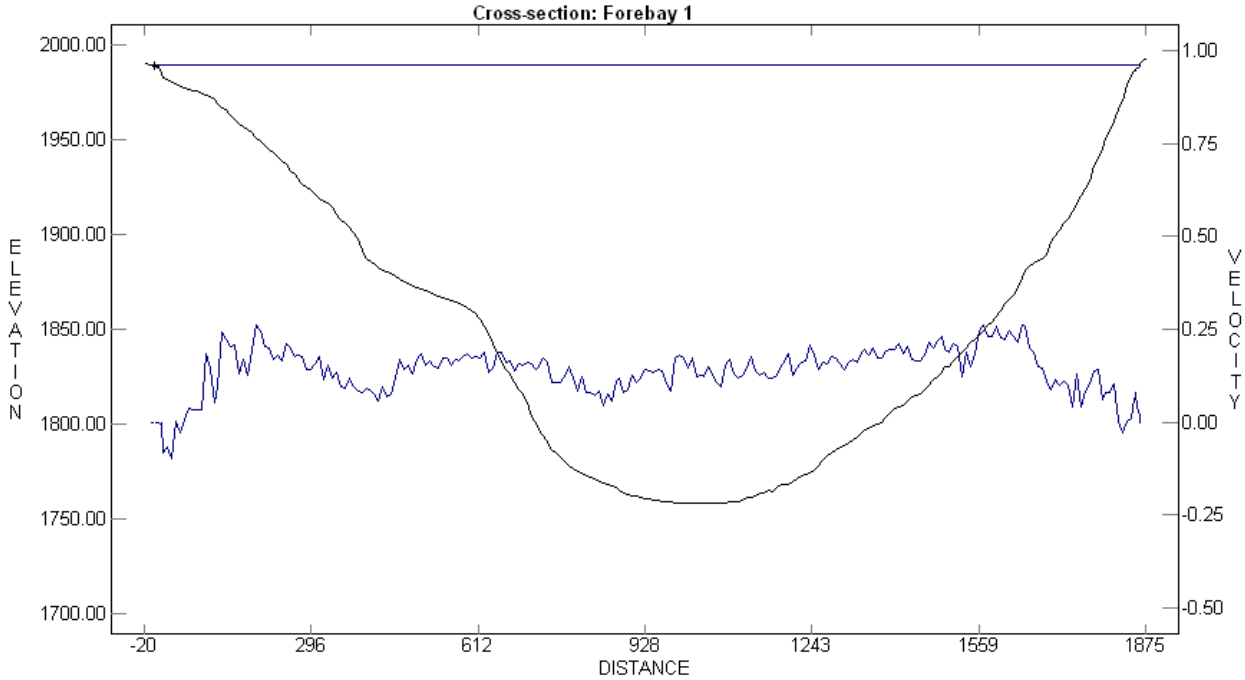


**Figure A-1.** Velocity profiles for Boundary Reservoir Forebay Reach, transect F-01.

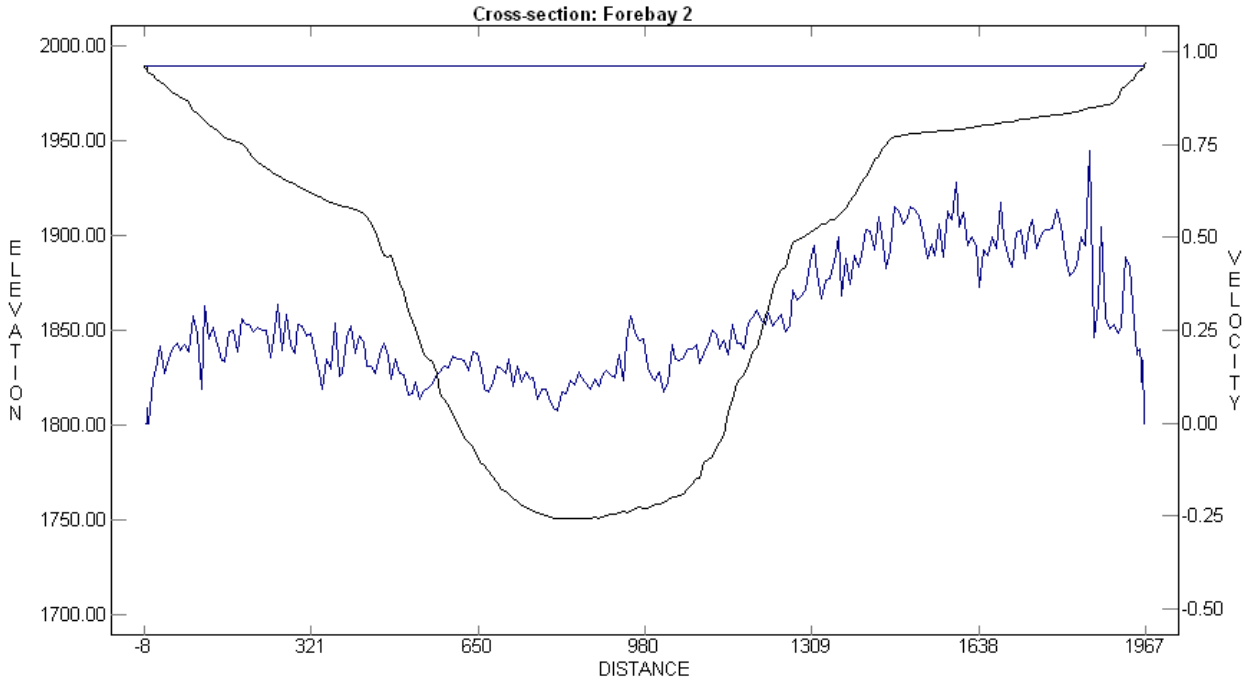


**Figure A-2.** Velocity profiles for Boundary Reservoir Forebay Reach, transect F-02.

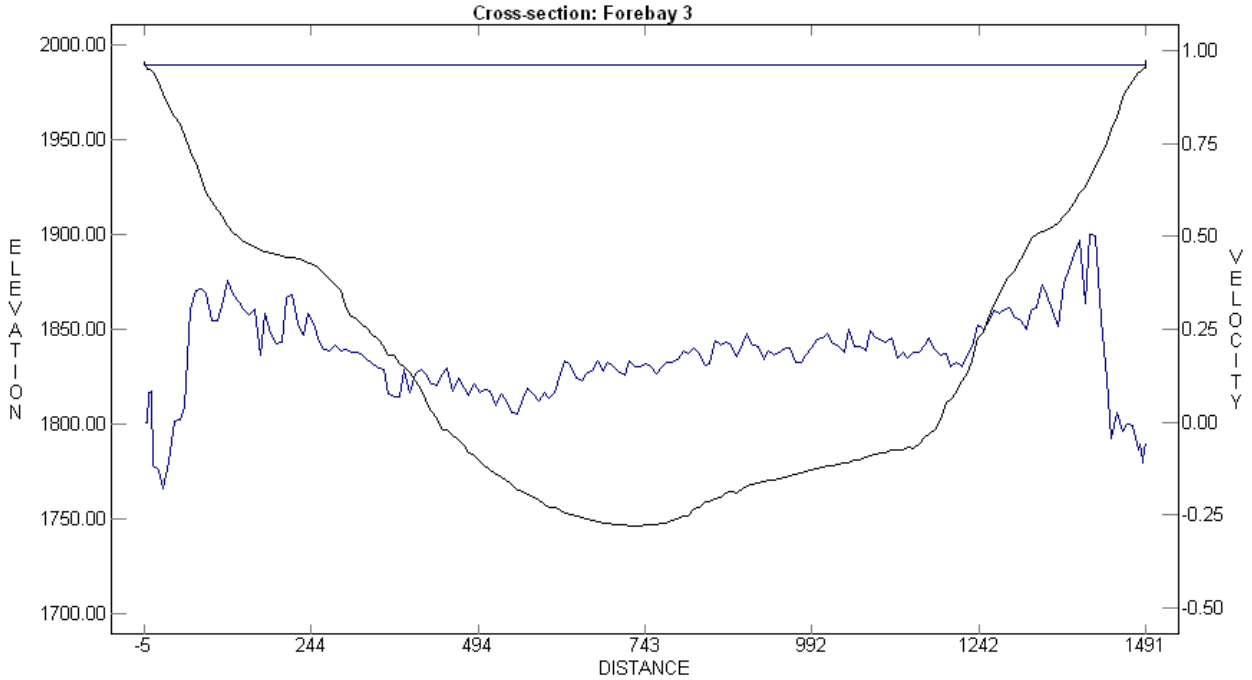


**Figure A-3.** Velocity profiles for Boundary Reservoir Forebay Reach, transect F-03.

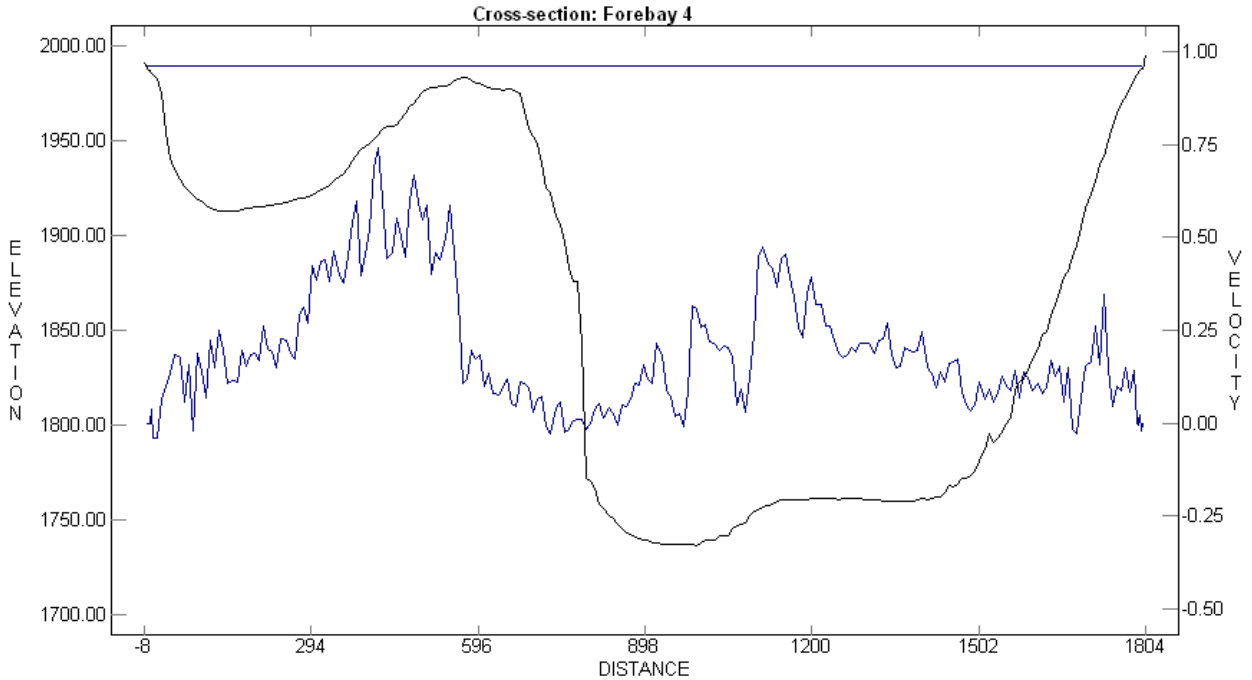


**Figure A-4.** Velocity profiles for Boundary Reservoir Forebay Reach, transect F-04.

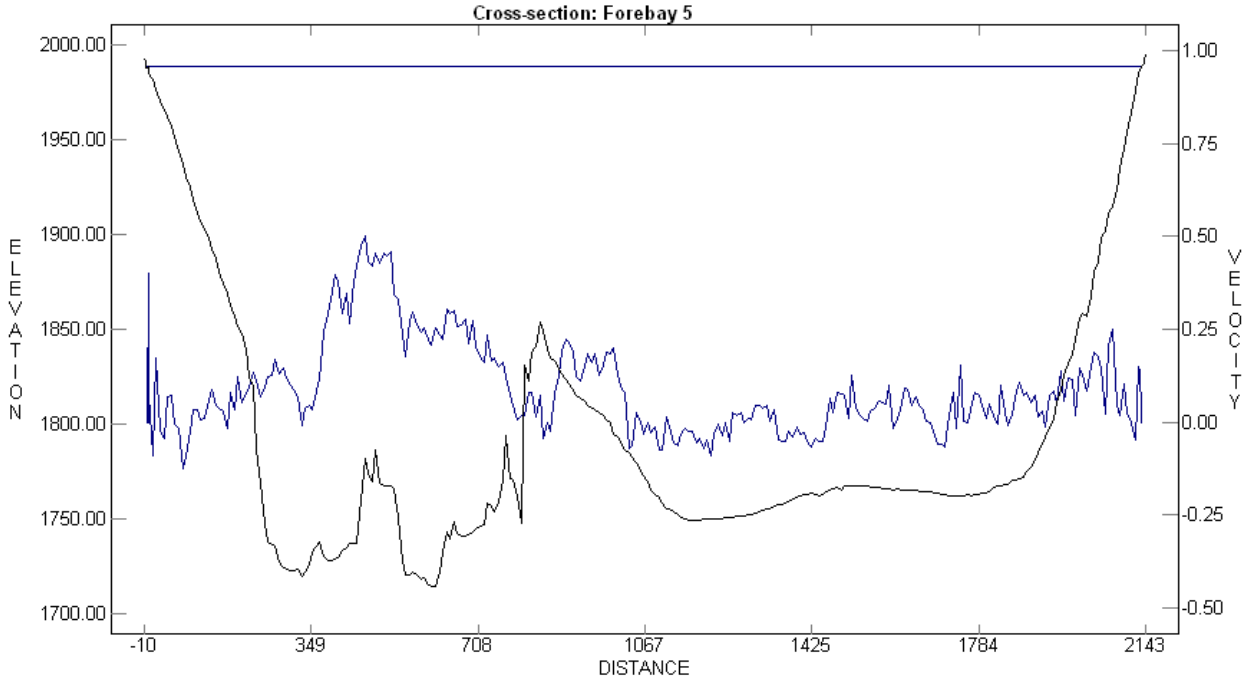


**Figure A-5.** Velocity profiles for Boundary Reservoir Forebay Reach, transect F-05.

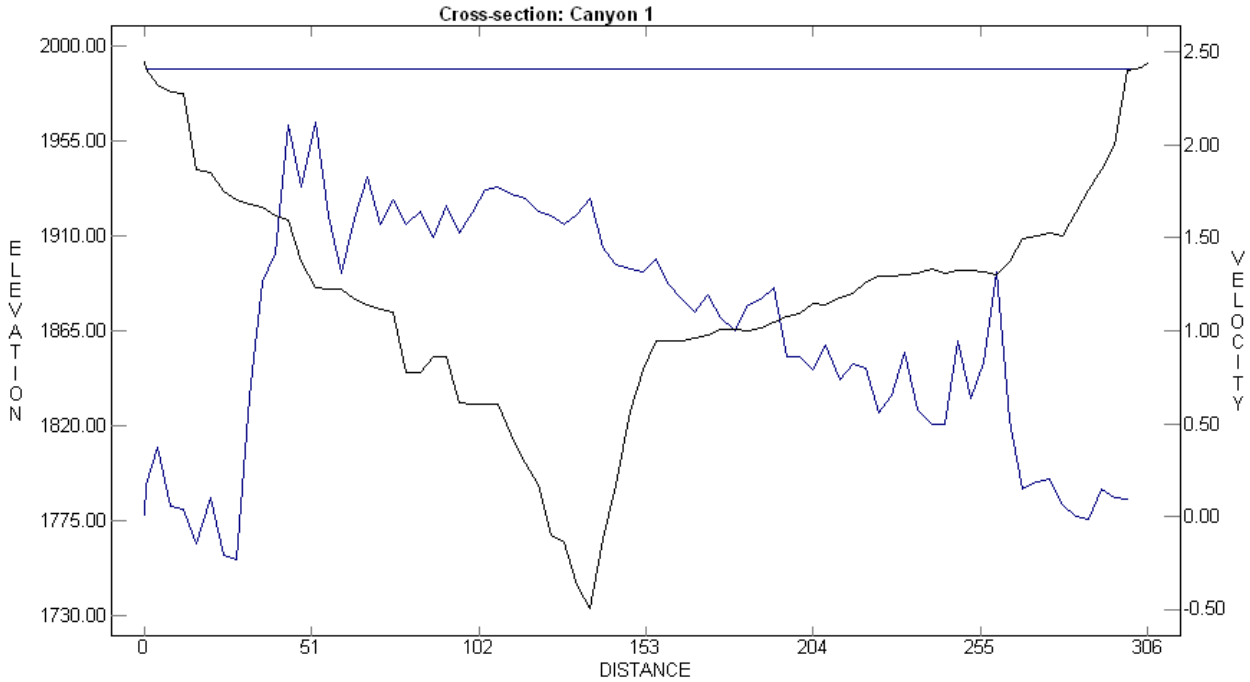


**Figure A-6.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-01.

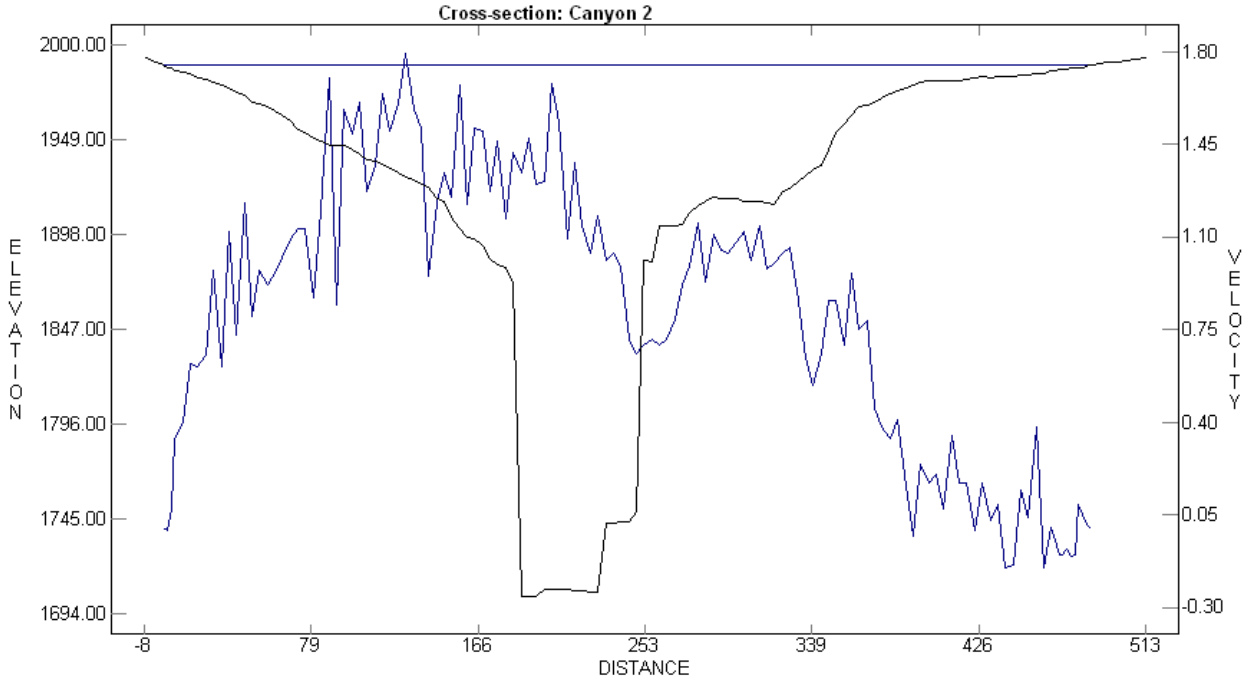


**Figure A-7.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-02.

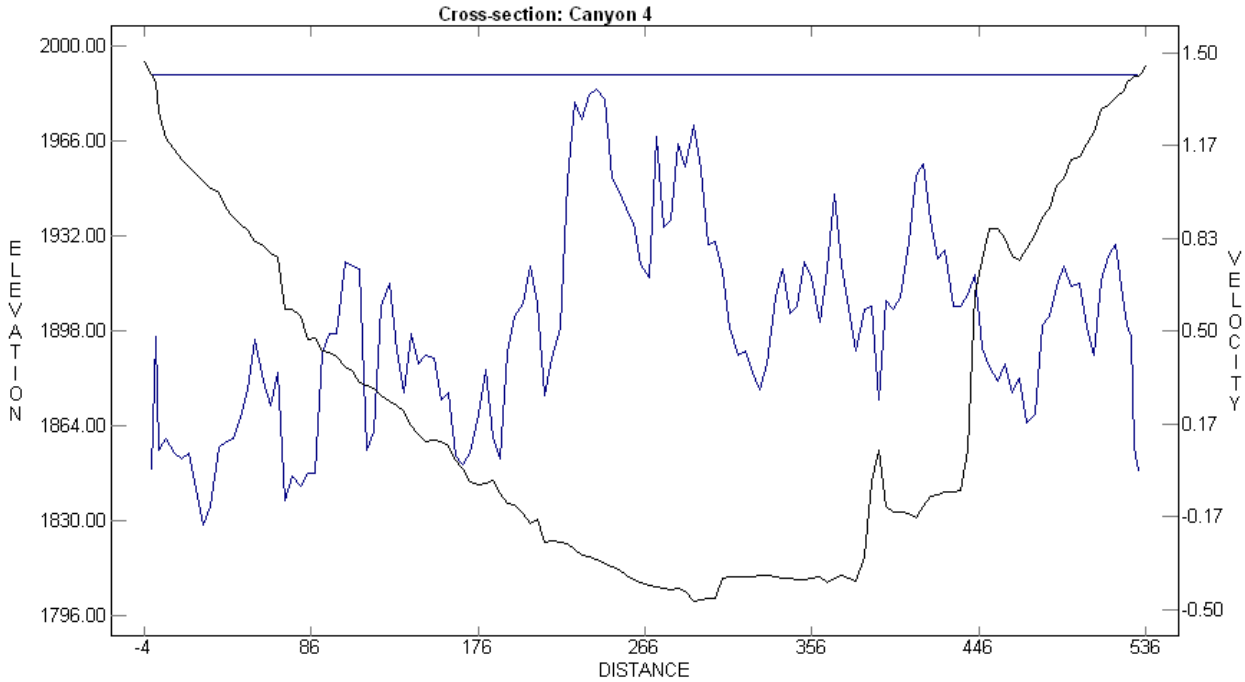


**Figure A-8.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-04.

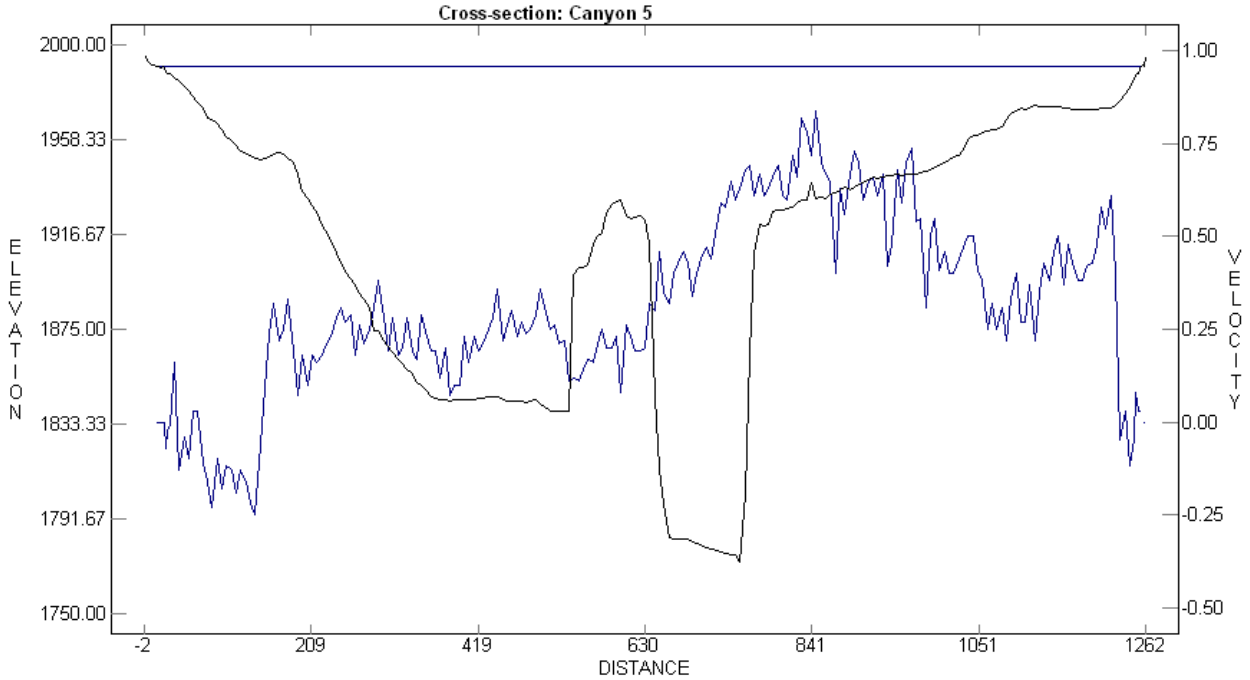


**Figure A-9.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-05.

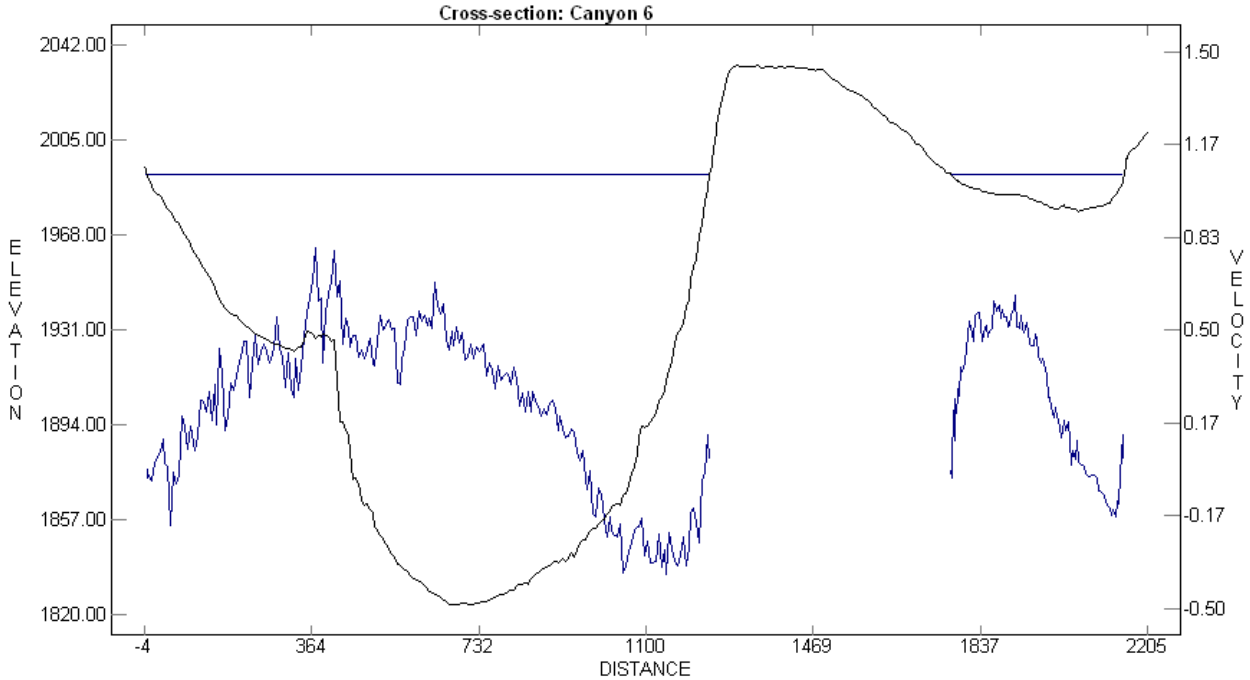


**Figure A-10.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-06.

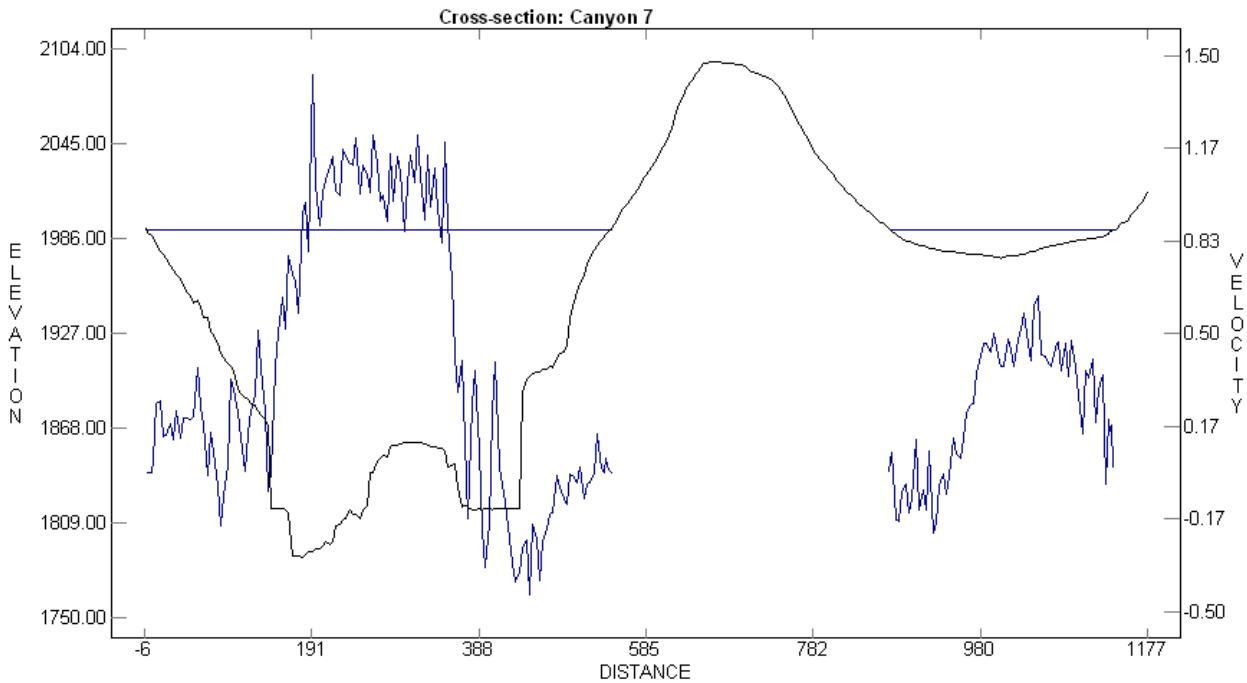


**Figure A-11.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-07.

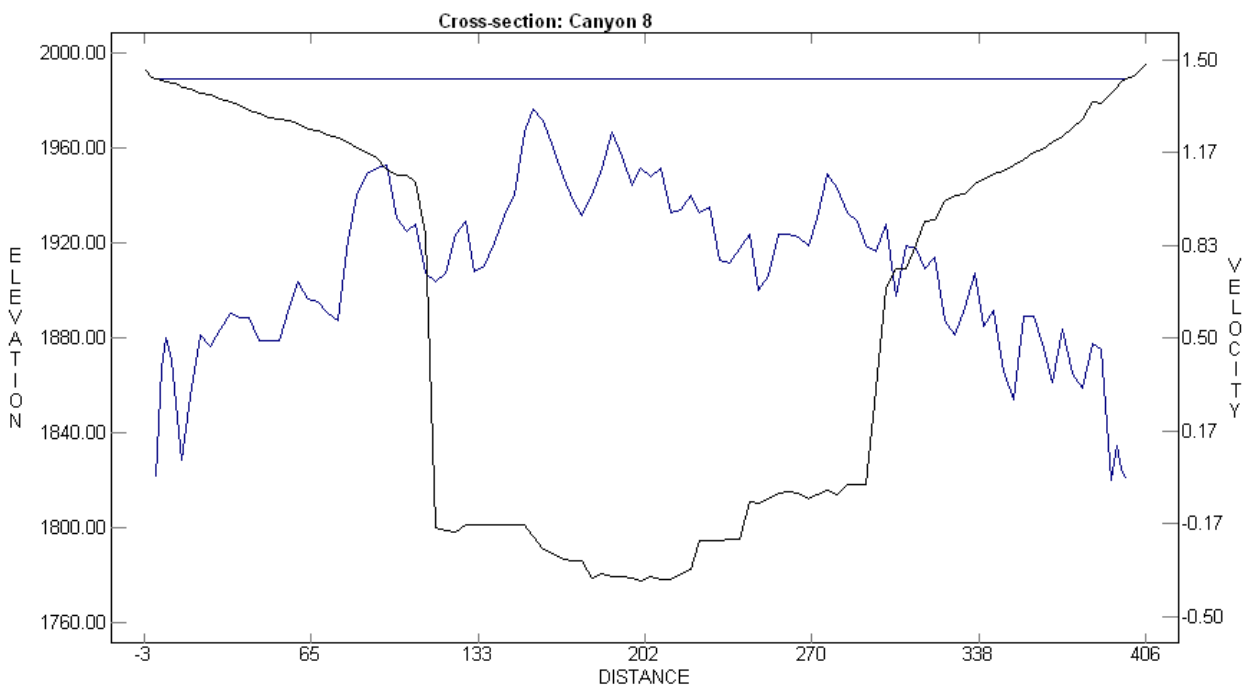


**Figure A-12.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-08.

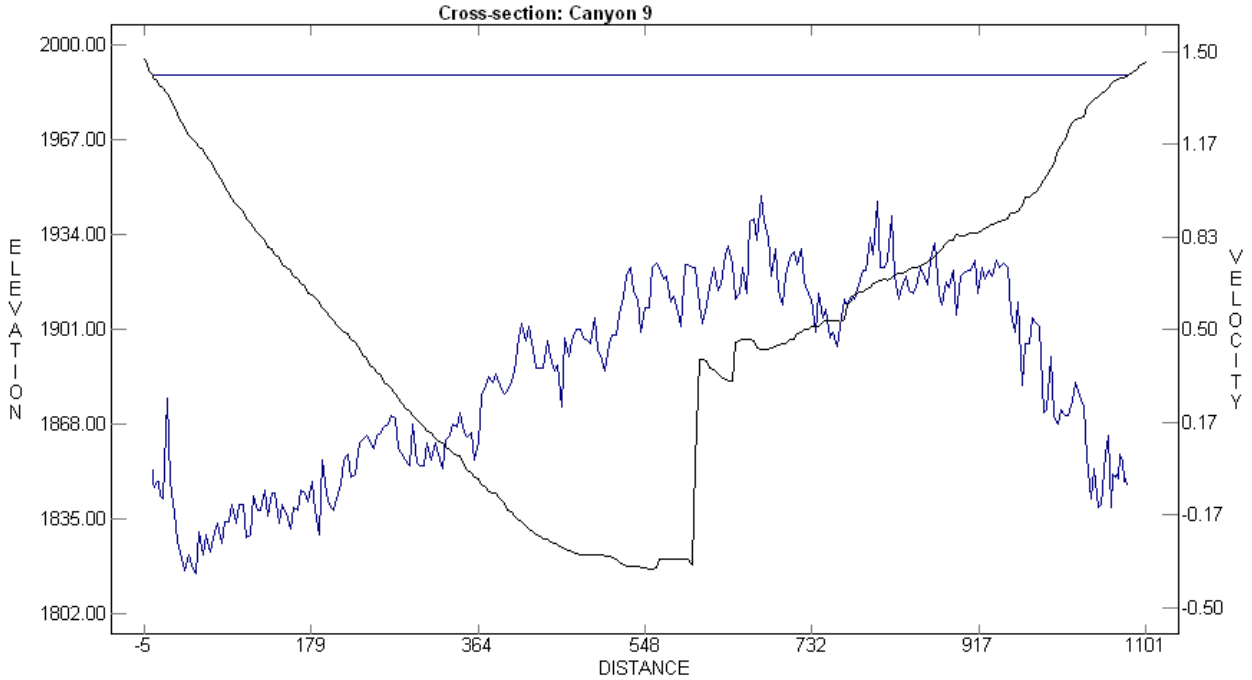


**Figure A-13.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-09.

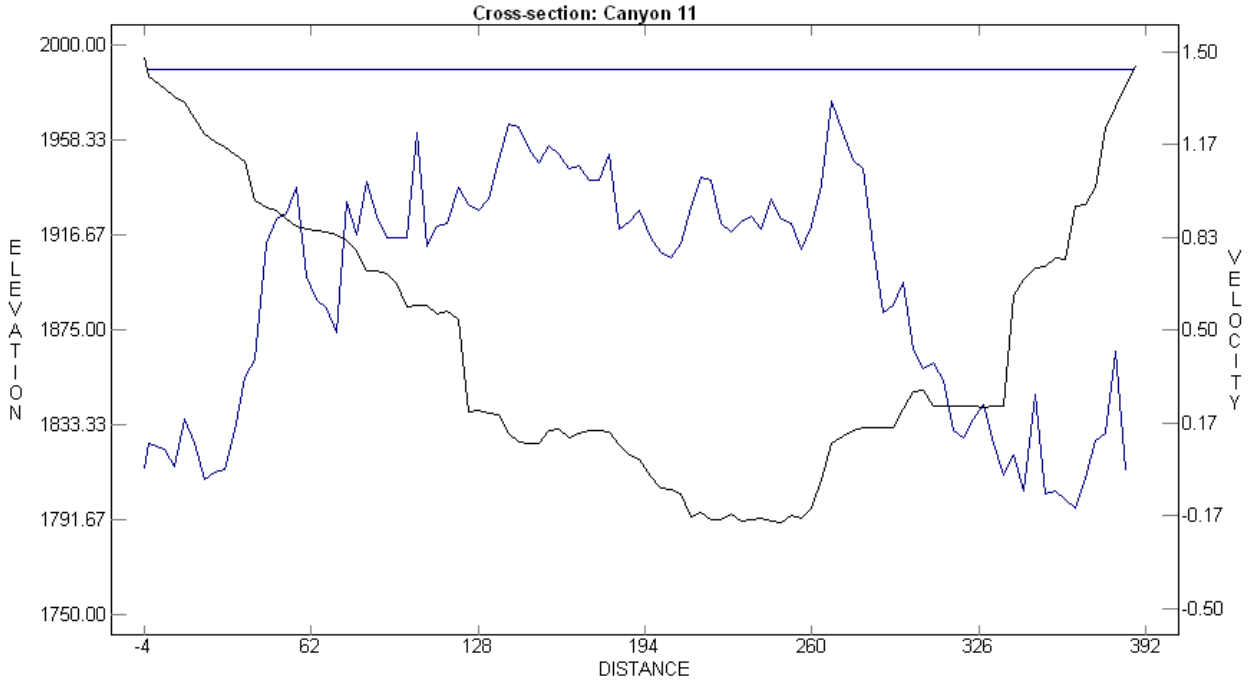


**Figure A-14.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-11.

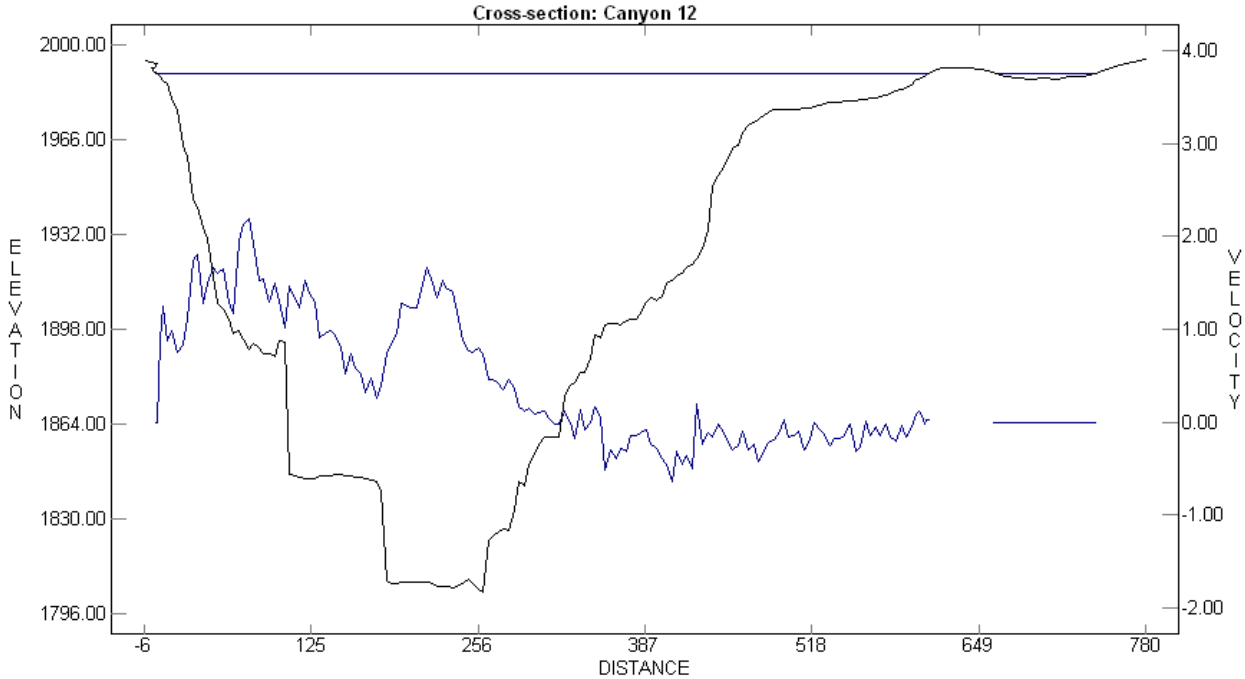


**Figure A-15.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-12.

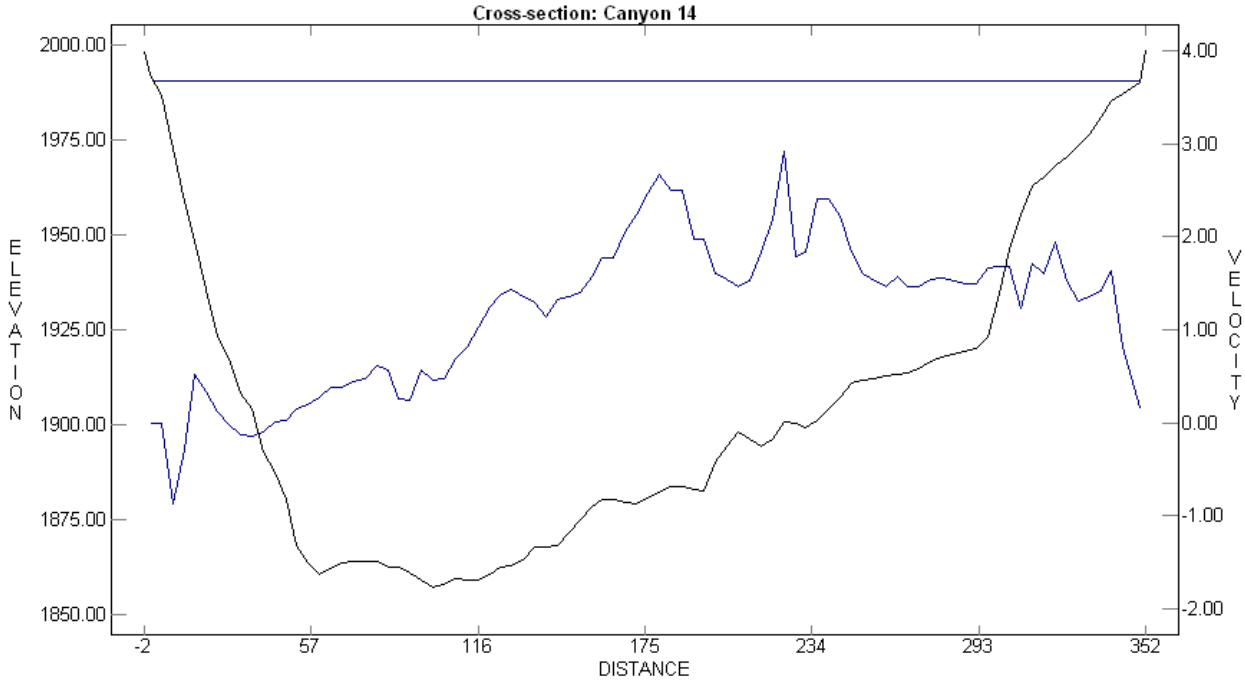


**Figure A-16.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-14.

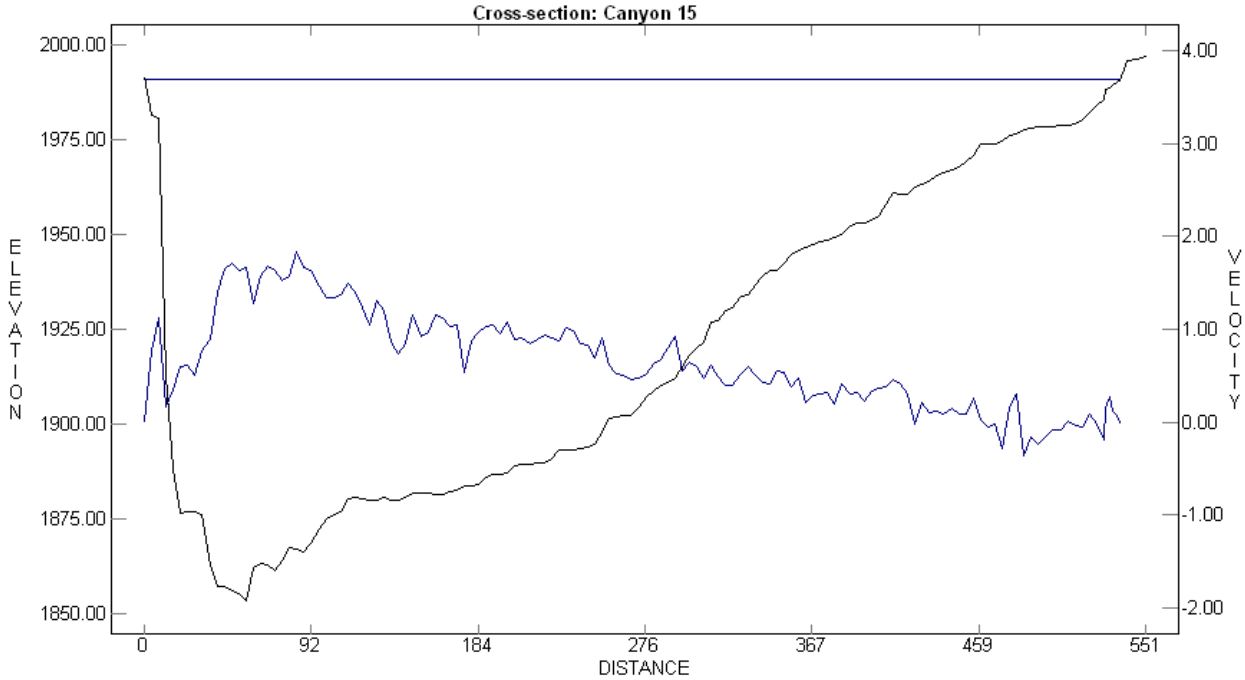


**Figure A-17.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-15.

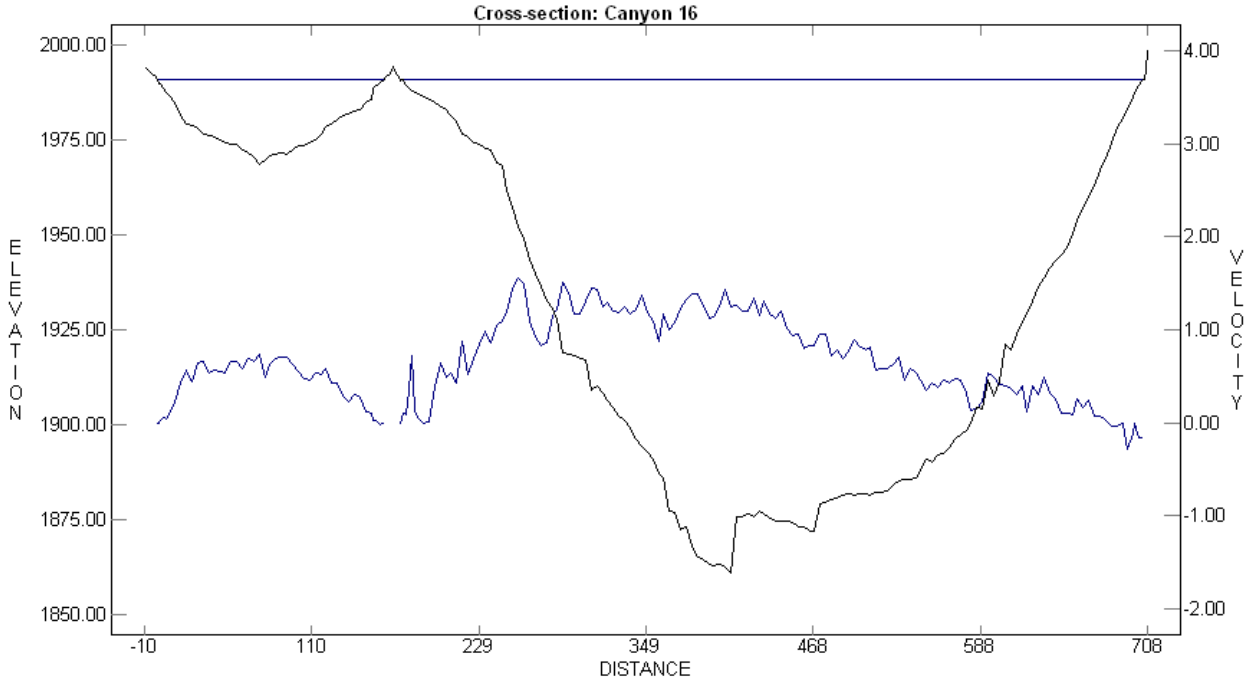


**Figure A-18.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-16.

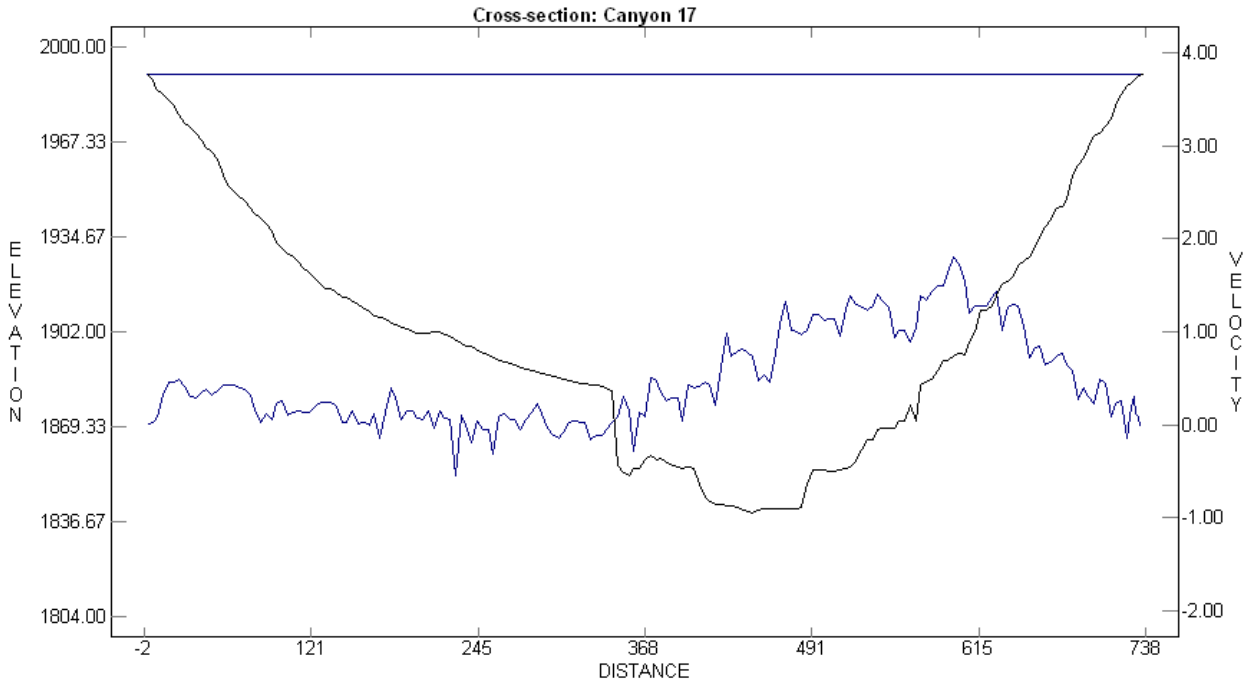


**Figure A-19.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-17.

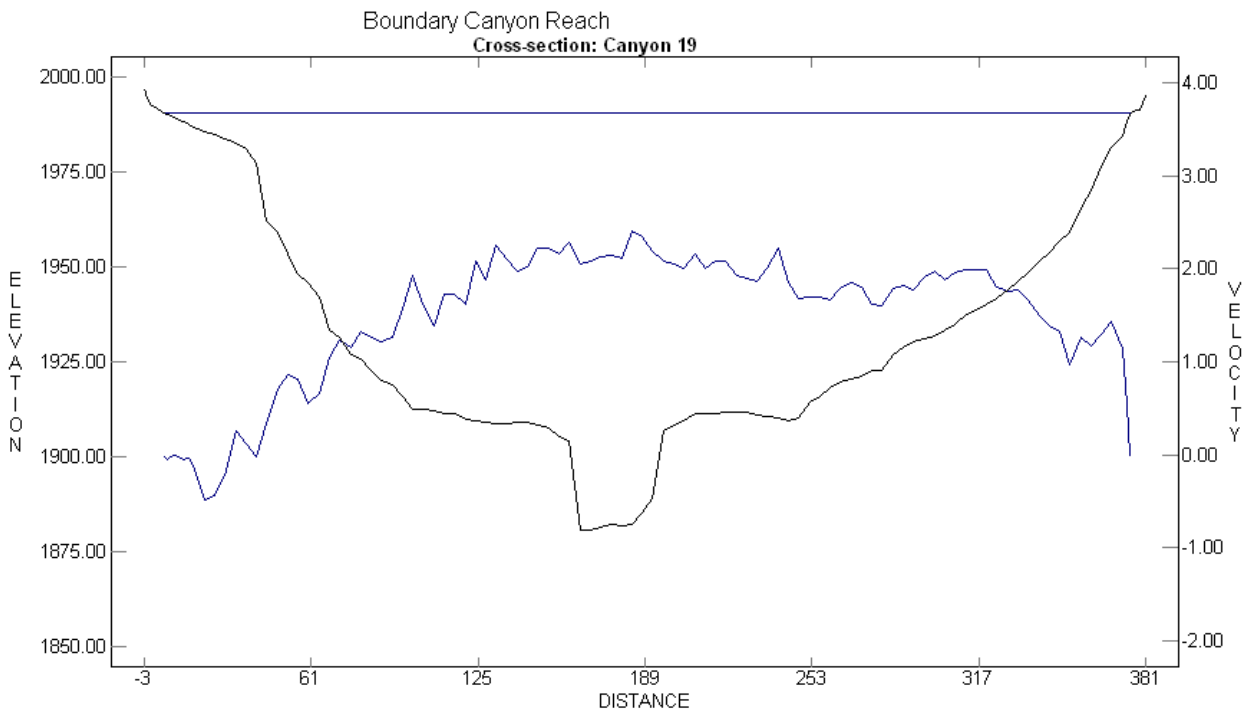


**Figure A-20.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-19.

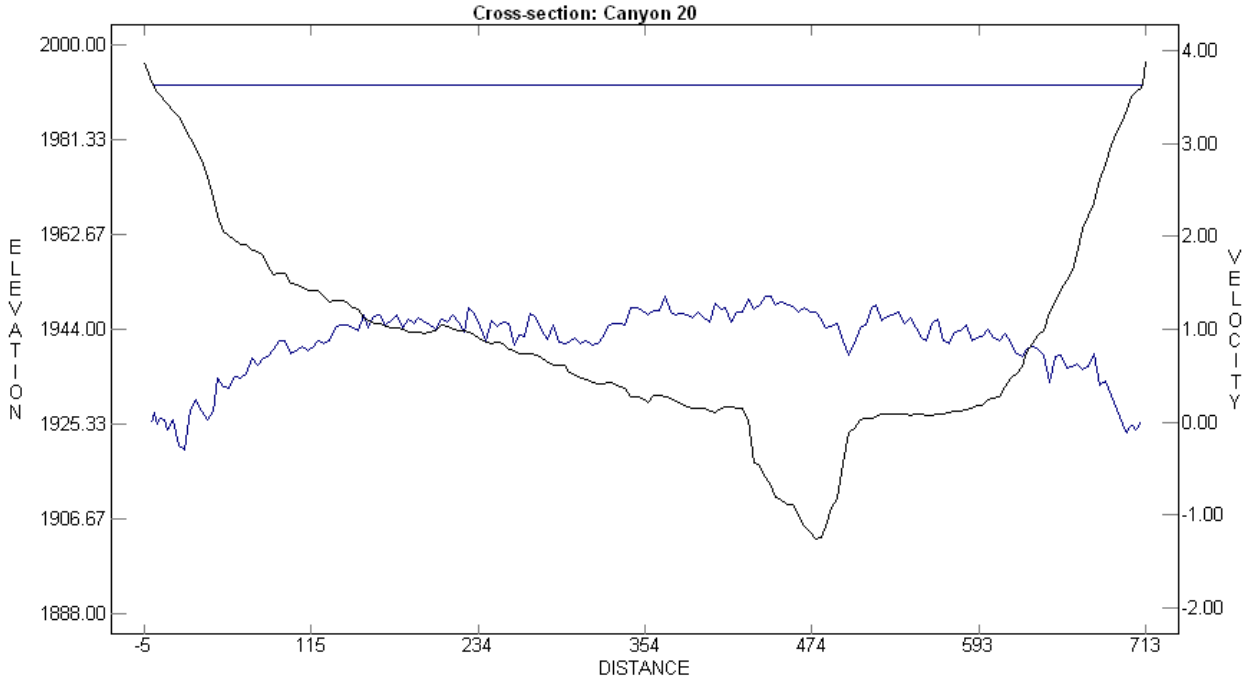


**Figure A-21.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-20.

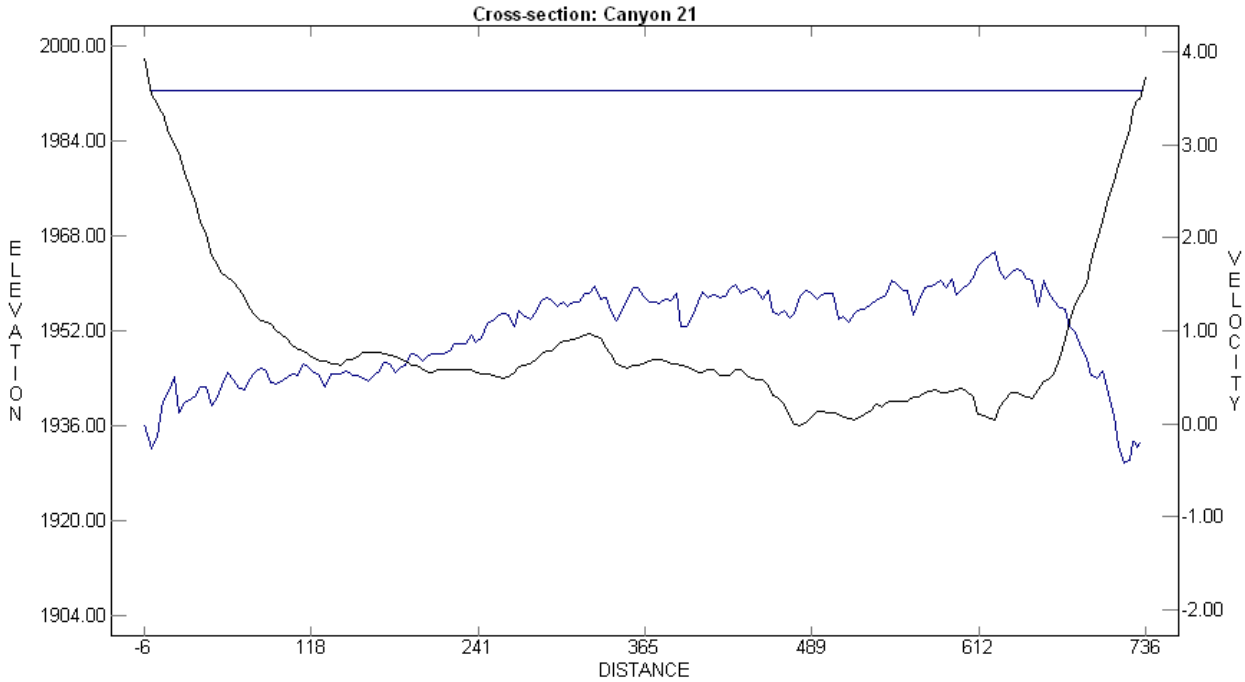


**Figure A-22.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-21.

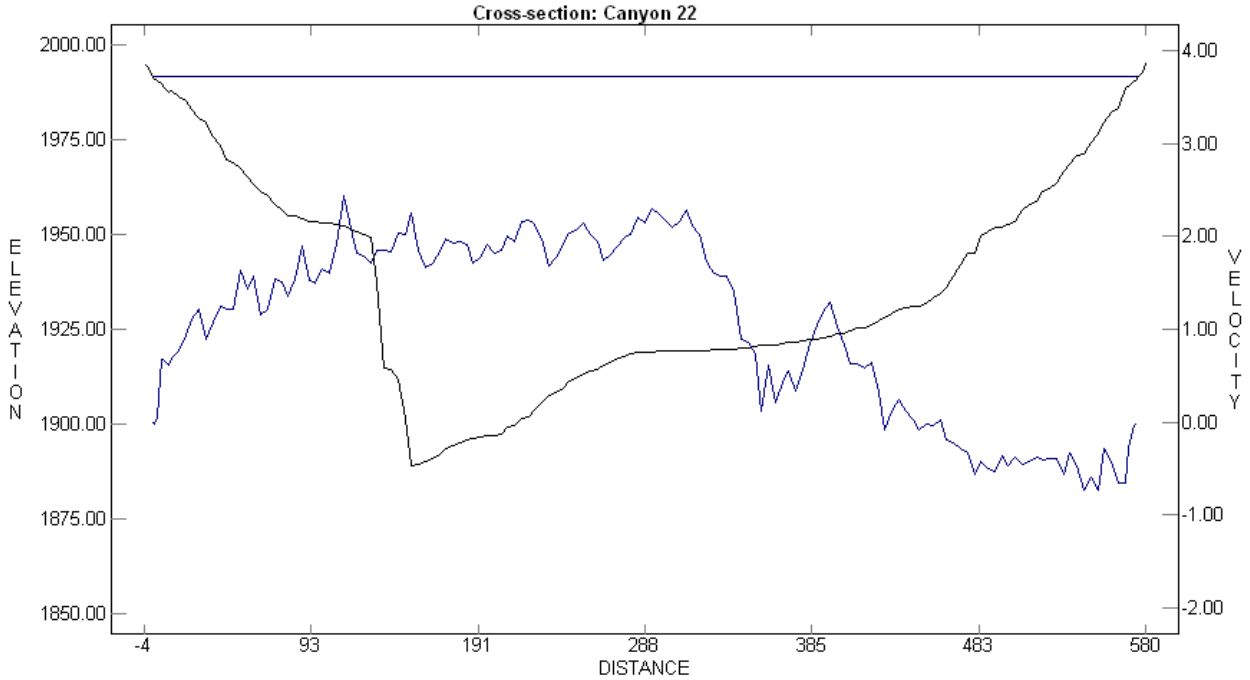


**Figure A-23.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-22.

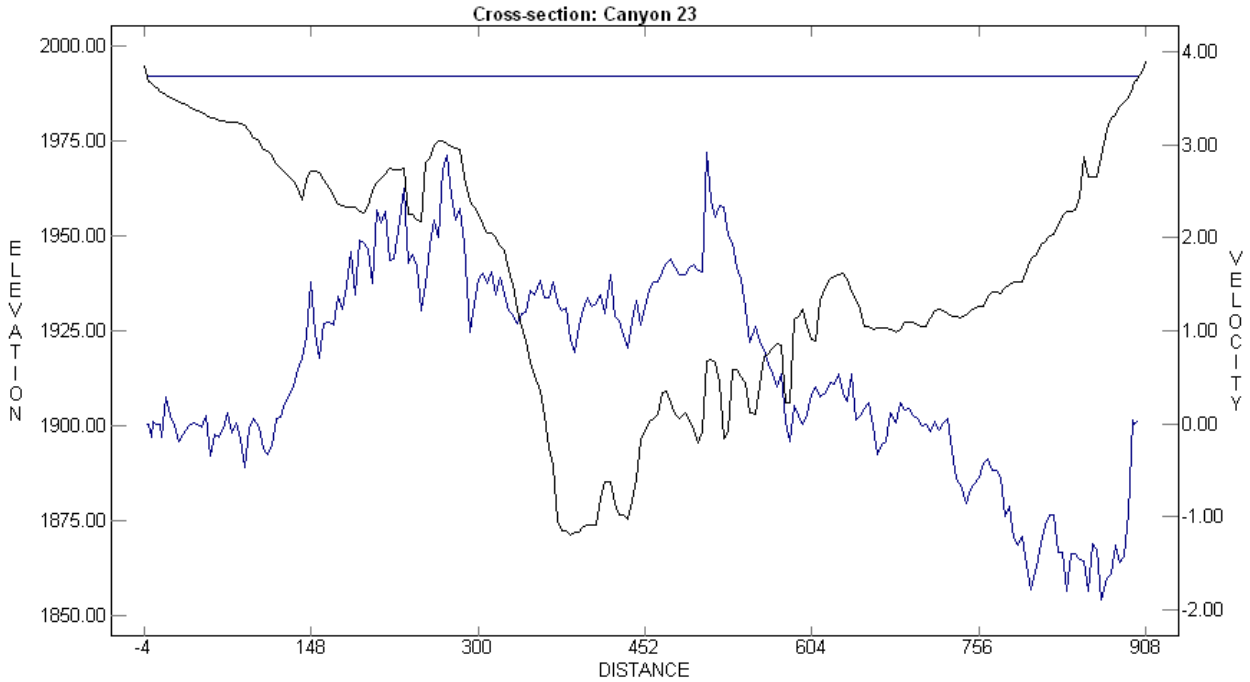


**Figure A-24.** Velocity profiles for Boundary Reservoir Canyon Reach, transect C-23.

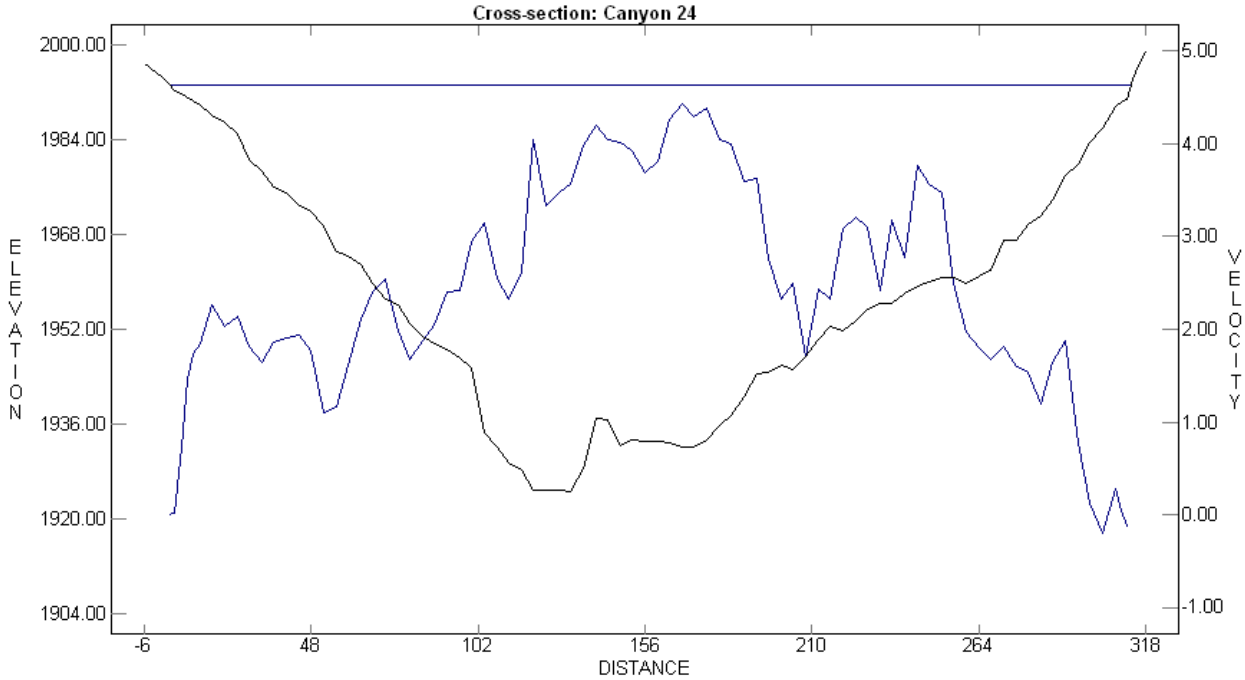


**Figure A-25**. Velocity profiles for Boundary Reservoir Canyon Reach, transect C-24.

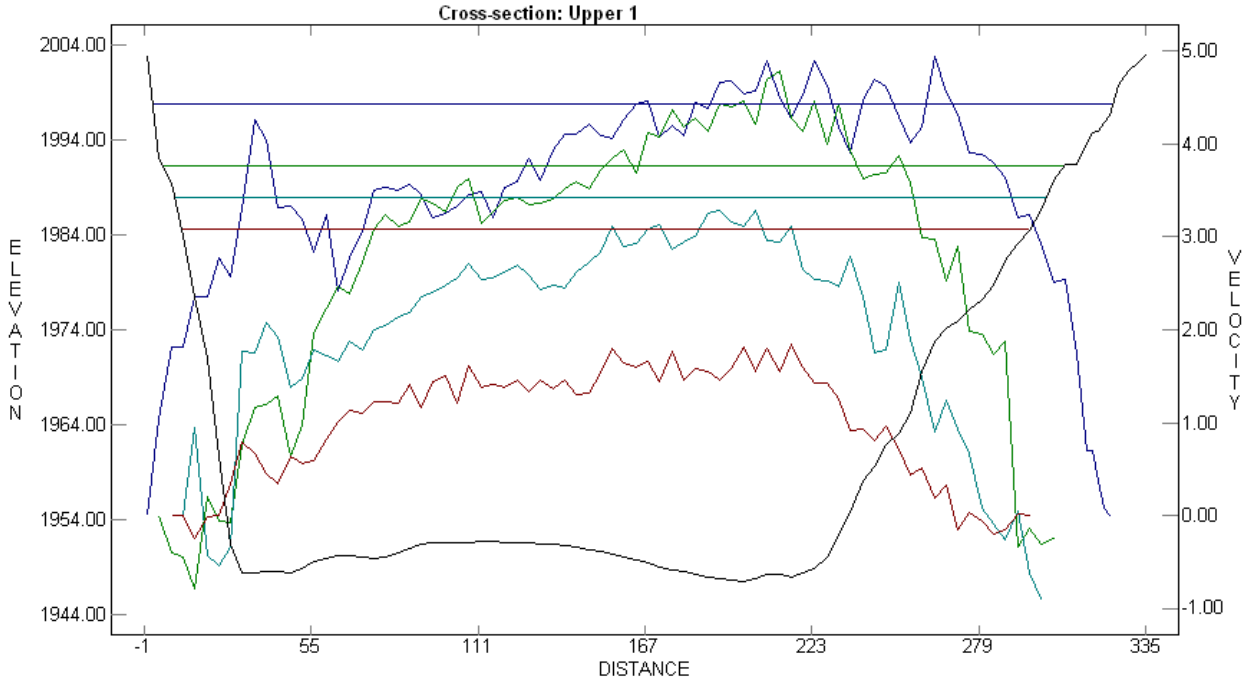


**Figure A-26.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U- 01.

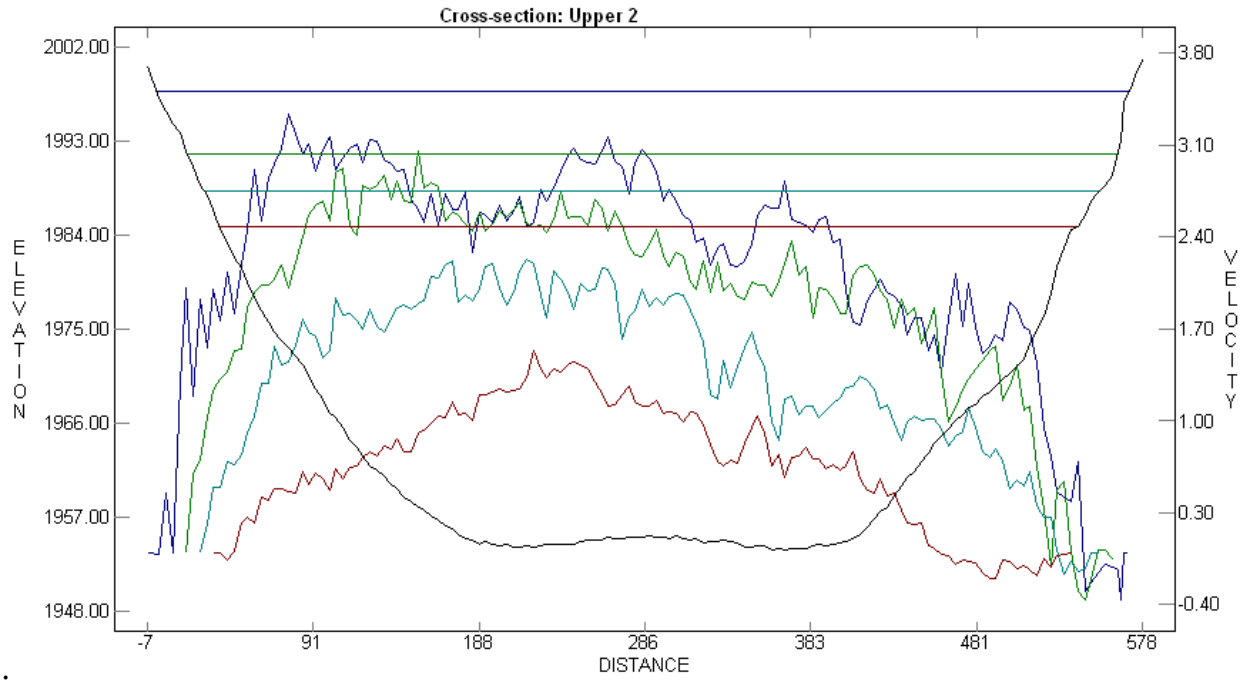


**Figure A-27.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-02.

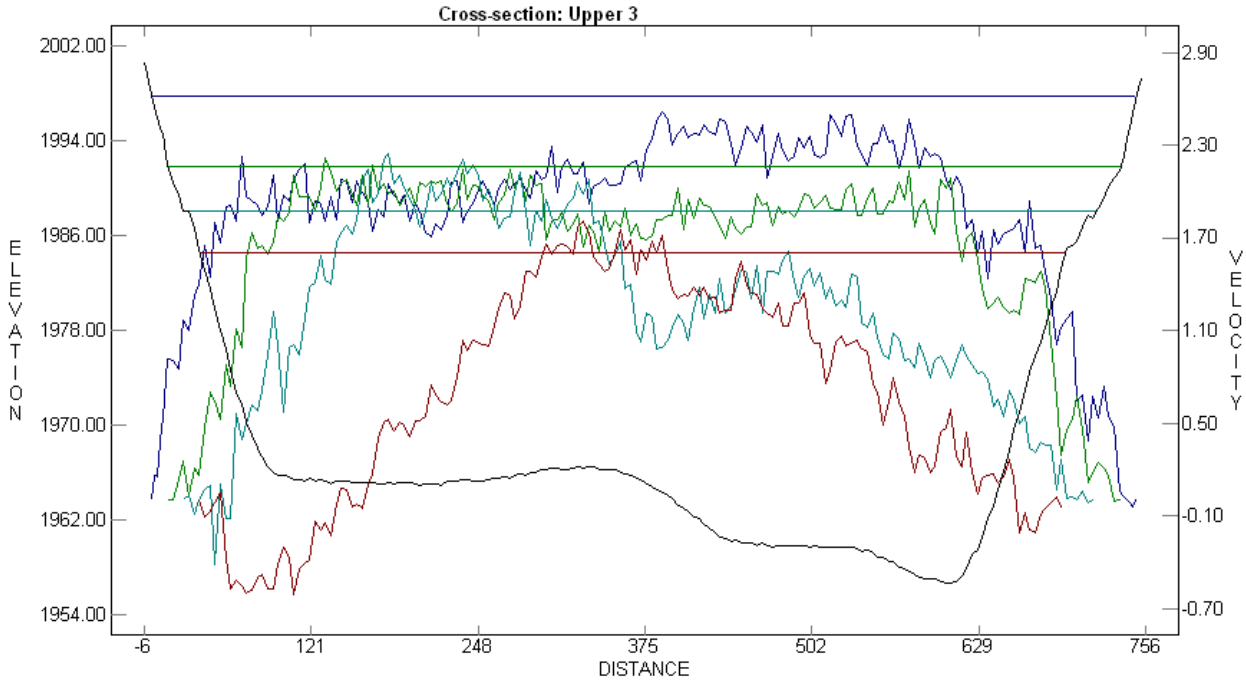


**Figure A-28.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-03.

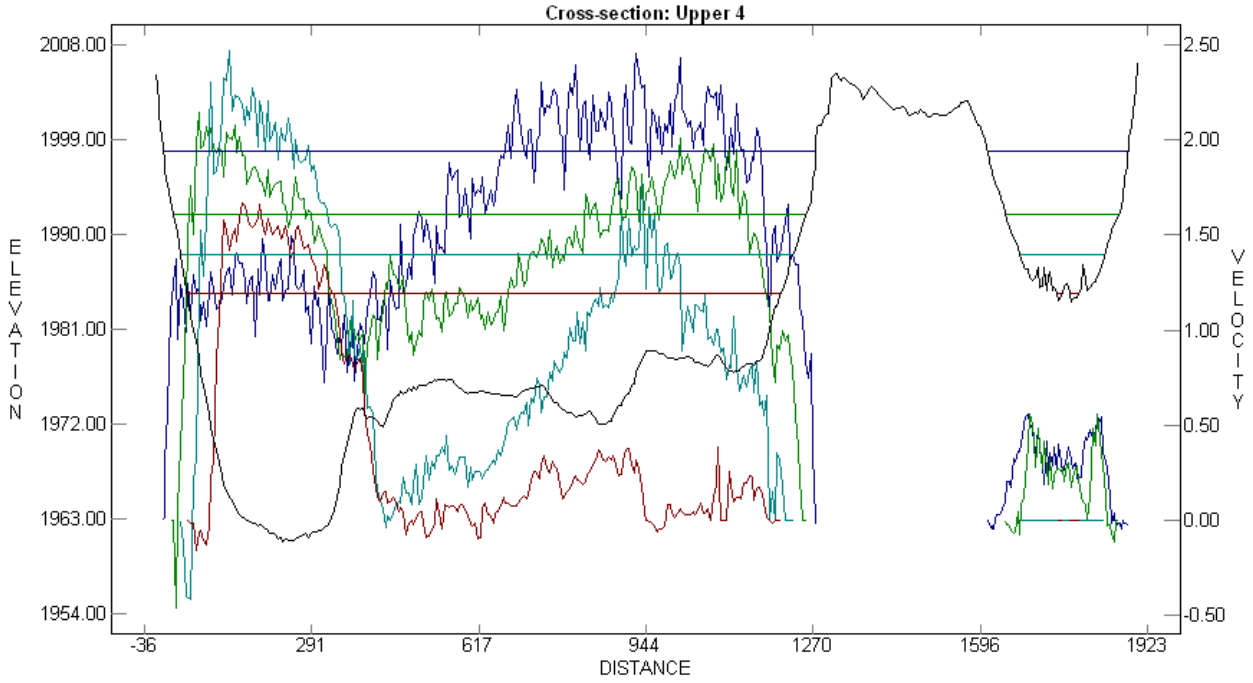


**Figure A-29.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-04.

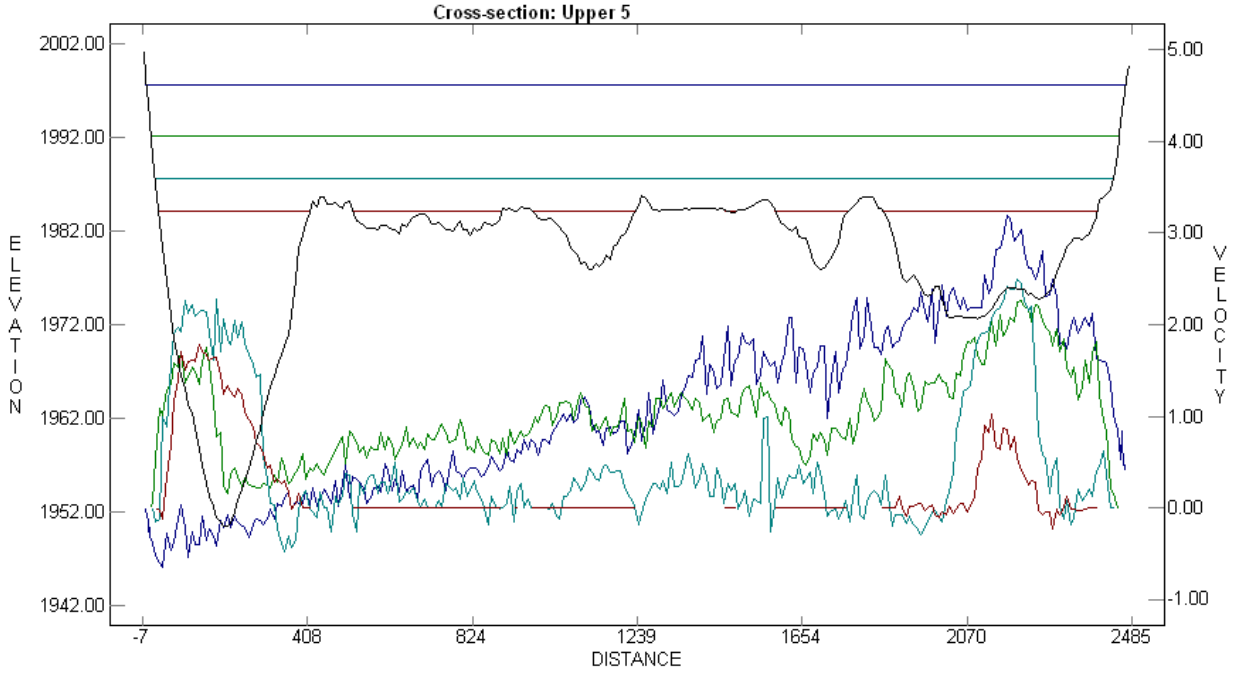


**Figure A-30.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-05.

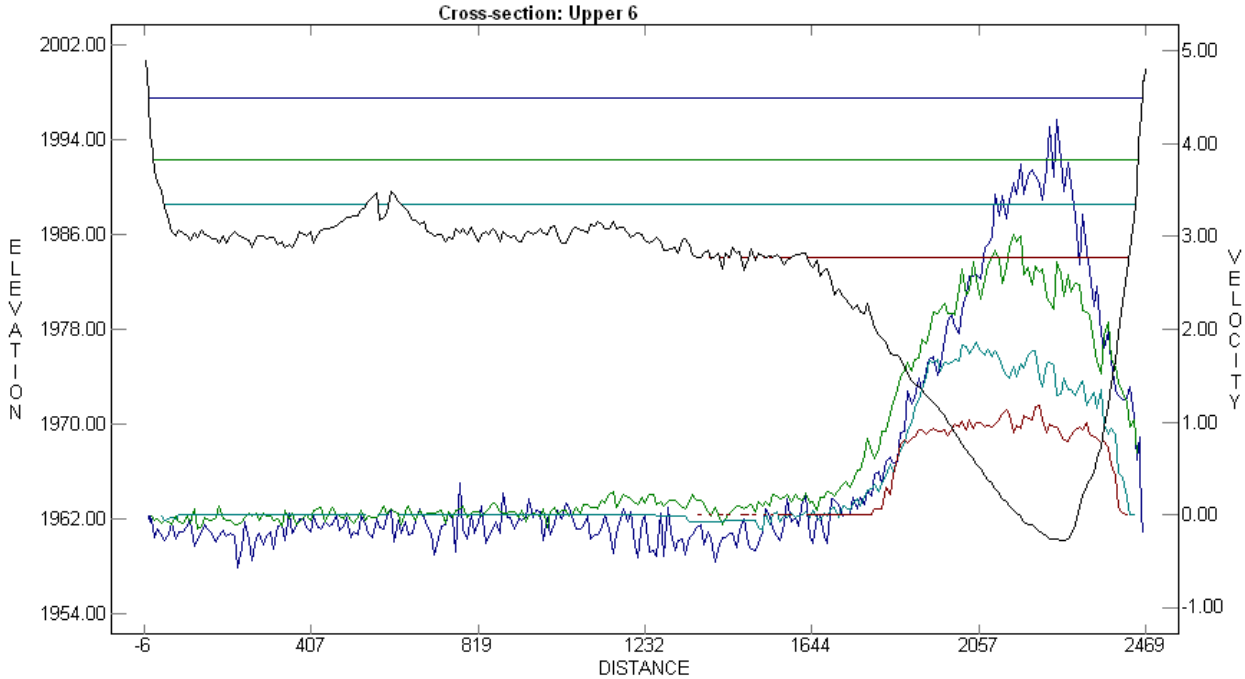


**Figure A-31.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-06.

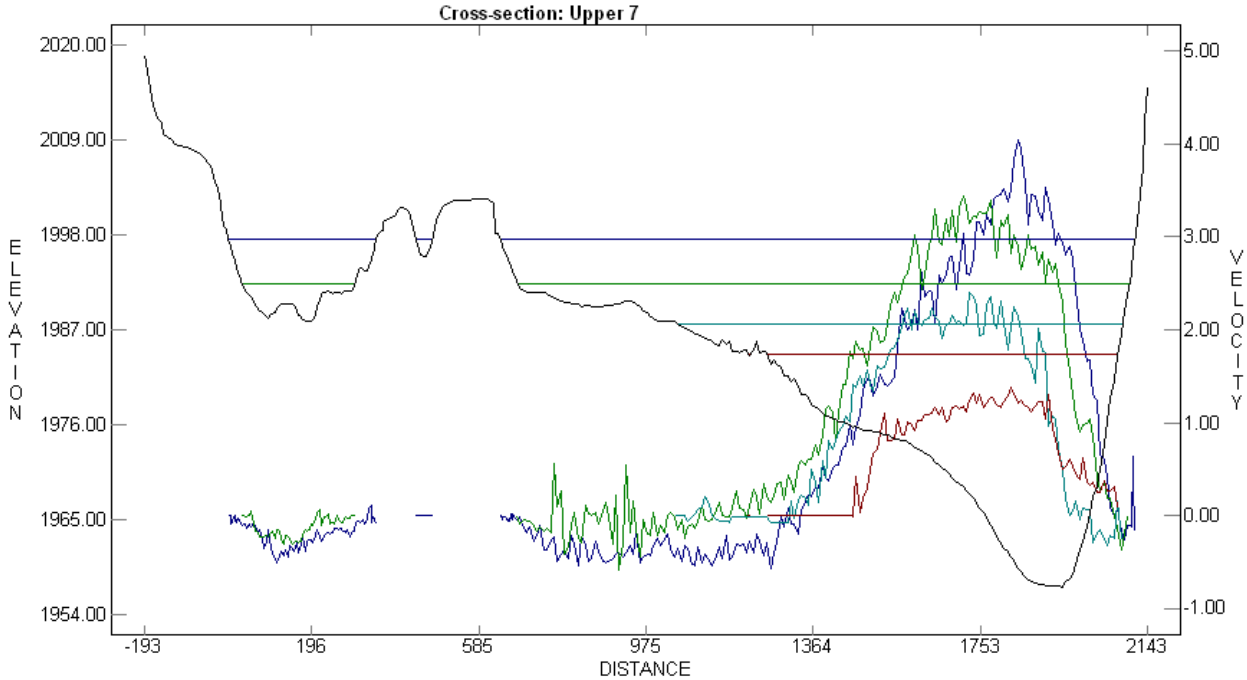


**Figure A-32.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-07.

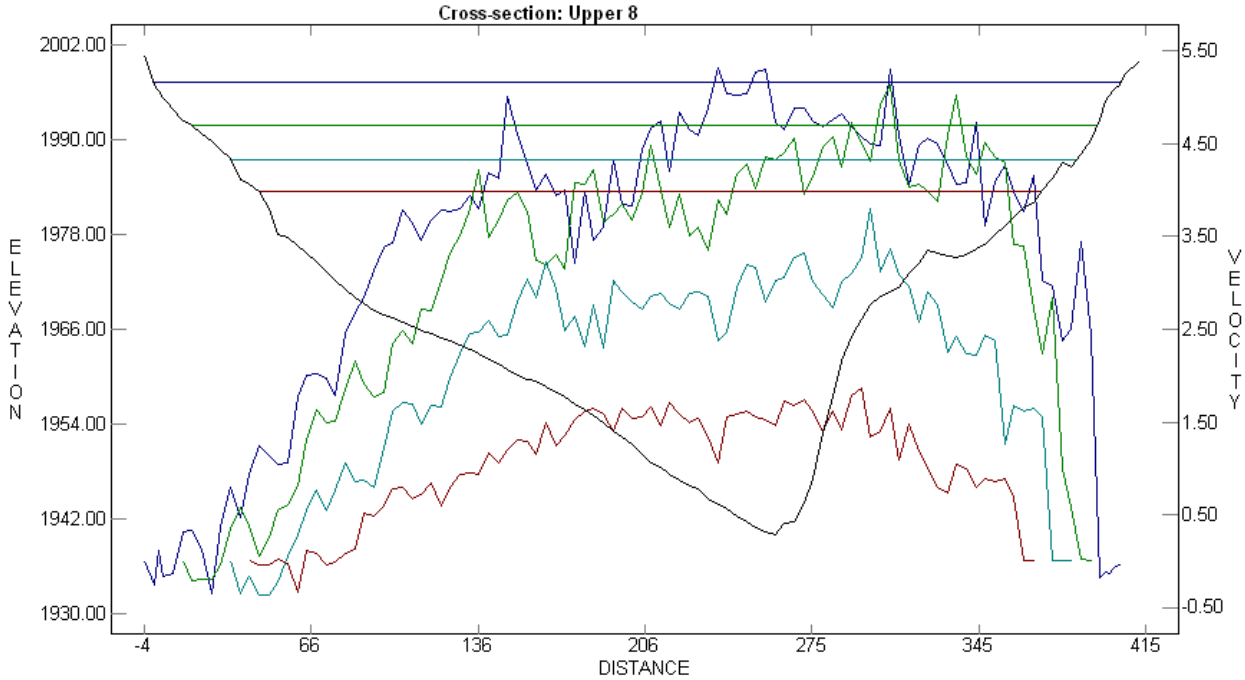


**Figure A-33.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-08.

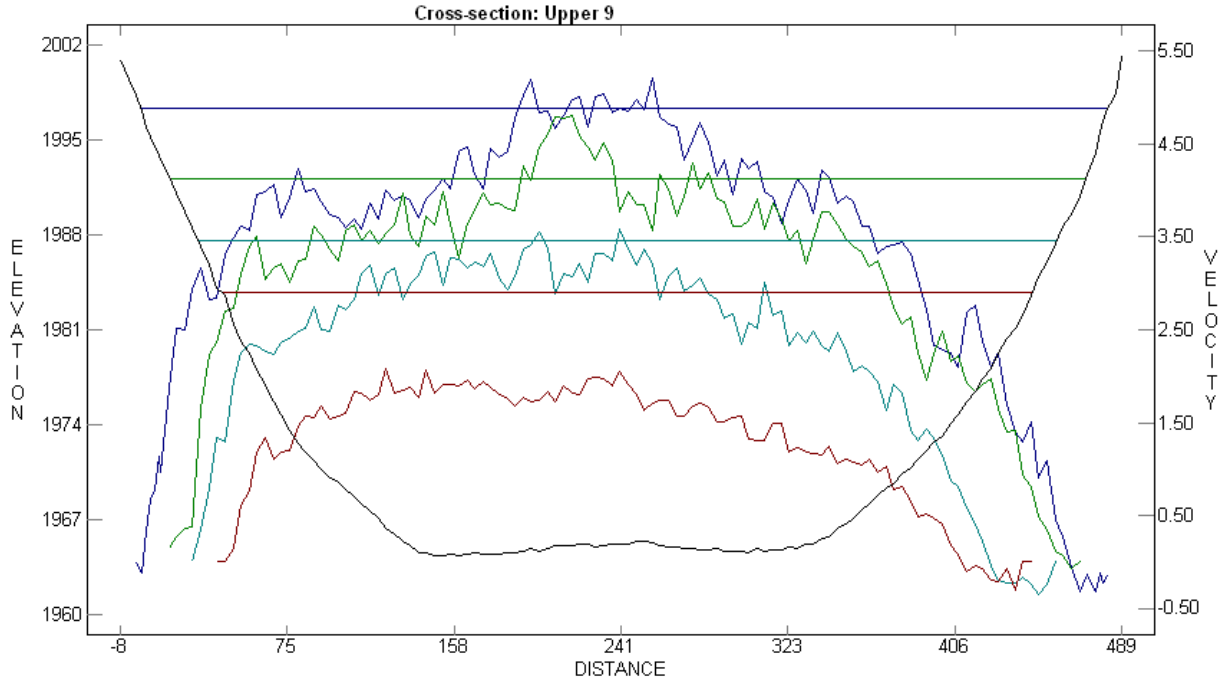


**Figure A-34.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-09.

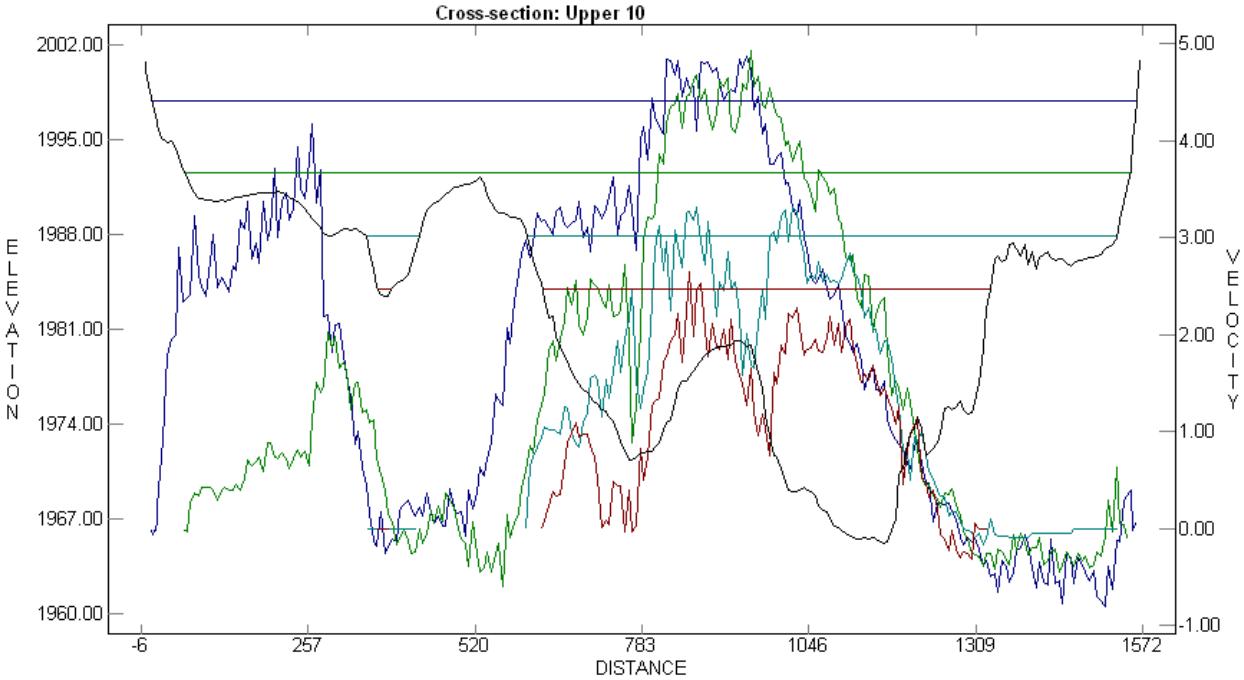


**Figure A-35.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-10.

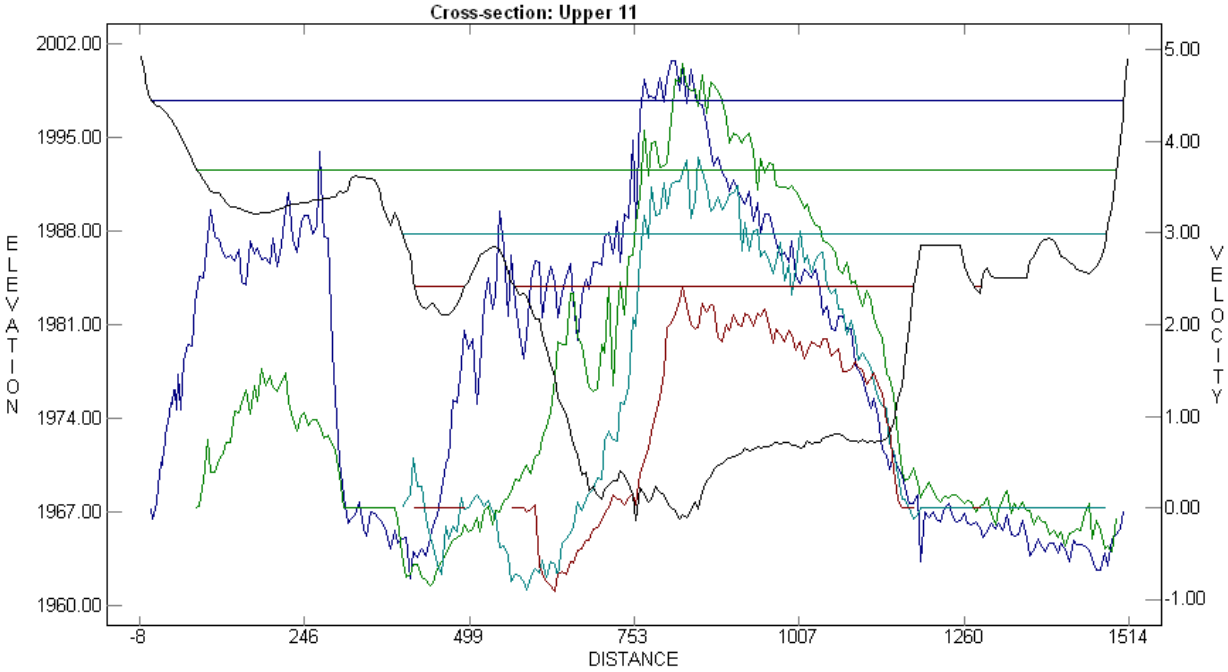


**Figure A-36.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-11.

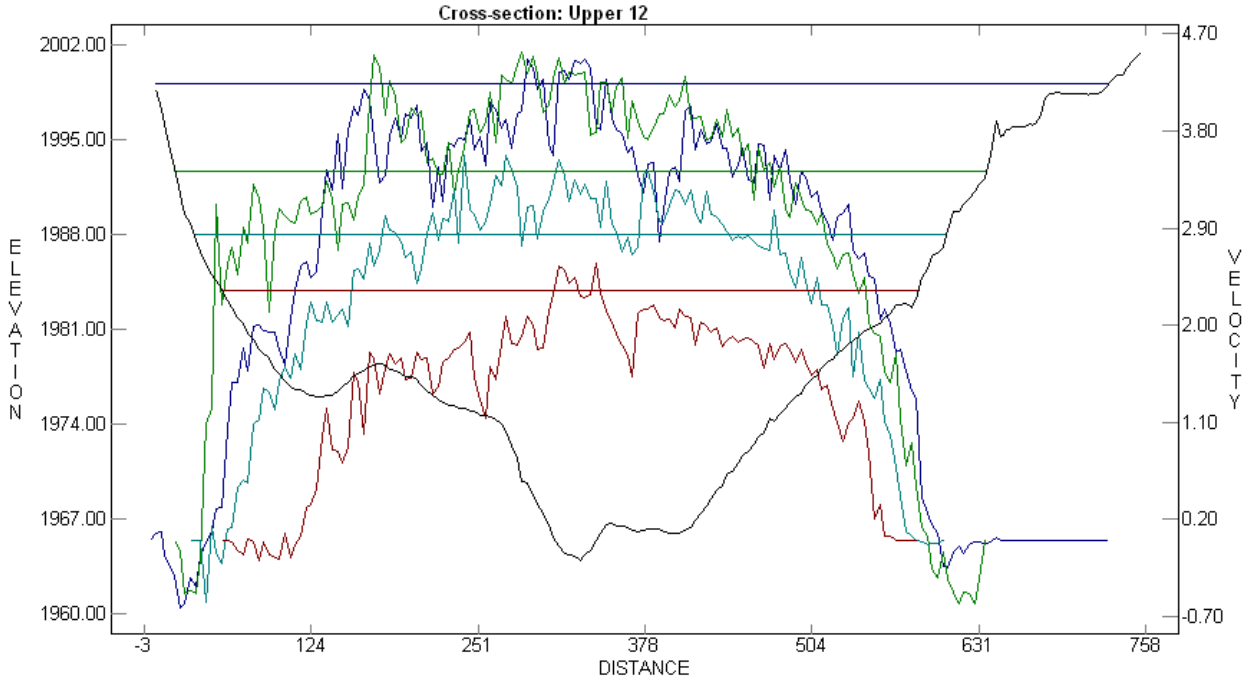


**Figure A-37.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-12.

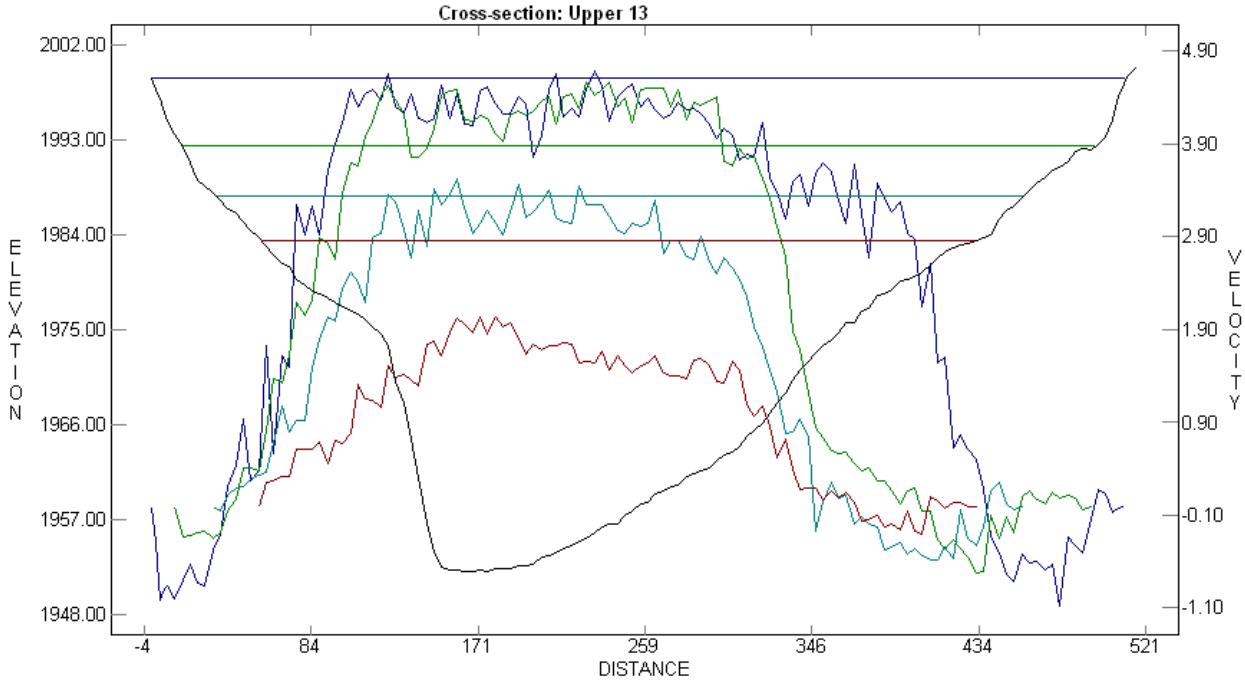


**Figure A-38.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-13.

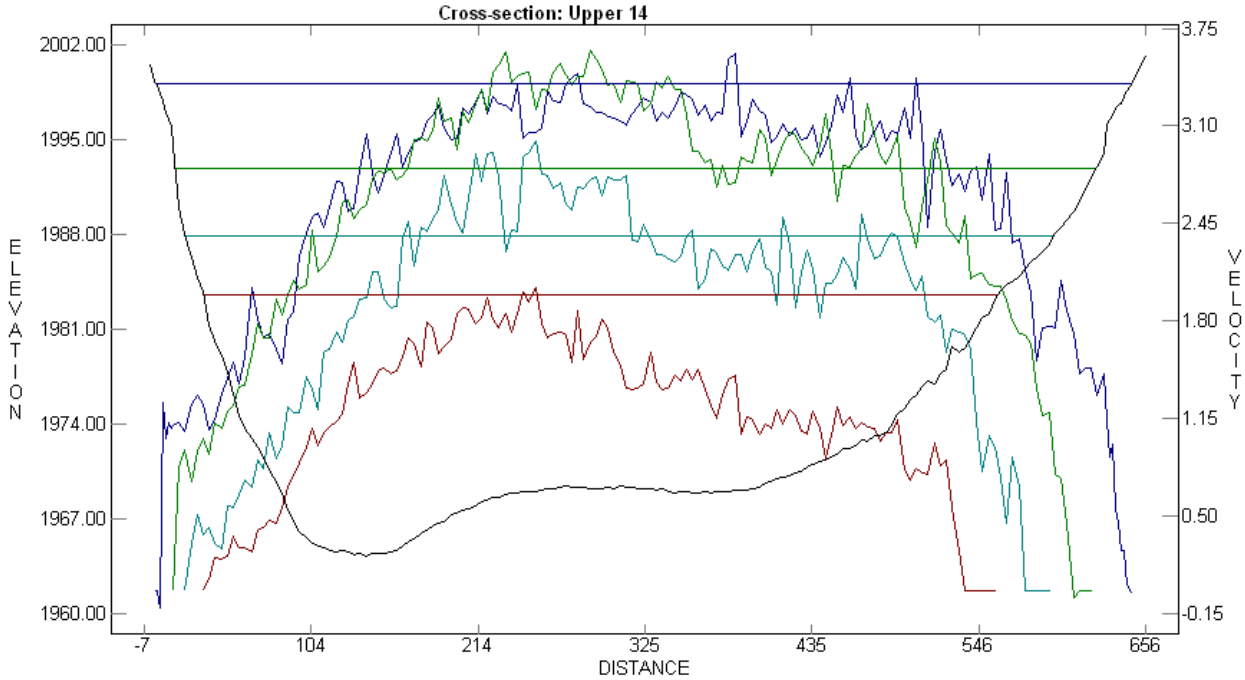


**Figure A-39.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-14.

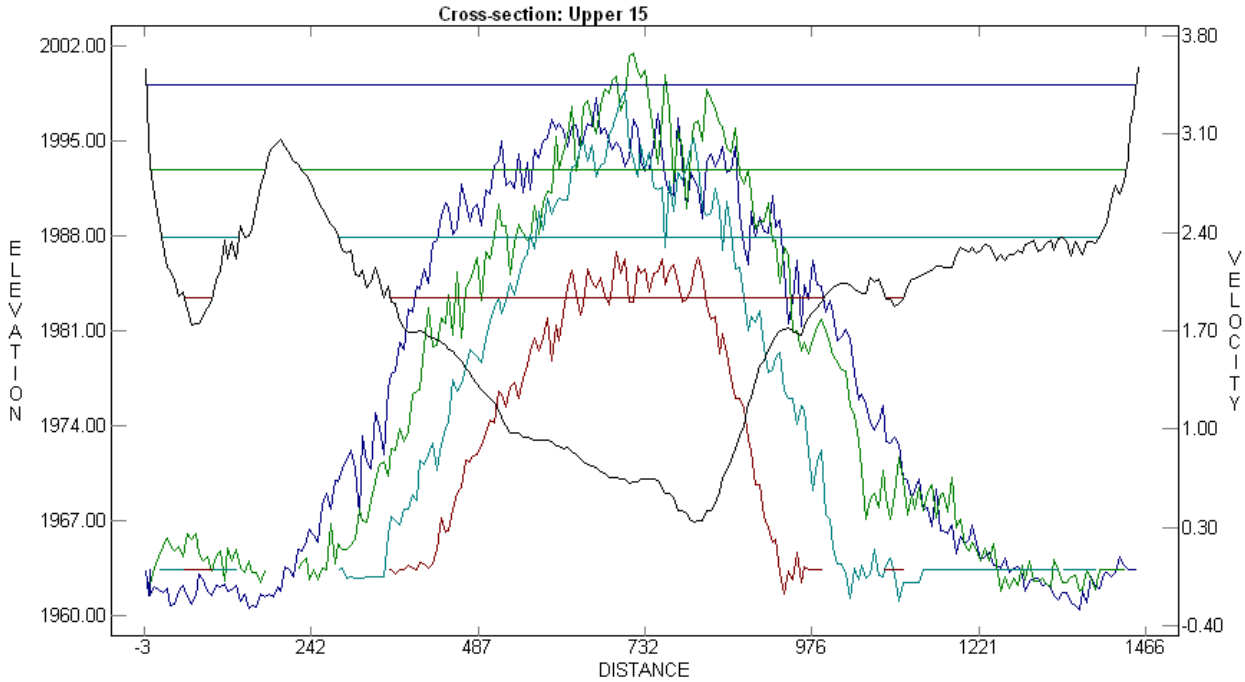


**Figure A-40.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-15.

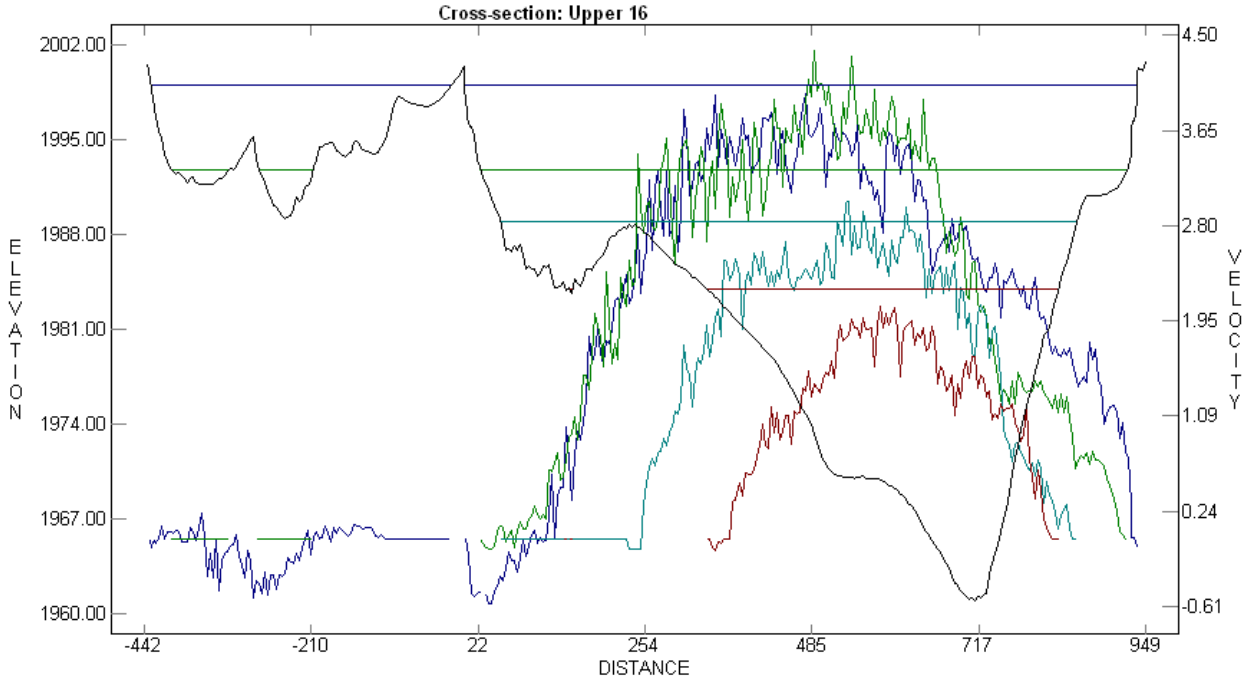


**Figure A-41.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-16.

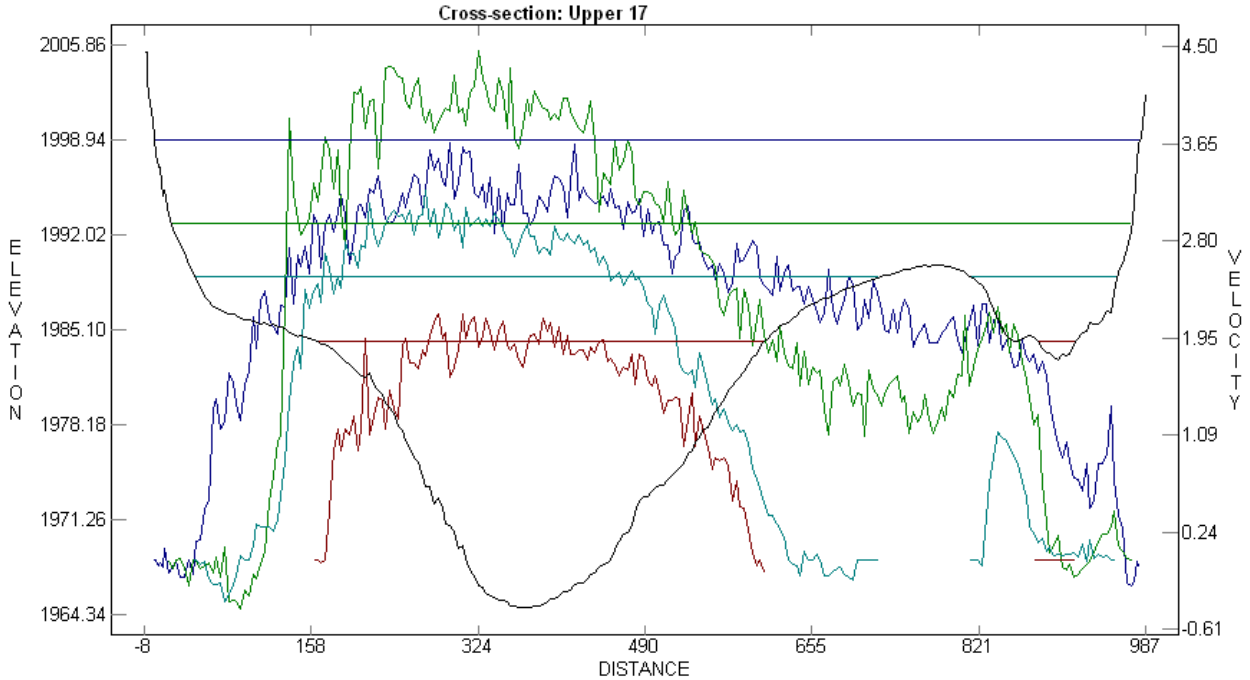


**Figure A-42.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-17.

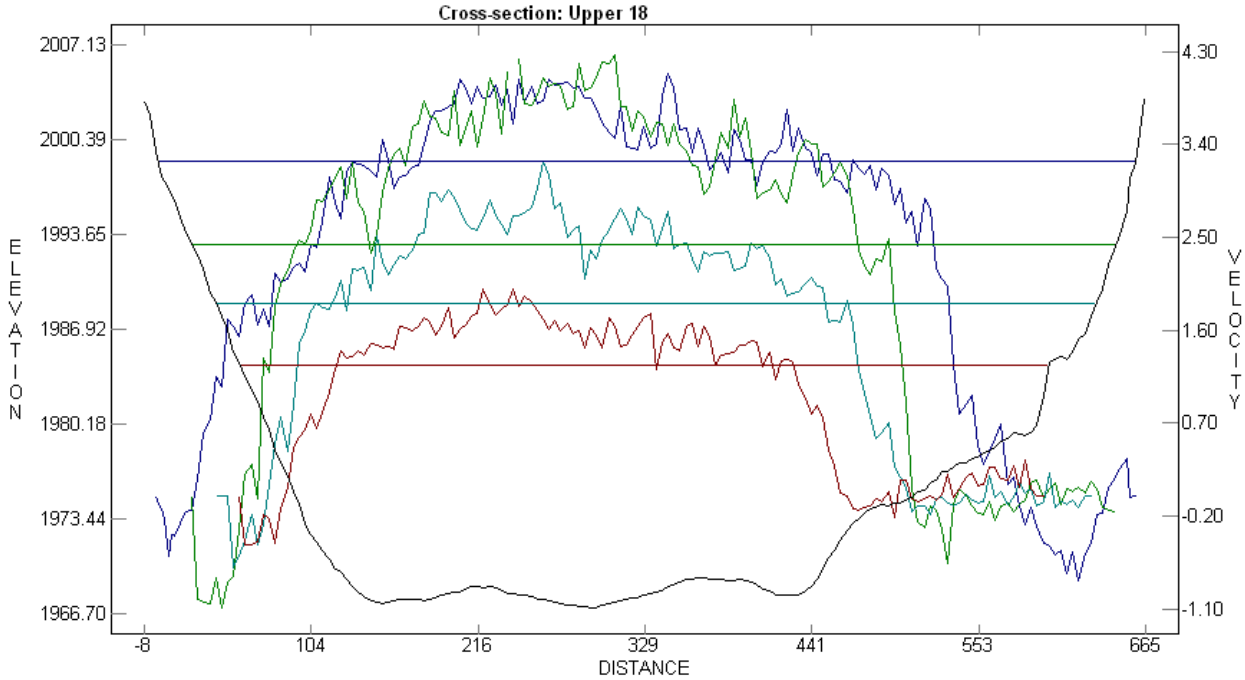


**Figure A-43.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-18.

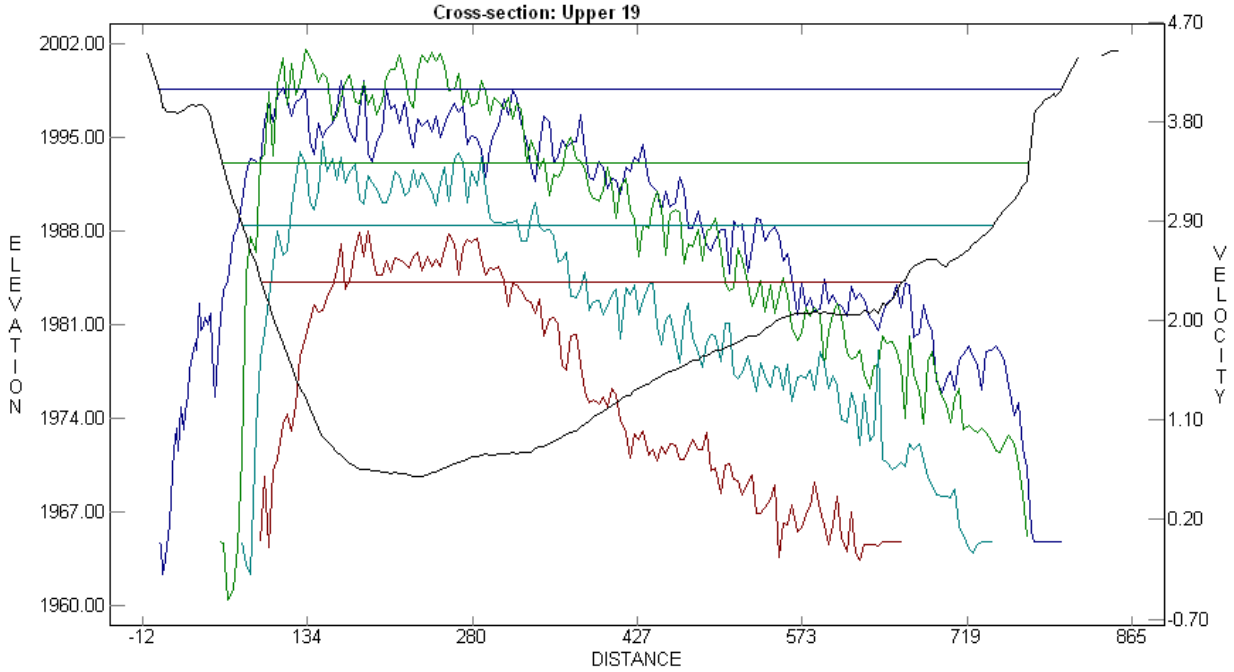


**Figure A-44.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-19.

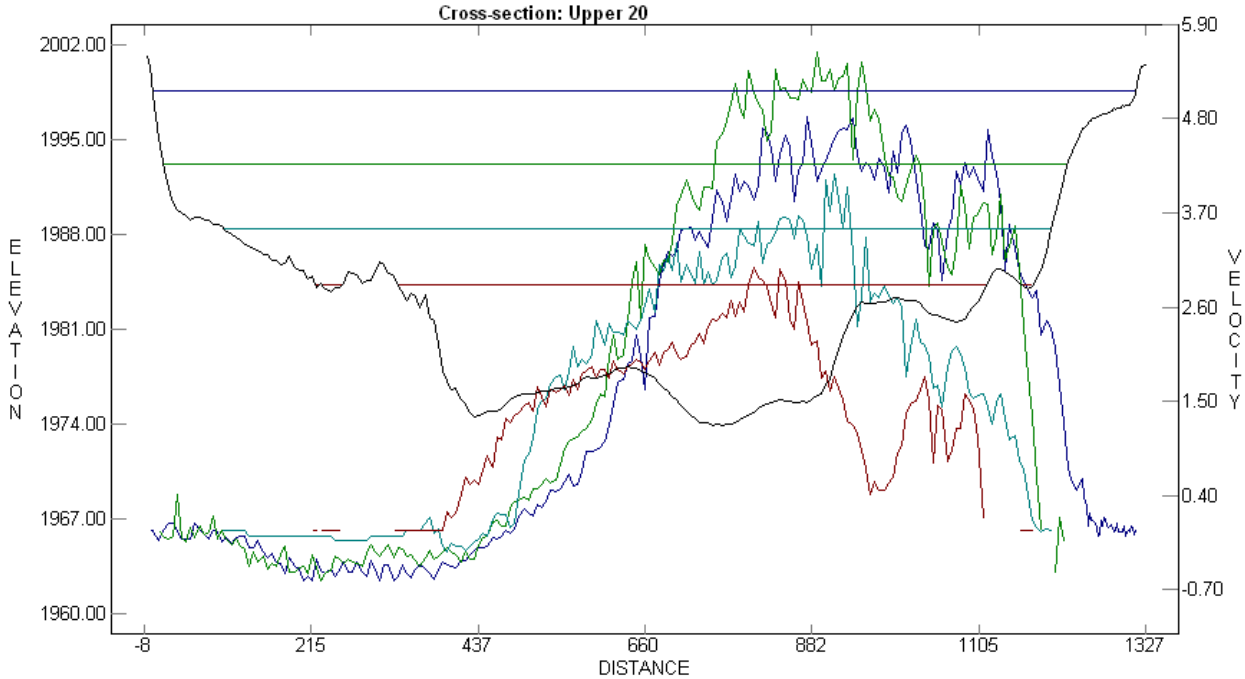


**Figure A-45.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-20.

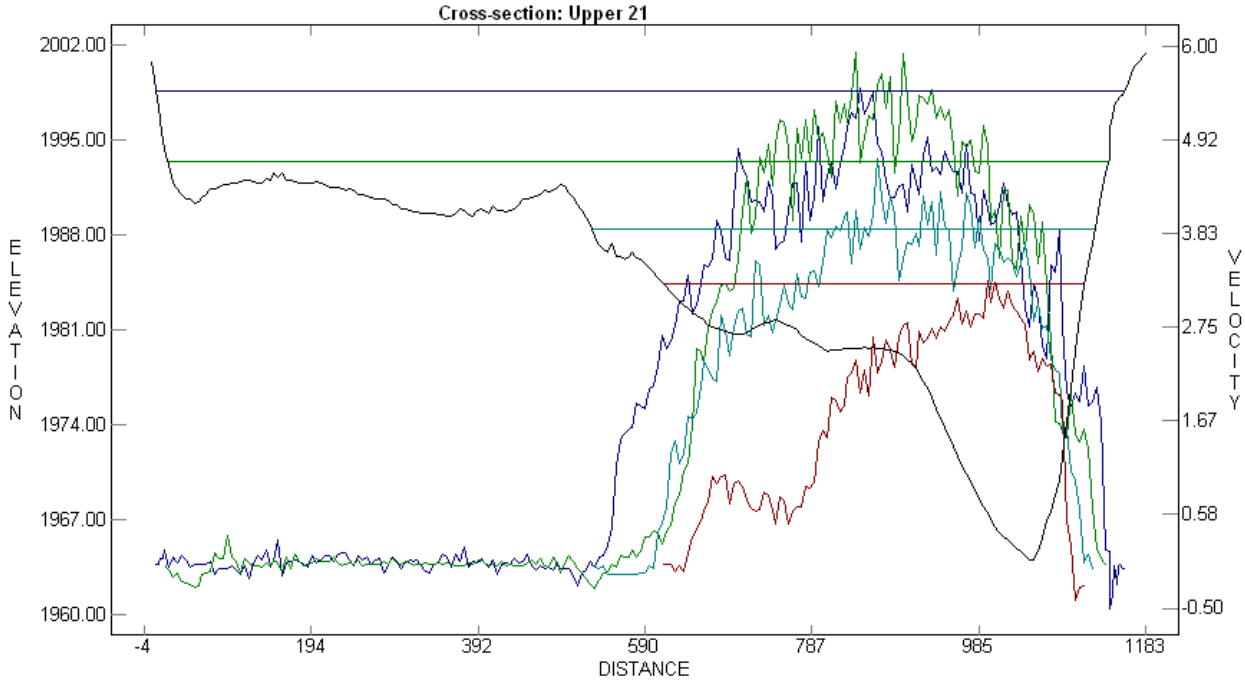


**Figure A-46.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-21.

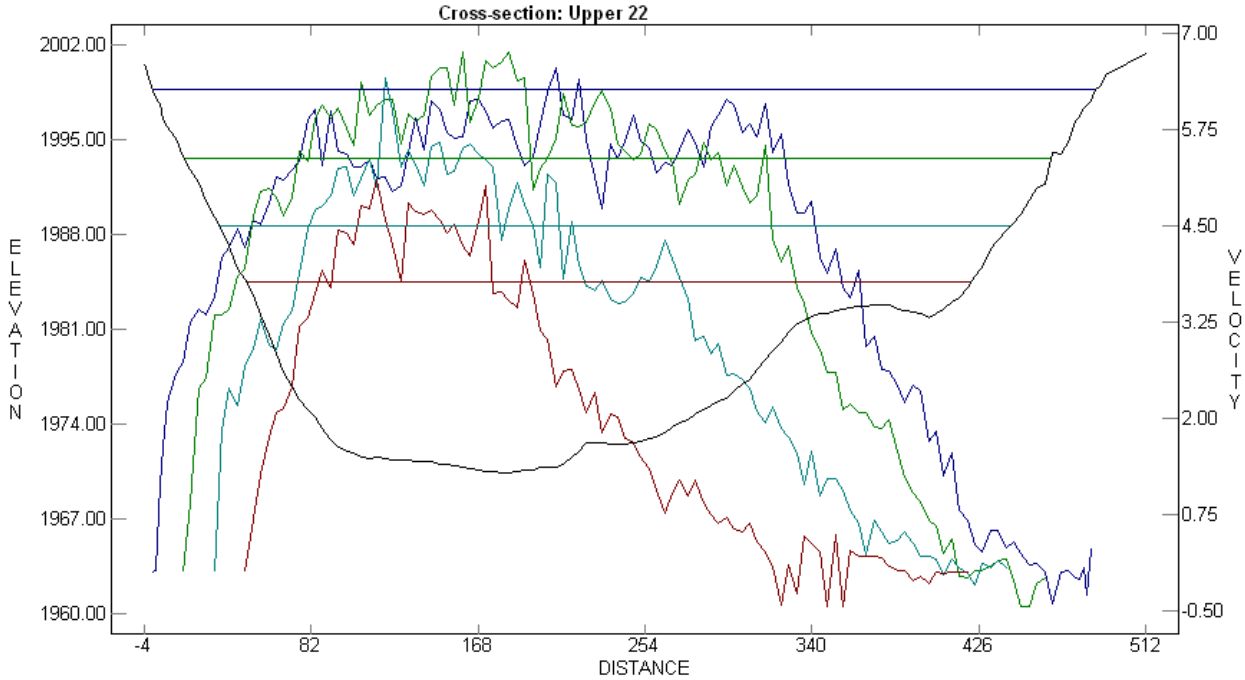


**Figure A-47.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-22.

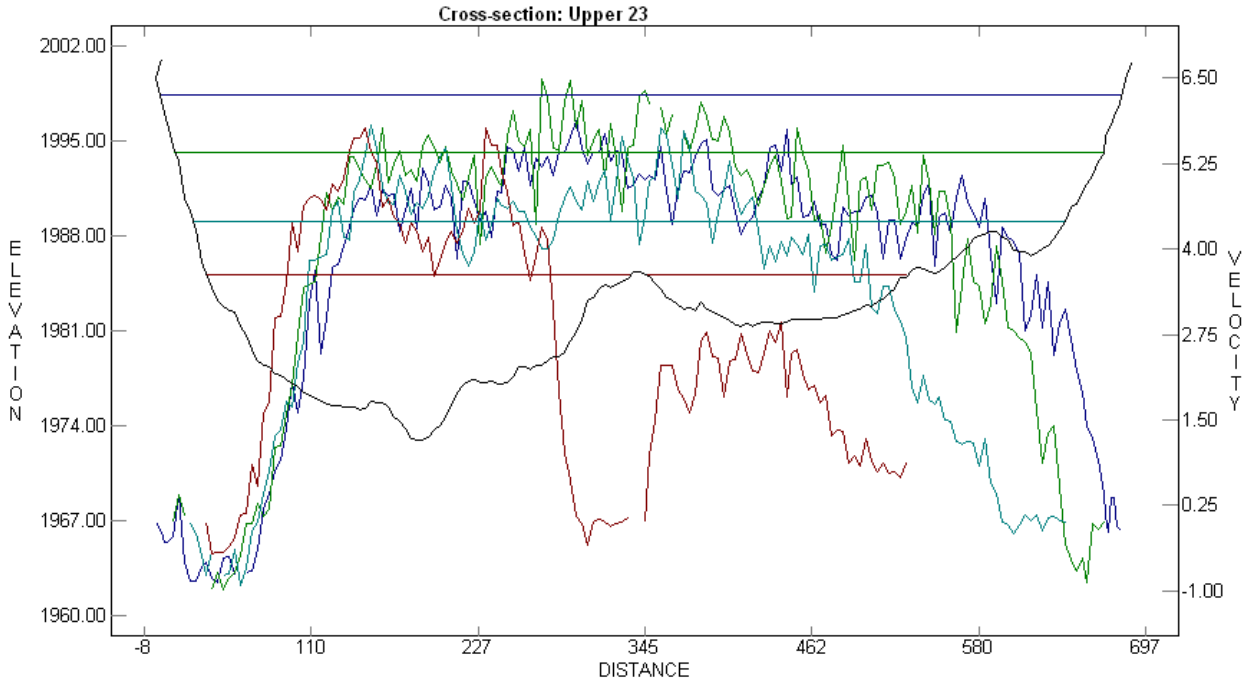


**Figure A-48.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-23.

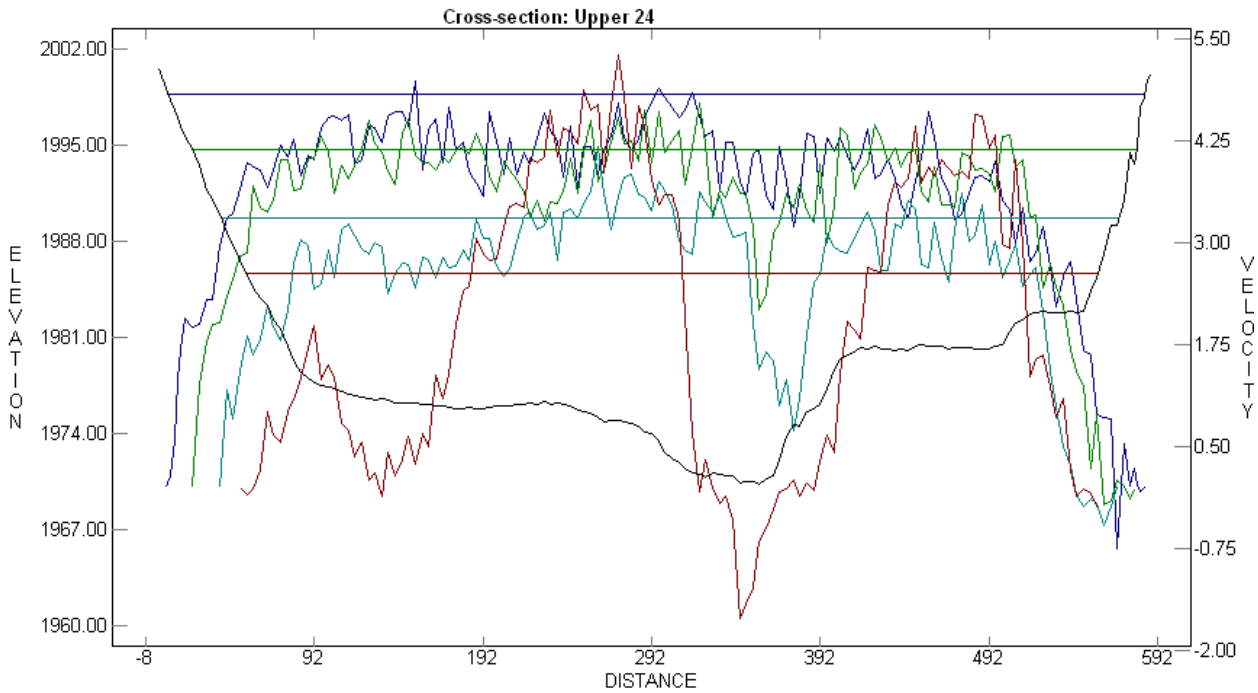


**Figure A-49.** Velocity profiles for Boundary Reservoir Upper Reservoir Reach, transect U-24.

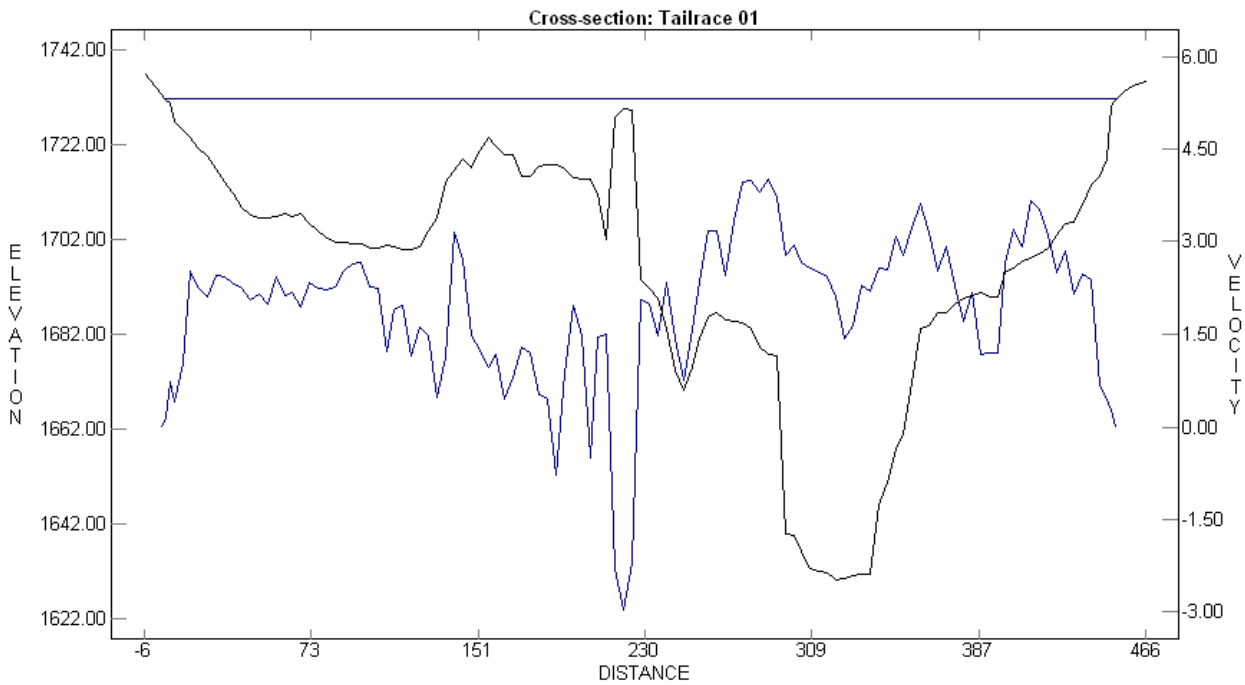


**Figure A-50.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-01.

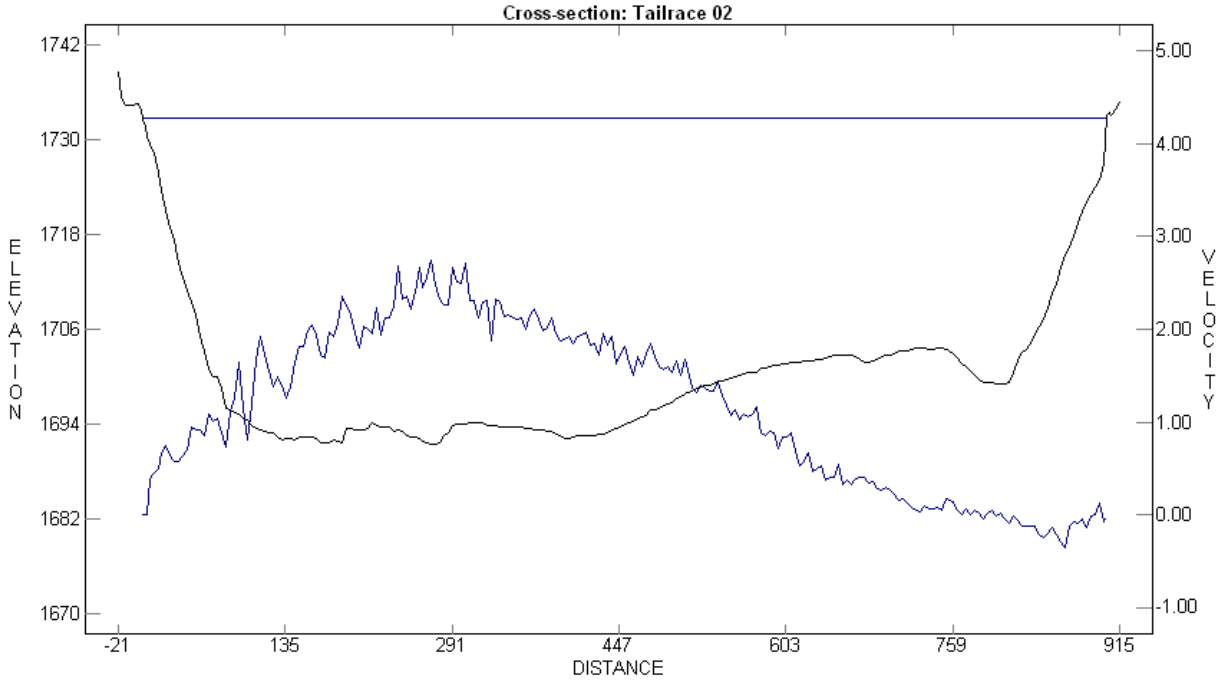


**Figure A-51.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-02.

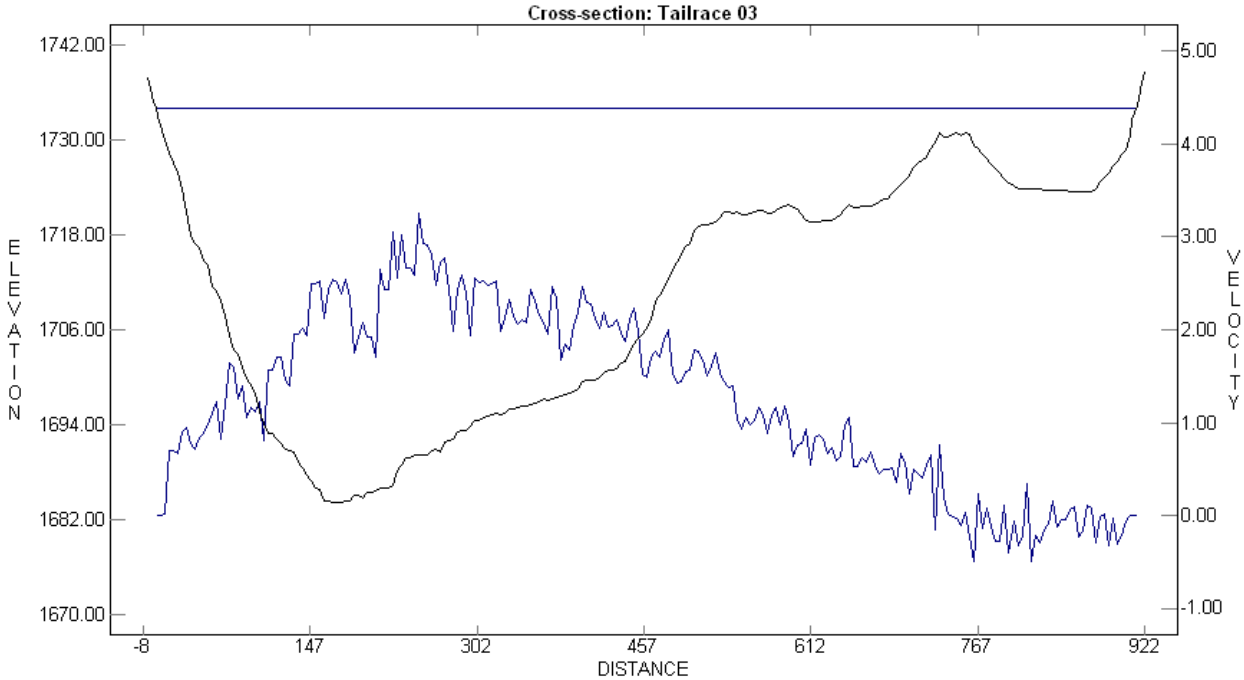


**Figure A-52.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-03.

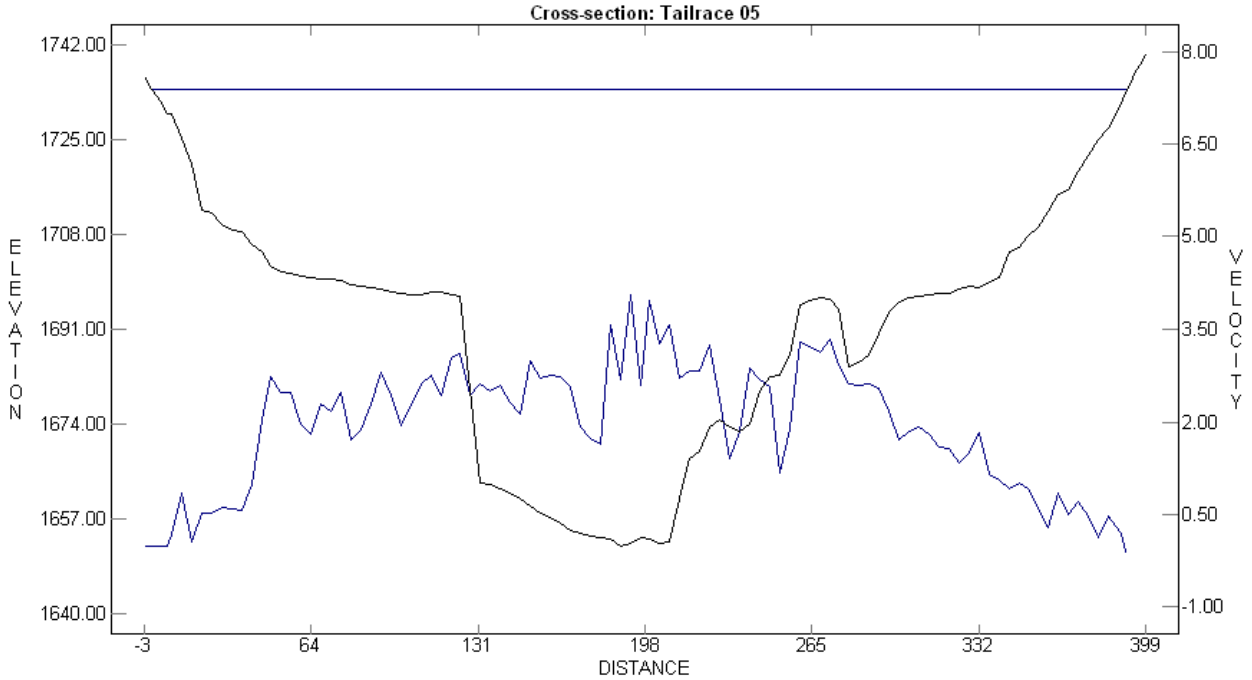


**Figure A-53.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-05.

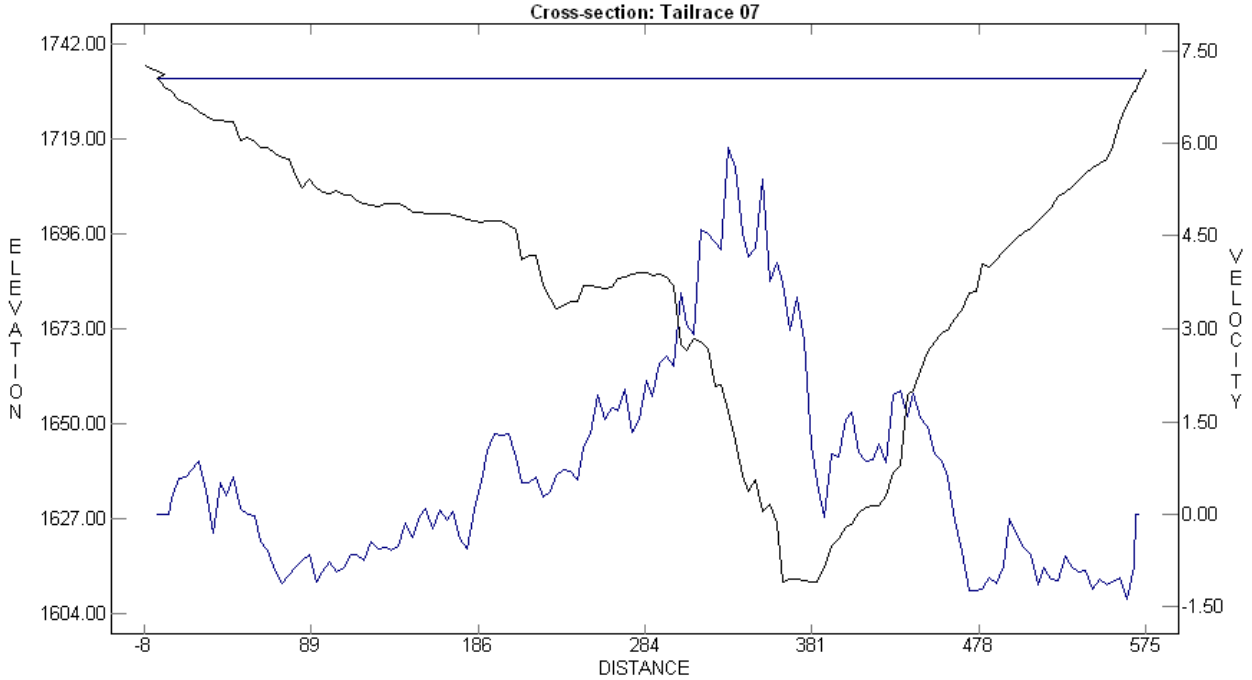


**Figure A-54.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-07.

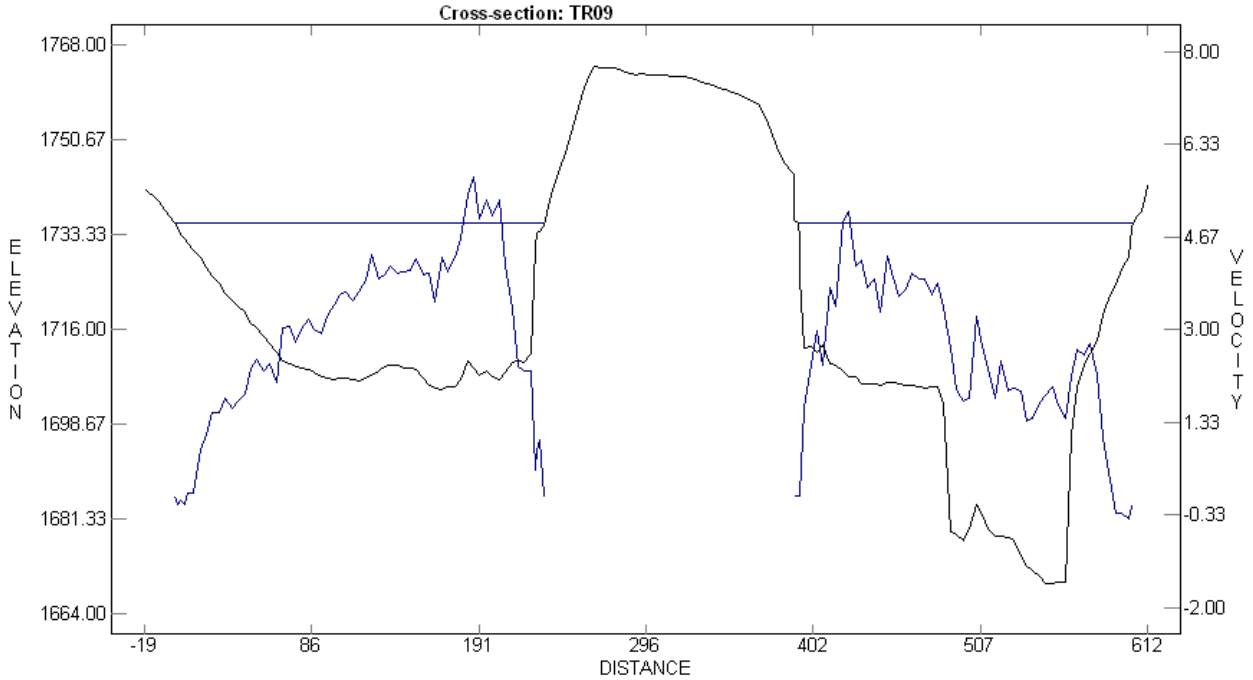


**Figure A-55.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-09.

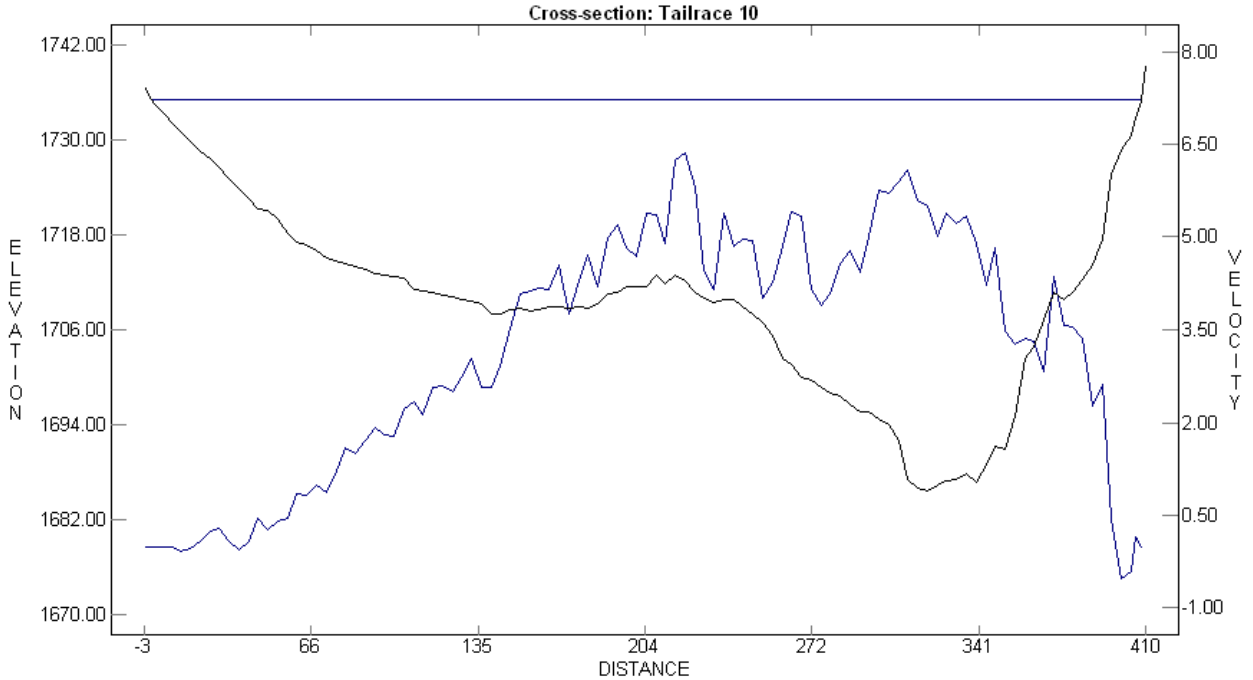


**Figure A-56.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-10.

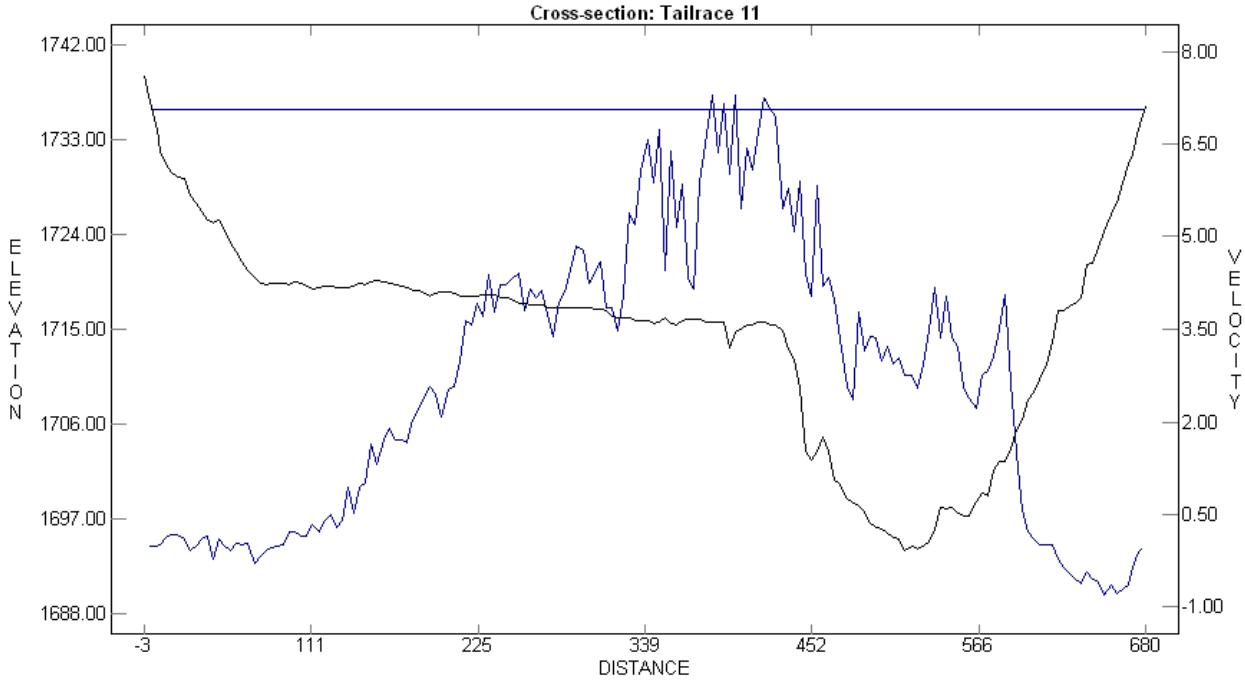


**Figure A-57.** Velocity profiles for Boundary Reservoir Canadian Tailrace Reach, transect TR-11.

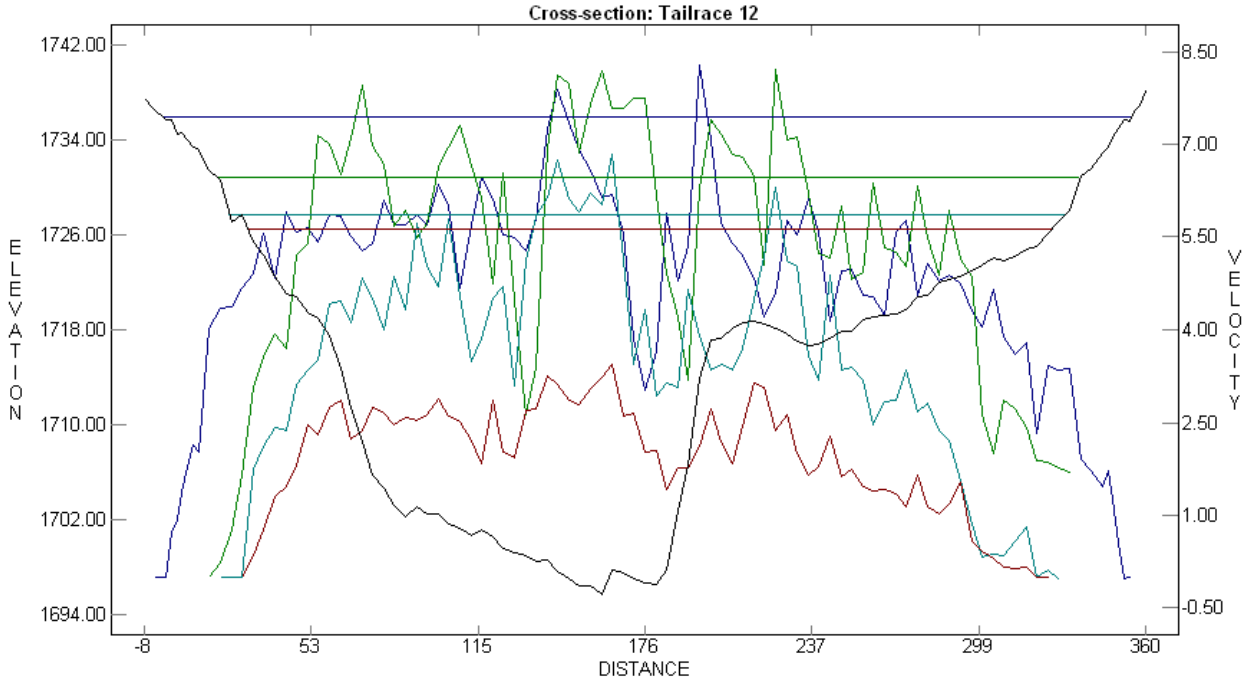


**Figure A-58.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-12.

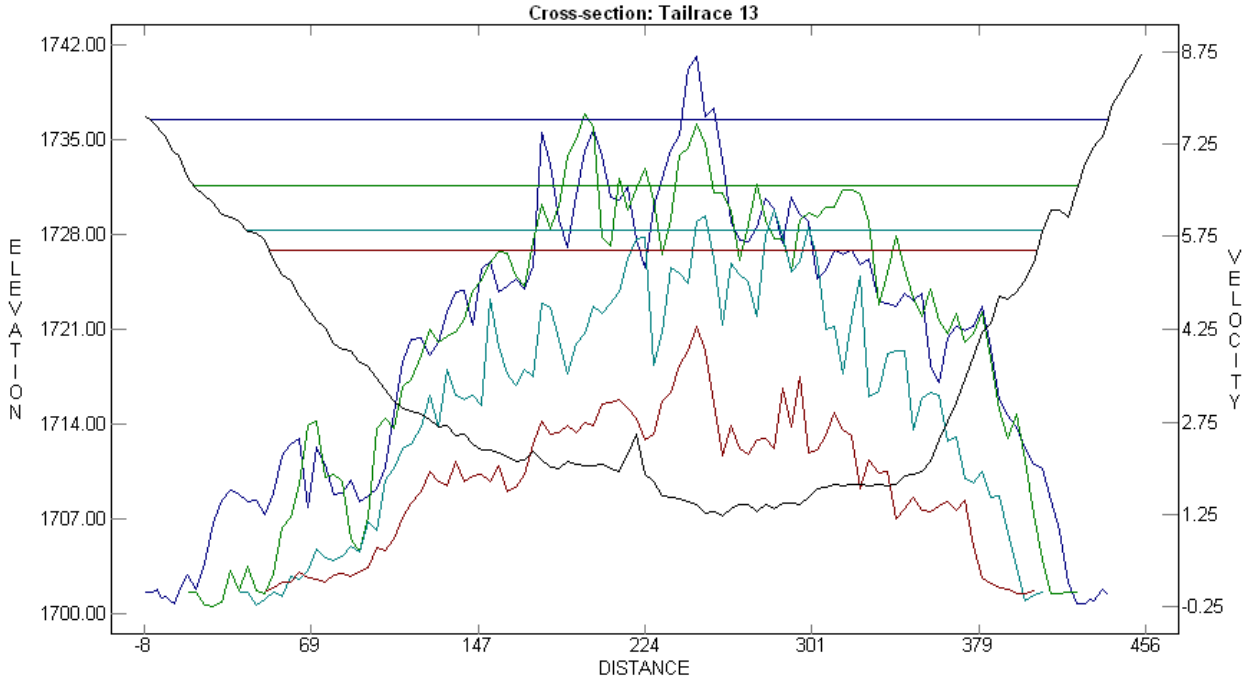


**Figure A-59.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-13.

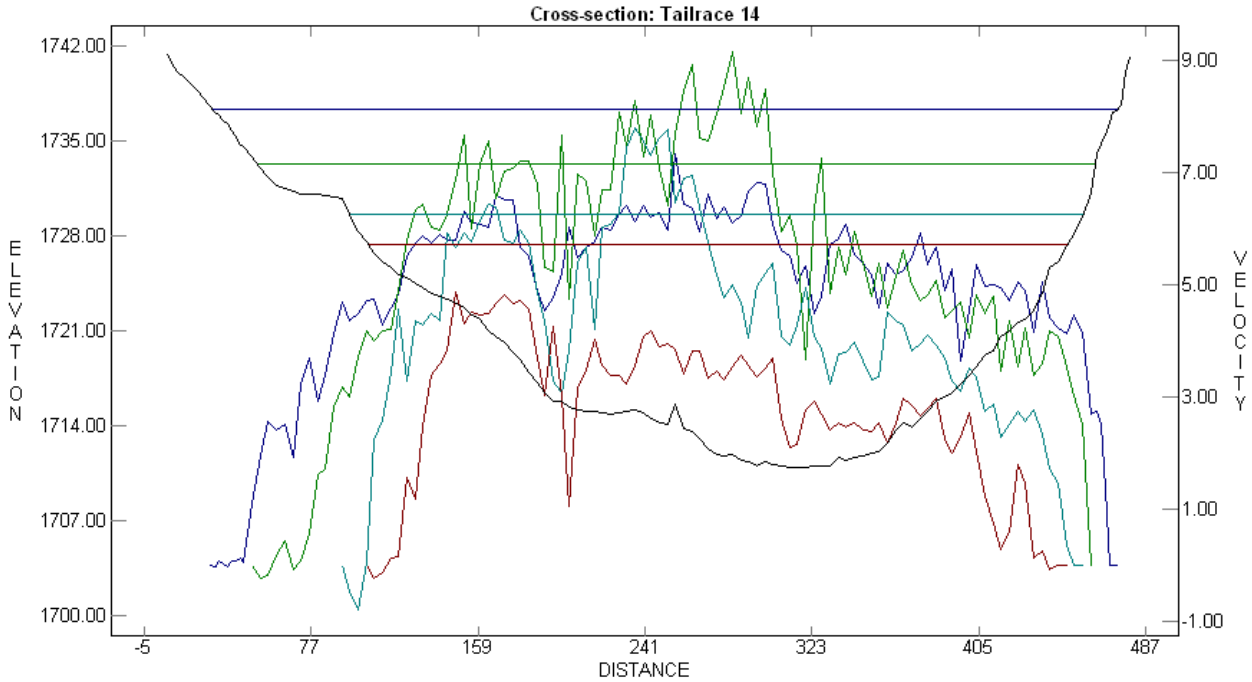


**Figure A-60.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-14.

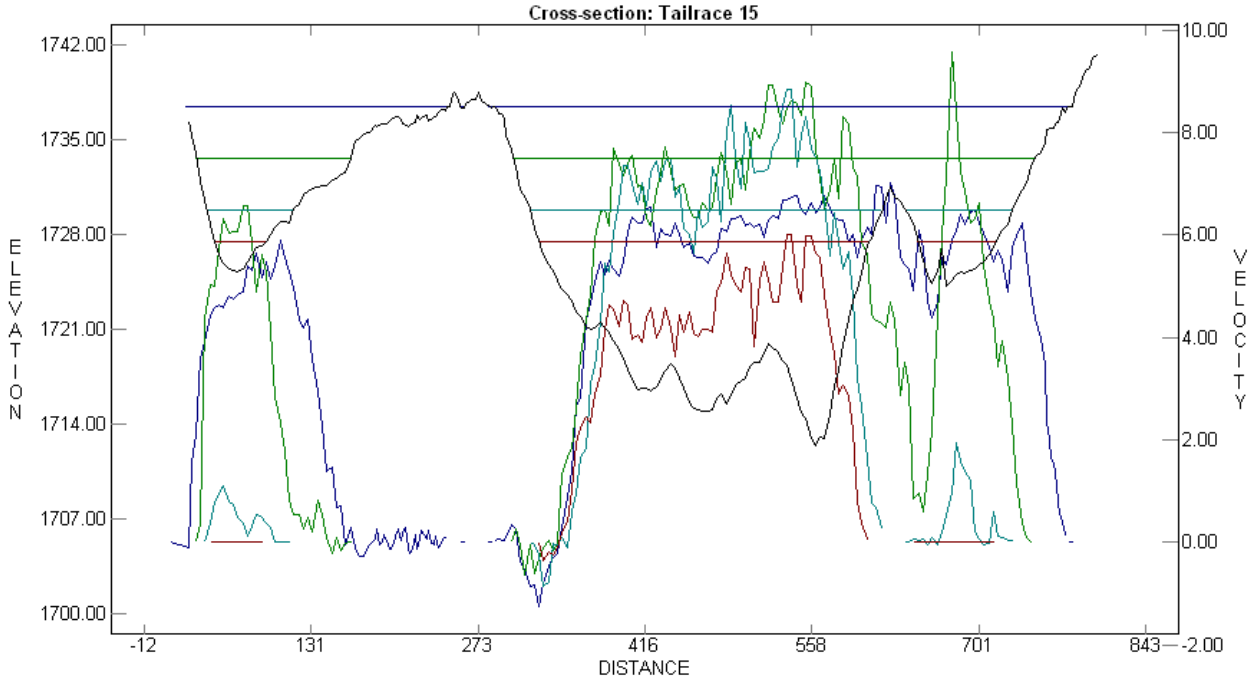


**Figure A-61.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-15.

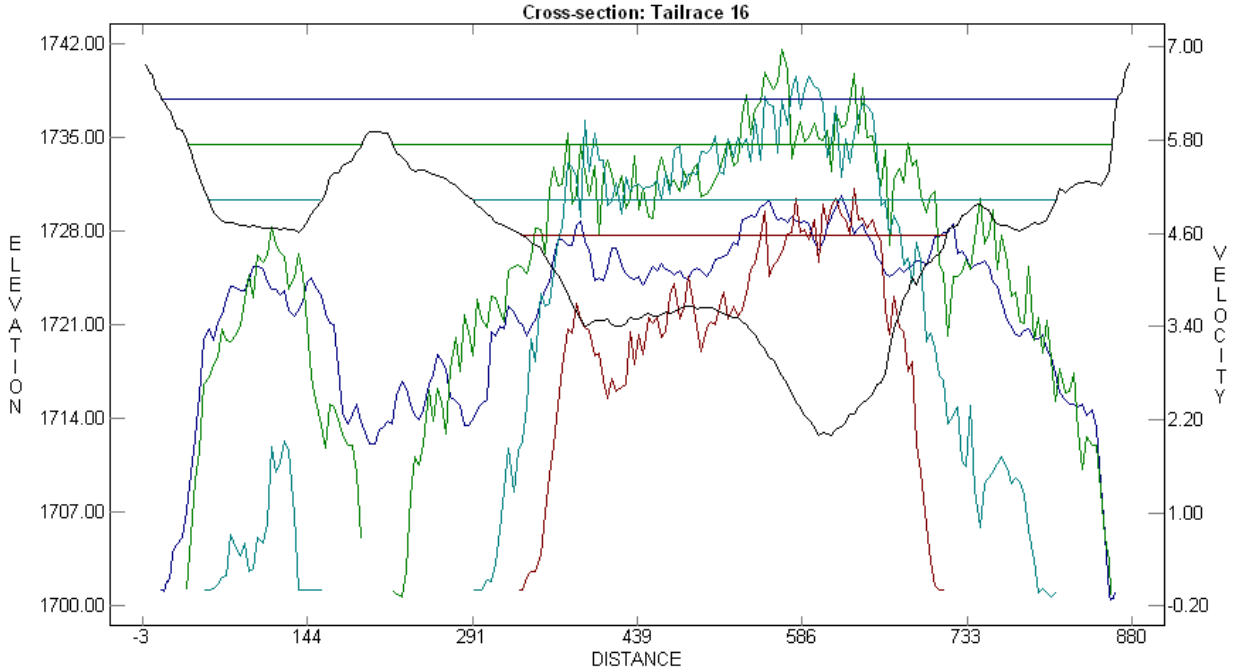


**Figure A-62.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-16.

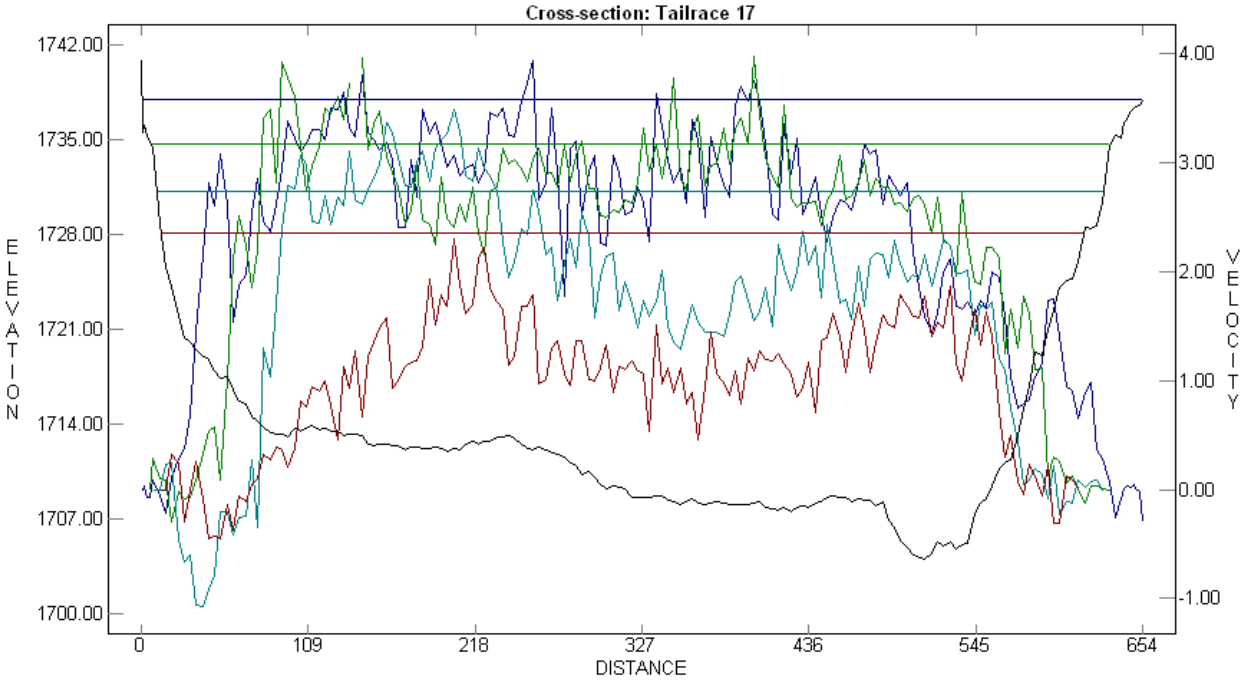


**Figure A-63.** Velocity profiles for Boundary Reservoir Tailrace Reach, transect TR-17.

# Attachment B: Velocity Adjustment Plots Showing Measured and Adjusted Velocities

This attachment contains the following figures:

Figure B-1. Velocity adjustments to Forebay Reach habitat transect F-01.
Figure B-2. Velocity adjustments to Forebay Reach habitat transect F-02.
Figure B-3. Velocity adjustments to Forebay Reach habitat transect F-03.
Figure B-4. Velocity adjustments to Forebay Reach habitat transect F-04.
Figure B-5. Velocity adjustments to Forebay Reach habitat transect F-05.
Figure B-6. Velocity adjustments to Canyon Reach habitat transect C-01.
Figure B-7. Velocity adjustments to Canyon Reach habitat transect C-02.
Figure B-8. Velocity adjustments to Canyon Reach habitat transect C-04.
Figure B-9. Velocity adjustments to Canyon Reach habitat transect C-05.
Figure B-10. Velocity adjustments to Canyon Reach habitat transect C-06.
Figure B-11. Velocity adjustments to Canyon Reach habitat transect C-07.
Figure B-12. Velocity adjustments to Canyon Reach habitat transect C-08.
Figure B-13. Velocity adjustments to Canyon Reach habitat transect C-09.
Figure B-14. Velocity adjustments to Canyon Reach habitat transect C-11.
Figure B-15. Velocity adjustments to Canyon Reach habitat transect C-12.
Figure B-16. Velocity adjustments to Canyon Reach habitat transect C-14.
Figure B-17. Velocity adjustments to Canyon Reach habitat transect C-15.
Figure B-18. Velocity adjustments to Canyon Reach habitat transect C-16.
Figure B-19. Velocity adjustments to Canyon Reach habitat transect C-17.
Figure B-20. Velocity adjustments to Canyon Reach habitat transect C-19.
Figure B-21. Velocity adjustments to Canyon Reach habitat transect C-20.
Figure B-22. Velocity adjustments to Canyon Reach habitat transect C-21.
Figure B-23. Velocity adjustments to Canyon Reach habitat transect C-22.
Figure B-24. Velocity adjustments to Canyon Reach habitat transect C-23.
Figure B-25. Velocity adjustments to Canyon Reach habitat transect C-24.
Figure B-26. Velocity adjustments to Tailrace Reach habitat transect T-01.
Figure B-27. Velocity adjustments to Tailrace Reach habitat transect T-05.
Figure B-28. Velocity adjustments to Tailrace Reach habitat transect T-07.
Figure B-29. Velocity adjustments to Tailrace Reach habitat transect T-09.

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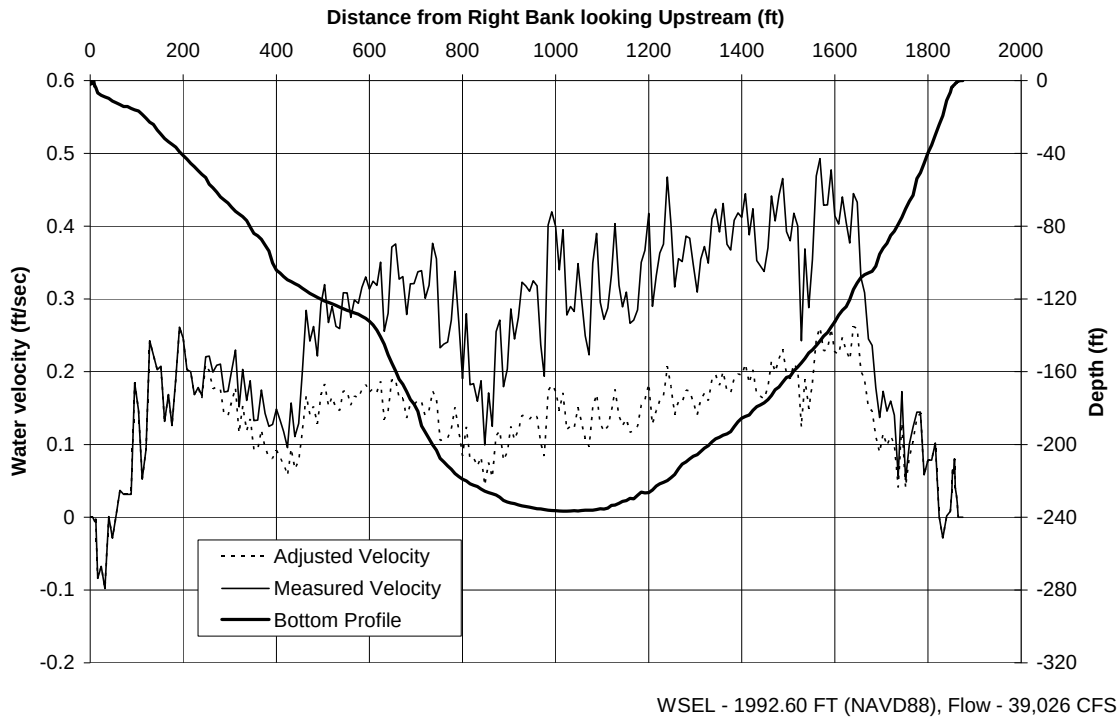


**Figure B-1.** Velocity adjustments to Forebay Reach habitat transect F-01.

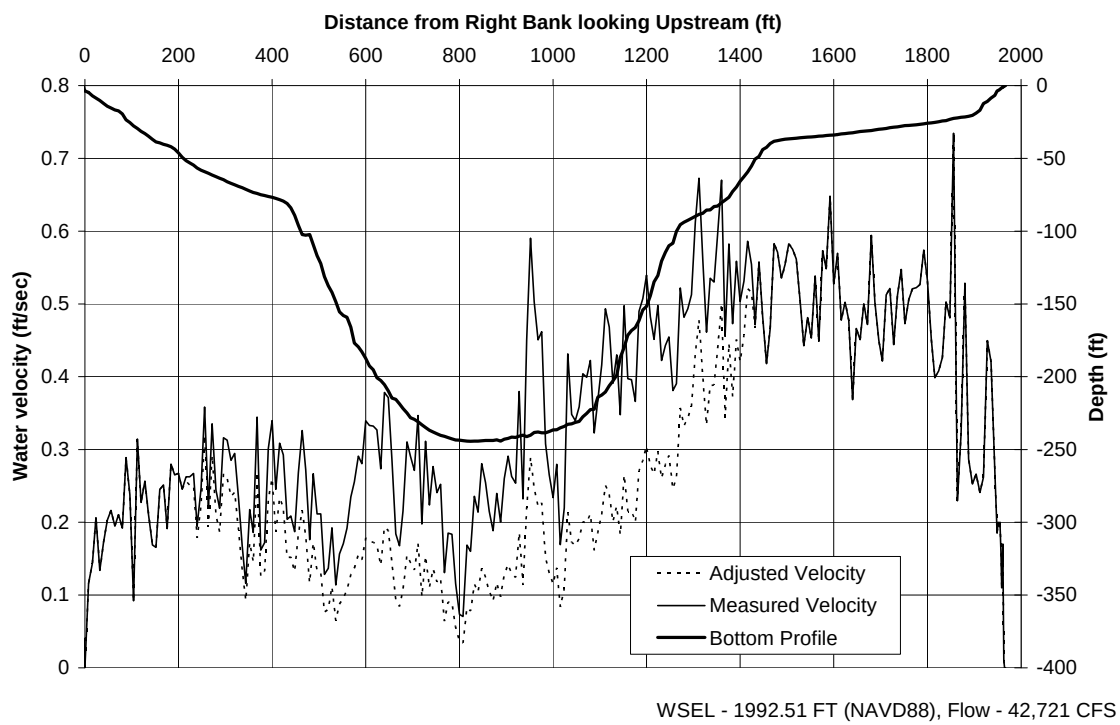


**Figure B-2.** Velocity adjustments to Forebay Reach habitat transect F-02.

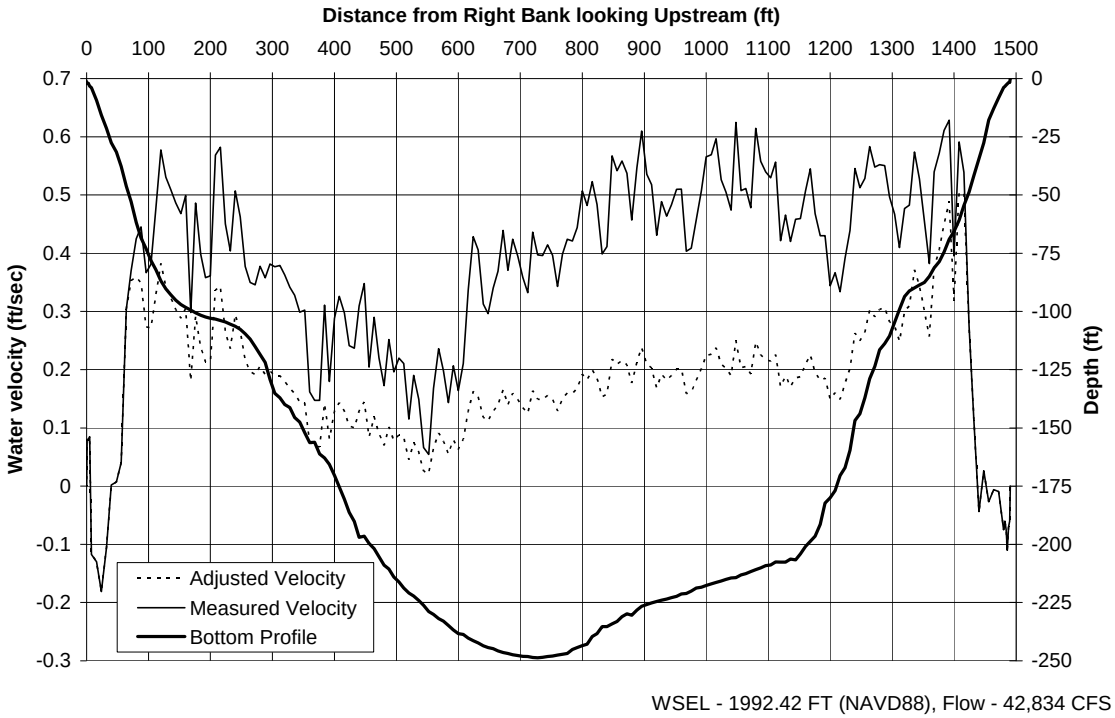


**Figure B-3.** Velocity adjustments to Forebay Reach habitat transect F-03.

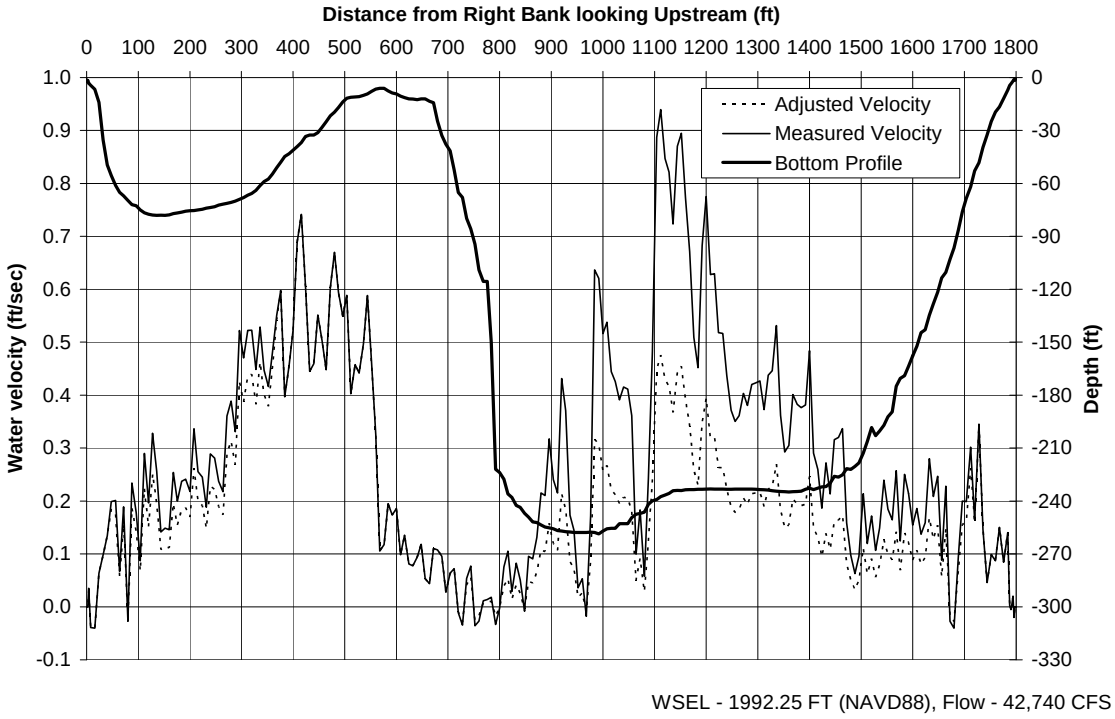


**Figure B-4.** Velocity adjustments to Forebay Reach habitat transect F-04.

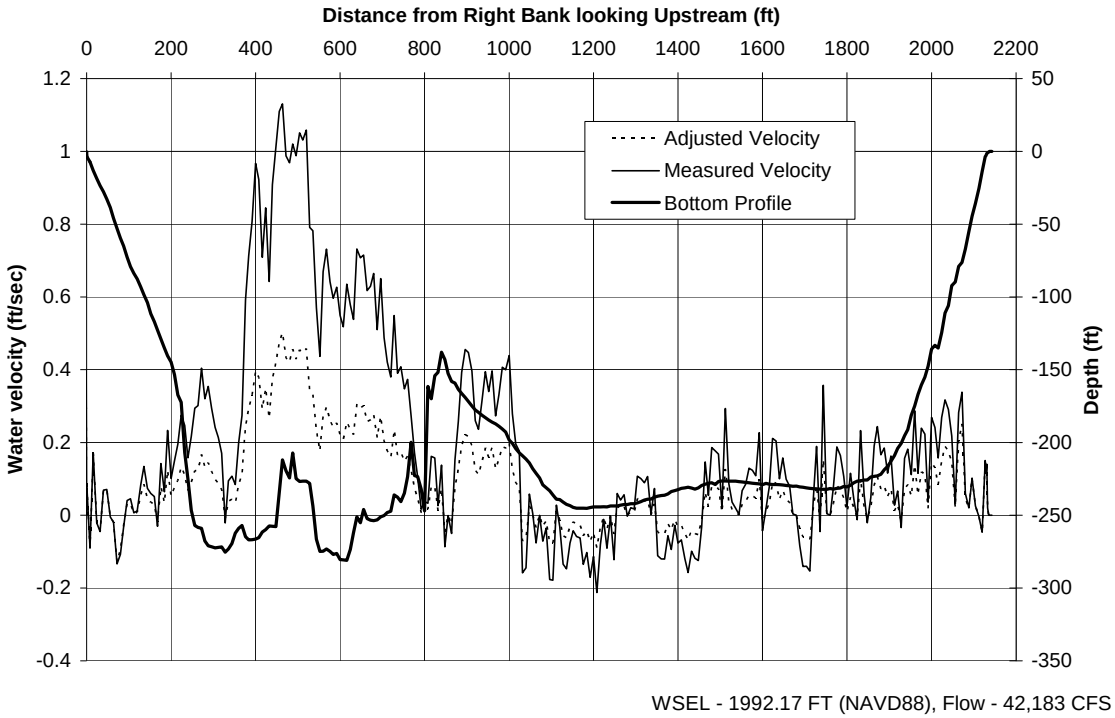


**Figure B-5.** Velocity adjustments to Forebay Reach habitat transect F-05.

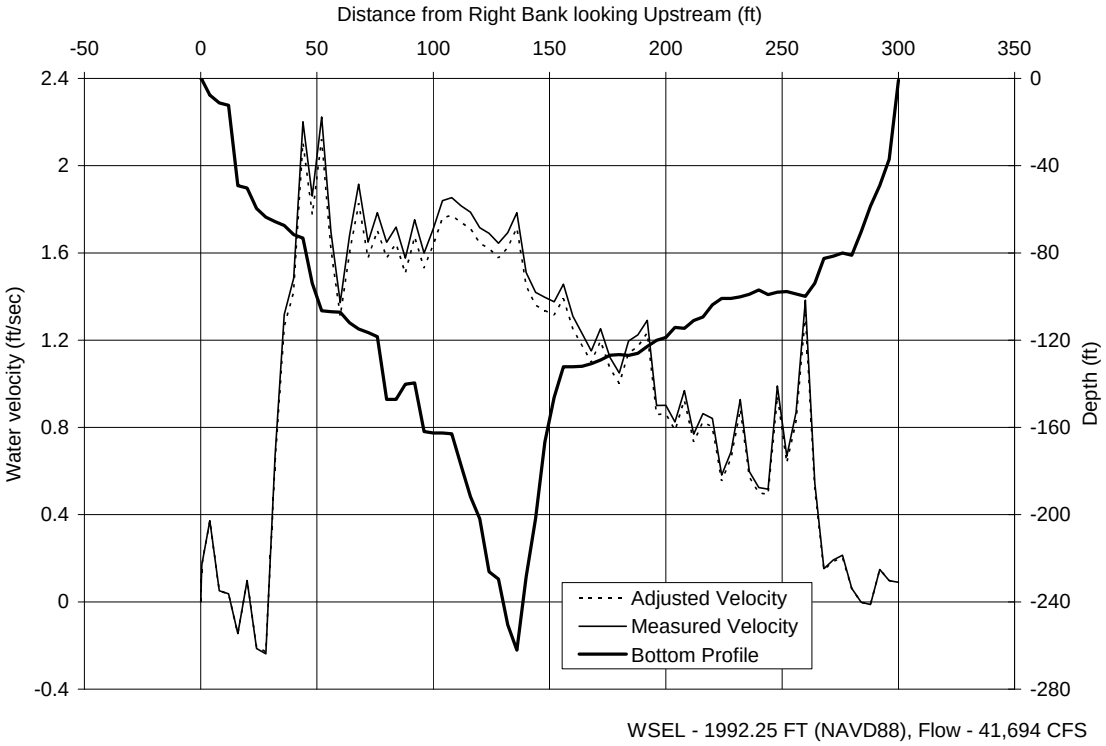


**Figure B-6.** Velocity adjustments to Canyon Reach habitat transect C-01.

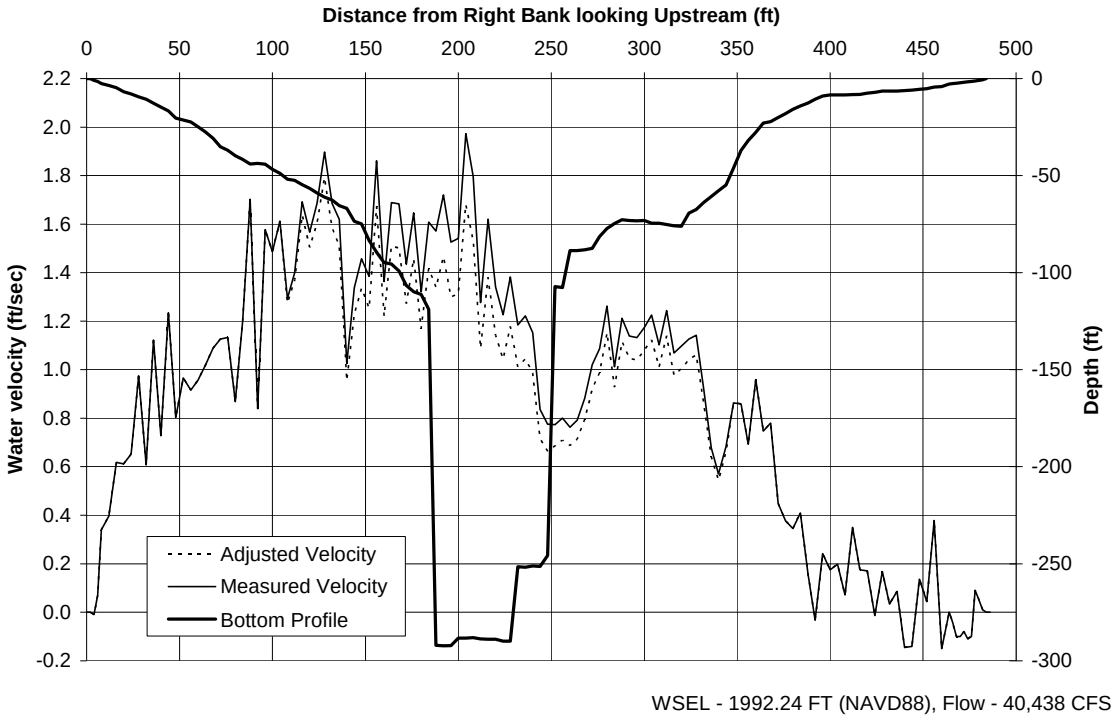


**Figure B-7.** Velocity adjustments to Canyon Reach habitat transect C-02.

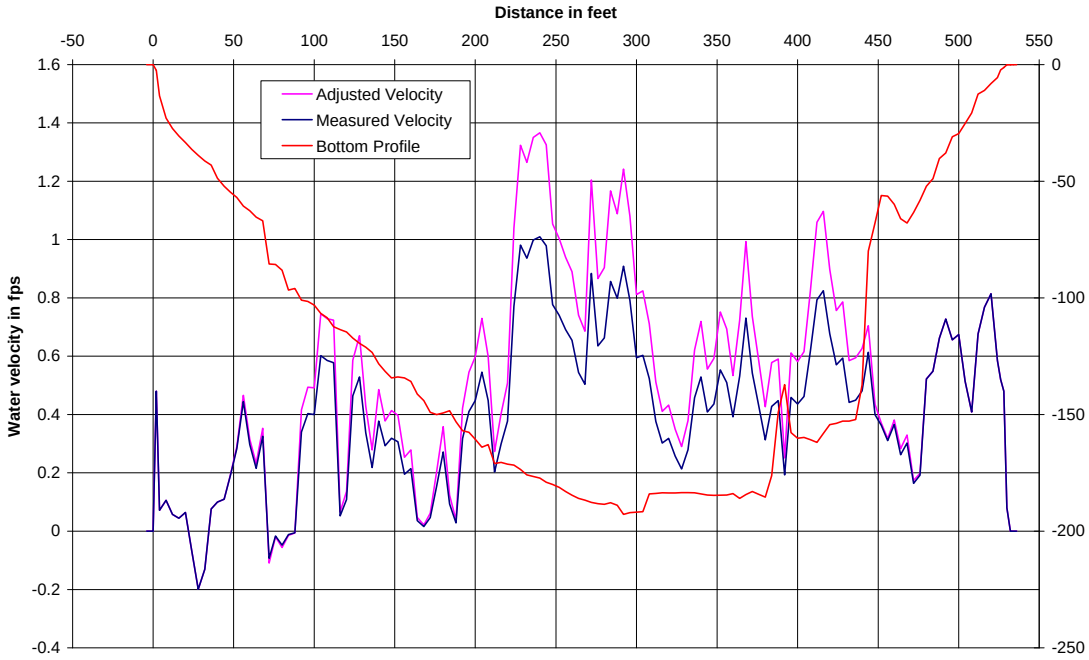


**Figure B-8.** Velocity adjustments to Canyon Reach habitat transect C-04.

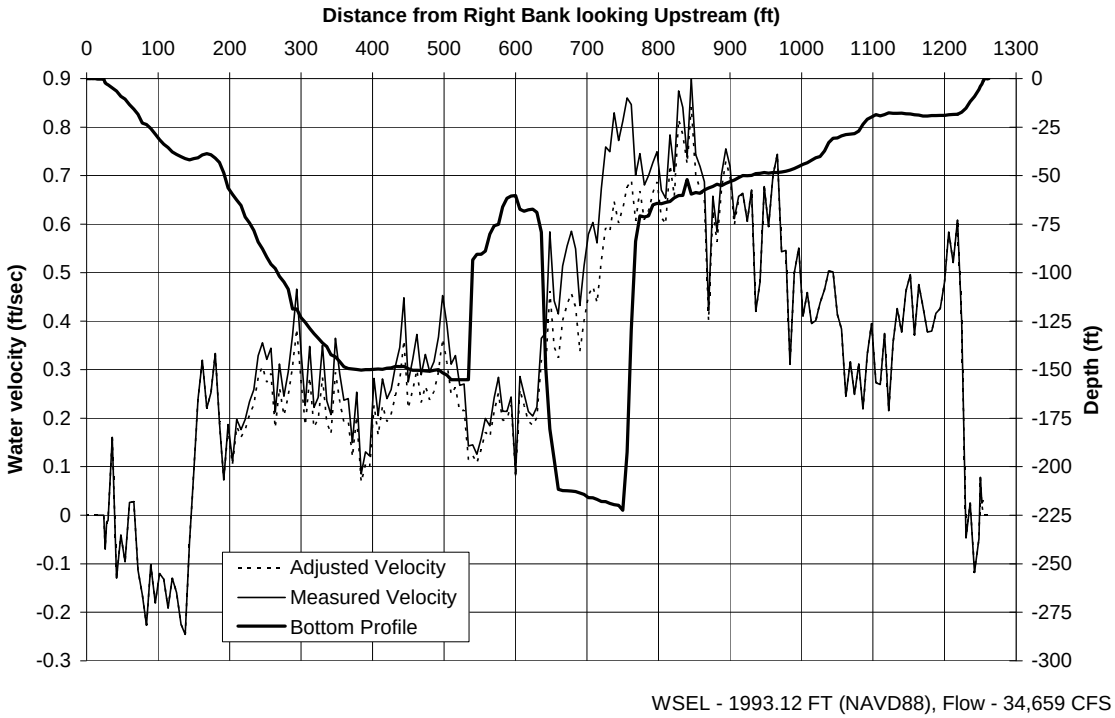


**Figure B-9.** Velocity adjustments to Canyon Reach habitat transect C-05.

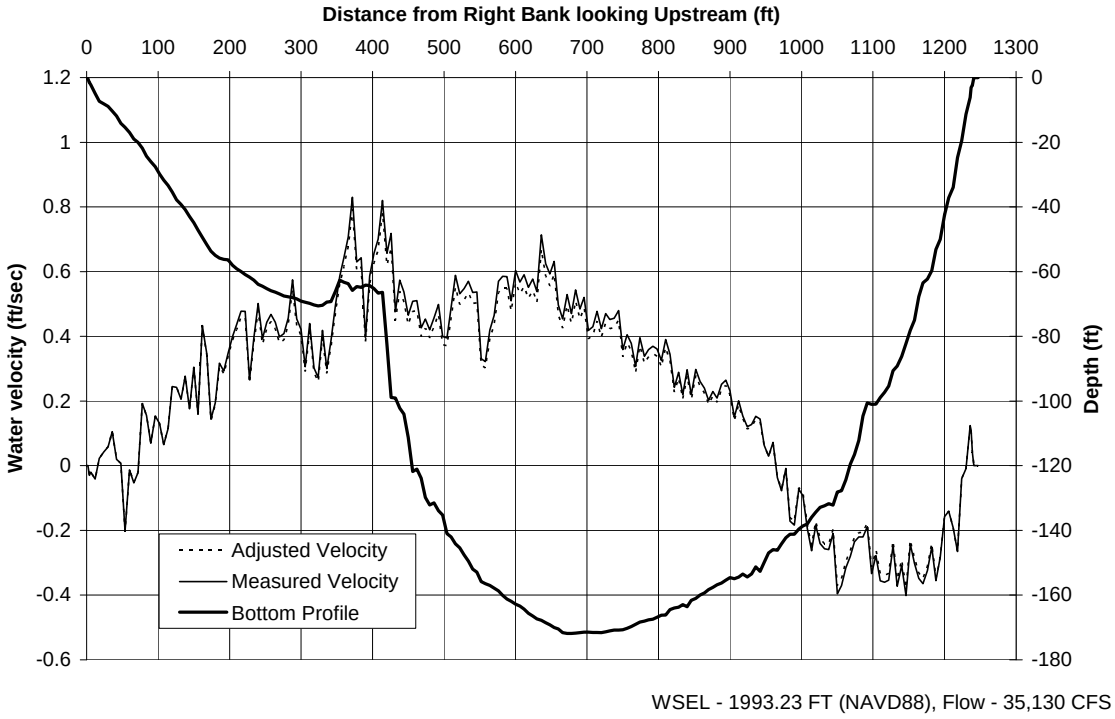


**Figure B-10.** Velocity adjustments to Canyon Reach habitat transect C-06.

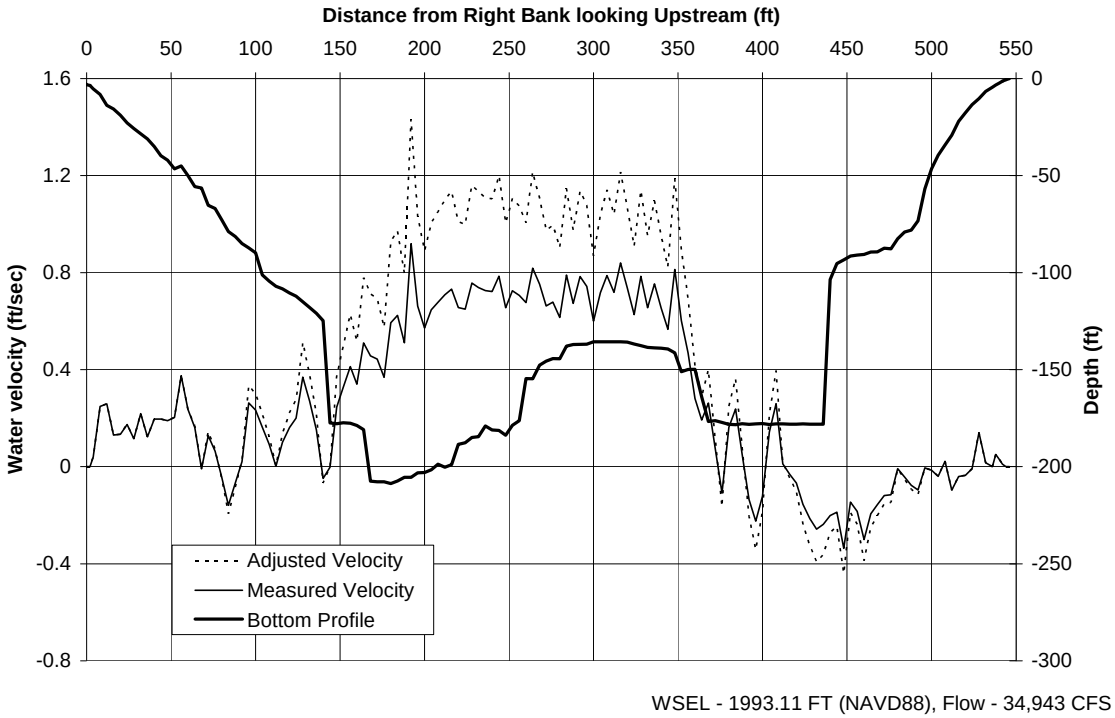


**Figure B-11.** Velocity adjustments to Canyon Reach habitat transect C-07.

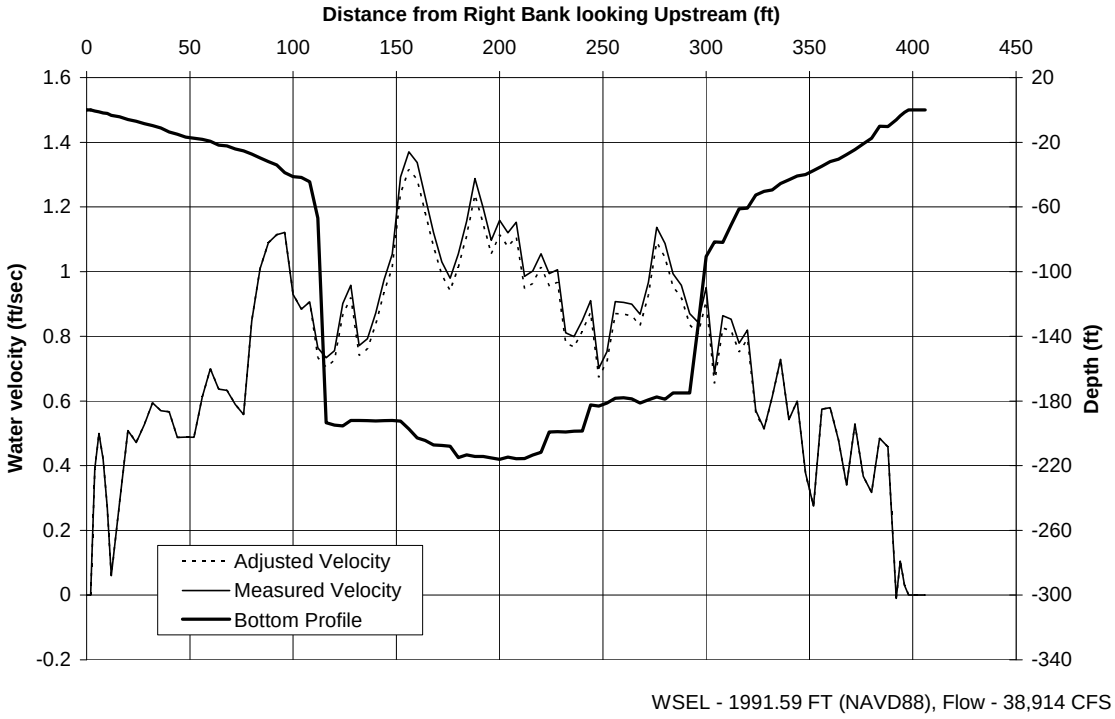


**Figure B-12.** Velocity adjustments to Canyon Reach habitat transect C-08.

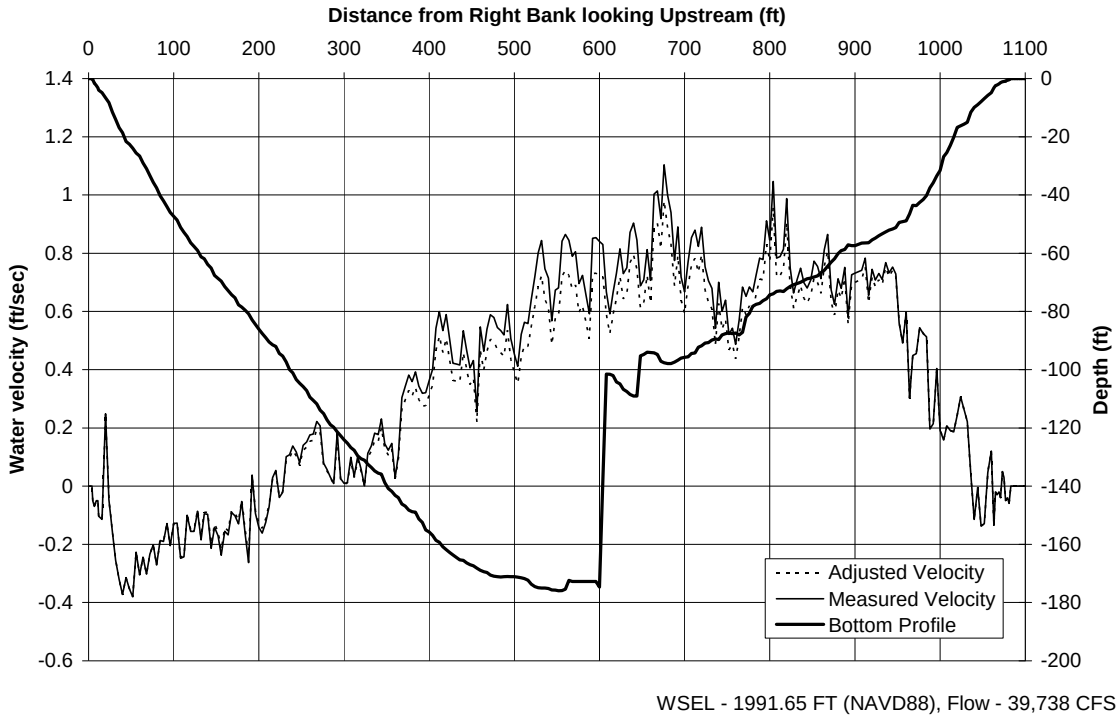


**Figure B-13.** Velocity adjustments to Canyon Reach habitat transect C-09.

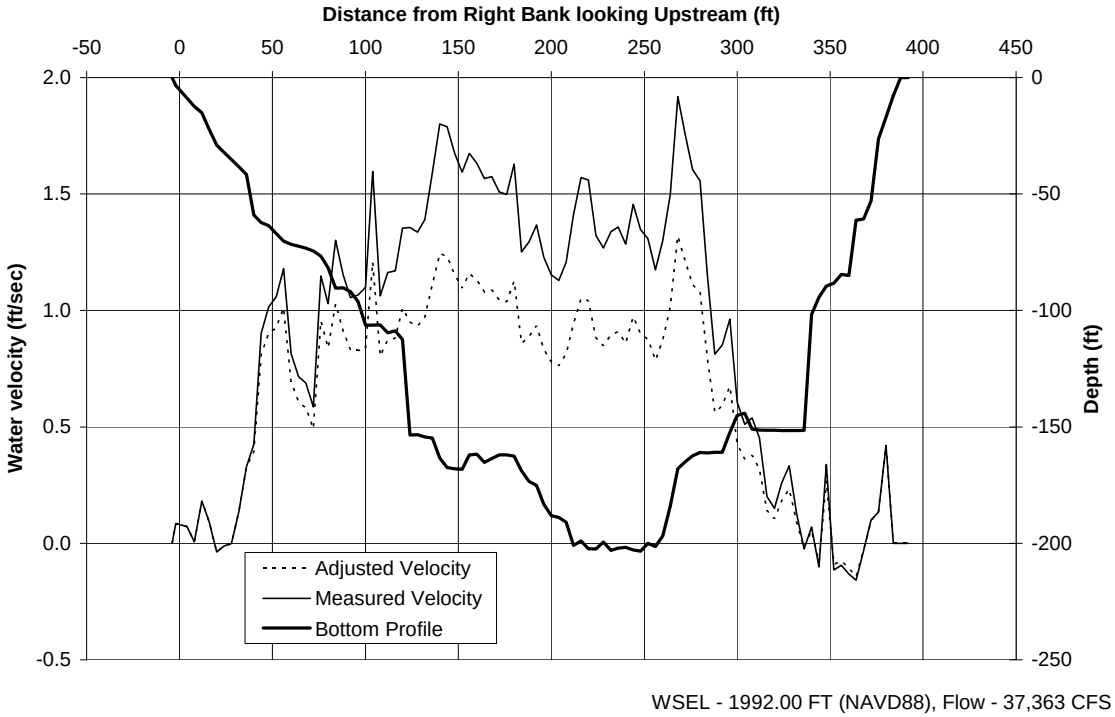


**Figure B-14.** Velocity adjustments to Canyon Reach habitat transect C-11.

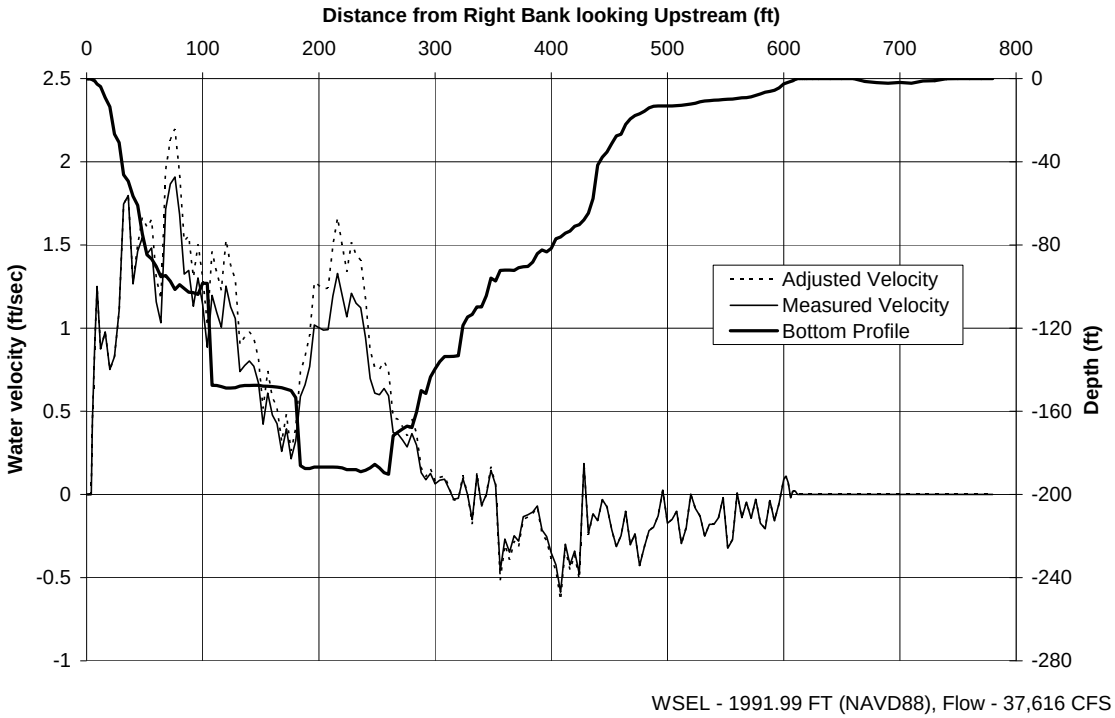


**Figure B-15.** Velocity adjustments to Canyon Reach habitat transect C-12.

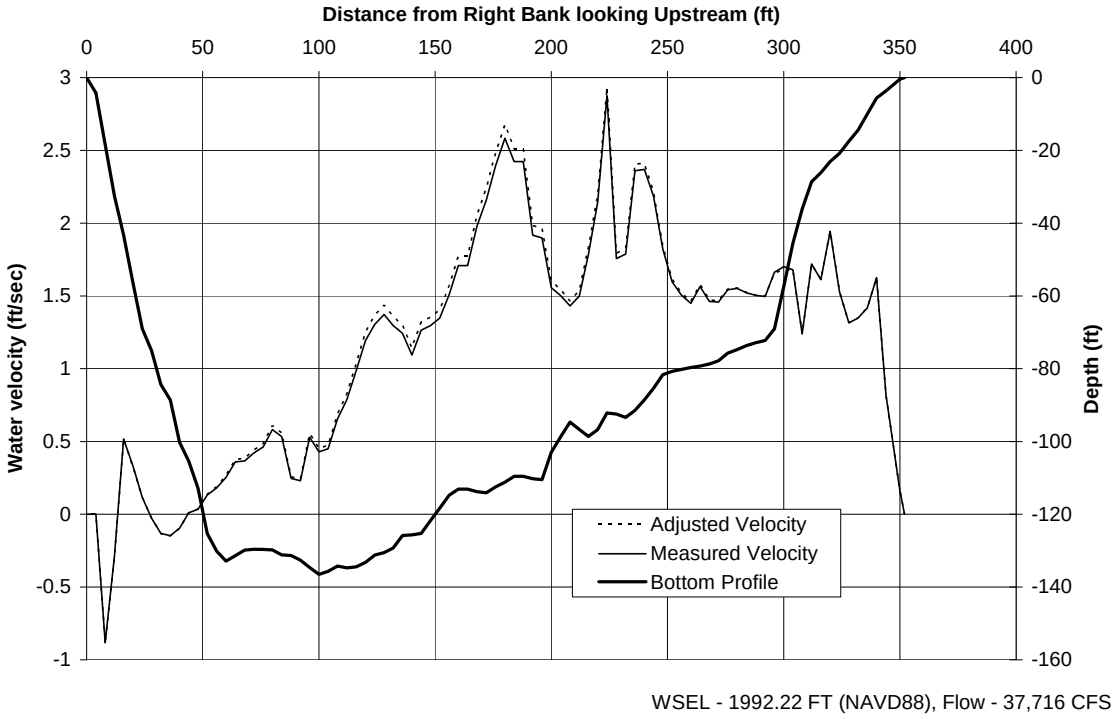


**Figure B-16.** Velocity adjustments to Canyon Reach habitat transect C-14.

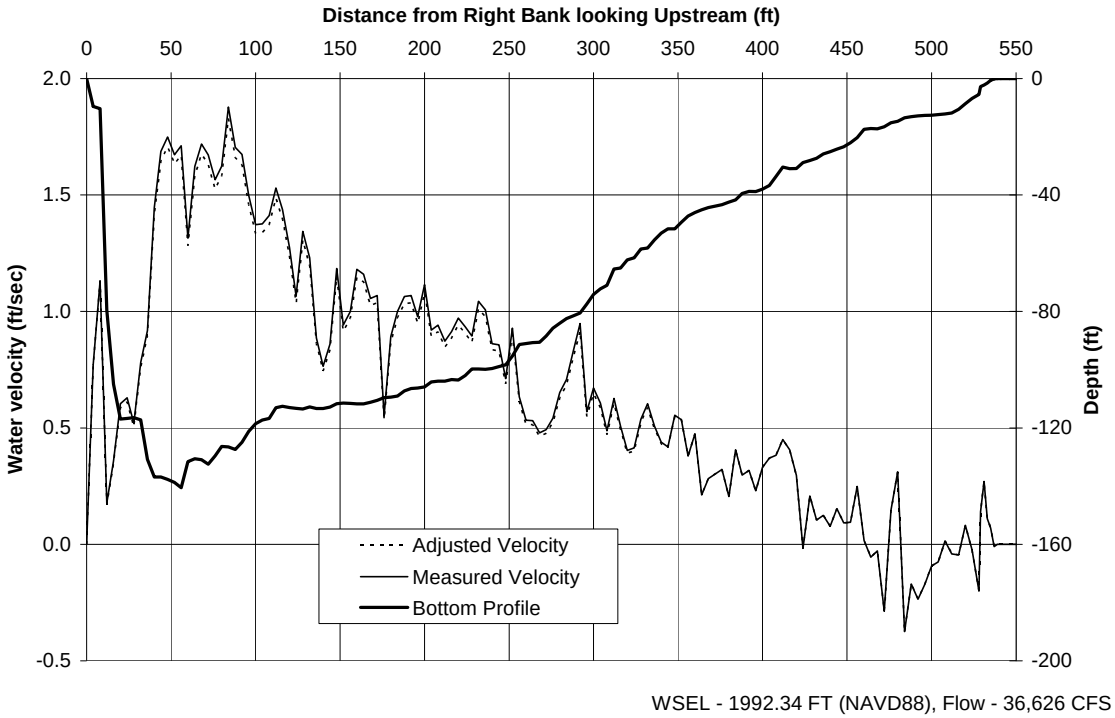


**Figure B-17.** Velocity adjustments to Canyon Reach habitat transect C-15.

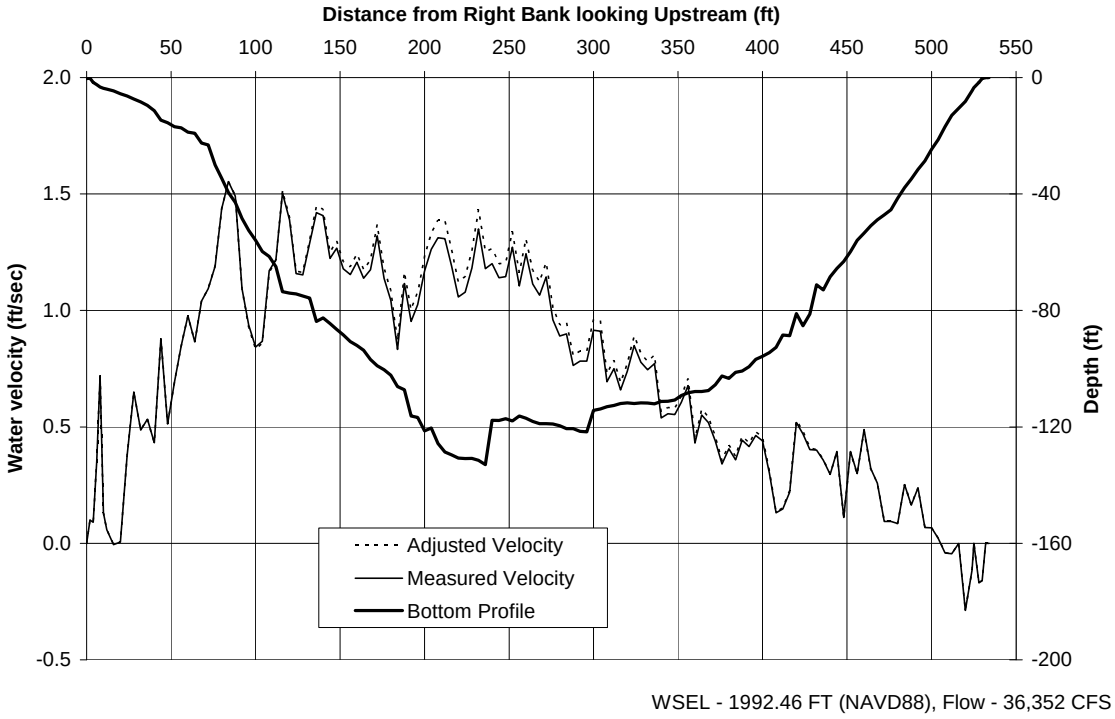


**Figure B-18.** Velocity adjustments to Canyon Reach habitat transect C-16.

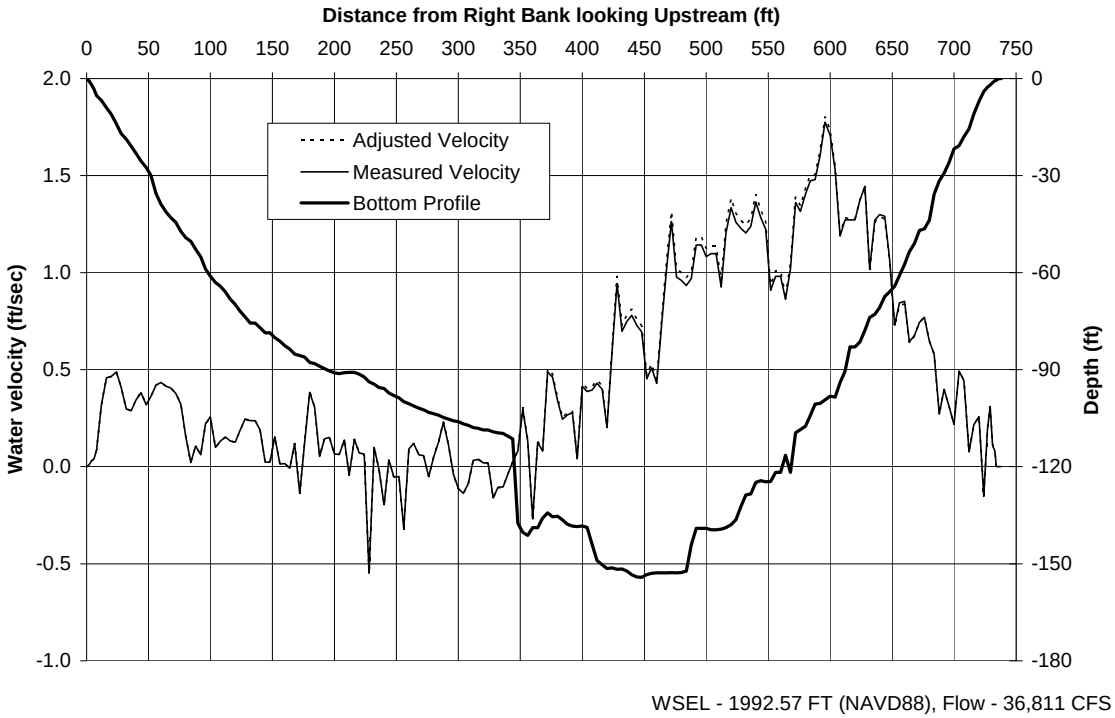


**Figure B-19.** Velocity adjustments to Canyon Reach habitat transect C-17.

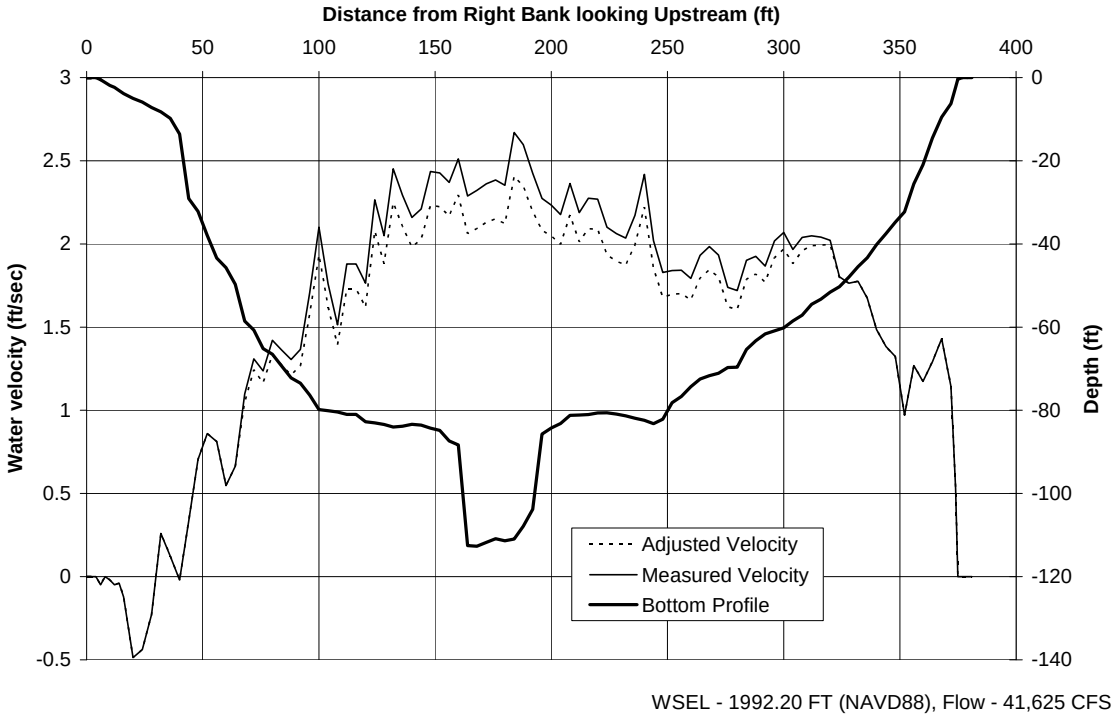


**Figure B-20.** Velocity adjustments to Canyon Reach habitat transect C-19.

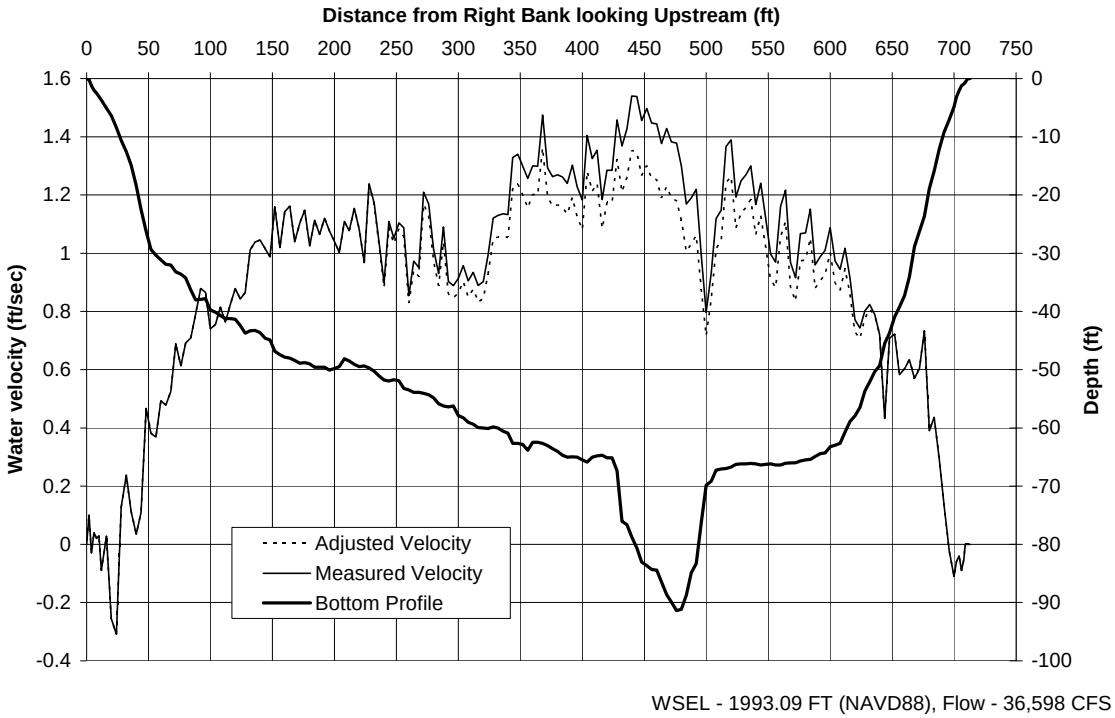


**Figure B-21.** Velocity adjustments to Canyon Reach habitat transect C-20.

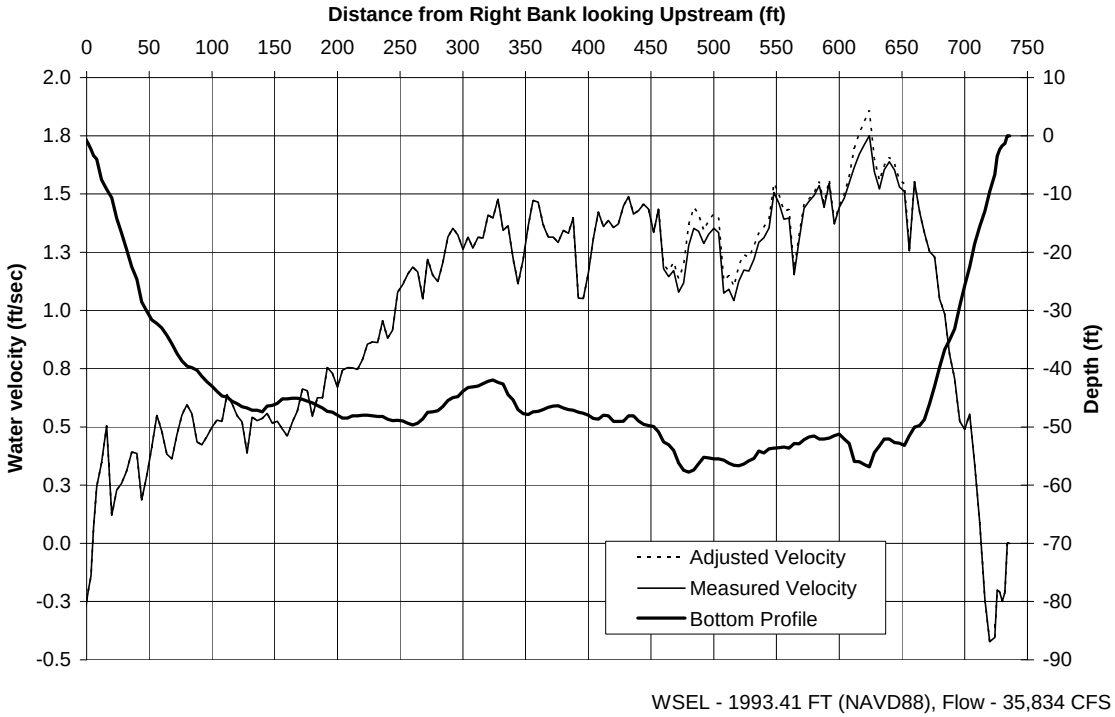


**Figure B-22.** Velocity adjustments to Canyon Reach habitat transect C-21.

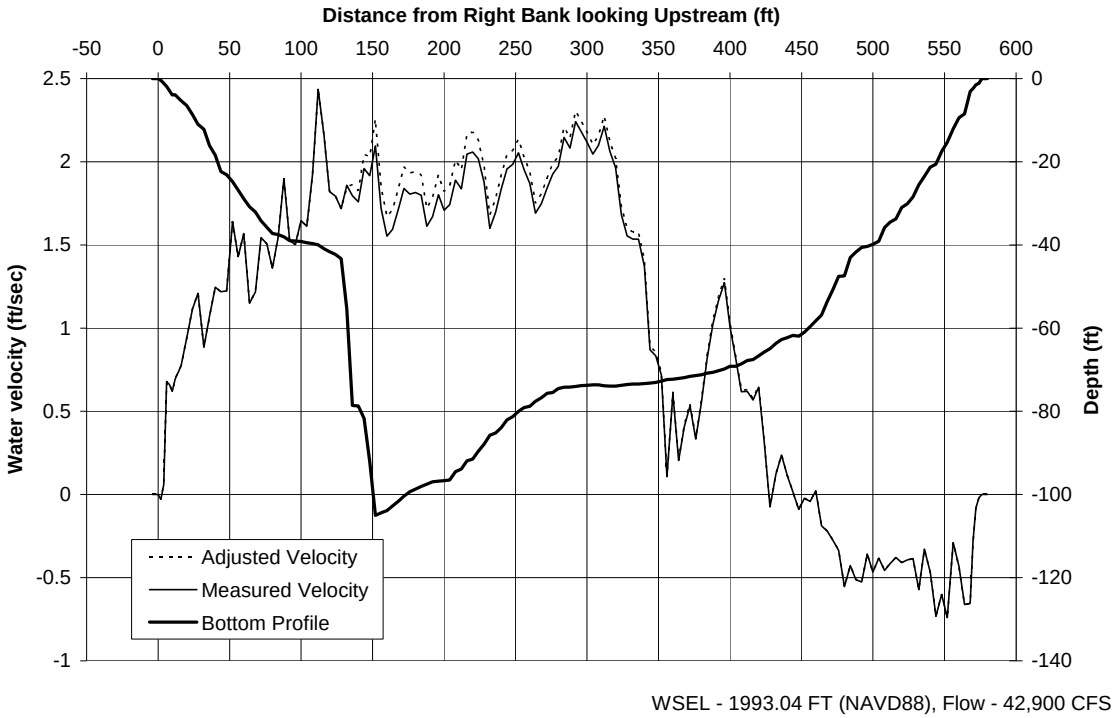


**Figure B-23.** Velocity adjustments to Canyon Reach habitat transect C-22.

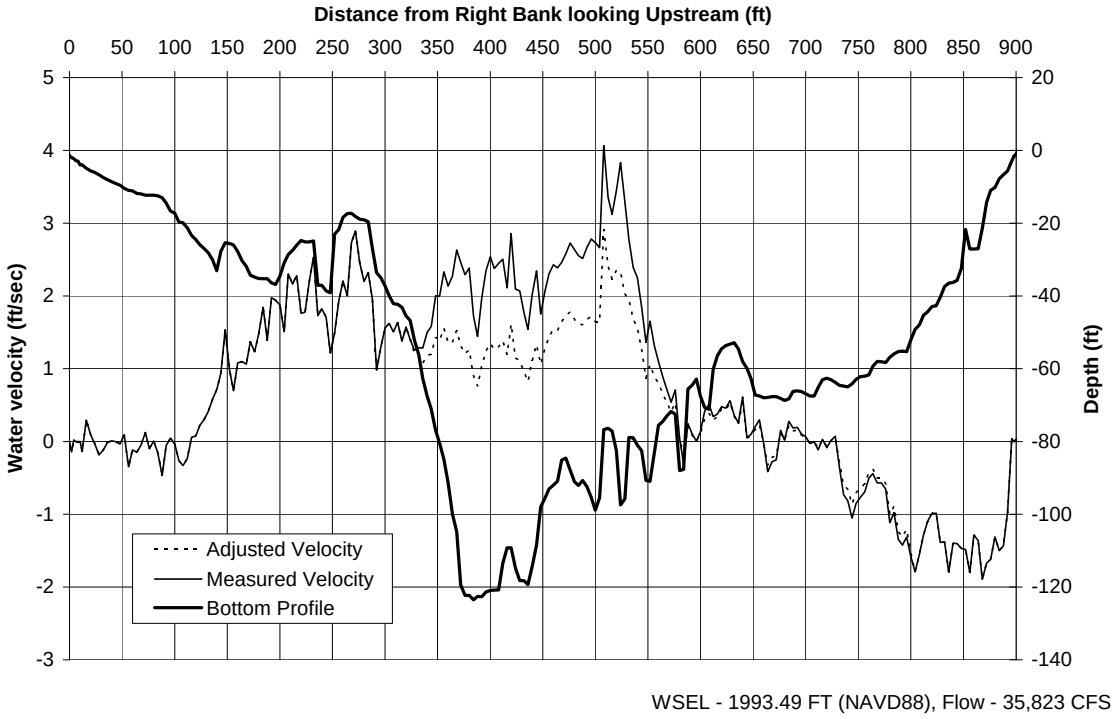


**Figure B-24.** Velocity adjustments to Canyon Reach habitat transect C-23.

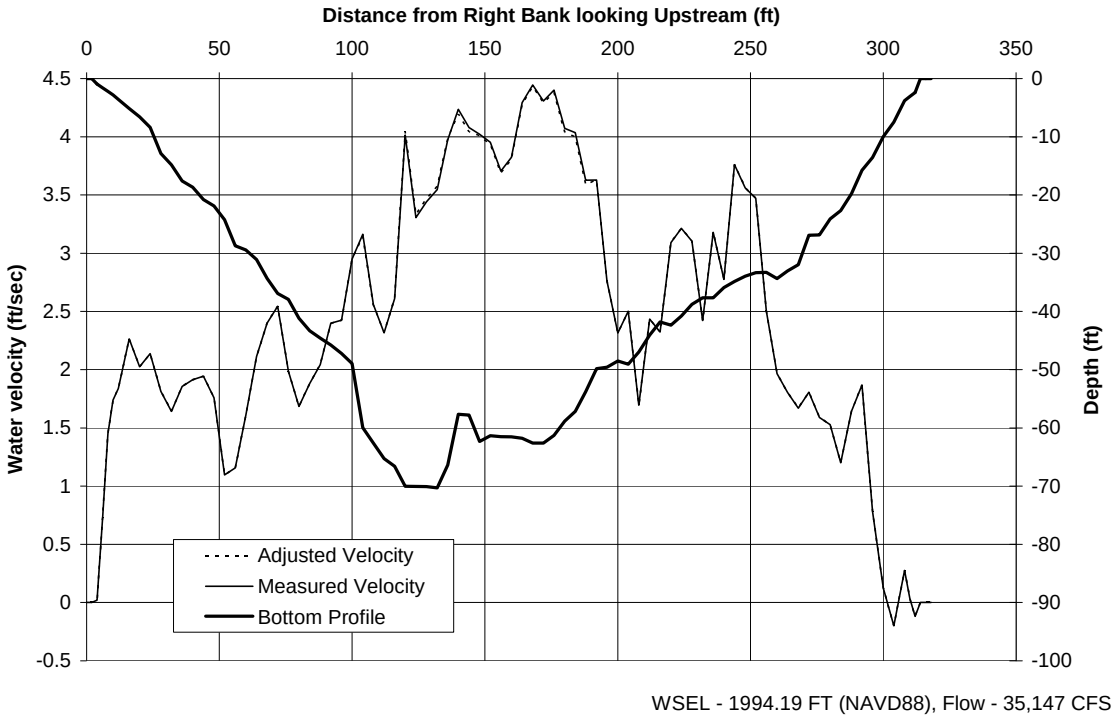


**Figure B-25.** Velocity adjustments to Canyon Reach habitat transect C-24.

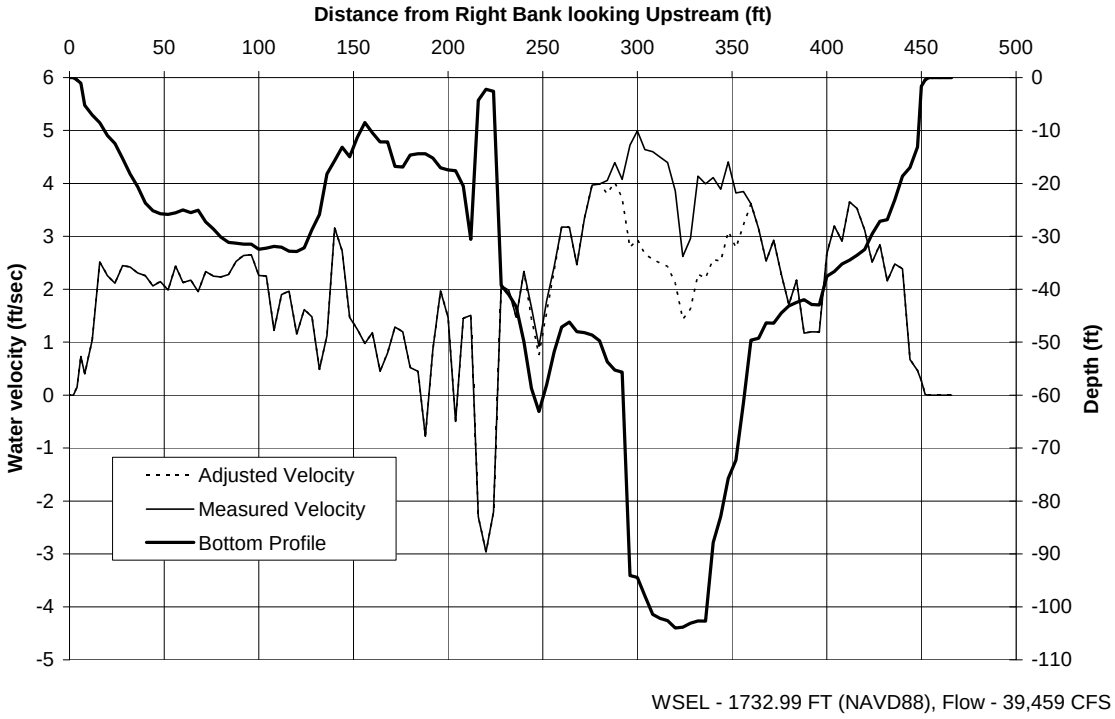


**Figure B-26.** Velocity adjustments to Tailrace Reach habitat transect T-01.

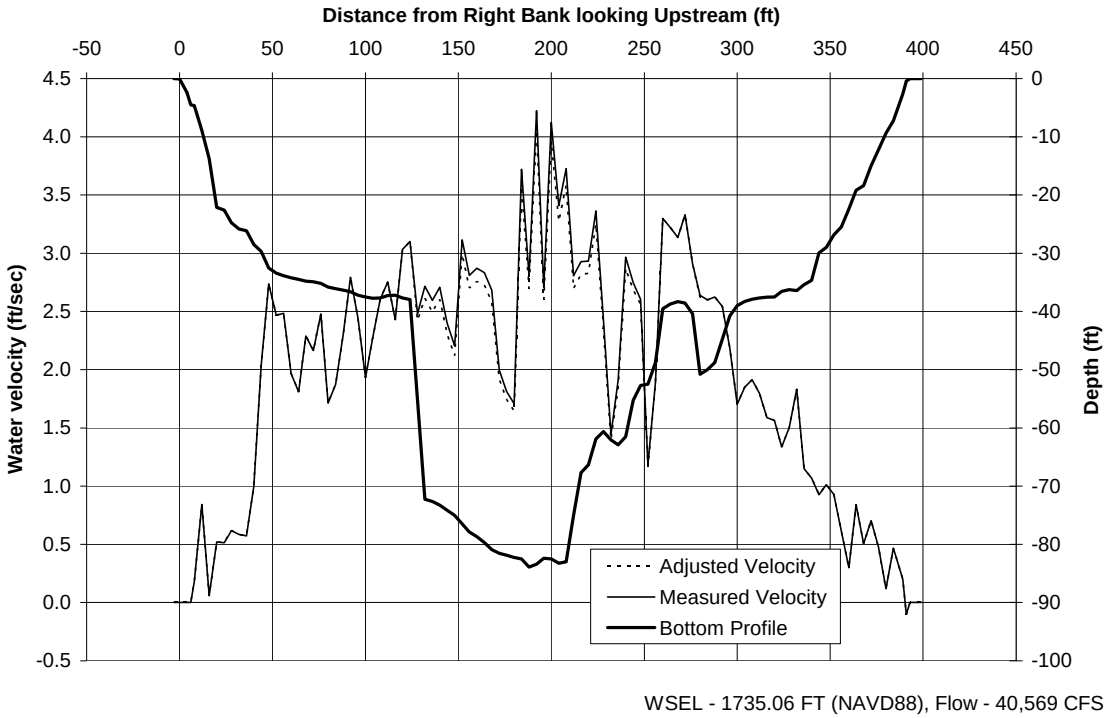


**Figure B-27.** Velocity adjustments to Tailrace Reach habitat transect T-05.

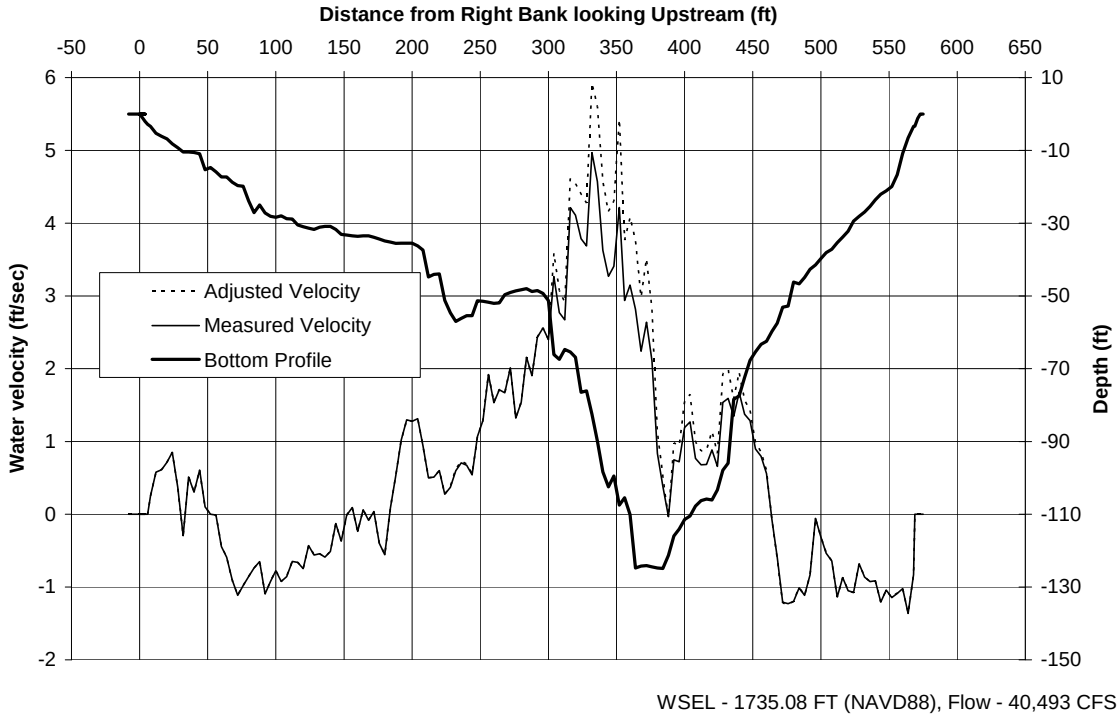


**Figure B-28.** Velocity adjustments to Tailrace Reach habitat transect T-07.

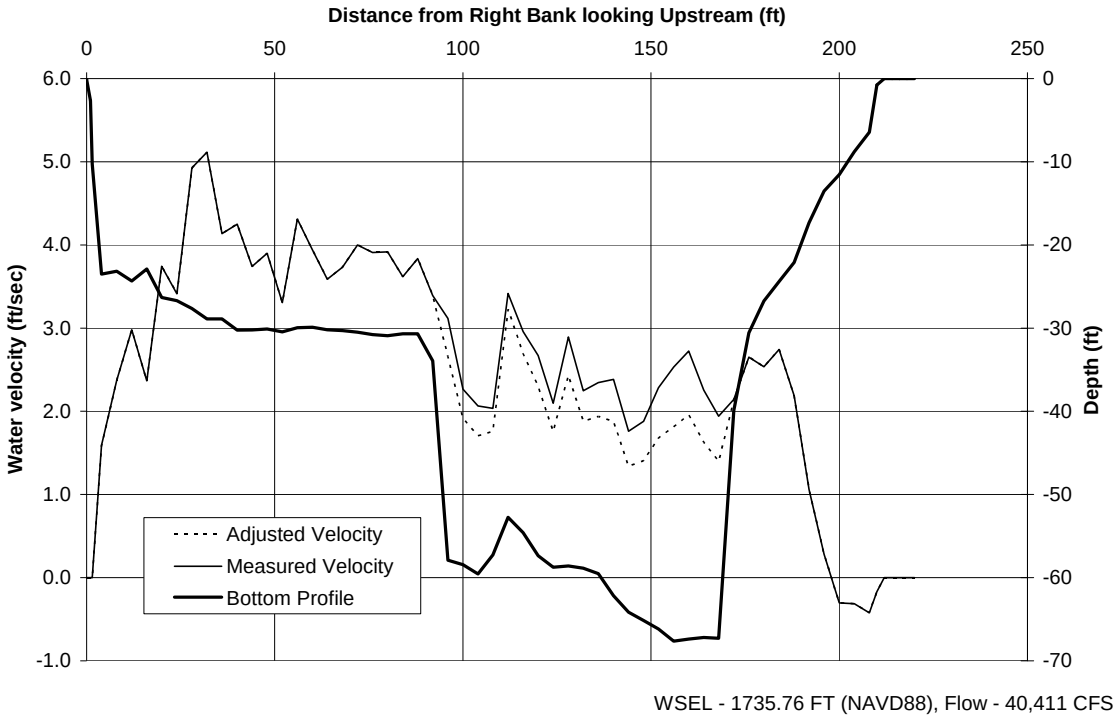


**Figure B-29.** Velocity adjustments to Tailrace Reach habitat transect T-09.

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# Attachment C: N-Value Calibration Notes

## Boundary High Pool High Flow Calibration Modification Notes

Forebay Reach (No calibration modifications applied)

Canyon Transects

- Transect C-08. Station 392.00 borrowed N-value from 388.00.
- Transect C-24. Station 4.00 borrowed N-value from station 6.00. Station 312.00 borrowed N-value from station 310.00.

Upper Reservoir Transects

- Transect U-01. Station 321 borrowed N from station 319 to provide a more realistic flow pattern along the margin when modeling up.
- Transect U-02. Station 0.00 N-value was borrowed from station 4.00, and station 565 borrowed the N-value from station 564 to remove edge effect.
- Transect U-03. Stations 744.00 and 746.00 signs were changed from negative to positive.
- Transect U-04. Station 3.00 N-value was borrowed from station 5.00, and station 1274.00 N-value was borrowed from station 1272.00 for edge effect.
- Transect U-05. Stations 2458.00, 2460.00, 2462.00, 2464.00, 2466.00 and 2468.00 all borrowed N-value from station 2457.00. This was done to prevent an unreasonably high velocity spike when modeling up.
- Transect U-06. Stations 2459.00 and 2461.00 borrowed N-value from station 2457.00
- Transect U-07. Station 345.00 borrowed N-value from station 343.00. Stations 2108.70, 2110.70 and 2112.70 borrowed N-value from station 2106.7.
- Transect U-08. Station 0.00 borrowed N-value from station 2.00. Station 24.00 changed sign from negative to positive.
- Transect U-09. Station 3.00 changed sign from negative to positive. Station 482.00 borrowed N-value from station 480.00.
- Transect U-10. Station 12.00 borrowed N-value from station 14.00, and station 1556.00 borrowed N-value from station 1554.00.
- Transect U-11. Stations 12.00 and 14.00 borrowed N-value from station 16.00.
- Transect U-13. Stations 4.00 and 6.00 borrowed N-values from station 8.00.

- Transect U-14. Stations 3.50, 5.50, 7.50, 9.50, 11.50, and 12.00 borrowed N-value from station 16.00. Stations 644.00 and 646.00 borrowed N-value from station 642.00.
- Transect U-16. Station -432.00 borrowed N-value from station -430.00. Station 6.00 borrowed N-value from station 8.00.
- Transect U-17. Stations 978.00 and 980.00 borrowed N-value from station 976.00.
- Transect U-18. Station 2.00 borrowed adjacent N-value from station 4.00. Station 8.00 borrowed adjacent N-value from station 10.00. Station 654.00 borrowed adjacent N-value from station 652.00.
- Transect U-19. Stations 4.00, 6.00, 8.00, 10.00 and 12.00 borrowed N value from station 14.00. Stations 18.00, 22.00, 24.00, 26.00, 28.00, 30.00, 32.00, 34.00, 36.00, 38.00, 40.00, 42.00, 44.00, 46.00, 48.00, and 50.00 borrowed N-value from station 52.00. Station 776.00 borrowed N-value from station 772.00.
- Transect U-20. Station 1311.00 sign of N-value changed from negative to positive.
- Transect U-21. Stations 1141.00 and 1143.00 borrowed N-value from station 1140.00. Station 1149.00 borrowed N-value from 1147.00.
- Transect U-22. Station 2.00 borrowed N-value from station 4.00. Stations 460.00, 464.00, and 468.00 borrowed N-value from station 456.00. Stations 482.00 and 484.00 borrowed N-value from station 480.00.
- Transect U-23. Stations 677.00 and 679.00 borrowed N-value from station 675.00.
- Transect U-24. Stations 580.00 and 582.00 borrowed N-value from station 578.00.

<u>Tailrace Transects</u>

- Transect TR-1. Station 452.00 borrowed N-value from station 450.00.
- Transect TR-3. Station 12.00 borrowed N-value from station 16.00.
- Transect TR-5. Station 391.00 borrowed N-value from station 389.00.
- Transect TR-9. Station 2.00 borrowed N-value from station 4.00. Stations 228.00 and 230.00 borrowed N-value from station 227.00.
- Transect TR-10. Stations 400.00 and 404.00 borrowed N-value from station 396.00.
- Transect TR-11. Station 8.00 borrowed N-value from station 12.00.
- Transect TR-12. Station 352.00 borrowed N-value from station 350.00.

- Transect TR-13. Station -2.00 borrowed N-value from station 0.00. Station 436.00 borrowed N-value from station 434.00.
- Transect TR-14. Station 30.00 and 36.00 change sign of N-value from positive to negative. Station 471.00 borrowed N-value from station 469.00.
- Transect TR-15. Station 30.00 borrowed N-value from station 28.00.
- Transect TR-16. Station 16.00 borrowed N-value from station 18.00. Stations 860.00, 861.00, 863.00, and 865.00 borrowed N-value from station856.00.
- Transect TR-17. Station 654.00 borrowed N-value from station 652.00.

**Boundary Low Pool High Flow Calibration Modification notes**
(No calibration modifications applied)

**Boundary Low Pool Medium Flow Calibration Modification notes**

Forebay Reach (No calibration modifications applied)

Canyon Reach (No calibration modifications applied)

- Transect U-04. Station 1215.00 the N-value was increased to prevent water flowing through the side channel.

Tailrace Reach (No calibration modifications applied)

**Boundary Low Pool Low Flow Calibration Modification notes**

Forebay Reach (No calibration modifications applied)

Canyon Reach (No calibration modifications applied)

- Transect U-05. Station 387.00 borrowed N-value from adjacent station 378.00.
- Transect U-06. Stations 1746.00, 1755.00, 1764.00, 1773.00, 1782.00 and 1791.00 borrowed N-value from adjacent station 1800.00.
- Transect U-17. Station 880.00 the N-value was increased to 2.00 to maintain low velocities in a small side channel.

Tailrace Reach (No calibration modifications applied)

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# Attachment D: Comparison of Surveyed and HRM Modeled Habitat Transect Water Surface Elevations

This attachment contains the following tables:

Table D-1. Comparison of measured and modeled habitat transect water surface elevations Oreille River, Forebay Reach.
Table D-2. Comparison of measured and modeled habitat transect water surface elevations Oreille River, Canyon Reach.
Table D-3. Comparison of measured and modeled habitat transect water surface elevations Oreille River, Upper Reservoir Reach.
Table D-4. Comparison of measured and modeled habitat transect water surface elevations Oreille River, Tailrace Reach.

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**Table D-1.** Comparison of measured and modeled habitat transect water surface elevations Oreille River, Forebay Reach.

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| F-1 | 5/27/07 | High Pool / High Flow | 39,026 | 1,992.60 | 1,992.46 | -0.14 |
| F-2 | 5/27/07 | High Pool / High Flow | 42,721 | 1,992.51 | 1,992.34 | -0.17 |
| F-3 | 5/27/07 | High Pool / High Flow | 42,834 | 1,992.42 | 1,992.20 | -0.22 |
| F-4 | 5/27/07 | High Pool / High Flow | 42,740 | 1,992.25 | 1,992.13 | -0.12 |
| F-5 | 5/27/07 | High Pool / High Flow | 42,183 | 1,992.17 | 1,992.08 | -0.09 |

**Table D-2.** Comparison of measured and modeled habitat transect water surface elevations Oreille River, Canyon Reach.

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| C-1 | 5/27/07 | High Pool / High Flow | 41,694 | 1,992.25 | 1,992.05 | -0.20 |
| C-2 | 5/27/07 | High Pool / High Flow | 40,438 | 1,992.24 | 1,992.09 | -0.15 |
| C-4 | 5/28/07 | High Pool / High Flow | 39,861 | 1,991.60 | 1,991.24 | -0.36 |
| C-5 | 5/29/07 | High Pool / High Flow | 34,659 | 1,993.12 | 1,992.84 | -0.28 |
| C-6 | 5/29/07 | High Pool / High Flow | 35,130 | 1,993.23 | 1,992.86 | -0.37 |
| C-7 | 5/29/07 | High Pool / High Flow | 34,943 | 1,993.11 | 1,992.85 | -0.26 |
| C-8 | 5/28/07 | High Pool / High Flow | 38,914 | 1991.59 | 1,991.25 | -0.34 |
| C-9 | 5/28/07 | High Pool / High Flow | 39,738 | 1,991.65 | 1,991.26 | -0.39 |
| C-11 | 5/28/07 | High Pool / High Flow | 37,363 | 1,992.00 | 1,992.03 | 0.03 |
| C-12 | 5/28/07 | High Pool / High Flow | 37,616 | 1,991.99 | 1,991.71 | -0.28 |
| C-14 | 5/28/07 | High Pool / High Flow | 37,716 | 1,992.22 | 1,991.77 | -0.45 |
| C-15 | 5/28/07 | High Pool / High Flow | 36,626 | 1,992.34 | 1,991.99 | -0.35 |
| C-16 | 5/28/07 | High Pool / High Flow | 36,352 | 1,992.46 | 1,992.12 | -0.34 |
| C-17 | 5/28/07 | High Pool / High Flow | 36,811 | 1,992.57 | 1,992.14 | -0.43 |
| C-19 | 5/29/07 | High Pool / High Flow | 41,625 | 1,992.20 | 1,991.56 | -0.64 |
| C-20 | 5/29/07 | High Pool / High Flow | 36,598 | 1,993.09 | 1,992.87 | -0.22 |
| C-21 | 5/29/07 | High Pool / High Flow | 35,834 | 1,993.41 | 1,993.09 | -0.32 |
| C-22 | 5/26/07 | High Pool / High Flow | 42,900 | 1,993.04 | 1,992.83 | -0.21 |
| C-23 | 5/29/07 | High Pool / High Flow | 35,823 | 1,993.49 | 1,993.24 | -0.25 |
| C-24 | 5/29/07 | High Pool / High Flow | 35,147 | 1,994.19 | 1,993.72 | -0.47 |

**Table D-3.** Comparison of measured and modeled habitat transect water surface elevations Oreille River, Upper Reservoir Reach.

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| U-1 | 5/25/07 | High Pool / High Flow | 47,326 | 1,998.28 | 1,997.96 | -0.32 |
| U-1 | 5/31/07 | Low Pool / High Flow | 35,834 | 1,991.75 | 1,991.69 | -0.06 |
| U-1 | 7/11/07 | Low Pool / Medium Flow | 22,344 | 1,988.22 | 1,988.06 | -0.16 |
| U-1 | 8/22/07 | Low Pool / Low Flow | 9,696 | 1,984.78 | 1,984.54 | -0.24 |
| | | | | | | |
| U-2 | 5/24/07 | High Pool / High Flow | 47,195 | 1,998.33 | 1,997.75 | -0.58 |
| U-2 | 5/31/07 | Low Pool / High Flow | 34,035 | 1,992.22 | 1,991.90 | -0.32 |
| U-2 | 7/11/07 | Low Pool / Medium Flow | 20,918 | 1,988.51 | 1,988.20 | -0.31 |
| U-2 | 8/22/07 | Low Pool / Low Flow | 9,904 | 1,985.01 | 1,984.71 | -0.30 |
| | | | | | | |
| U-3 | 5/24/07 | High Pool / High Flow | 48,116 | 1,998.25 | 1,997.79 | -0.46 |
| U-3 | 5/31/07 | Low Pool / High Flow | 34,041 | 1,992.12 | 1,991.94 | -0.18 |
| U-3 | 7/11/07 | Low Pool / Medium Flow | 21,499 | 1,988.33 | 1,988.23 | -0.10 |
| U-3 | 8/22/07 | Low Pool / Low Flow | 9,393 | 1,984.64 | 1,984.53 | -0.11 |
| | | | | | | |
| U-4 | 5/24/07 | High Pool / High Flow | 49,061 | 1,998.28 | 1,997.82 | -0.46 |
| U-4 | 5/31/07 | Low Pool / High Flow | 34,248 | 1,992.20 | 1,991.98 | -0.22 |
| U-4 | 7/11/07 | Low Pool / Medium Flow | 19,262 | 1,988.22 | 1,988.18 | -0.04 |
| U-4 | 8/22/07 | Low Pool / Low Flow | 9,292 | 1,984.49 | 1,984.38 | -0.11 |
| | | | | | | |
| U-5 | 5/24/07 | High Pool / High Flow | 46,398 | 1,998.23 | 1,997.81 | -0.42 |
| U-5 | 5/30/07 | Low Pool / High Flow | 34,961 | 1,992.69 | 1,992.43 | -0.26 |
| U-5 | 7/11/07 | Low Pool / Medium Flow | 19,533 | 1,987.98 | 1,988.01 | 0.03 |
| U-5 | 8/22/07 | Low Pool / Low Flow | 9,213 | 1,984.46 | 1,984.33 | -0.13 |
| | | | | | | |
| U-6 | 5/24/07 | High Pool / High Flow | 45,723 | 1,997.92 | 1,997.82 | -0.10 |
| U-6 | 5/31/07 | Low Pool / High Flow | 36,711 | 1,992.64 | 1,992.40 | -0.24 |
| U-6 | 7/11/07 | Low Pool / Medium Flow | 17,271 | 1,988.82 | 1,988.57 | -0.25 |
| U-6 | 8/22/07 | Low Pool / Low Flow | 8,459 | 1,984.26 | 1,984.21 | -0.05 |
| | | | | | | |
| U-7 | 5/24/07 | High Pool / High Flow | 45,952 | 1,997.67 | 1,997.46 | -0.21 |
| U-7 | 5/30/07 | Low Pool / High Flow | 39,198 | 1,992.46 | 1,992.35 | -0.11 |
| U-7 | 7/11/07 | Low Pool / Medium Flow | 18,122 | 1,987.75 | 1,987.82 | 0.07 |
| U-7 | 8/22/07 | Low Pool / Low Flow | 8,714 | 1,984.09 | 1,984.12 | 0.03 |
| | | | | | | |
| U-8 | 5/24/07 | High Pool / High Flow | 50,210 | 1,998.09 | 1,997.67 | -0.42 |
| U-8 | 5/30/07 | Low Pool / High Flow | 35,804 | 1,992.34 | 1,992.14 | -0.20 |
| U-8 | 7/11/07 | Low Pool / Medium Flow | 21,480 | 1,987.92 | 1,987.97 | 0.05 |
| U-8 | 8/22/07 | Low Pool / Low Flow | 8,973 | 1,983.94 | 1,984.01 | 0.07 |
| | | | | | | |

**Table D-3, continued…**

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| U-9 | 5/24/07 | High Pool / High Flow | 48,110 | 1,997.73 | 1,997.52 | -0.21 |
| U-9 | 5/31/07 | Low Pool / High Flow | 34,533 | 1,992.38 | 1,992.38 | 0.00 |
| U-9 | 7/11/07 | Low Pool / Medium Flow | 21,144 | 1,987.69 | 1,987.87 | 0.18 |
| U-9 | 8/22/07 | Low Pool / Low Flow | 8,850 | 1,983.78 | 1,983.96 | 0.18 |
| | | | | | | |
| U-10 | 5/24/07 | High Pool / High Flow | 53,028 | 1,998.27 | 1,997.85 | -0.42 |
| U-10 | 5/30/07 | Low Pool / High Flow | 36,489 | 1,992.86 | 1,992.57 | -0.29 |
| U-10 | 7/11/07 | Low Pool / Medium Flow | 20,904 | 1,988.01 | 1,987.99 | -0.02 |
| U-10 | 8/22/07 | Low Pool / Low Flow | 8,807 | 1,983.99 | 1,983.93 | -0.06 |
| | | | | | | |
| U-11 | 5/24/07 | High Pool / High Flow | 48,114 | 1,998.19 | 1,997.99 | -0.20 |
| U-11 | 5/30/07 | Low Pool / High Flow | 34,575 | 1,992.83 | 1,992.51 | -0.32 |
| U-11 | 7/11/07 | Low Pool / Medium Flow | 20,624 | 1,987.97 | 1,987.99 | 0.02 |
| U-11 | 8/22/07 | Low Pool / Low Flow | 8,352 | 1,983.96 | 1,983.96 | 0.00 |
| | | | | | | |
| U-12 | 5/25/07 | High Pool / High Flow | 46,828 | 1,999.37 | 1,998.86 | -0.51 |
| U-12 | 5/30/07 | Low Pool / High Flow | 36,146 | 1,992.78 | 1,992.60 | -0.18 |
| U-12 | 7/11/07 | Low Pool / Medium Flow | 20,528 | 1,987.95 | 1,988.02 | 0.07 |
| U-12 | 8/22/07 | Low Pool / Low Flow | 8,612 | 1,983.73 | 1,983.86 | 0.13 |
| | | | | | | |
| U-13 | 5/25/07 | High Pool / High Flow | 46,242 | 1,999.36 | 1,998.93 | -0.43 |
| U-13 | 5/30/07 | Low Pool / High Flow | 34,232 | 1,992.88 | 1,992.76 | -0.12 |
| U-13 | 7/11/07 | Low Pool / Medium Flow | 19,791 | 1,987.99 | 1,988.09 | 0.10 |
| U-13 | 8/22/07 | Low Pool / Low Flow | 8,568 | 1,983.67 | 1,983.82 | 0.15 |
| | | | | | | |
| U-14 | 5/25/07 | High Pool / High Flow | 45,669 | 1,999.60 | 1,999.05 | -0.55 |
| U-14 | 5/30/07 | Low Pool / High Flow | 34,407 | 1,993.12 | 1,992.88 | -0.24 |
| U-14 | 7/11/07 | Low Pool / Medium Flow | 19,750 | 1,988.08 | 1,988.12 | 0.04 |
| U-14 | 8/22/07 | Low Pool / Low Flow | 8,569 | 1,983.64 | 1,983.75 | 0.11 |
| | | | | | | |
| U-15 | 5/25/07 | High Pool / High Flow | 46,346 | 1,999.59 | 1,999.08 | -0.51 |
| U-15 | 5/30/07 | Low Pool / High Flow | 34,124 | 1,993.15 | 1,992.94 | -0.21 |
| U-15 | 7/11/07 | Low Pool / Medium Flow | 18,761 | 1,988.07 | 1,988.12 | 0.05 |
| U-15 | 8/22/07 | Low Pool / Low Flow | 8,386 | 1,983.50 | 1,983.58 | 0.08 |
| | | | | | | |
| U-16 | 5/25/07 | High Pool / High Flow | 47,334 | 1,999.43 | 1,999.01 | -0.42 |
| U-16 | 5/30/07 | Low Pool / High Flow | 34,173 | 1,993.05 | 1,992.94 | -0.11 |
| U-16 | 7/12/07 | Low Pool / Medium Flow | 18,389 | 1,989.17 | 1,989.06 | -0.11 |
| U-16 | 8/22/07 | Low Pool / Low Flow | 8,191 | 1,984.06 | 1,984.15 | 0.09 |
| | | | | | | |
| U-17 | 5/25/07 | High Pool / High Flow | 45,778 | 1,999.27 | 1,998.87 | -0.40 |
| U-17 | 5/30/07 | Low Pool / High Flow | 35,465 | 1,992.99 | 1,992.97 | -0.02 |
| U-17 | 7/12/07 | Low Pool / Medium Flow | 18,025 | 1,989.03 | 1,989.02 | -0.01 |
| U-17 | 8/23/07 | Low Pool / Low Flow | 8,222 | 1,984.24 | 1,984.33 | 0.09 |
| | | | | | | |

**Table D-3, continued…**

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| U-18 | 5/25/07 | High Pool / High Flow | 45,986 | 1,999.17 | 1,998.92 | -0.25 |
| U-18 | 5/30/07 | Low Pool / High Flow | 34,115 | 1,993.05 | 1,993.15 | 0.10 |
| U-18 | 7/12/07 | Low Pool / Medium Flow | 19,050 | 1,988.75 | 1,988.87 | 0.12 |
| U-18 | 8/23/07 | Low Pool / Low Flow | 8,094 | 1,984.30 | 1,984.55 | 0.25 |
| | | | | | | |
| U-19 | 5/25/07 | High Pool / High Flow | 47,452 | 1,999.05 | 1,998.97 | -0.08 |
| U-19 | 5/31/07 | Low Pool / High Flow | 35,021 | 1,993.39 | 1,993.58 | 0.19 |
| U-19 | 7/11/07 | Low Pool / Medium Flow | 18,467 | 1,988.58 | 1,988.90 | 0.32 |
| U-19 | 8/23/07 | Low Pool / Low Flow | 8,274 | 1,984.22 | 1,984.70 | 0.48 |
| | | | | | | |
| U-20 | 5/25/07 | High Pool / High Flow | 44,271 | 1,999.03 | 1,999.06 | 0.03 |
| U-20 | 5/31/07 | Low Pool / High Flow | 35,409 | 1,993.51 | 1,993.79 | 0.28 |
| U-20 | 7/12/07 | Low Pool / Medium Flow | 18,736 | 1,988.61 | 1,988.98 | 0.37 |
| U-20 | 8/23/07 | Low Pool / Low Flow | 7,796 | 1,984.33 | 1,983.88 | -0.45 |
| | | | | | | |
| U-21 | 5/25/07 | High Pool / High Flow | 47,050 | 1,999.06 | 1,999.03 | -0.03 |
| U-21 | 5/31/07 | Low Pool / High Flow | 35,700 | 1,993.68 | 1,993.84 | 0.16 |
| U-21 | 7/12/07 | Low Pool / Medium Flow | 18,893 | 1,988.55 | 1,988.99 | 0.44 |
| U-21 | 8/23/07 | Low Pool / Low Flow | 8,365 | 1,984.45 | 1,984.99 | 0.54 |
| | | | | | | |
| U-22 | 5/25/07 | High Pool / High Flow | 46,516 | 1,999.09 | 1,999.20 | 0.11 |
| U-22 | 5/31/07 | Low Pool / High Flow | 35,039 | 1,993.91 | 1,994.21 | 0.30 |
| U-22 | 7/12/07 | Low Pool / Medium Flow | 19,459 | 1,988.80 | 1,989.31 | 0.51 |
| U-22 | 8/23/07 | Low Pool / Low Flow | 8,786 | 1,984.63 | 1,985.33 | 0.70 |
| | | | | | | |
| U-23 | 5/26/07 | High Pool / High Flow | 43,199 | 1,999.05 | 1,998.97 | -0.08 |
| U-23 | 5/31/07 | Low Pool / High Flow | 35,681 | 1,994.75 | 1,994.91 | 0.16 |
| U-23 | 7/12/07 | Low Pool / Medium Flow | 19,931 | 1,989.56 | 1,990.04 | 0.48 |
| U-23 | 8/23/07 | Low Pool / Low Flow | 8,117 | 1,985.49 | 1,986.22 | 0.73 |
| | | | | | | |
| U-24 | 5/26/07 | High Pool / High Flow | 44,356 | 1,999.10 | 1,999.17 | 0.07 |
| U-24 | 5/31/07 | Low Pool / High Flow | 35,449 | 1,995.03 | 1,995.25 | 0.22 |
| U-24 | 7/12/07 | Low Pool / Medium Flow | 18,478 | 1,989.94 | 1,990.42 | 0.48 |
| U-24 | 8/23/07 | Low Pool / Low Flow | 7,444 | 1,985.75 | 1,986.40 | 0.65 |

**Table D-4.** Comparison of measured and modeled habitat transect water surface elevations Oreille River, Tailrace Reach.

| Transect | Date (MM/DD/YY) | Pool and Flow Condition | Flow Rate (cfs) | Measured Water Surface Elevation (ft NAVD 88) | Modeled Water Surface Elevation (ft NAVD 88) | Difference between Water Surface Elevations (ft) |
|---|---|---|---|---|---|---|
| TR-1 | 4/24/08 | High Pool / High Flow | 39,459 | 1,732.99 | 1,732.57 | -0.42 |
| TR-2 | 4/24/08 | High Pool / High Flow | 42,667 | 1,733.39 | 1,732.83 | -0.56 |
| TR-3 | 4/23/08 | High Pool / High Flow | 42,460 | 1,734.65 | 1,734.23 | -0.42 |
| TR-5 | 4/23/08 | High Pool / High Flow | 40,569 | 1,735.06 | 1,734.66 | -0.40 |
| TR-7 | 4/23/08 | High Pool / High Flow | 40,493 | 1,735.08 | 1,734.79 | -0.29 |
| TR-9 | 4/23/08 | High Pool / High Flow | 40,411 | 1,735.76 | 1,735.02 | -0.74 |
| TR-10 | 4/23/08 | High Pool / High Flow | 43,441 | 1,735.85 | 1,735.15 | -0.70 |
| TR-11 | 4/23/08 | High Pool / High Flow | 47,052 | 1,736.38 | 1,735.85 | -0.53 |
| | | | | | | |
| TR-12 | 4/22/08 | High Pool / High Flow | 44,703 | 1,736.41 | 1,735.89 | -0.52 |
| TR-12 | 3/10/08 | Low Pool / High Flow | 37,192 | 1,731.12 | 1,730.96 | -0.16 |
| TR-12 | 3/07/08 | Low Pool / Medium Flow | 21,626 | 1,727.97 | 1,727.83 | -0.14 |
| TR-12 | 3/09/08 | Low Pool / Low Flow | 10,924 | 1,726.74 | 1,726.62 | -0.12 |
| | | | | | | |
| TR-13 | 4/22/08 | High Pool / High Flow | 45,614 | 1,736.83 | 1,736.36 | -0.47 |
| TR-13 | 3/10/08 | Low Pool / High Flow | 37,549 | 1,731.83 | 1,731.69 | -0.14 |
| TR-13 | 3/07/08 | Low Pool / Medium Flow | 22,200 | 1,728.51 | 1,728.18 | -0.33 |
| TR-13 | 3/09/08 | Low Pool / Low Flow | 11,141 | 1,726.99 | 1,727.75 | 0.76 |
| | | | | | | |
| TR-14 | 4/22/08 | High Pool / High Flow | 44,836 | 1,737.69 | 1,737.60 | -0.09 |
| TR-14 | 3/10/08 | Low Pool / High Flow | 38,322 | 1,733.61 | 1,733.82 | 0.21 |
| TR-14 | 3/07/08 | Low Pool / Medium Flow | 21,397 | 1,729.80 | 1,729.63 | -0.17 |
| TR-14 | 3/09/08 | Low Pool / Low Flow | 11,573 | 1,727.50 | 1,727.33 | -0.17 |
| | | | | | | |
| TR-15 | 4/22/08 | High Pool / High Flow | 45,026 | 1,737.81 | 1,737.80 | -0.01 |
| TR-15 | 3/10/08 | Low Pool / High Flow | 38,109 | 1,733.91 | 1,734.15 | 0.24 |
| TR-15 | 3/07/08 | Low Pool / Medium Flow | 22,379 | 1,730.05 | 1,729.74 | -0.31 |
| TR-15 | 3/09/08 | Low Pool / Low Flow | 11,191 | 1,727.67 | 1,727.37 | -0.30 |
| | | | | | | |
| TR-16 | 4/22/08 | High Pool / High Flow | 43,309 | 1,738.30 | 1,738.08 | -0.22 |
| TR-16 | 3/10/08 | Low Pool / High Flow | 38,174 | 1,734.79 | 1,734.70 | -0.09 |
| TR-16 | 3/07/08 | Low Pool / Medium Flow | 22,773 | 1,730.54 | 1,730.44 | -0.10 |
| TR-16 | 3/09/08 | Low Pool / Low Flow | 11,704 | 1,727.86 | 1,727.74 | -0.12 |
| | | | | | | |
| TR-17 | 4/22/08 | High Pool / High Flow | 44,465 | 1,738.34 | 1,738.48 | 0.14 |
| TR-17 | 3/10/08 | Low Pool / High Flow | 38,771 | 1,734.95 | 1,735.36 | 0.41 |
| TR-17 | 3/07/08 | Low Pool / Medium Flow | 23,411 | 1,731.41 | 1,731.28 | -0.13 |
| TR-17 | 3/09/08 | Low Pool / Low Flow | 11,454 | 1,728.22 | 1,728.27 | 0.05 |

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Appendix 1b. Macrophyte Mapping Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 1b*

## *Macrophyte Mapping*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Darlene Siegel, Harry Gibbons, Robert Plotnikoff, Adam Baines, Kari Kimura and Shannon Brattebo**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 1b
# Macrophyte Mapping
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

This report presents the results of the macrophyte mapping effort for Study 7, Mainstem Aquatic Habitat Modeling Study, and was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by FERC in its Study Plan Determination letter dated March 15, 2007. This final report describes the 2007 and 2008 study efforts associated with the aquatic macrophyte coverage mapping; as part of the mapping of the current aquatic habitat in Boundary Reservoir.

Aquatic macrophyte coverage mapping supported the development of the Mainstem Aquatic Habitat Model, the Tributary Delta Habitat Modeling Study (Study 8), and the Aquatic Productivity Study (Study 11) to gain a better understanding of aquatic primary production in terms of ecological function, biomass quantity, and distribution in the Project area. This portion of the study was designed to map the current aquatic macrophyte coverage within Boundary Reservoir.

## 2 OBJECTIVES

The objective of the macrophyte mapping effort was to provide accurate mapping products to support the habitat modeling effort. Specific tasks or objectives to accomplish the goals of this effort included the following:

- Identify macrophyte coverage throughout Boundary Reservoir
- Identify macrophyte species present throughout Boundary Reservoir
- Identify macrophyte densities throughout Boundary Reservoir

## 3 STUDY AREA

The study area for the Aquatic Macrophyte Coverage mapping encompassed both the upper and lower Boundary Reservoir (upstream and downstream of Metaline Falls). The Boundary Tailrace was also surveyed for macrophytes to a location just past the boat launch below the dam.

# 4 METHODS

Macrophyte distribution and abundance surveys were conducted in August 2007 when peak growth was assumed to occur. The entire shoreline from Box Canyon tailrace to Boundary Dam was surveyed for the presence of macrophytes. A Global Positioning System (GPS) point was taken every 1,000 meters (3,280 feet) or when macrophytes were encountered. When macrophytes were present, GPS points were taken at the boundaries of these beds and at least every 100 meters (328 feet) along the outside of the beds. Enough points were taken to clearly define the limits of each bed. At each GPS point within the beds, species present and the respective percent cover were recorded. If dewatered and dry macrophytes were encountered, the species identification and the respective percent cover were estimated. The Boundary Tailrace was also surveyed for macrophytes; however, none were found. Verification of macrophyte beds plus the additional mapping of stranding and trapping areas was completed in August 2008.

# 5 FIELD DATA RESULTS

The existing distribution and abundance of macrophytes in upper and lower Boundary Reservoir were assessed during field surveys conducted in August 2007 and August 2008. The macrophyte distribution, abundance, and species present in upper and lower Boundary Reservoir as determined during the macrophyte mapping effort are presented in Attachment A, with an example map presented in Figure 5.0-1. Table 5.0-1 also summarizes the macrophyte species found in upper and lower Boundary Reservoir.

**Table 5.0-1.** Macrophyte species in Boundary Reservoir.

| Scientific Name | Common Name | Status |
|---|---|---|
| *Myriophyllum sibericum* | northern milfoil | Native |
| *Myriophyllum spicatum* | Eurasian watermilfoil | Non-native |
| *Ceratophyllum demersum* | coontail | Native |
| *Elodea canadensis* | common waterweed | Native |
| *Potamogeton crispus* | curly pondweed | Non-native |
| *Potamogeton pectinatus* | sago pondweed | Native |
| *Potamogeton vaginatus* | sheathing pondweed | Native |
| *Potamogeton richardsonii* | Richardson's pondweed | Native |
| *Potamogeton zosteriformis* | flat-stem pondweed | Native |
| *Ranunculus aquatilis* | white water buttercup | Native |

Macrophyte beds within the main reservoir covered 20.7 acres downstream of Metaline Falls and 202.5 acres upstream of Metaline Falls. Aquatic macrophyte beds, mainly in the upper Boundary Reservoir within stranding and trapping areas, covered 25.3 acres. Eurasian watermilfoil (*Potamogeton* species), and coontail (*Ceratophyllum demersum)* were the dominant

plant species found in Boundary Reservoir. Curly pondweed appears to be invading areas of established Eurasian watermilfoil beds displacing both Eurasian watermilfoil and coontail in these more established beds. Table 5.0-2 summarizes the relative number of macrophyte beds found above and below Metaline Falls.

**Table 5.0-2.** Date and locations of macrophyte bed sampling during 2007 and 2008.

| Collection Date | Reservoir Zone[1] | No. of Macrophyte Beds | Macrophyte Bed Size Range (acres) | Total Macrophyte Area (acres) |
|---|---|---|---|---|
| August 25–27, 2007 | Forebay | 12 | 0.001–8.4 | 8.4 |
| August 25–27, 2007 | Canyon | 27 | 0.001-–7.9 | 12.3 |
| August 25–27, 2007 | Upper Reservoir | 33 | 0.02–61.7 | 202.5 |
| August 25–27, 2007 | Tailrace | 0 | 0 | 0 |
| August 18–19, 2008 | Fish stranding and trapping areas above Metaline Falls | 14 | 0.001–9.5 | 24.0 |
| August 18–19, 2008 | Fish stranding and trapping areas below Metaline Falls | 4 | 0.001–1.0 | 1.3 |
| | | | **Total[1]** | **223.2** |

Note:
1 Stranding and trapping areas are included in all reservoir zones.

The distribution and abundance measures were correlated with habitat features in the reservoir including depth, velocity, substrate, and duration of inundation and dewatering. Depths at which macrophytes were found in the 2007 August survey calculated using GPS and bathymetry were crossed-checked with actual depth data collected at habitat transects in August 2007. This cross-check ensures that the most accurate determination of macrophyte habitat was achieved.

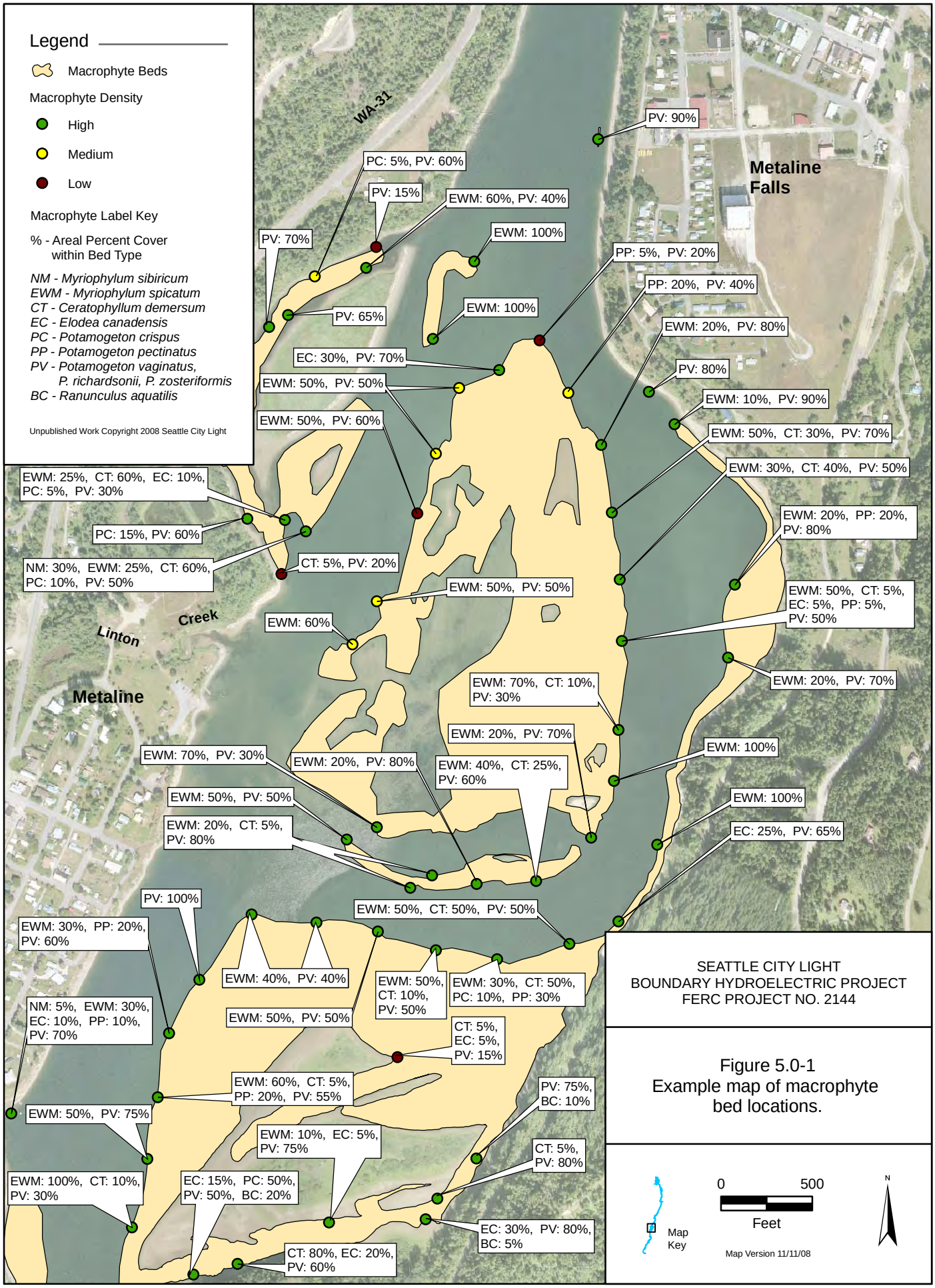
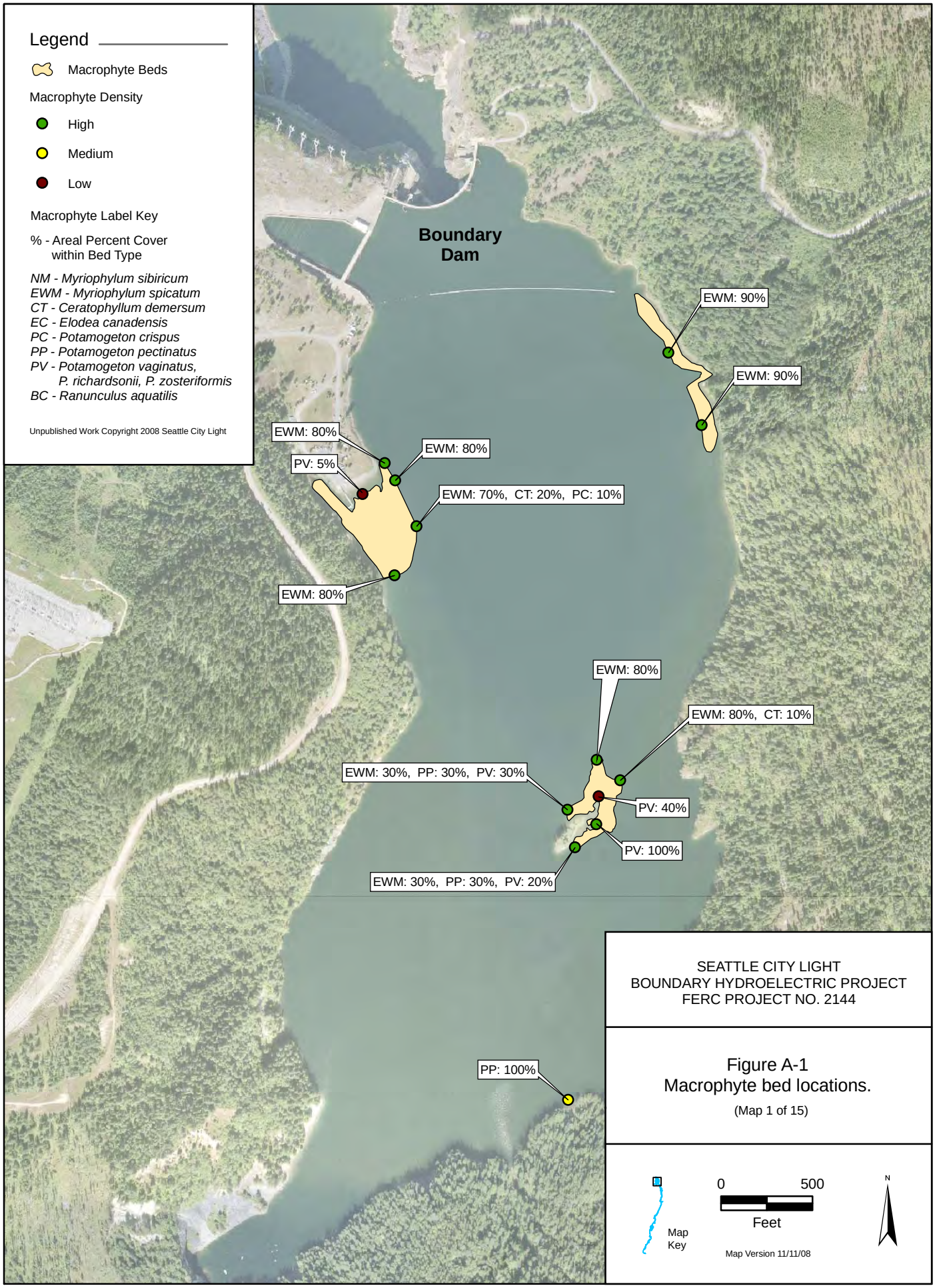
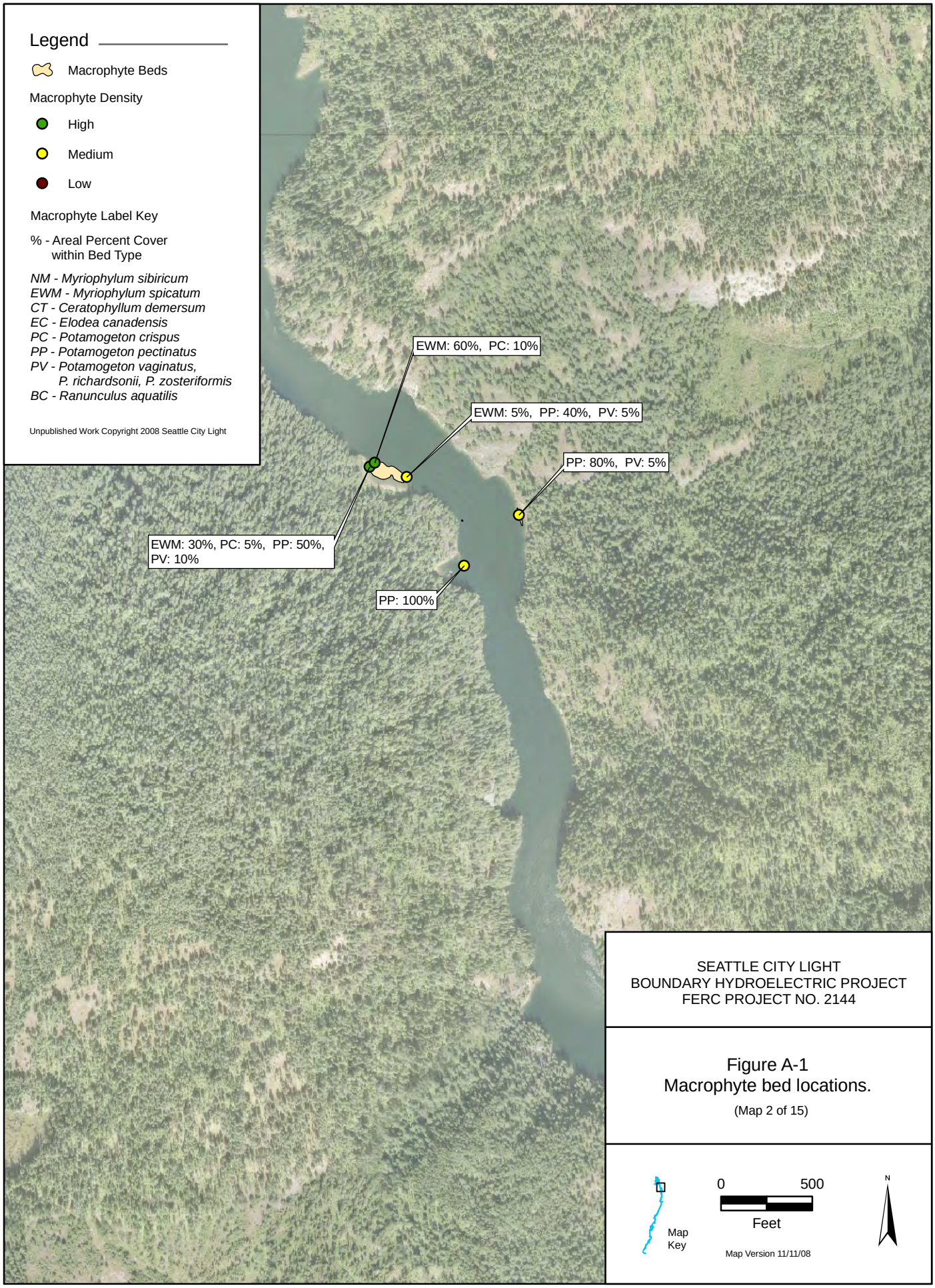



Figure 5.0-1
Example map of macrophyte bed locations.

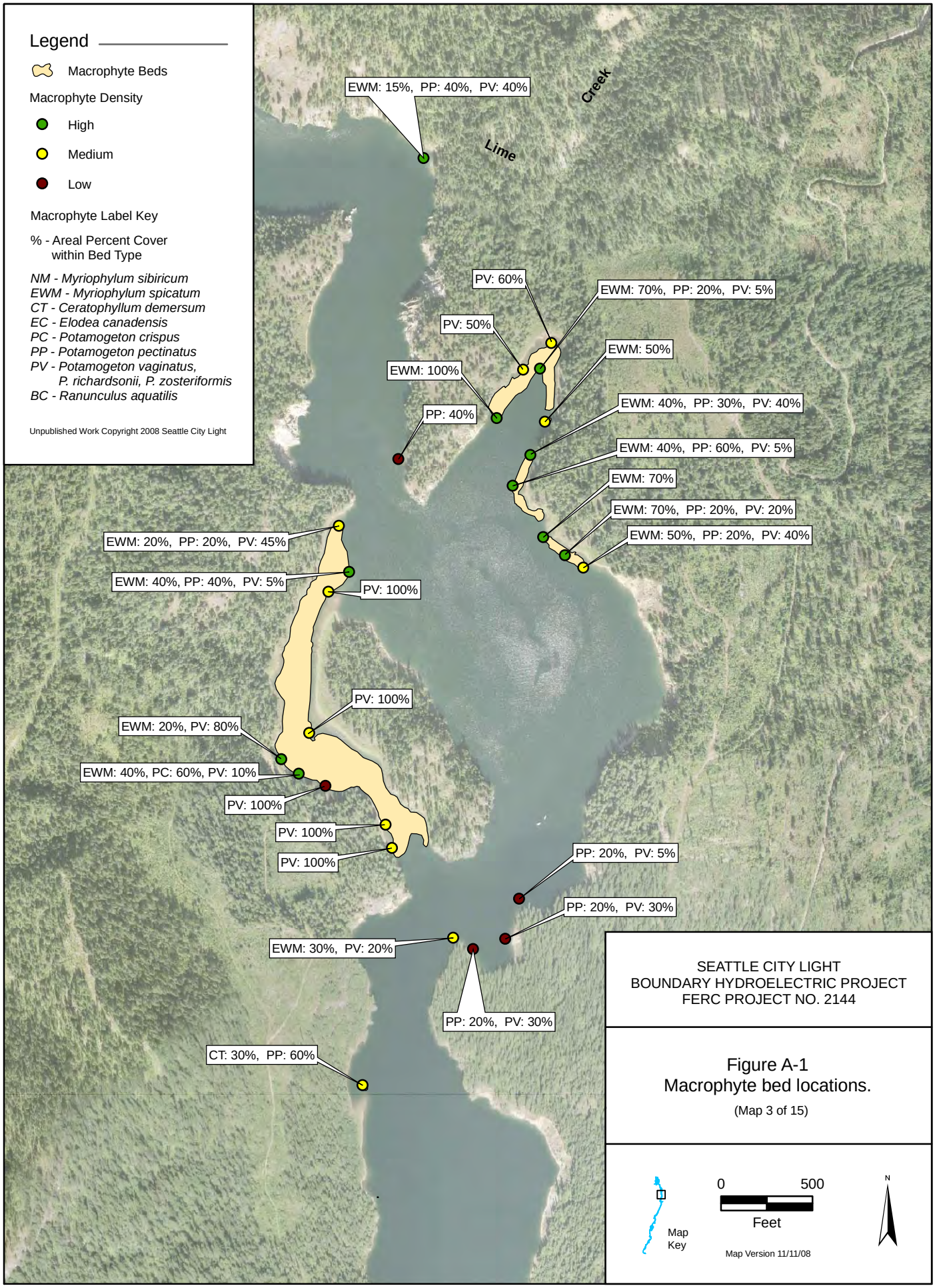
# Attachment A: Maps of Macrophyte Bed Locations


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
Boundary Dam
EWM: 90%
EWM: 90%
EWM: 80%
EWM: 80%
PV: 5%
EWM: 70%, CT: 20%, PC: 10%
EWM: 80%
EWM: 80%
EWM: 80%, CT: 10%
EWM: 30%, PP: 30%, PV: 30%
PV: 40%
PV: 100%
EWM: 30%, PP: 30%, PV: 20%
PP: 100%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 1 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-1
Macrophyte bed locations.
(Map 2 of 15)


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
Lime
Creek
EWM: 15%, PP: 40%, PV: 40%
PV: 60%
EWM: 70%, PP: 20%, PV: 5%
PV: 50%
EWM: 50%
EWM: 100%
EWM: 40%, PP: 30%, PV: 40%
PP: 40%
EWM: 40%, PP: 60%, PV: 5%
EWM: 70%
EWM: 70%, PP: 20%, PV: 20%
EWM: 50%, PP: 20%, PV: 40%
EWM: 20%, PP: 20%, PV: 45%
EWM: 40%, PP: 40%, PV: 5%
PV: 100%
PV: 100%
EWM: 20%, PV: 80%
EWM: 40%, PC: 60%, PV: 10%
PV: 100%
PV: 100%
PV: 100%
PP: 20%, PV: 5%
PP: 20%, PV: 30%
EWM: 30%, PV: 20%
PP: 20%, PV: 30%
CT: 30%, PP: 60%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 3 of 15)
Map Key
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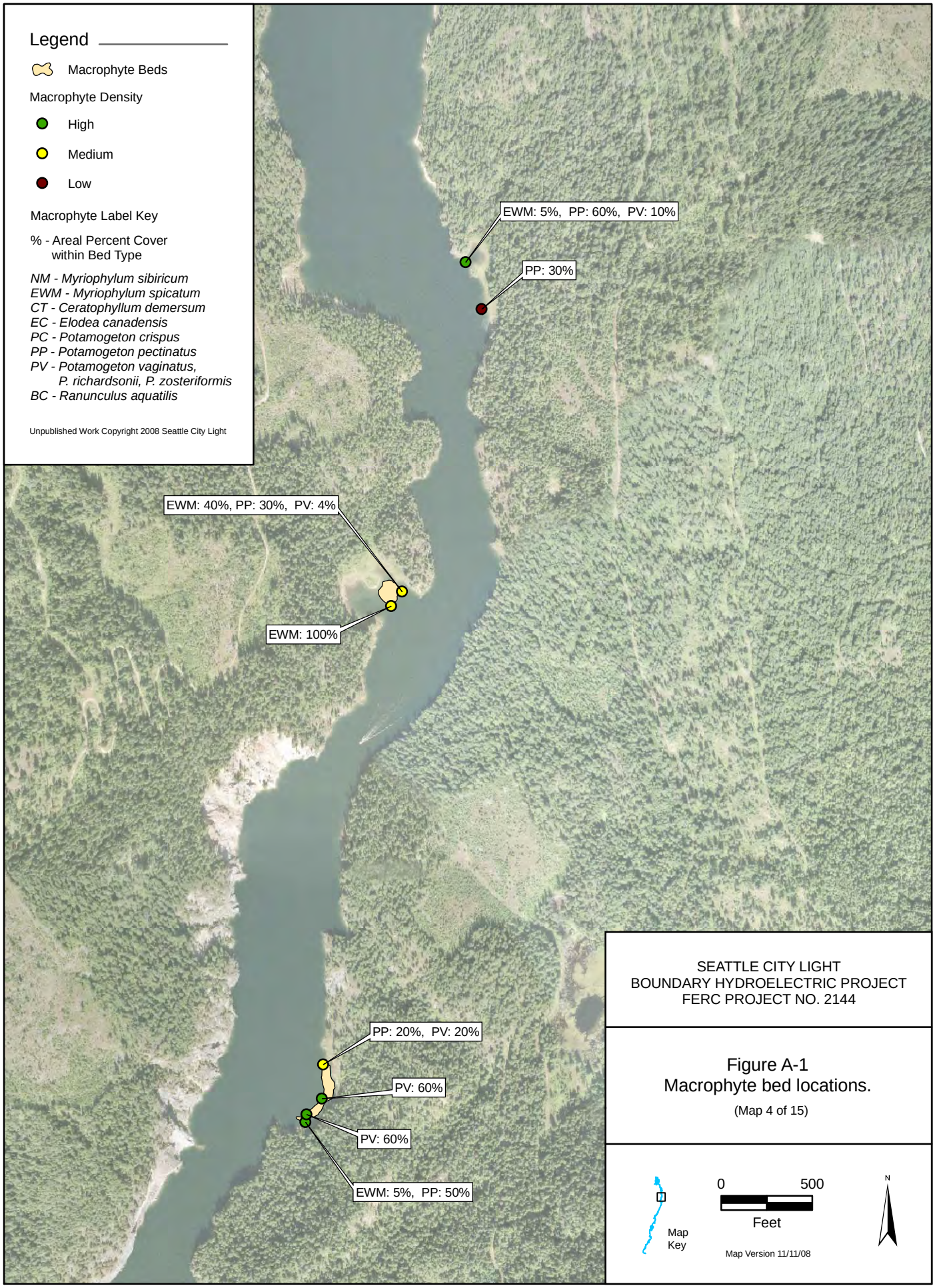
Feet
Map Version 11/11/08
N


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 5%, PP: 60%, PV: 10%
PP: 30%
EWM: 40%, PP: 30%, PV: 4%
EWM: 100%
PP: 20%, PV: 20%
PV: 60%
PV: 60%
EWM: 5%, PP: 50%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 4 of 15)
Map Key
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Map Version 11/11/08
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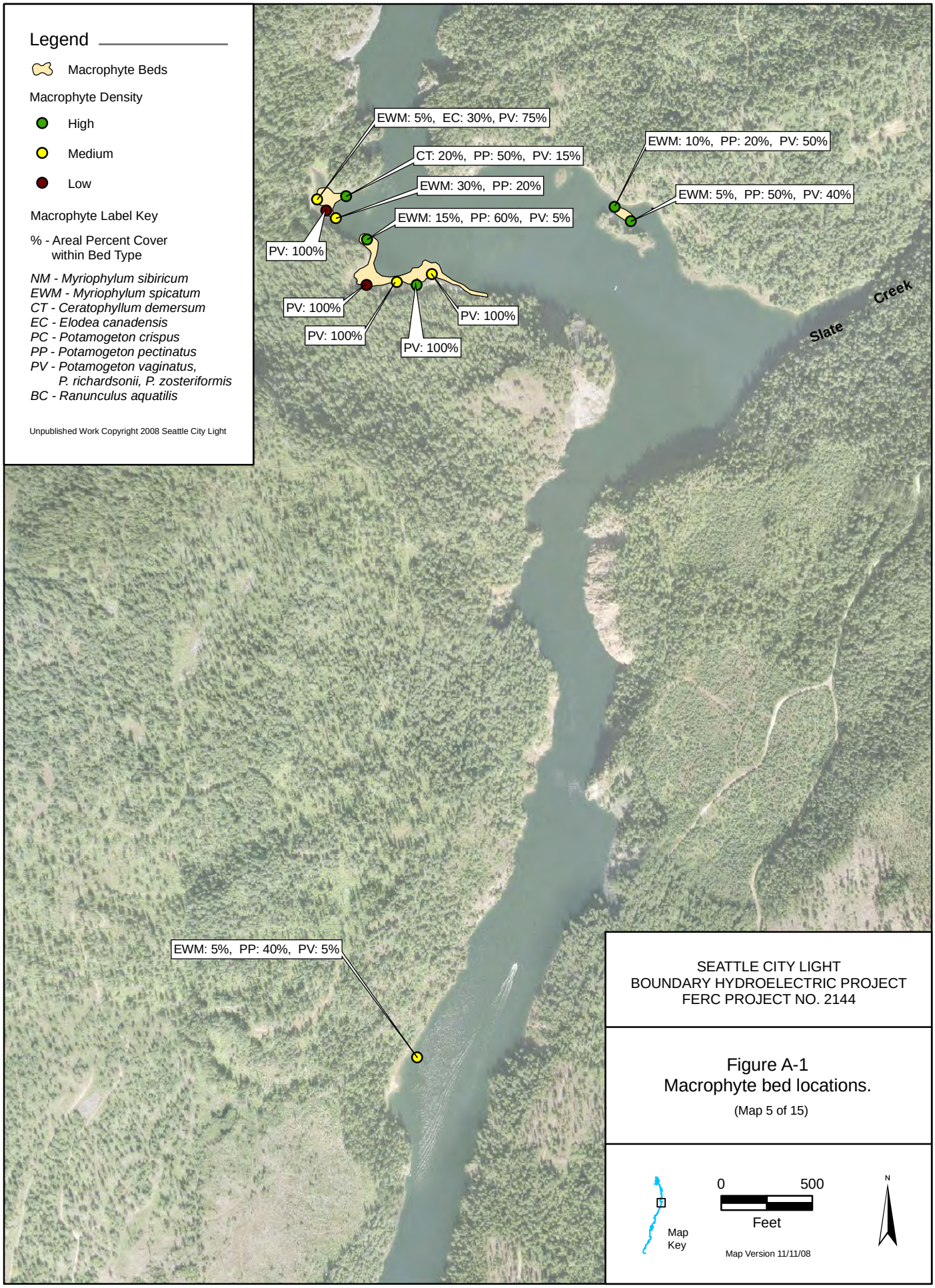
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Macrophyte Density
High
Medium
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Macrophyte Label Key
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NM - Myriophylum sibiricum
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CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 5%, EC: 30%, PV: 75%
CT: 20%, PP: 50%, PV: 15%
EWM: 30%, PP: 20%
EWM: 15%, PP: 60%, PV: 5%
PV: 100%
PV: 100%
PV: 100%
PV: 100%
PV: 100%
EWM: 10%, PP: 20%, PV: 50%
EWM: 5%, PP: 50%, PV: 40%
Slate Creek
EWM: 5%, PP: 40%, PV: 5%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 5 of 15)
Map Key
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Feet
Map Version 11/11/08
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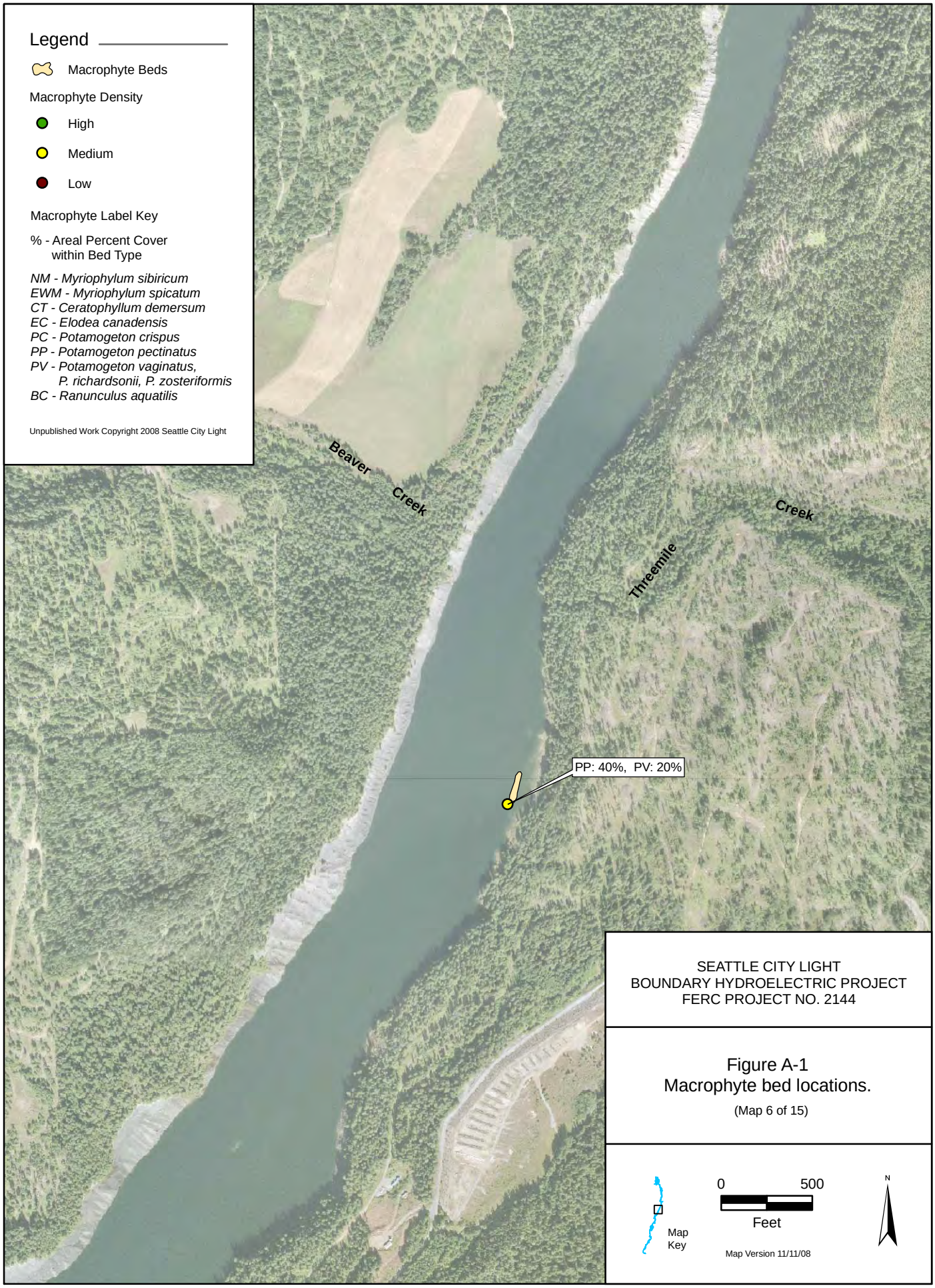
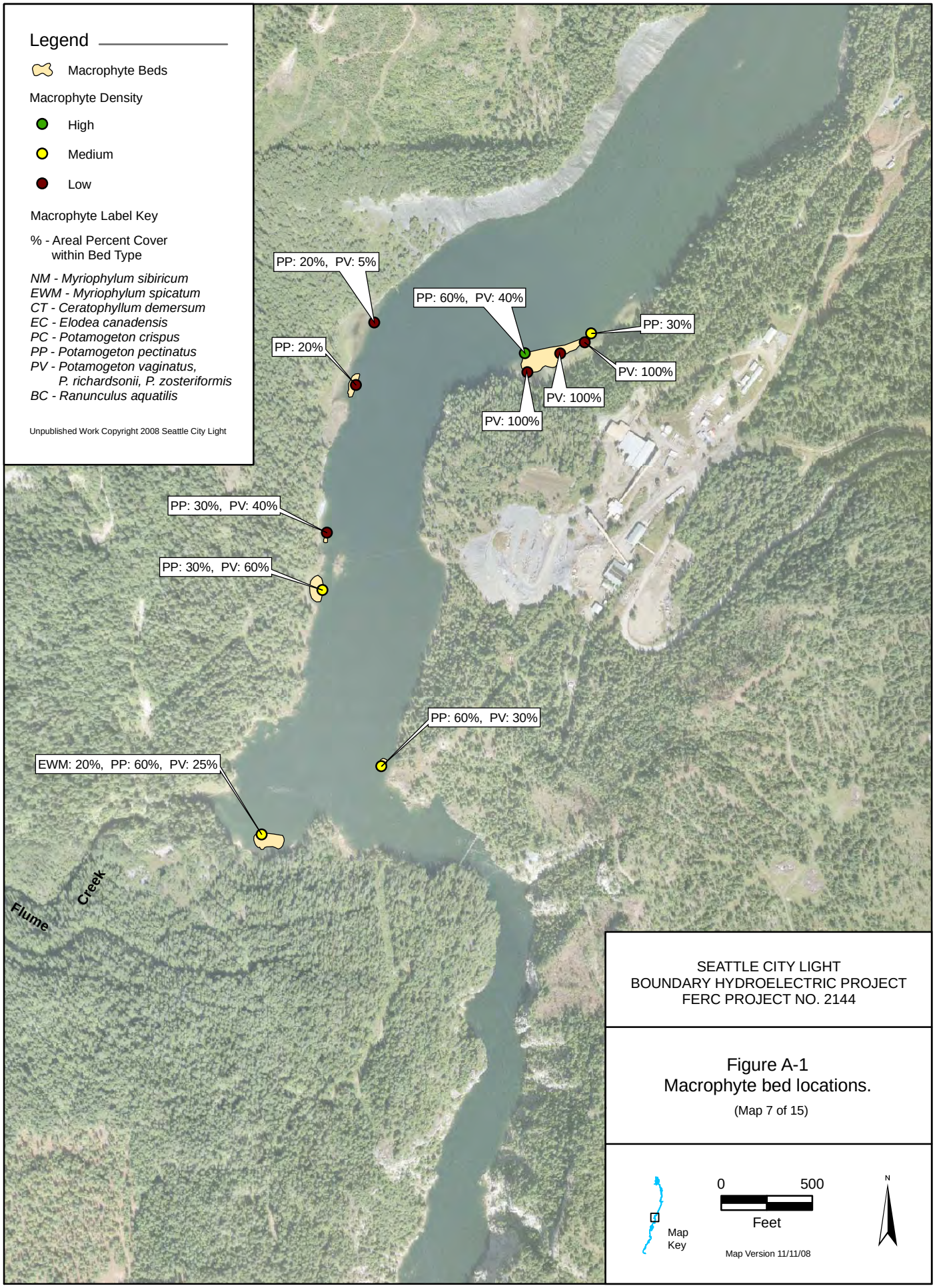
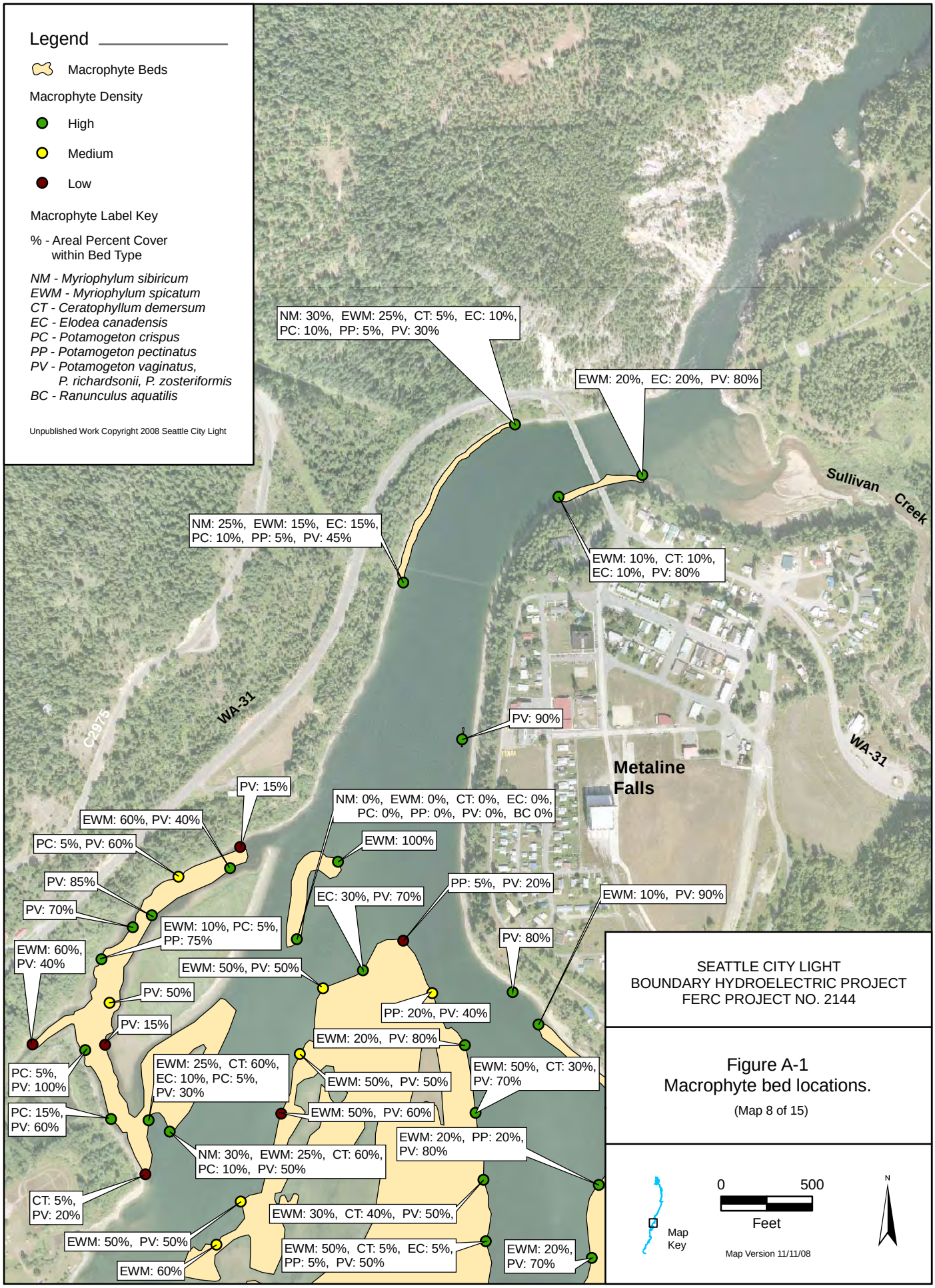



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-1
Macrophyte bed locations.
(Map 6 of 15)


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
PP: 20%, PV: 5%
PP: 60%, PV: 40%
PP: 30%
PP: 20%
PV: 100%
PV: 100%
PV: 100%
PP: 30%, PV: 40%
PP: 30%, PV: 60%
PP: 60%, PV: 30%
EWM: 20%, PP: 60%, PV: 25%
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 7 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
NM: 30%, EWM: 25%, CT: 5%, EC: 10%, PC: 10%, PP: 5%, PV: 30%
EWM: 20%, EC: 20%, PV: 80%
Sullivan Creek
NM: 25%, EWM: 15%, EC: 15%, PC: 10%, PP: 5%, PV: 45%
EWM: 10%, CT: 10%, EC: 10%, PV: 80%
WA-31
C2975
PV: 90%
Metaline Falls
WA-31
PV: 15%
NM: 0%, EWM: 0%, CT: 0%, EC: 0%, PC: 0%, PP: 0%, PV: 0%, BC 0%
EWM: 60%, PV: 40%
PC: 5%, PV: 60%
EWM: 100%
PV: 85%
PP: 5%, PV: 20%
EC: 30%, PV: 70%
EWM: 10%, PV: 90%
PV: 70%
EWM: 10%, PC: 5%, PP: 75%
PV: 80%
EWM: 60%, PV: 40%
EWM: 50%, PV: 50%
PV: 50%
PP: 20%, PV: 40%
PV: 15%
EWM: 20%, PV: 80%
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EWM: 50%, PV: 50%
EWM: 50%, CT: 30%, PV: 70%
PC: 15%, PV: 60%
EWM: 50%, PV: 60%
EWM: 20%, PP: 20%, PV: 80%
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CT: 5%, PV: 20%
EWM: 30%, CT: 40%, PV: 50%,
EWM: 50%, PV: 50%
EWM: 50%, CT: 5%, EC: 5%, PP: 5%, PV: 50%
EWM: 20%, PV: 70%
EWM: 60%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 8 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
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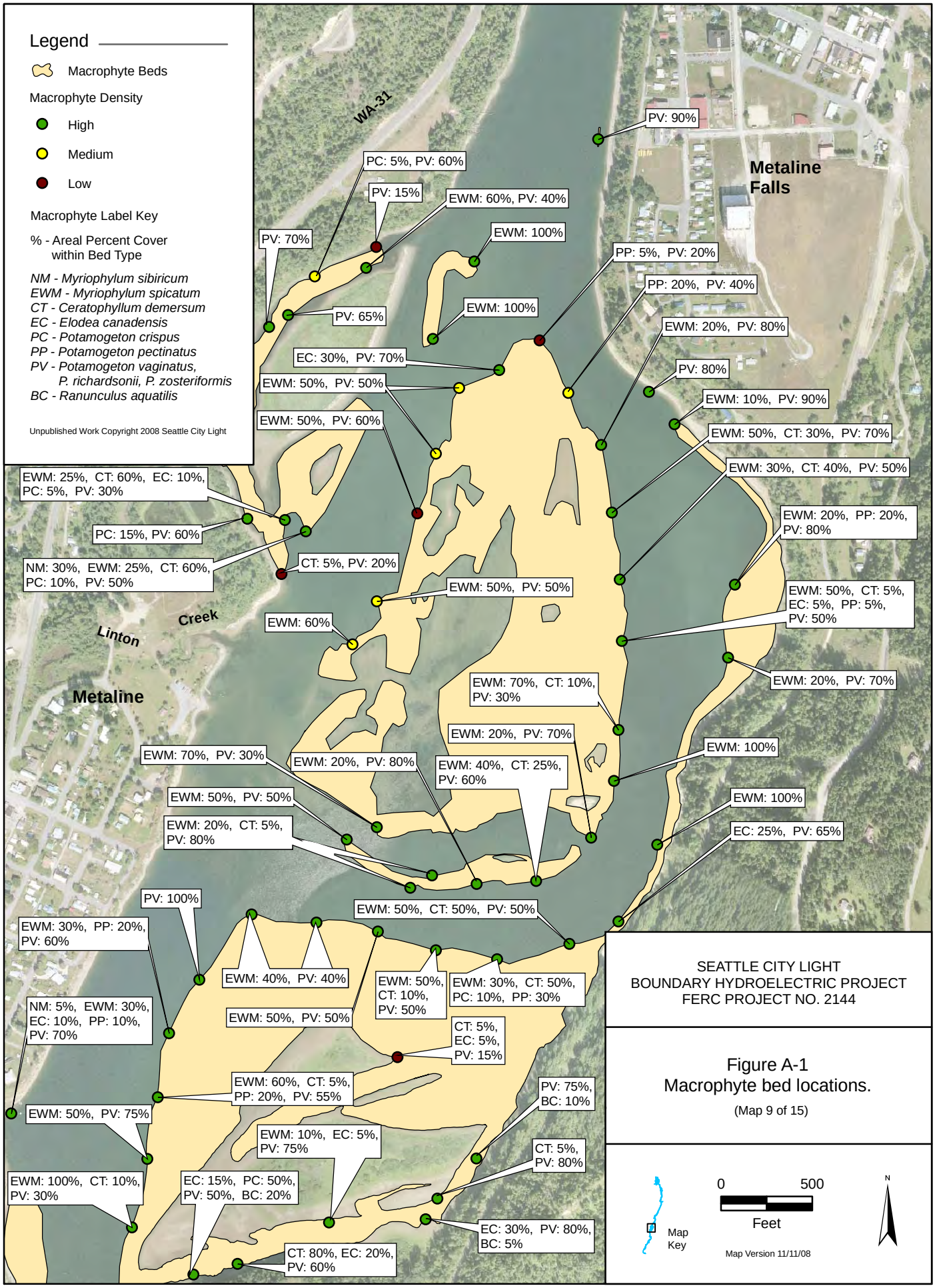
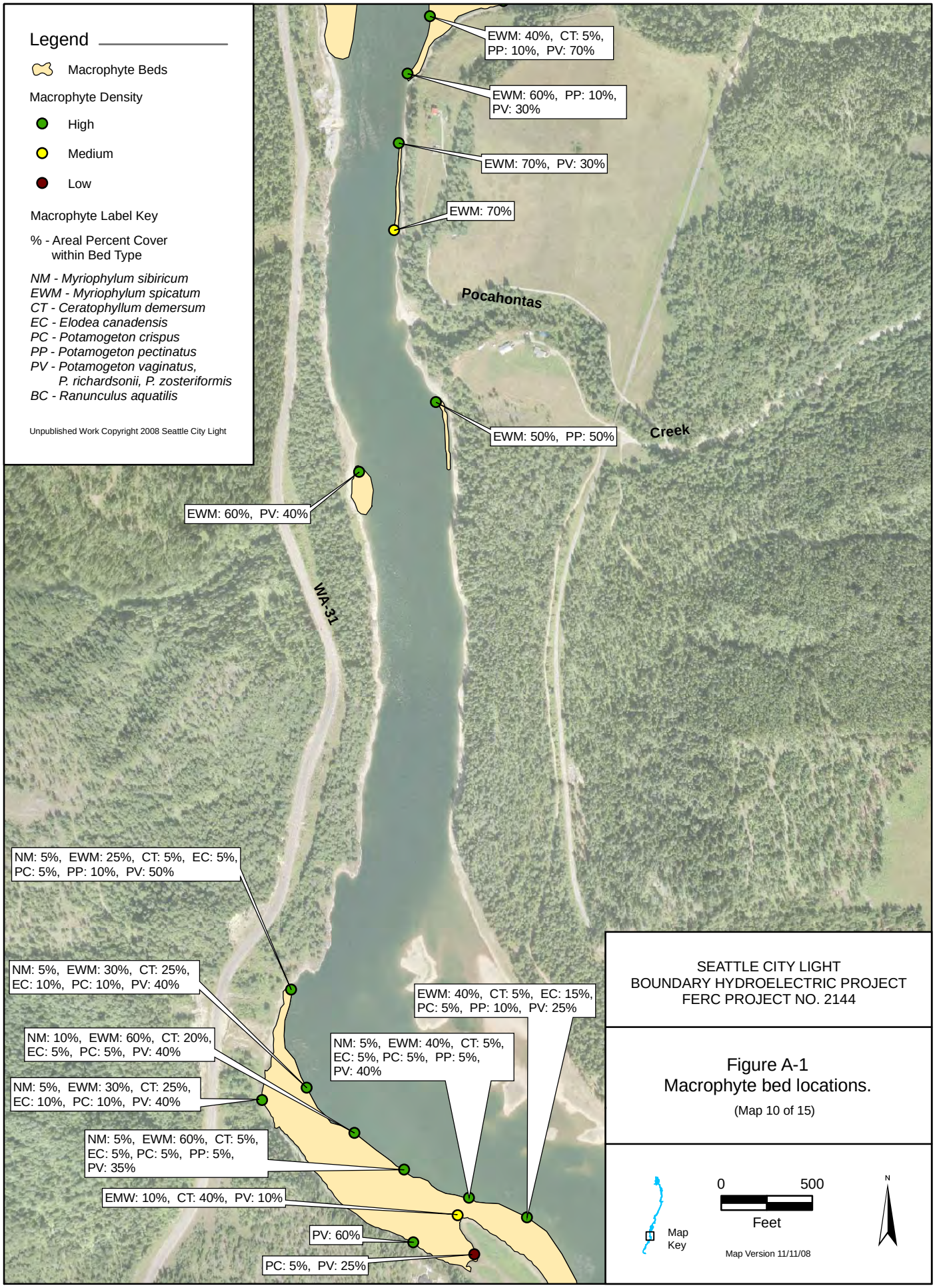
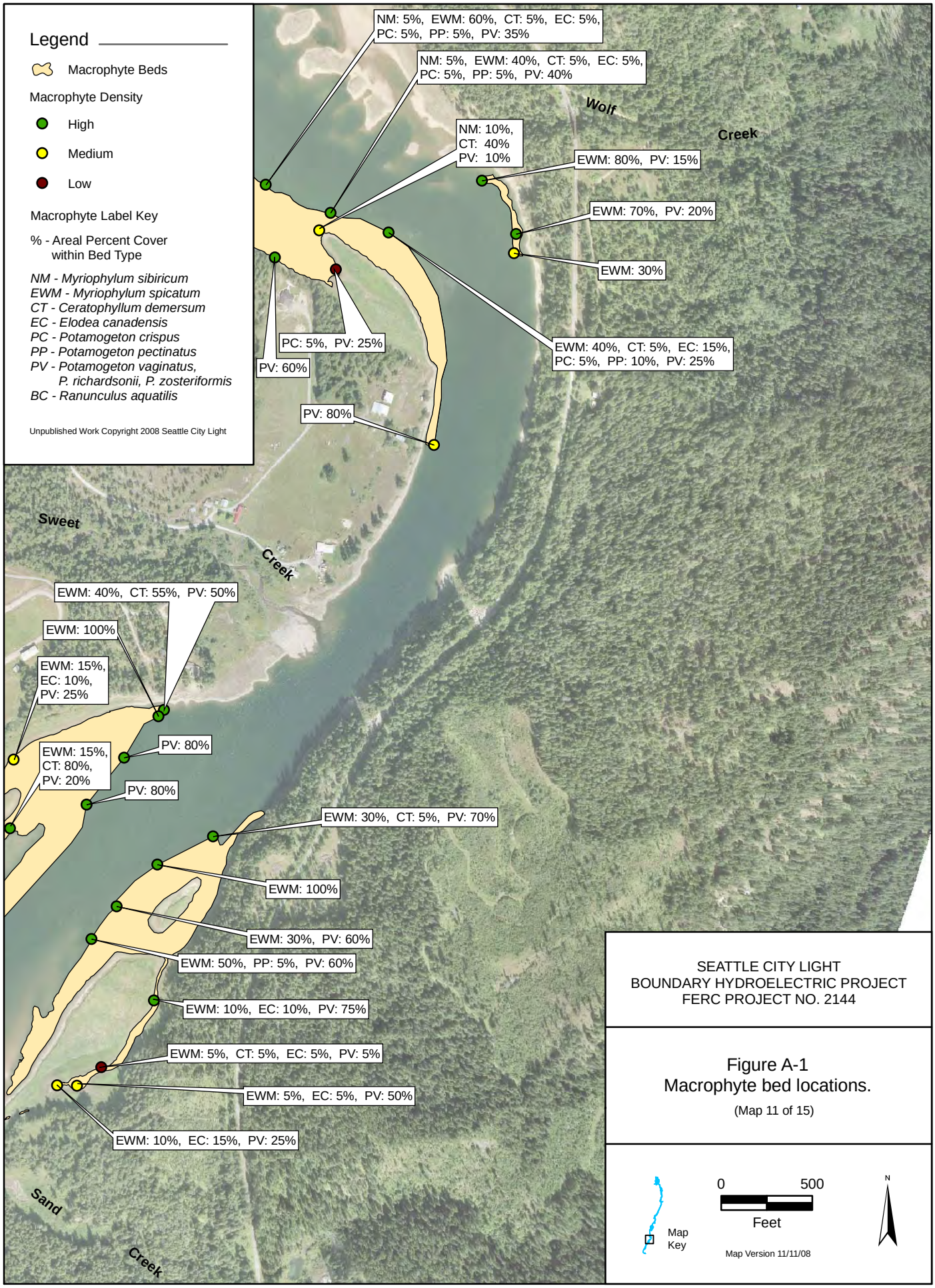

Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
WA-31
Metaline Falls
Linton Creek
Metaline
PV: 90%
PC: 5%, PV: 60%
PV: 15%
EWM: 60%, PV: 40%
EWM: 100%
PV: 70%
PV: 65%
EWM: 100%
PP: 5%, PV: 20%
PP: 20%, PV: 40%
EWM: 20%, PV: 80%
EC: 30%, PV: 70%
EWM: 50%, PV: 50%
PV: 80%
EWM: 10%, PV: 90%
EWM: 50%, PV: 60%
EWM: 50%, CT: 30%, PV: 70%
EWM: 30%, CT: 40%, PV: 50%
EWM: 25%, CT: 60%, EC: 10%, PC: 5%, PV: 30%
PC: 15%, PV: 60%
EWM: 20%, PP: 20%, PV: 80%
NM: 30%, EWM: 25%, CT: 60%, PC: 10%, PV: 50%
CT: 5%, PV: 20%
EWM: 50%, PV: 50%
EWM: 50%, CT: 5%, EC: 5%, PP: 5%, PV: 50%
EWM: 60%
EWM: 20%, PV: 70%
EWM: 70%, CT: 10%, PV: 30%
EWM: 20%, PV: 70%
EWM: 100%
EWM: 70%, PV: 30%
EWM: 20%, PV: 80%
EWM: 40%, CT: 25%, PV: 60%
EWM: 50%, PV: 50%
EWM: 100%
EWM: 20%, CT: 5%, PV: 80%
EC: 25%, PV: 65%
PV: 100%
EWM: 50%, CT: 50%, PV: 50%
EWM: 30%, PP: 20%, PV: 60%
EWM: 40%, PV: 40%
EWM: 50%, CT: 10%, PV: 50%
EWM: 30%, CT: 50%, PC: 10%, PP: 30%
NM: 5%, EWM: 30%, EC: 10%, PP: 10%, PV: 70%
EWM: 50%, PV: 50%
CT: 5%, EC: 5%, PV: 15%
EWM: 60%, CT: 5%, PP: 20%, PV: 55%
PV: 75%, BC: 10%
EWM: 50%, PV: 75%
EWM: 10%, EC: 5%, PV: 75%
CT: 5%, PV: 80%
EWM: 100%, CT: 10%, PV: 30%
EC: 15%, PC: 50%, PV: 50%, BC: 20%
EC: 30%, PV: 80%, BC: 5%
CT: 80%, EC: 20%, PV: 60%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 9 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 40%, CT: 5%, PP: 10%, PV: 70%
EWM: 60%, PP: 10%, PV: 30%
EWM: 70%, PV: 30%
EWM: 70%
Pocahontas
Creek
EWM: 50%, PP: 50%
EWM: 60%, PV: 40%
WA-31
NM: 5%, EWM: 25%, CT: 5%, EC: 5%, PC: 5%, PP: 10%, PV: 50%
NM: 5%, EWM: 30%, CT: 25%, EC: 10%, PC: 10%, PV: 40%
EWM: 40%, CT: 5%, EC: 15%, PC: 5%, PP: 10%, PV: 25%
NM: 10%, EWM: 60%, CT: 20%, EC: 5%, PC: 5%, PV: 40%
NM: 5%, EWM: 40%, CT: 5%, EC: 5%, PC: 5%, PP: 5%, PV: 40%
NM: 5%, EWM: 30%, CT: 25%, EC: 10%, PC: 10%, PV: 40%
NM: 5%, EWM: 60%, CT: 5%, EC: 5%, PC: 5%, PP: 5%, PV: 35%
EMW: 10%, CT: 40%, PV: 10%
PV: 60%
PC: 5%, PV: 25%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 10 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N


Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
NM: 5%, EWM: 60%, CT: 5%, EC: 5%, PC: 5%, PP: 5%, PV: 35%
NM: 5%, EWM: 40%, CT: 5%, EC: 5%, PC: 5%, PP: 5%, PV: 40%
Wolf
Creek
NM: 10%, CT: 40% PV: 10%
EWM: 80%, PV: 15%
EWM: 70%, PV: 20%
EWM: 30%
PC: 5%, PV: 25%
PV: 60%
EWM: 40%, CT: 5%, EC: 15%, PC: 5%, PP: 10%, PV: 25%
PV: 80%
Sweet
Creek
EWM: 40%, CT: 55%, PV: 50%
EWM: 100%
EWM: 15%, EC: 10%, PV: 25%
PV: 80%
EWM: 15%, CT: 80%, PV: 20%
PV: 80%
EWM: 30%, CT: 5%, PV: 70%
EWM: 100%
EWM: 30%, PV: 60%
EWM: 50%, PP: 5%, PV: 60%
EWM: 10%, EC: 10%, PV: 75%
EWM: 5%, CT: 5%, EC: 5%, PV: 5%
EWM: 5%, EC: 5%, PV: 50%
EWM: 10%, EC: 15%, PV: 25%
Sand
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 11 of 15)
Map Key
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500
Feet
Map Version 11/11/08
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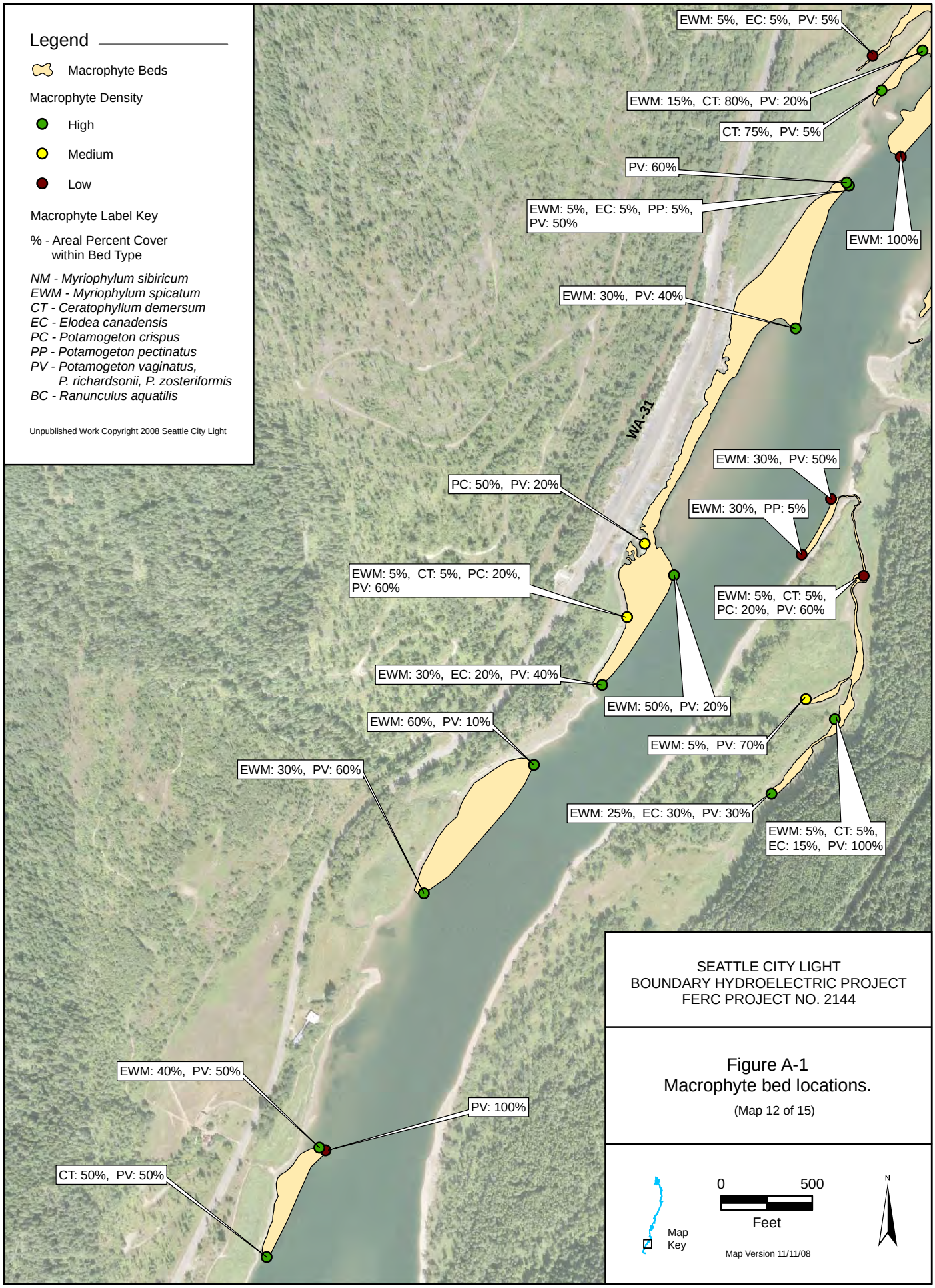
Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
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EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 5%, EC: 5%, PV: 5%
EWM: 15%, CT: 80%, PV: 20%
CT: 75%, PV: 5%
PV: 60%
EWM: 5%, EC: 5%, PP: 5%, PV: 50%
EWM: 100%
EWM: 30%, PV: 40%
WA-31
EWM: 30%, PV: 50%
PC: 50%, PV: 20%
EWM: 30%, PP: 5%
EWM: 5%, CT: 5%, PC: 20%, PV: 60%
EWM: 5%, CT: 5%, PC: 20%, PV: 60%
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EWM: 50%, PV: 20%
EWM: 60%, PV: 10%
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EWM: 40%, PV: 50%
PV: 100%
CT: 50%, PV: 50%
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 12 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
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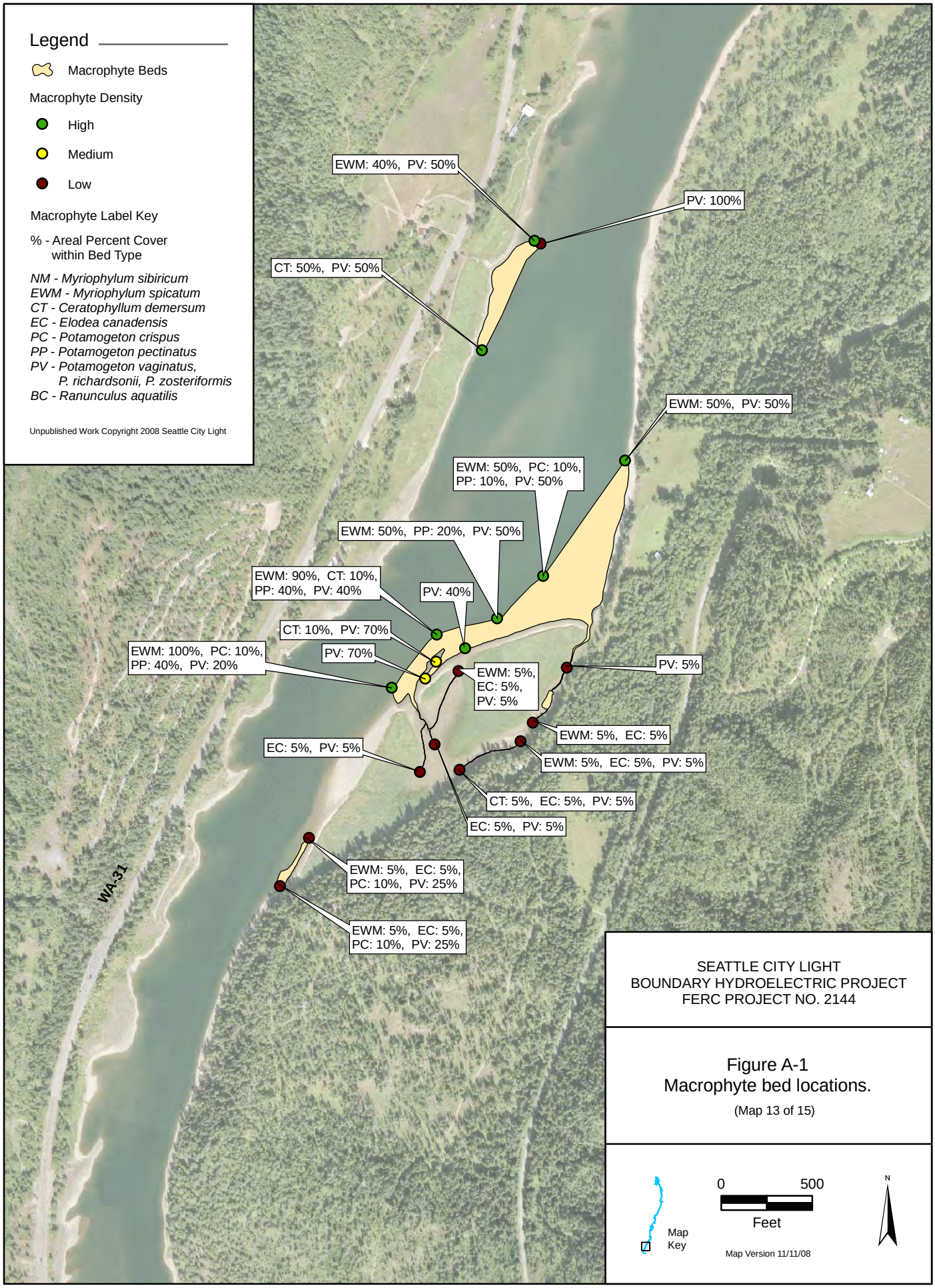
Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
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CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 40%, PV: 50%
PV: 100%
CT: 50%, PV: 50%
EWM: 50%, PV: 50%
EWM: 50%, PC: 10%, PP: 10%, PV: 50%
EWM: 50%, PP: 20%, PV: 50%
EWM: 90%, CT: 10%, PP: 40%, PV: 40%
PV: 40%
CT: 10%, PV: 70%
PV: 70%
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EWM: 5%, EC: 5%, PV: 5%
PV: 5%
EWM: 5%, EC: 5%
EC: 5%, PV: 5%
EWM: 5%, EC: 5%, PV: 5%
CT: 5%, EC: 5%, PV: 5%
EC: 5%, PV: 5%
EWM: 5%, EC: 5%, PC: 10%, PV: 25%
EWM: 5%, EC: 5%, PC: 10%, PV: 25%
WA-31
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 13 of 15)
Map Key
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500
Feet
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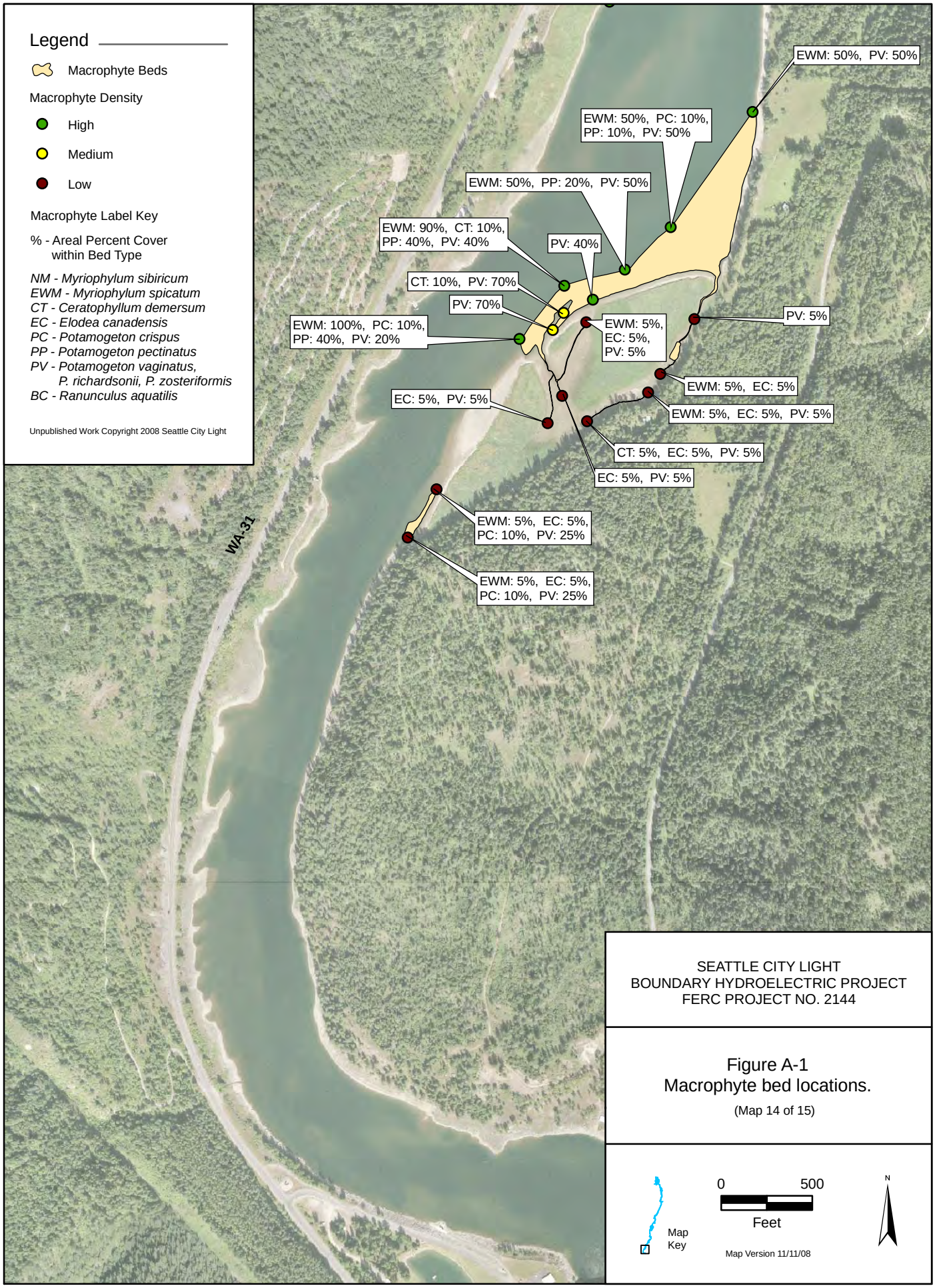
Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
EWM: 50%, PV: 50%
EWM: 50%, PC: 10%, PP: 10%, PV: 50%
EWM: 50%, PP: 20%, PV: 50%
EWM: 90%, CT: 10%, PP: 40%, PV: 40%
PV: 40%
CT: 10%, PV: 70%
PV: 70%
EWM: 100%, PC: 10%, PP: 40%, PV: 20%
EWM: 5%, EC: 5%, PV: 5%
PV: 5%
EWM: 5%, EC: 5%
EWM: 5%, EC: 5%, PV: 5%
EC: 5%, PV: 5%
CT: 5%, EC: 5%, PV: 5%
EC: 5%, PV: 5%
EWM: 5%, EC: 5%, PC: 10%, PV: 25%
EWM: 5%, EC: 5%, PC: 10%, PV: 25%
WA-31
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 14 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N

Legend
Macrophyte Beds
Macrophyte Density
High
Medium
Low
Macrophyte Label Key
% - Areal Percent Cover within Bed Type
NM - Myriophylum sibiricum
EWM - Myriophylum spicatum
CT - Ceratophyllum demersum
EC - Elodea canadensis
PC - Potamogeton crispus
PP - Potamogeton pectinatus
PV - Potamogeton vaginatus, P. richardsonii, P. zosteriformis
BC - Ranunculus aquatilis
Unpublished Work Copyright 2008 Seattle City Light
Box Canyon Dam
WA-31
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Macrophyte bed locations.
(Map 15 of 15)
Map Key
0
500
Feet
Map Version 11/11/08
N

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# Appendix 1c. Stranding and Trapping GIS Mapping and Physical Characteristics Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 1c*

## *Stranding and Trapping GIS Mapping and Physical Characteristics*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Bill Fullerton, Justin Nodolf, and Morgan Omdal**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 1c
# Stranding and Trapping GIS Mapping and Physical Characteristics Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

This report presents the results of the stranding and trapping mapping effort for Study 7, Mainstem Aquatic Habitat Modeling Study, and was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by FERC in its Study Plan Determination letter dated March 15, 2007. This final report describes the study efforts associated with the stranding and trapping Geographic Information System (GIS) maps and the development of the physical characteristics associated with these areas.

Maps depicting the stranding areas and trapping pools within the study area were developed using GIS. Physical characteristics derived either directly from GIS coverages or from GIS-based parameters were the basis for development of site factors used in the stranding and trapping analysis. Characteristics such as area, outlet elevations, and the presence of macrophytes were compiled into a geospatial database. This database provided several inputs used in the stranding and trapping models discussed in Appendix 4 and Sections 4.4 and 5.4 of the Study 7, Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009).

## 2 OBJECTIVES

The goal of the stranding and trapping GIS mapping effort was to provide accurate mapping products to support field efforts in locating and characterizing areas where fish may become stranded or trapped during reduction in water surface elevations. Additionally, the mapping effort provided an accurate basis for characterizing the stranding and trapping areas to conduct the modeling effort. Specific tasks or objectives to accomplish the goals of this effort included the following:

- Identify possible stranding areas and trapping pools
- Identify physical characteristics of stranding areas (e.g., area, slope, macrophyte coverage, etc.)
- Identify physical characteristics of trapping pools (e.g., area, elevation, substrate, and vegetation)

## 3 STUDY AREA

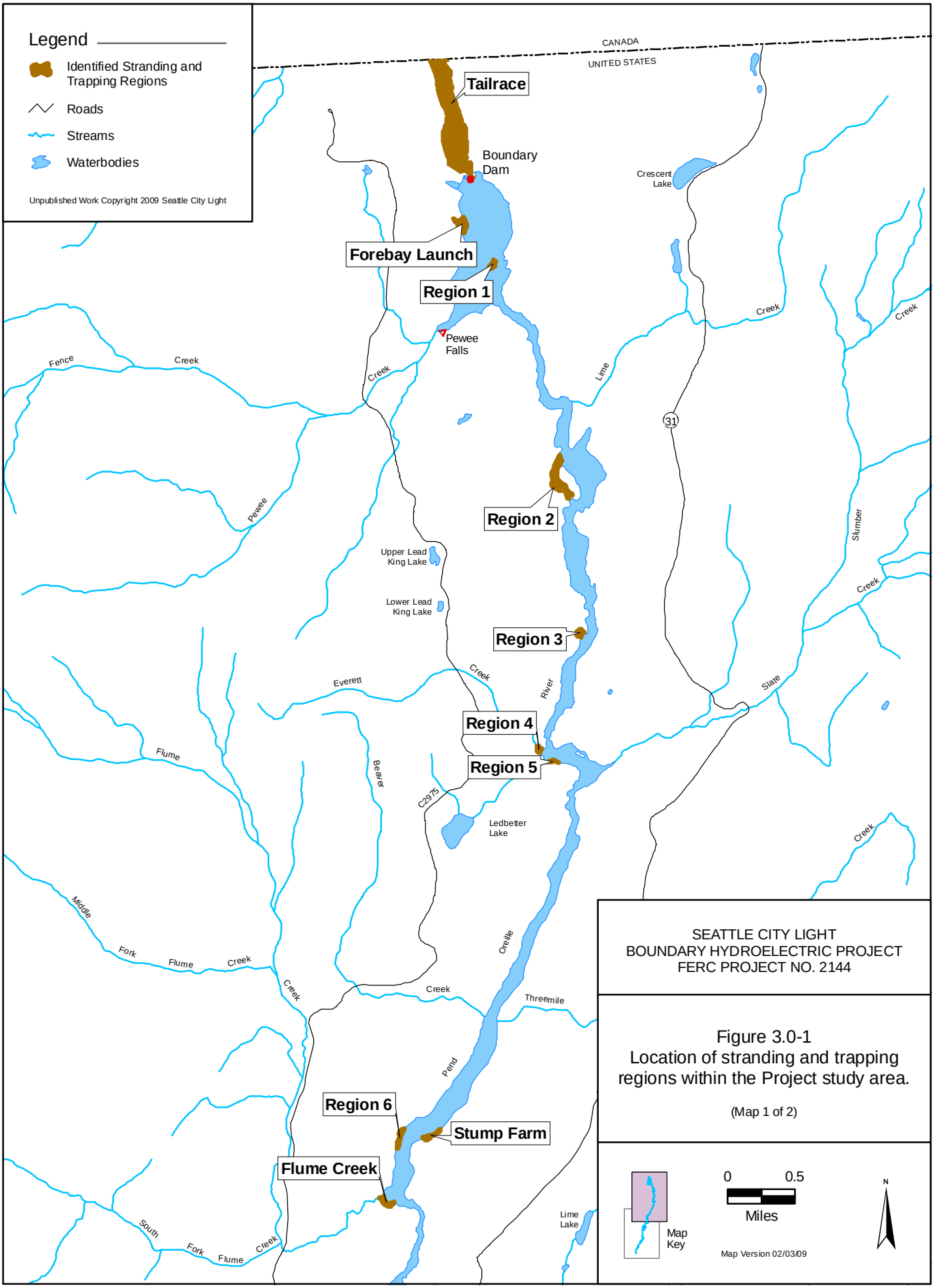
The study area for the stranding and trapping GIS mapping effort coincides with the detailed study area for Study 7. It includes all of Boundary Reservoir and portions of the Pend Oreille

River mainstem downstream of Boundary Dam that could potentially be affected by operations scenarios and extends to the confluence with Red Bird Creek.

The study area is divided into the following four reaches:

- Upper Reservoir Reach—Box Canyon Dam to Metaline Falls (Project river mile [PRM] 34.5–26.8)
- Canyon Reach—Metaline Falls to downstream end of Z-Canyon (PRM 26.8–18.0)
- Forebay Reach—Downstream end of Z-Canyon to Boundary Dam (PRM 18.0–17.0)
- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

In 2007, initial investigations of trapping and stranding conditions conducted through field reconnaissance and review of aerial photographs and the bathymetric mapping indicated there were distinct regions within the study area where areas for potential stranding and trapping were concentrated. This resulted in the decision to divide the study area into 23 regions. The location of the study area as well the identified regions are presented in Figure 3.0-1.


Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
CANADA
UNITED STATES
Tailrace
Boundary Dam
Crescent Lake
Forebay Launch
Region 1
Pewee Falls
Fence
Creek
Pewee
Lime
31
Region 2
Upper Lead King Lake
Lower Lead King Lake
Slumber
Region 3
Everett
River
Slate
Region 4
Region 5
Flume
Beaver
C2975
Ledbetter Lake
Middle
Fork
Orville
Threemile
Pend
Region 6
Stump Farm
Flume Creek
South
Lime Lake
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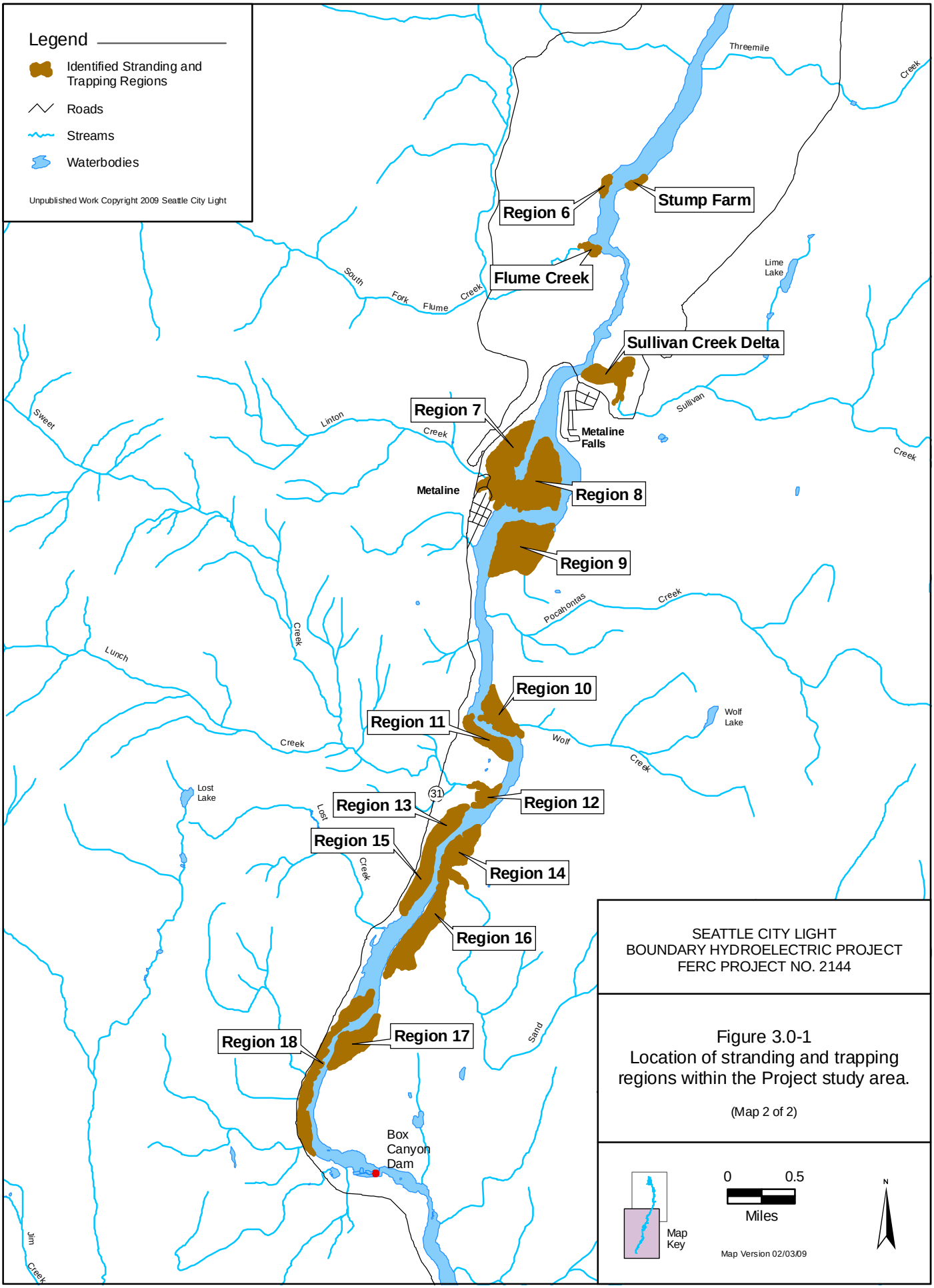
FERC PROJECT NO. 2144
Figure 3.0-1
Location of stranding and trapping regions within the Project study area.
(Map 1 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
N


Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
Threemile
Creek
Region 6
Stump Farm
Flume Creek
South
Fork
Flume
Creek
Lime Lake
Sullivan Creek Delta
Sullivan
Creek
Sweet
Linton
Creek
Region 7
Metaline Falls
Metaline
Region 8
Region 9
Pocahontas
Creek
Lunch
Creek
Region 10
Region 11
Wolf Lake
Wolf
Creek
Creek
Lost Lake
31
Region 13
Region 12
Lost
Region 15
Creek
Region 14
Region 16
Region 18
Region 17
Sand
Box Canyon Dam
Jim
Creek
SEATTLE CITY LIGHT
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FERC PROJECT NO. 2144
Figure 3.0-1
Location of stranding and trapping regions within the Project study area.
(Map 2 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
N

# 4 METHODS

This section presents the methods used to identify and perform field verification data collection of the stranding areas and trapping pools. The steps in this process include GIS-based identification of stranding and trapping pools, field verification of GIS-based information, adjustments to trapping pools based on field verification, and development of physical characteristic parameters associated with the stranding areas and trapping pools.

## 4.1. GIS-Based Analysis

Detailed mapping of potential stranding and trapping regions was developed from the bathymetry of the Boundary Reservoir and tailrace using ArcGIS (version 9.2). The resulting maps serve two primary purposes. The first is aiding field efforts in locating and characterizing areas where fish may become stranded or trapped during reduction in water surface elevations. The second is providing an accurate basis for characterizing the stranding and trapping regions to conduct the modeling effort described in Appendix 4 and Sections 4.4 and 5.4 of the main body of the report. Use of the GIS system allowed for the incorporation of both physical and biological conditions on a geographic basis to determine the characteristics used for the stranding and trapping modeling effort discussed in Appendix 4 and Sections 4.4 and 5.4. Information in addition to the bathymetry, such as macrophyte mapping, can be overlaid on the stranding and trapping maps to further aid in the development of the site characteristics. Many of the site characteristics that are used to develop the stranding and trapping parameters and to link with the Hydraulic Routing Model (HRM) are developed from the mapping through application of the GIS tools.

### 4.1.1. Identify Potential Stranding and Trapping Areas

The development of the GIS map included multiple steps and sources of information. The first step was developing the initial criteria for areas to consider as potential stranding and trapping areas. Potential stranding areas were considered to be areas with low slope, generally less than 4 percent gradient. Trapping areas are regions where depressions or pools form when mainstem river water surface elevations drop below the lowest sill point or draining channel opening of the pool.

The detailed bathymetric data, which were developed from bathymetric surveys and shoreline light detection and ranging (LiDAR), were used to develop the maps for the two categories of areas—stranding and trapping. The overall elevation measurement points were on approximately 3-foot centers for the bathymetry and 6-foot centers for the LiDAR. The majority of the potential stranding and trapping area was based on the 3-foot center bathymetric surveys.

### 4.1.2. Refine Elevation Limits for Stranding and Trapping Areas

The development of the potential stranding and trapping sites was performed for the entire study area and included the range of elevations which become inundated and then dewatered over the limit of potential Project operations. High flow elevations that occur only during spring freshet or floods were also included in this analysis because stranding and trapping can occur on the recession limb of the inflow hydrograph. Therefore, the first step in the development of the potential stranding and trapping maps was to determine the range of elevations that become dewatered in the case of stranding areas or become isolated pools in the case of trapping. The

hydraulic routing model of reservoir elevations was run for two flow conditions to determine the ranges of elevation in the respective reservoir regions that would become inundated and then dewatered (Figures 4.1-1 and 4.1-2).

The model of reservoir elevation was run for constant low flow of 4,000 cubic feet per second (cfs) and constant high flow of 136,000 cfs with a corresponding forebay elevations of 1,954 feet NAVD 88 (1,950 feet NGVD 29)[1] and 1,994 feet NAVD 88 (1,990 feet NGVD 29), respectively. The lower elevation represents the low pool, low flow condition while the upper elevation represents the high pool, high flow condition. The runs were performed with the maximum and minimum forebay elevation that could occur for existing Project operations as authorized under the existing license to indicate the upper and lower ranges of potential Project operations in Boundary Reservoir. As shown in Figure 4.1-1, the upper reservoir above Metaline Falls has an elevation range that varies between 36 to 40 feet between the low pool, low flow condition and the high pool, high flow condition. Water surface elevations below Metaline Falls have an elevation range that varies between 40 to 53 feet between the two conditions. Elevations presented in Figure 4.1-1 were used as the basis of the upper and lower bounds of the stranding areas and trapping pools that become dewatered.

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

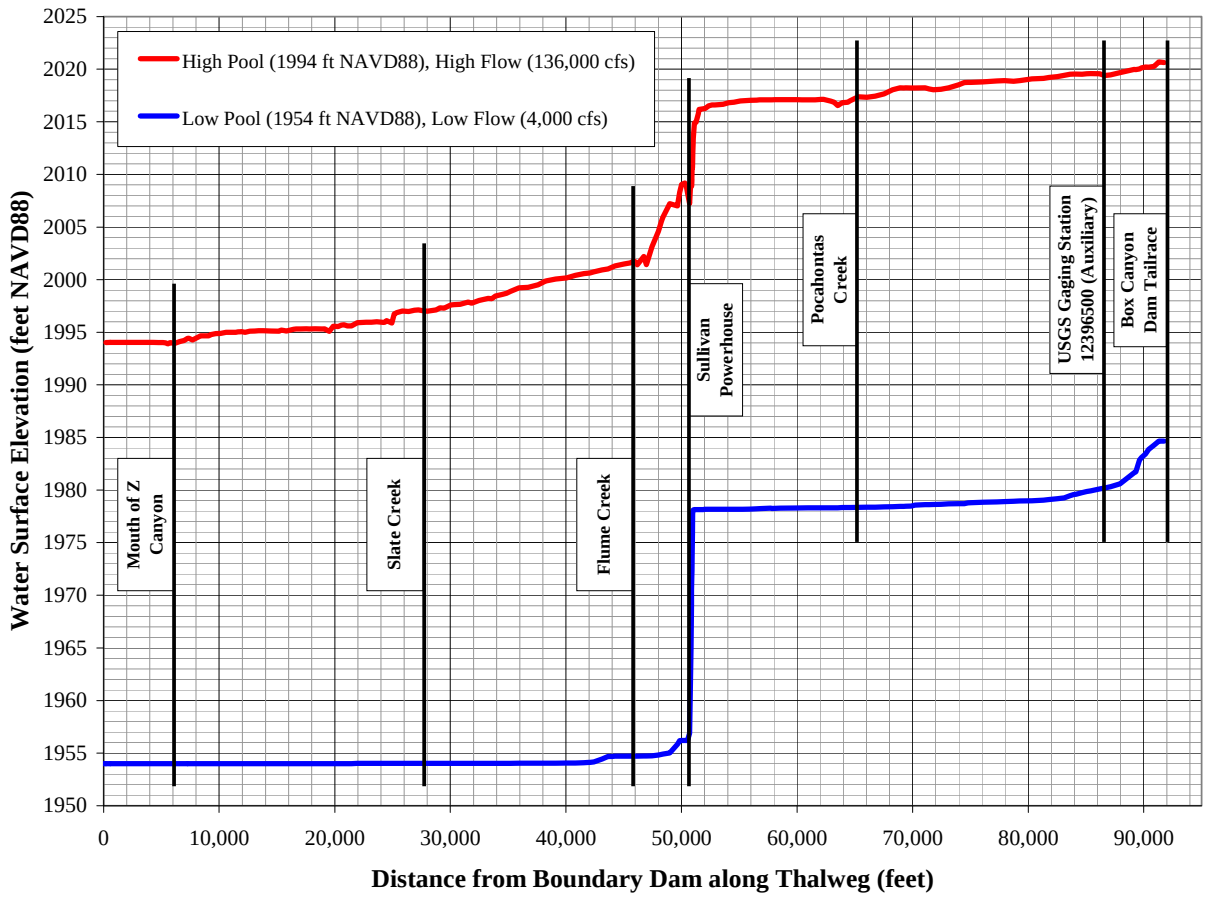


**Figure 4.1-1.** Water surface profiles used to determine elevation range of stranding and trapping areas based on constant flow of 4,000 cfs and 136,000 cfs at a forebay elevation of 1,954 feet NAVD 88 and 1,994 feet NAVD 88.

For the area downstream of Boundary Reservoir to Red Bird Creek, the Boundary Tailrace HRM was run for a constant low flow of 500 cfs and a constant high flow of 136,000 cfs with a Seven Mile Dam forebay elevation of 1,719 feet NAVD 88 (1,715 feet NGVD 29) and 1,734 feet NAVD 88 (1,730 feet NGVD 29), respectively. The lower elevation represents the low pool, low flow condition while the upper elevation represents the high pool, high flow condition. The runs were performed with the maximum and minimum forebay elevation that occurred since the completion of Seven Mile Dam in 1979. Since Seven Mile Dam was completed after Boundary Dam, a model simulation without the hydraulic influence of Seven Mile Dam was also performed during low flow conditions. As shown in Figure 4.1-2, the Tailrace Reach has a maximum elevation range that varies between 15 to 36 feet between the low pool, low flow condition and the high pool, high flow condition. Without the hydraulic influence of Seven Mile Dam, the maximum elevation range between the low flow condition and high flow condition is significantly greater downstream of the U.S.-Canada border. Elevations presented in Figure 4.1-2 representing the water surface elevations without the hydraulic influence of Seven Mile Dam and during high pool, high flow conditions within the Tailrace Region (U.S.-Canada Border to

Boundary Dam Tailrace) were used as the basis of the upper and lower bounds of the stranding areas and trapping pools that become dewatered.

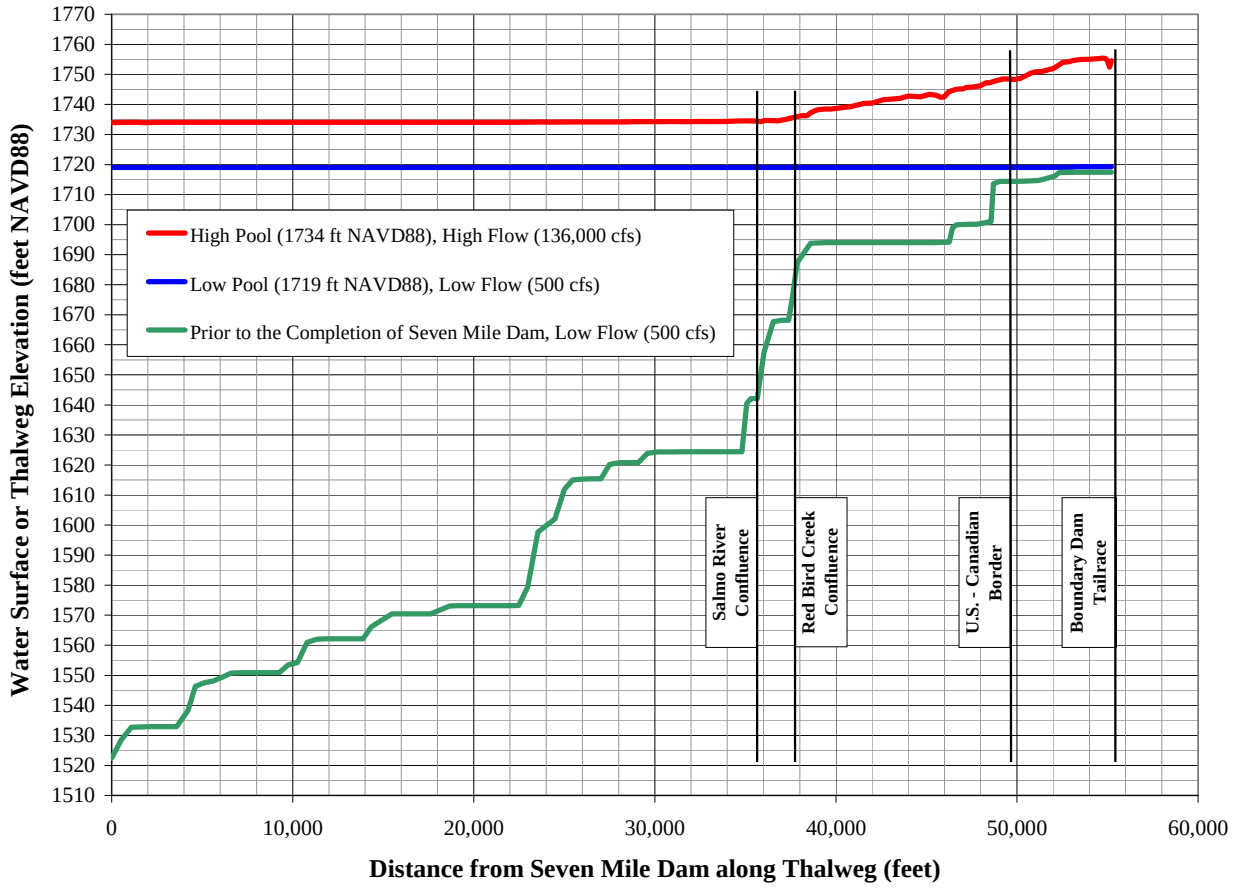


**Figure 4.1-2.** Water surface profiles used to determine elevation range of stranding and trapping areas based on constant flow of 300 cfs and 136,000 cfs at a Seven Mile forebay elevation of 1,719 feet NAVD 88 and 1,734 feet NAVD 88 and at natural streamflow conditions.

### 4.1.3. Final Determination of Stranding Areas and Trapping Pools

Within each region, stranding areas were identified using GIS within the elevation ranges displayed in Figures 4.1-1 and 4.1-2 having a contiguous area of more than 1,000 square feet with slopes of 4 percent or less. Additionally, contiguous areas of more than 1,000 square feet with slopes greater than 4 percent and the presence of mapped macrophytes were identified as stranding areas.

Trapping pools within each region were identified as depressions greater than 100 square feet. The areas associated with each pool along with its outlet invert elevation and pool bottom (lowest point) were initially determined using GIS. Field activities that occurred in 2008 performed elevation verifications of the trapping pools within the Upper Reservoir Reach.

Adjustments, as discussed in greater detail in Appendix 4, were made to the outlet invert elevations of the trapping pools as a result of the field activities.

### 4.1.4. Development of Physical Characteristics for Stranding and Trapping Areas

Table 4.1-1 provides an overview of the basis for development of various site characteristics and factors used in the stranding and trapping analysis. This table lists the various parameters and factors and identifies whether they are developed directly from GIS, derived from GIS-based parameters, or determined using the hydraulic routing model and GIS-based parameters. In the latter two cases, the GIS parameters that provide the basis for determination are identified by their table ID numbers. A parameter developed directly from GIS is a physical characteristic determined directly using the GIS tools that analyze the bathymetry and other spatial data such as macrophyte and substrate mapping. Examples of parameters derived directly from GIS are the stranding area and trapping area. An example of a parameter derived from GIS-based parameters is the stranding cover factor. The presence of mapped macrophytes is used to look up the cover factor which varies depending on the time of year (periodicity) and the slope of the trapping areas discussed in greater detail in Appendix 4. Other parameters, such as duration, that were determined from the application of the Boundary Reservoir HRM are also discussed in greater detail in Appendix 4.

**Table 4.1-1.** Summary of stranding and trapping parameters and factors with information basis for their development.

| ID No. | Parameter/Factor (units) | Determination Source | | |
|---|---|---|---|---|
| | | Directly from GIS | Based on GIS Parameter (ID No.) | From Application of the HRM |
| 1 | Trapping area (square feet) | Y | --- | --- |
| 2 | Outlet elevation – trapping (feet NAVD 88) | Y | --- | --- |
| 3 | Effective outlet elevation – trapping (ft NAVD 88) | N | 2,5 | --- |
| 4 | Substrate type – trapping | Y | --- | --- |
| 5 | Duration – trapping (hours) | N | 6 | Y |
| 6 | Mapped macrophytes (Y/N) trapping | Y | --- | --- |
| 7 | Cover factor – trapping (macrophytes or cobble) | N | 6 | --- |
| 8 | Mapped macrophytes – stranding (Y/N) | Y | --- | --- |
| 9 | Stranding slope (percent) | Y | --- | --- |
| 10 | Stranding area (square feet) | Y | 8,9,10 | --- |
| 11 | Cover factor for stranding | N | 8,9 | --- |
| 12 | Elevation of stranding area (feet NAVD 88) | Y | --- | --- |
| 13 | Hourly water surface elevation (feet NAVD 88) | N | --- | Y |
| 14 | Inundation and dewatering – stranding | N | 12 | Y |

# 5 RESULTS

The following sections contain the results from the effort to develop the stranding areas and trappings pools mapping within GIS. Application of the results is discussed in greater detail in Appendix 4.

## 5.1. GIS Based Mapping

Through the methods presented in Section 4.1, the location of the stranding areas and trapping pools for the study area were identified. An approximate total stranding area of 13,002,000 square feet and a total trapping pool area of 2,619,000 square feet was calculated. A summary of the stranding area by reaches and the number of trapping pools and associated area by reaches is presented in Table 5.1-1. Additional area not within a designated stranding and trapping region is also included within Table 5.1-1 and summarized by reach.

An example of one of the stranding and trapping maps is provided in Figure 5.1-1. All 23 stranding areas and trapping pools within the study area as well as the 23 regions where the potential for stranding and trapping is greatest are provided in Attachment A. Figure 5.1-2 provides an example of an overlay of the macrophyte mapping with the identified stranding areas and trapping pools. This mapping is used to determine the percentage of the stranding or trapping area with aquatic macrophytes present. In the case of trapping, the presence of substrate type was also evaluated from the GIS database for each trapping pool. Figure 5.1-3 provides an

enlargement to illustrate the detail provided by the mapping for specific stranding and trapping areas.

**Table 5.1-1.** Summary of approximate area of identified stranding and trapping for a given region.

| Reach | Region | Total Stranding Area within Region ($ft^2$) | Total Number of Trapping Pools within Region | Total Trapping Area within Region ($ft^2$) |
|---|---|---|---|---|
| Forebay | Forebay Launch | 150,800 | 4 | 11,142 |
| | 1 | 62,642 | 1 | 189 |
| | Additional Area | 67,732 | 0 | 0 |
| Canyon | 2 | 248,363 | 20 | 81,669 |
| | 3 | 18,405 | 1 | 108 |
| | 4 | 13,628 | 3 | 2,169 |
| | 5 | 42,845 | 1 | 135 |
| | Stump Farm | 28,321 | 1 | 153 |
| | 6 | 4,576 | 5 | 1,980 |
| | Flume Creek | 11,559 | 2 | 1,809 |
| | Additional Area | 170,466 | 11 | 11,781 |
| Upper Reservoir | Sullivan Creek | 244,138 | 63 | 99,657 |
| | 7 | 407,994 | 40 | 269,793 |
| | 8 | 2,521,424 | 217 | 677,155 |
| | 9 | 2,227,835 | 121 | 252,558 |
| | 10 | 193,775 | 24 | 86,055 |
| | 11 | 847,881 | 16 | 83,979 |
| | 12 | 12,177 | 22 | 15,417 |
| | 13 | 391,009 | 35 | 49,374 |
| | 14 | 389,839 | 41 | 99,045 |
| | 15 | 569,991 | 22 | 52,182 |
| | 16 | 91,409 | 139 | 317,925 |
| | 17 | 583,908 | 61 | 40,248 |
| | 18 | 438,874 | 63 | 67,770 |
| | Additional Area | 2,976,599 | 165 | 376,004 |
| Tailrace | Tailrace | 127,873 | 17 | 10,629 |
| | Additional Area | 157,471 | 17 | 9,711 |

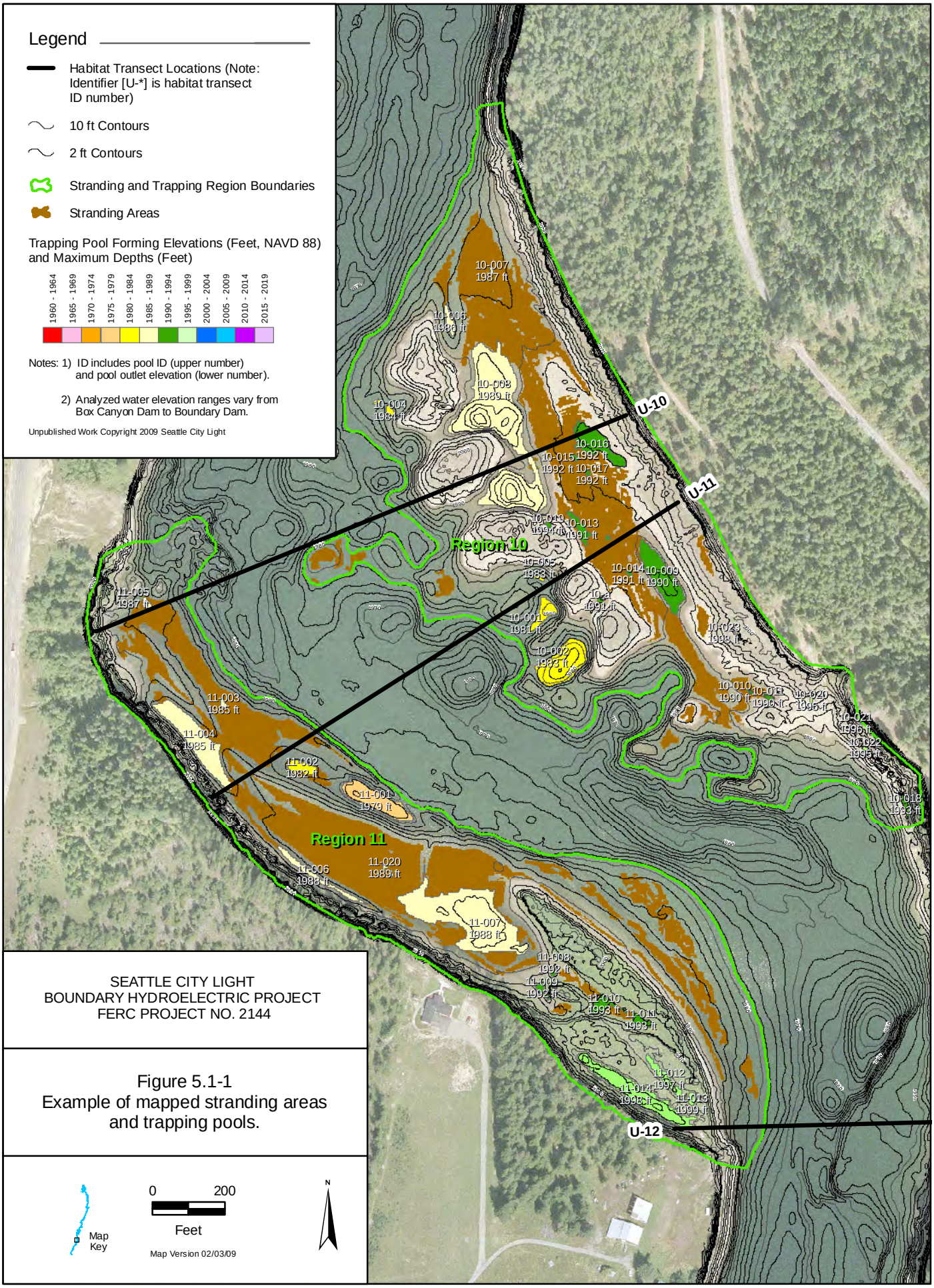


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Figure 5.1-1
Example of mapped stranding areas and trapping pools.

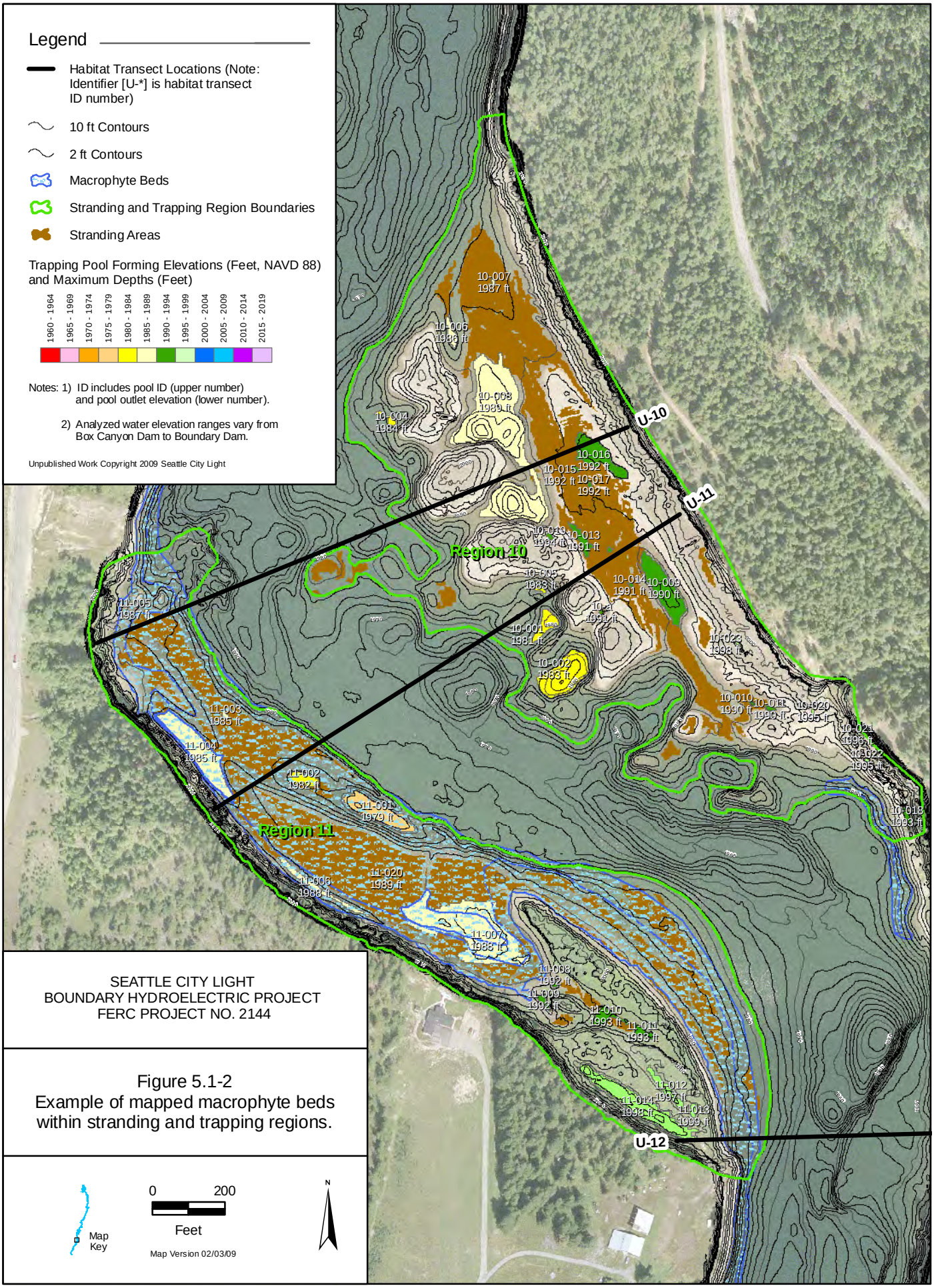


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Figure 5.1-2
Example of mapped macrophyte beds within stranding and trapping regions.

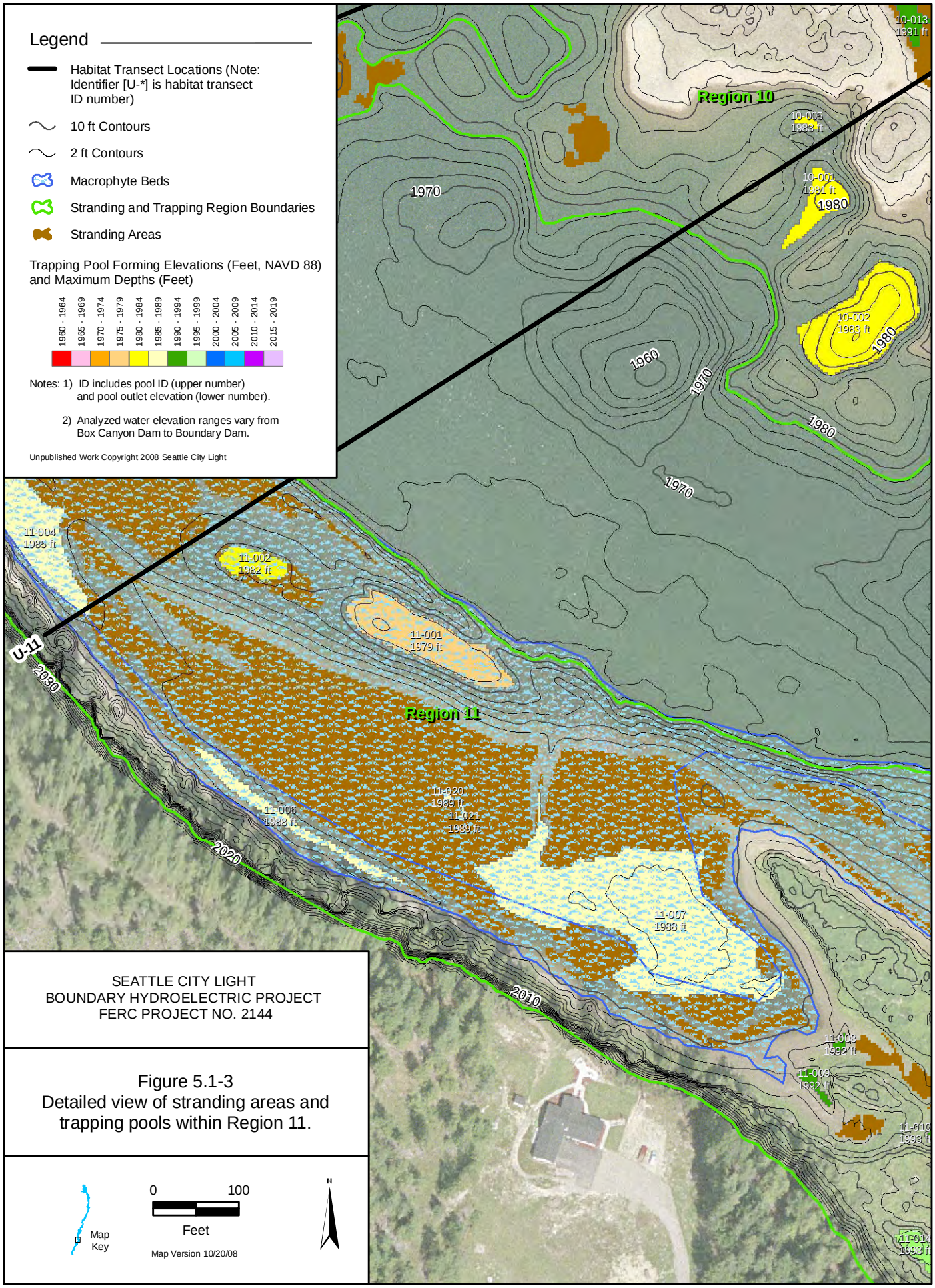


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Figure 5.1-3
Detailed view of stranding areas and trapping pools within Region 11.

## 5.2. Physical Characteristics for Stranding Areas and Trapping Pools

Physical characteristics presented earlier in Table 4.1-1 for the identified stranding areas are presented in Attachment B. Physical characteristics identified for trapping pools are presented in Attachment C. The application of these characteristics in the development of the stranding and trapping models is presented in detail in Appendix 4.

# 6 REFERENCES

SCL (Seattle City Light). 2007. Revised Study Plan for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. February 2007. Available online at: http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

SCL. 2009. Study 7 – Mainstem Aquatic Habitat Modeling Study Final Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech, Thomas R. Payne and Associates, Golder Associates, and Terrapin Environmental. March 2009.

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# Attachment A: Stranding and Trapping GIS Maps

This attachment contains the following figures:

Figure A-1. Identified stranding areas and trapping pools within the north Tailrace Region.
Figure A-2. Identified stranding areas and trapping pools within the middle Tailrace Region.
Figure A-3. Identified stranding areas and trapping pools within the south Tailrace Region.
Figure A-4. Identified stranding areas and trapping pools within the Forebay Launch Region.
Figure A-5. Identified stranding areas and trapping pools within Region 1.
Figure A-6. Identified stranding areas and trapping pools within Region 2.
Figure A-7. Identified stranding areas and trapping pools within Region 3.
Figure A-8. Identified stranding areas and trapping pools within Region 4.
Figure A-9. Identified stranding areas and trapping pools within Region 5.
Figure A-10. Identified stranding areas and trapping pools within Stump Farm Region.
Figure A-11. Identified stranding areas and trapping pools within Region 6.
Figure A-12. Identified stranding areas and trapping pools within the Flume Creek Region.
Figure A-13. Identified stranding areas and trapping pools within the Sullivan Creek Delta Region.
Figure A-14. Identified stranding areas and trapping pools within Region 7.
Figure A-15. Identified stranding areas and trapping pools within Region 8.
Figure A-16. Identified stranding areas and trapping pools within Region 9.
Figure A-17. Identified stranding areas and trapping pools within Region 10.
Figure A-18. Identified stranding areas and trapping pools within Region 11.
Figure A-19. Identified stranding areas and trapping pools within Region 12.
Figure A-20. Identified stranding areas and trapping pools within Region 13.
Figure A-21. Identified stranding areas and trapping pools within Region 14.
Figure A-22. Identified stranding areas and trapping pools within Region 15.
Figure A-23. Identified stranding areas and trapping pools within Region 16.
Figure A-24. Identified stranding areas and trapping pools within Region 17.
Figure A-25. Identified stranding areas and trapping pools within Region 18.
Figure A-26. Identified stranding areas and trapping pools within.

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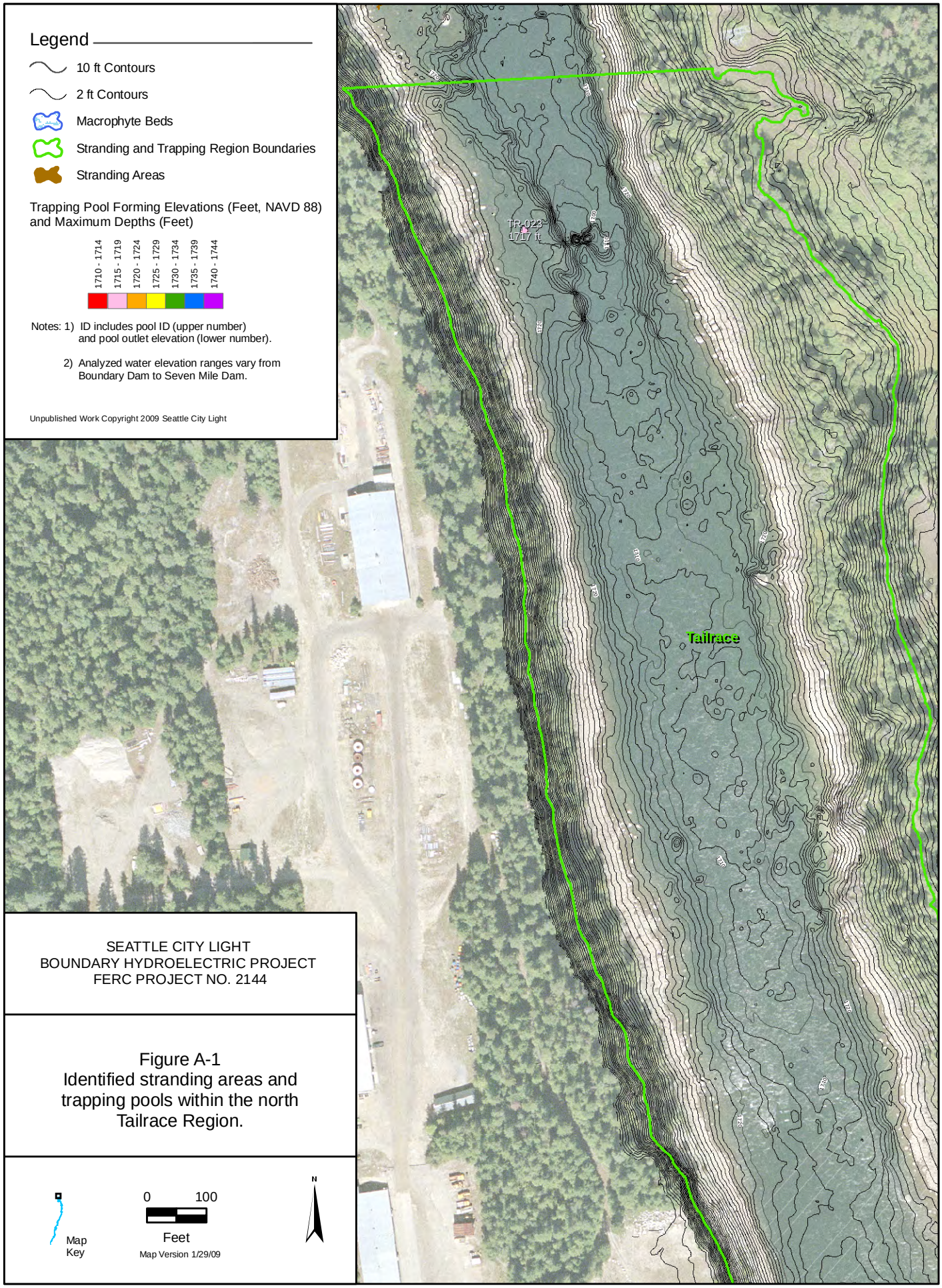


Figure A-1
Identified stranding areas and trapping pools within the north Tailrace Region.

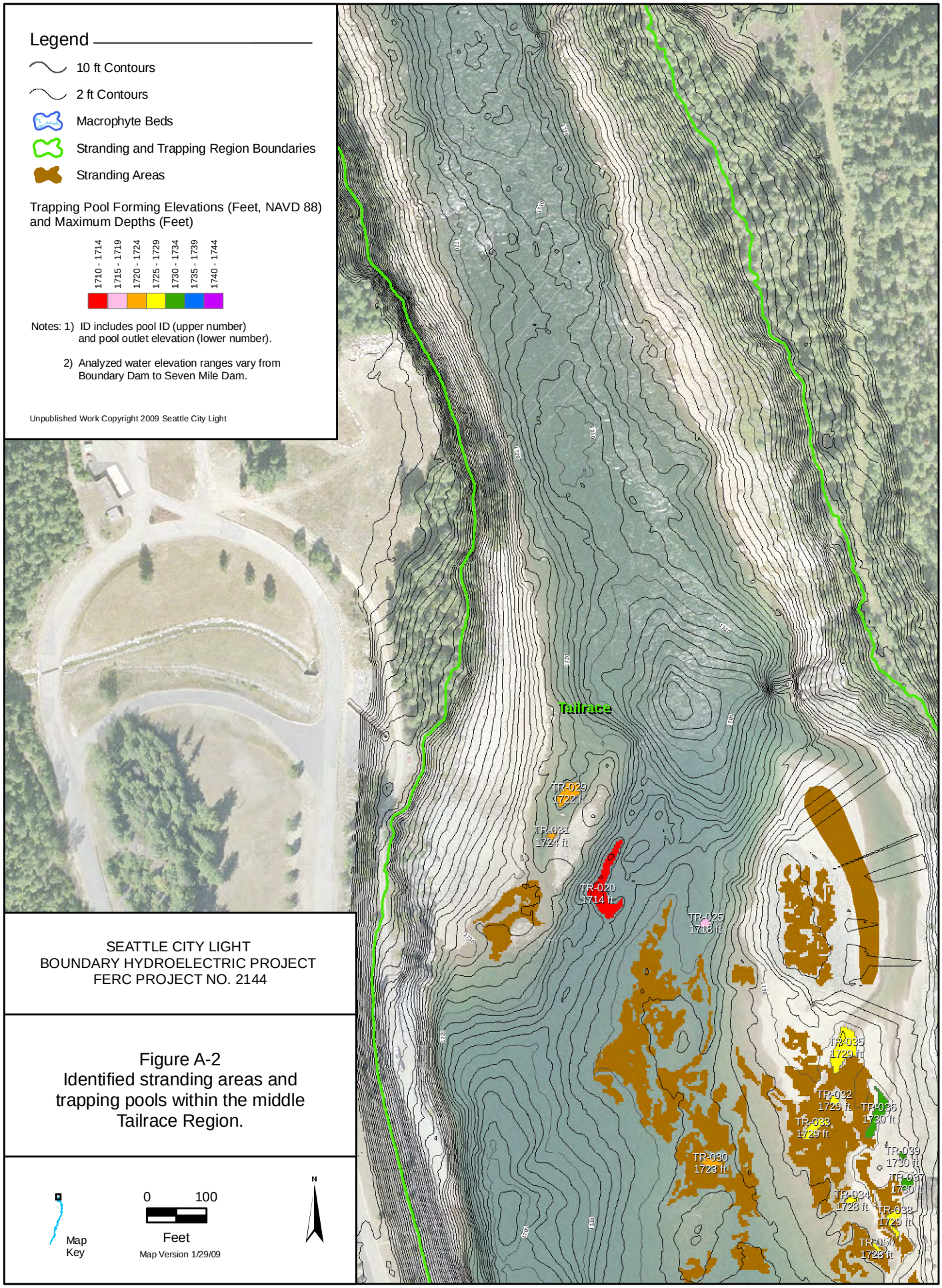


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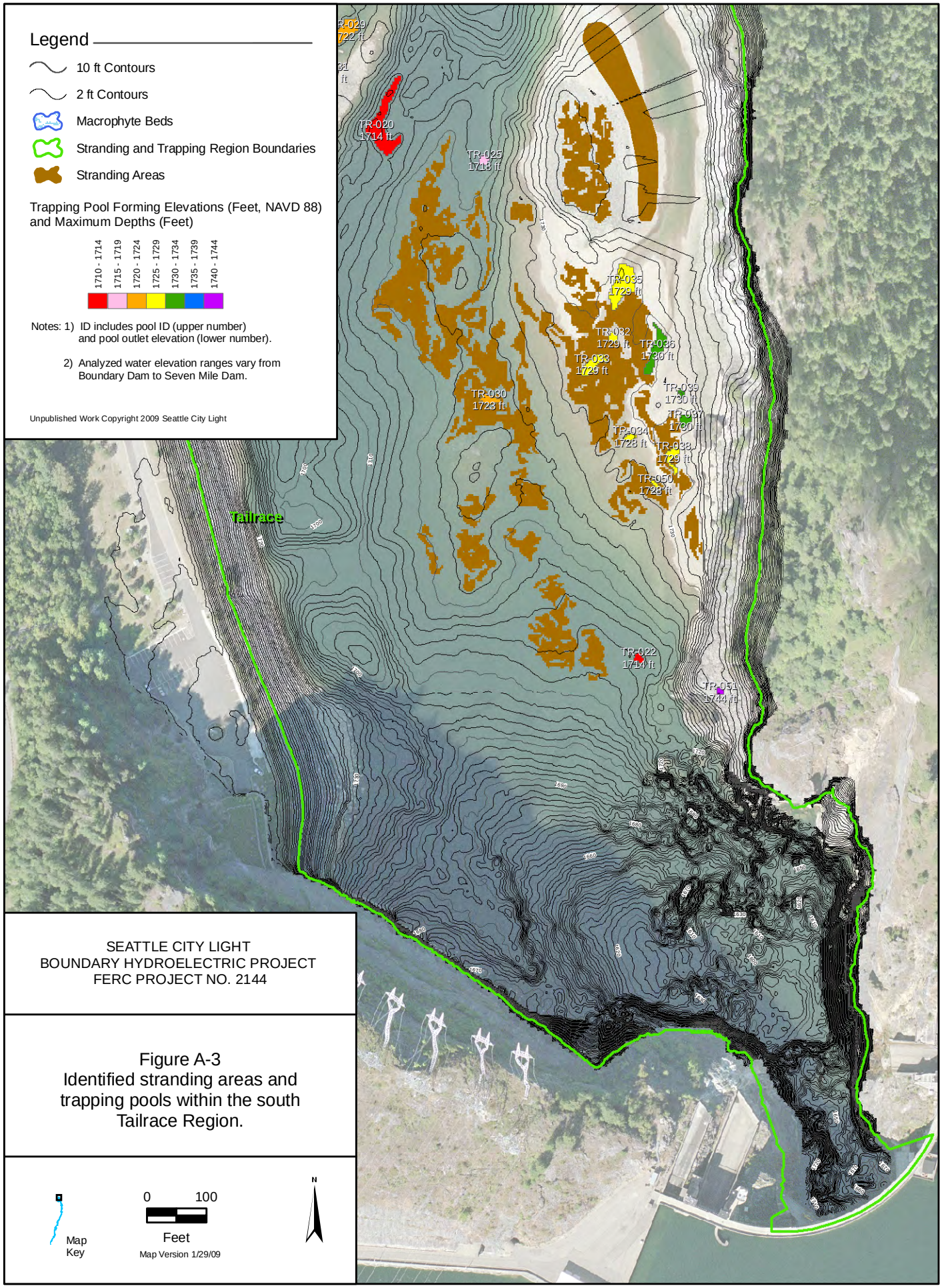
Figure A-2
Identified stranding areas and trapping pools within the middle Tailrace Region.


Legend
10 ft Contours
2 ft Contours
Macrophyte Beds
Stranding and Trapping Region Boundaries
Stranding Areas
Trapping Pool Forming Elevations (Feet, NAVD 88) and Maximum Depths (Feet)
1710 - 1714
1715 - 1719
1720 - 1724
1725 - 1729
1730 - 1734
1735 - 1739
1740 - 1744
Notes: 1) ID includes pool ID (upper number) and pool outlet elevation (lower number).
2) Analyzed water elevation ranges vary from Boundary Dam to Seven Mile Dam.
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TR-020 1714 ft
TR-025 1718 ft
TR-035 1729 ft
TR-032 1729 ft
TR-036 1730 ft
TR-033 1729 ft
TR-039 1730 ft
TR-030 1723 ft
TR-037 1730 ft
TR-034 1728 ft
TR-038 1729 ft
TR-050 1728 ft
Tailrace
TR-022 1714 ft
TR-051 1744 ft
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Figure A-3
Identified stranding areas and trapping pools within the south Tailrace Region.
Map Key
0
100
Feet
Map Version 1/29/09
N

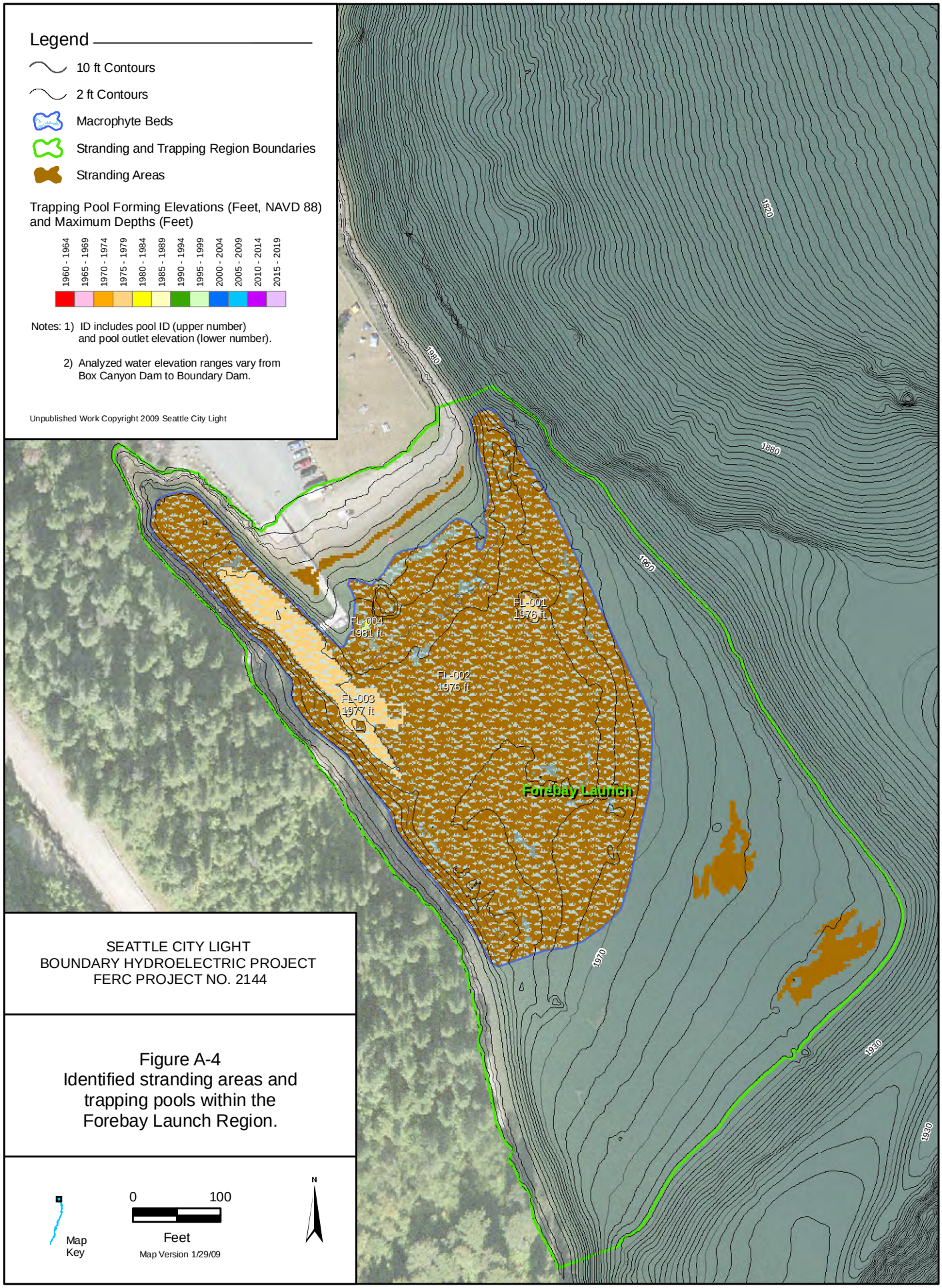


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Figure A-4
Identified stranding areas and trapping pools within the Forebay Launch Region.

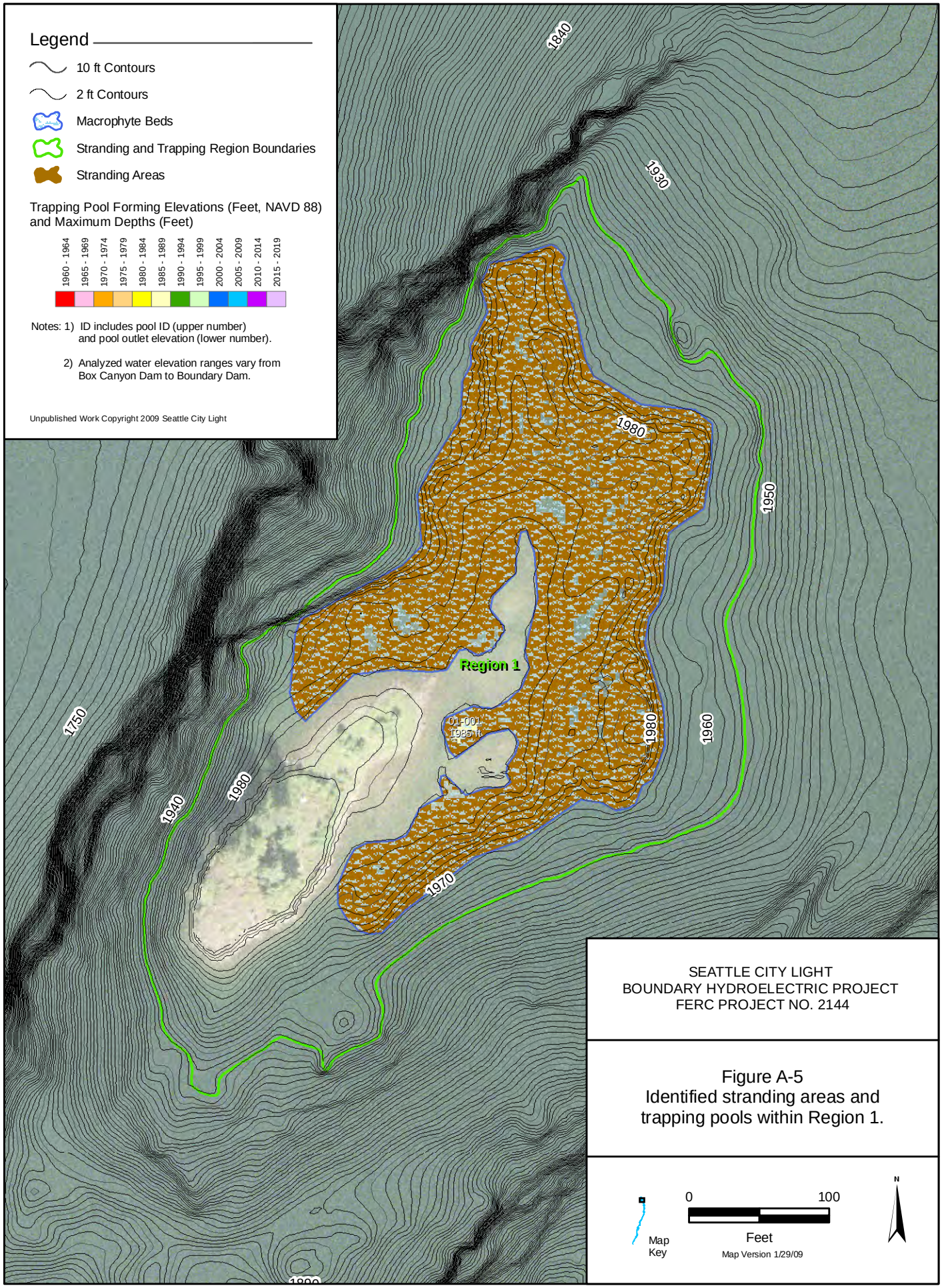


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Figure A-5
Identified stranding areas and trapping pools within Region 1.

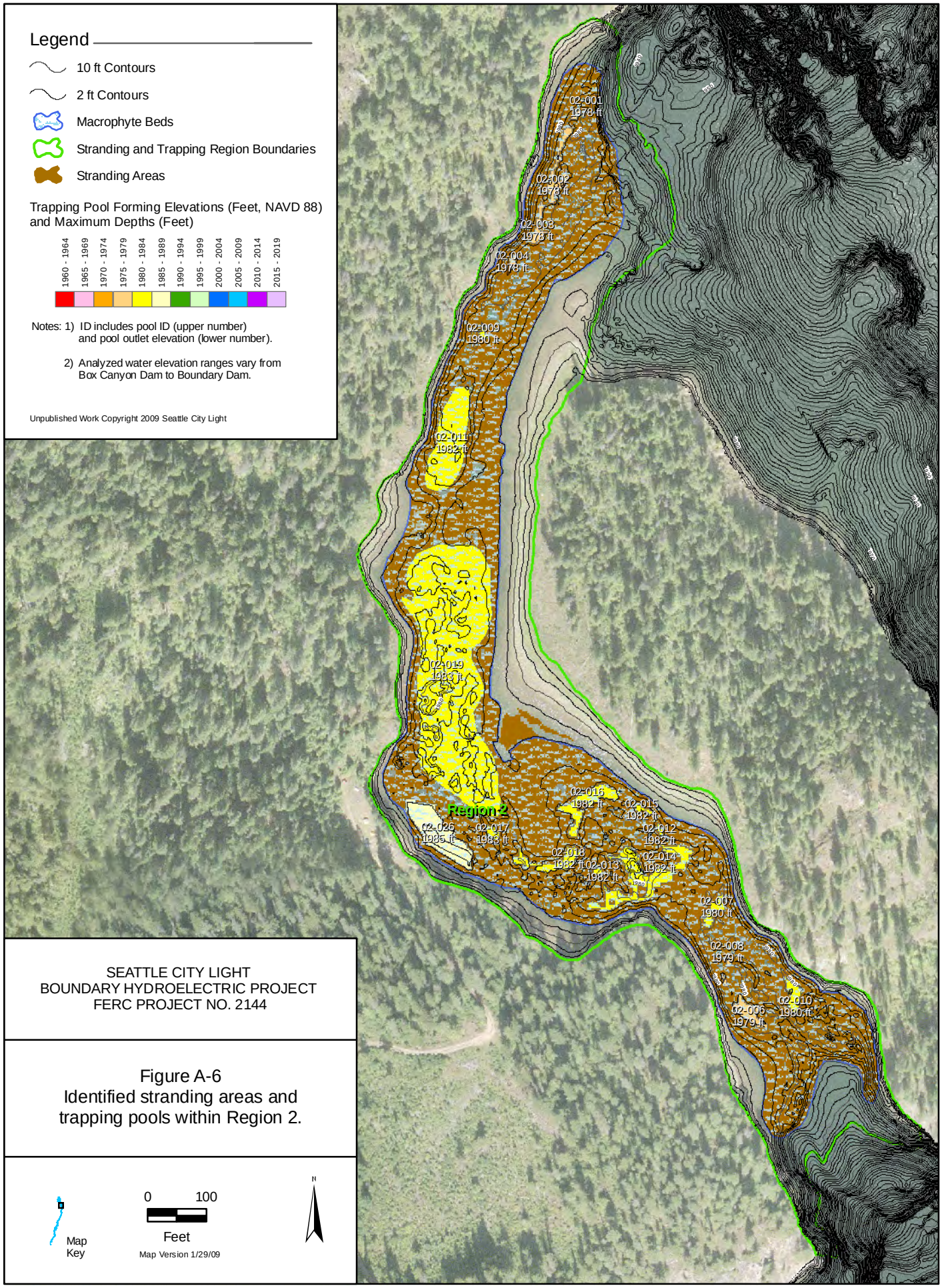


Figure A-6
Identified stranding areas and trapping pools within Region 2.

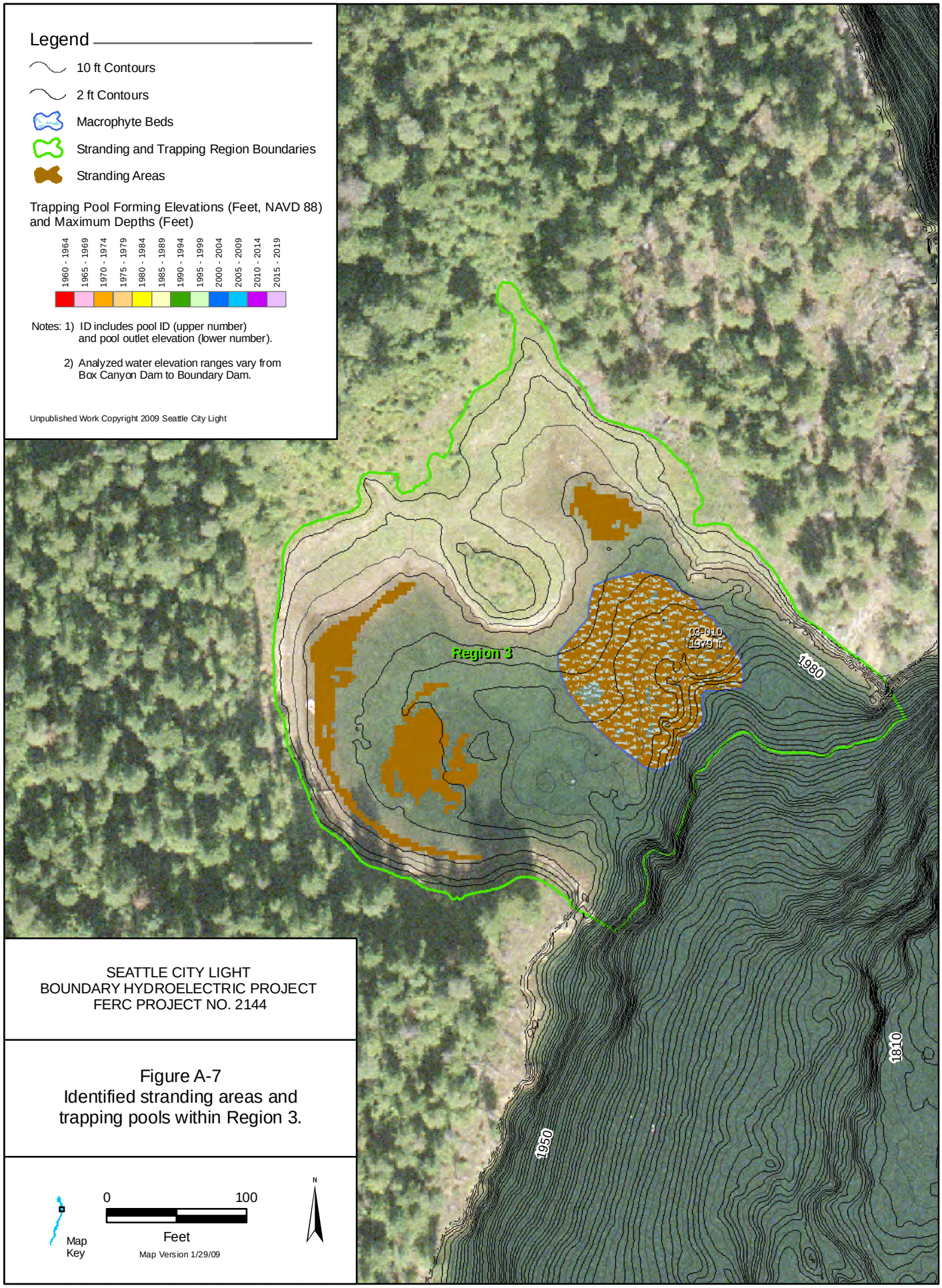


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Figure A-7
Identified stranding areas and trapping pools within Region 3.

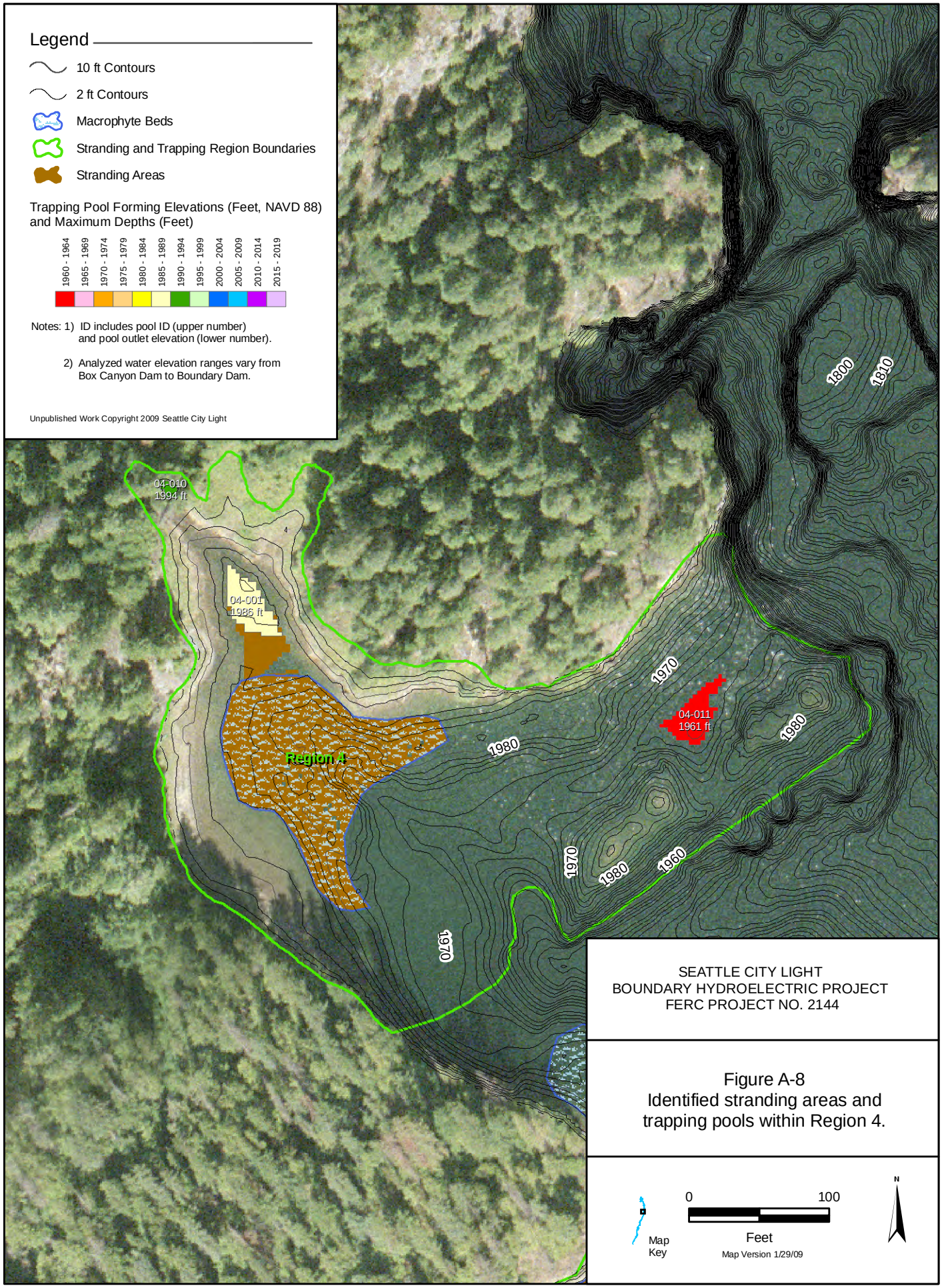


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Figure A-8
Identified stranding areas and trapping pools within Region 4.

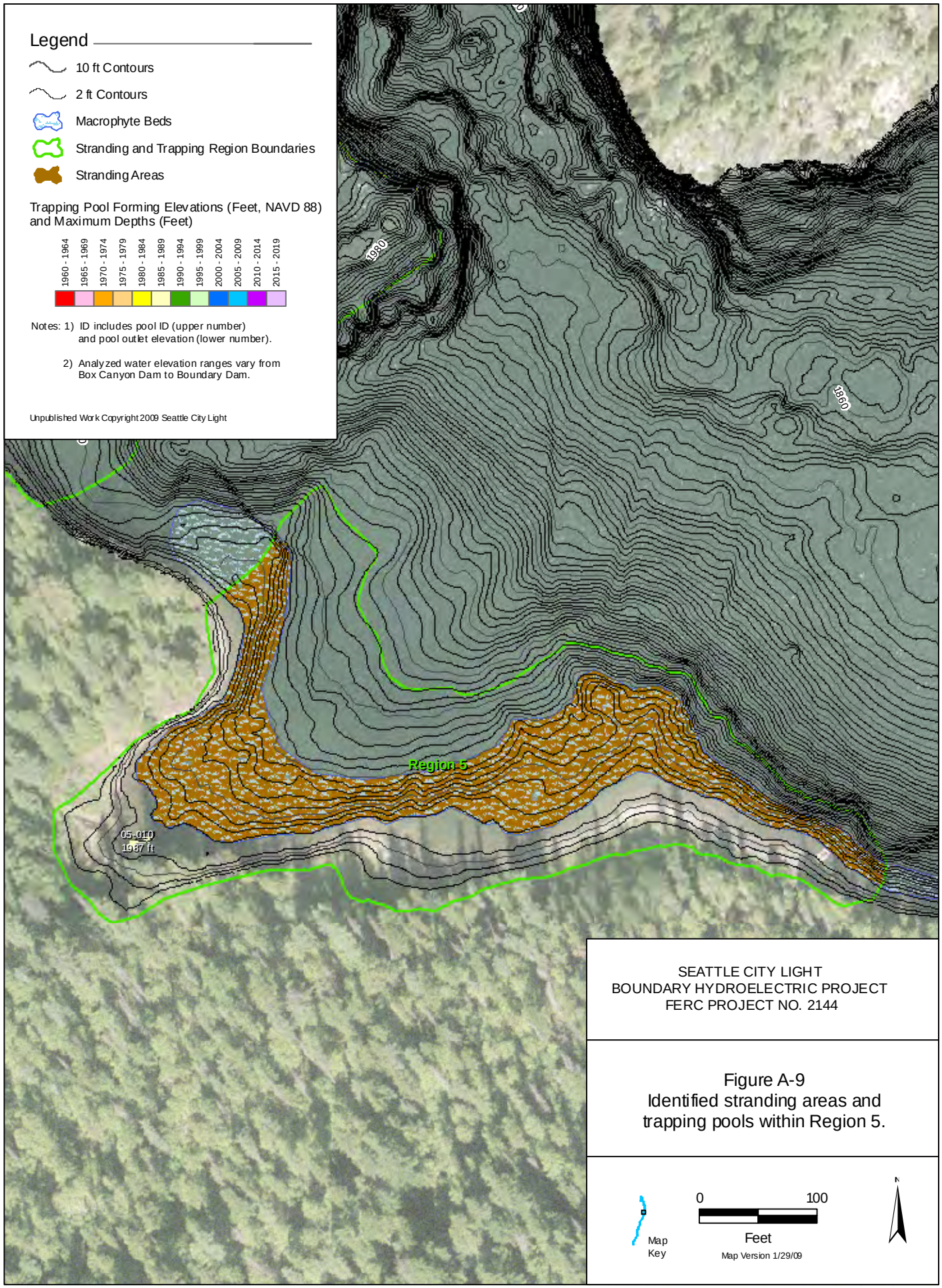


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Figure A-9
Identified stranding areas and trapping pools within Region 5.

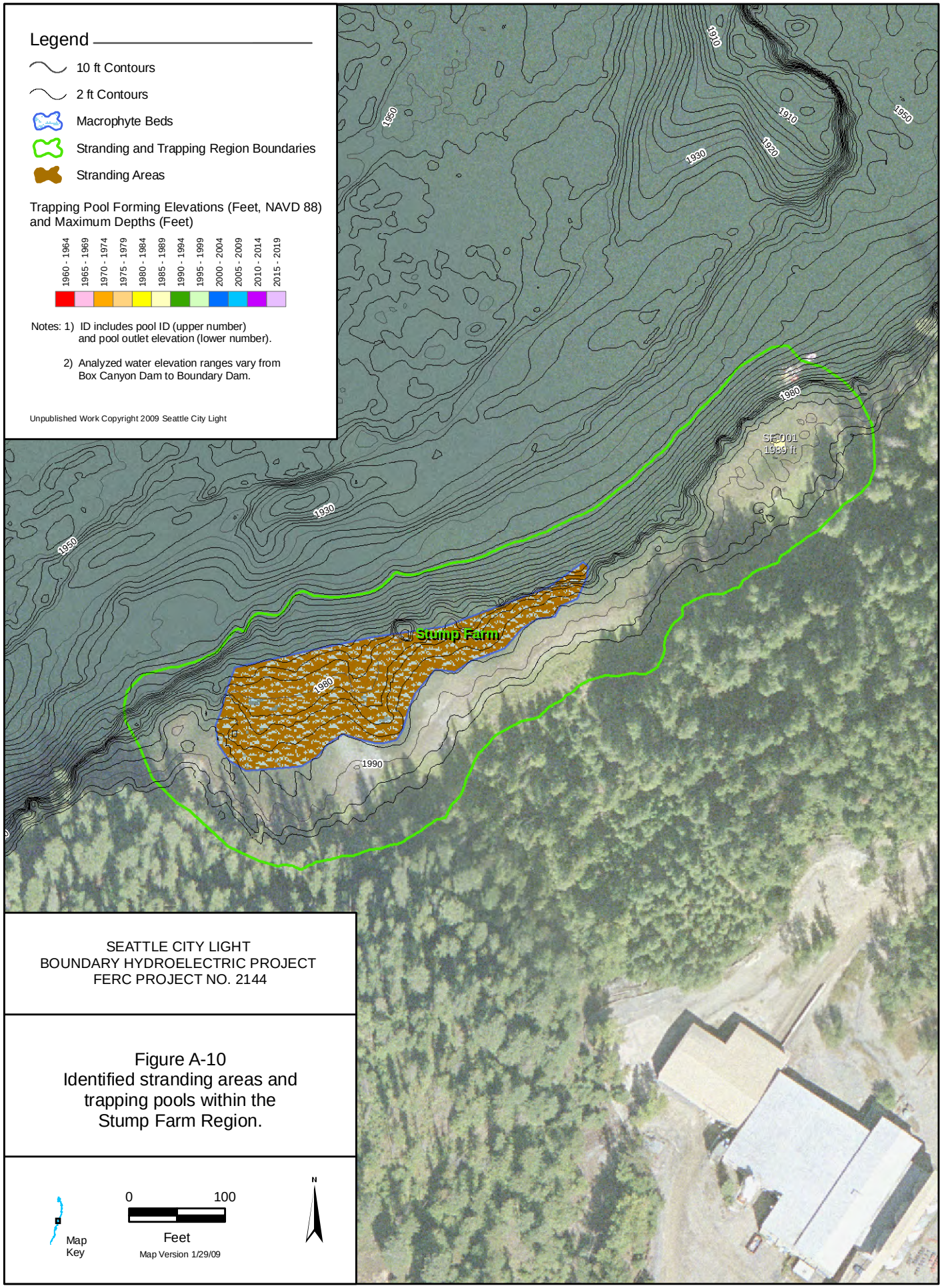


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Figure A-10
Identified stranding areas and trapping pools within the Stump Farm Region.

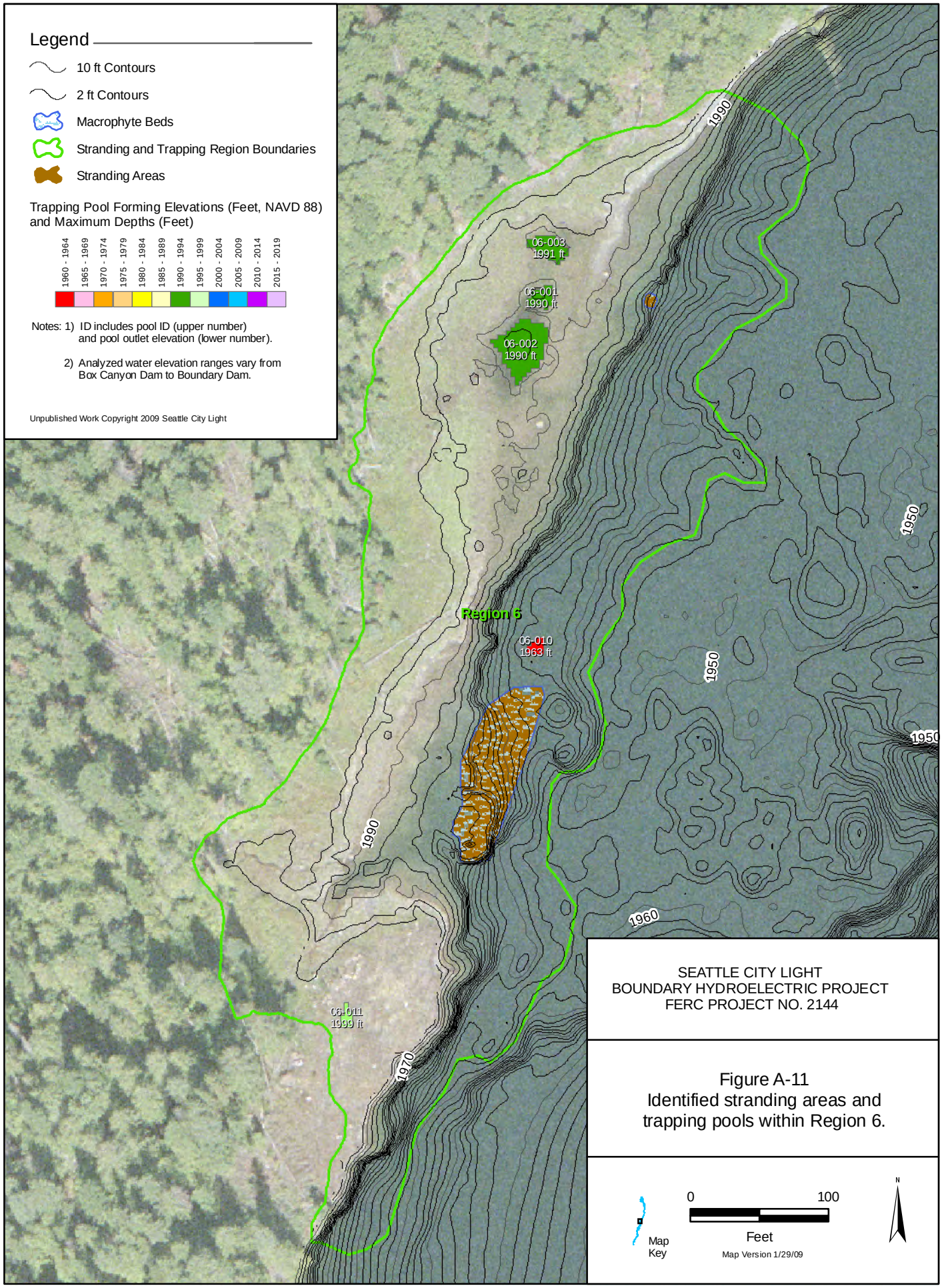


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Figure A-11
Identified stranding areas and trapping pools within Region 6.

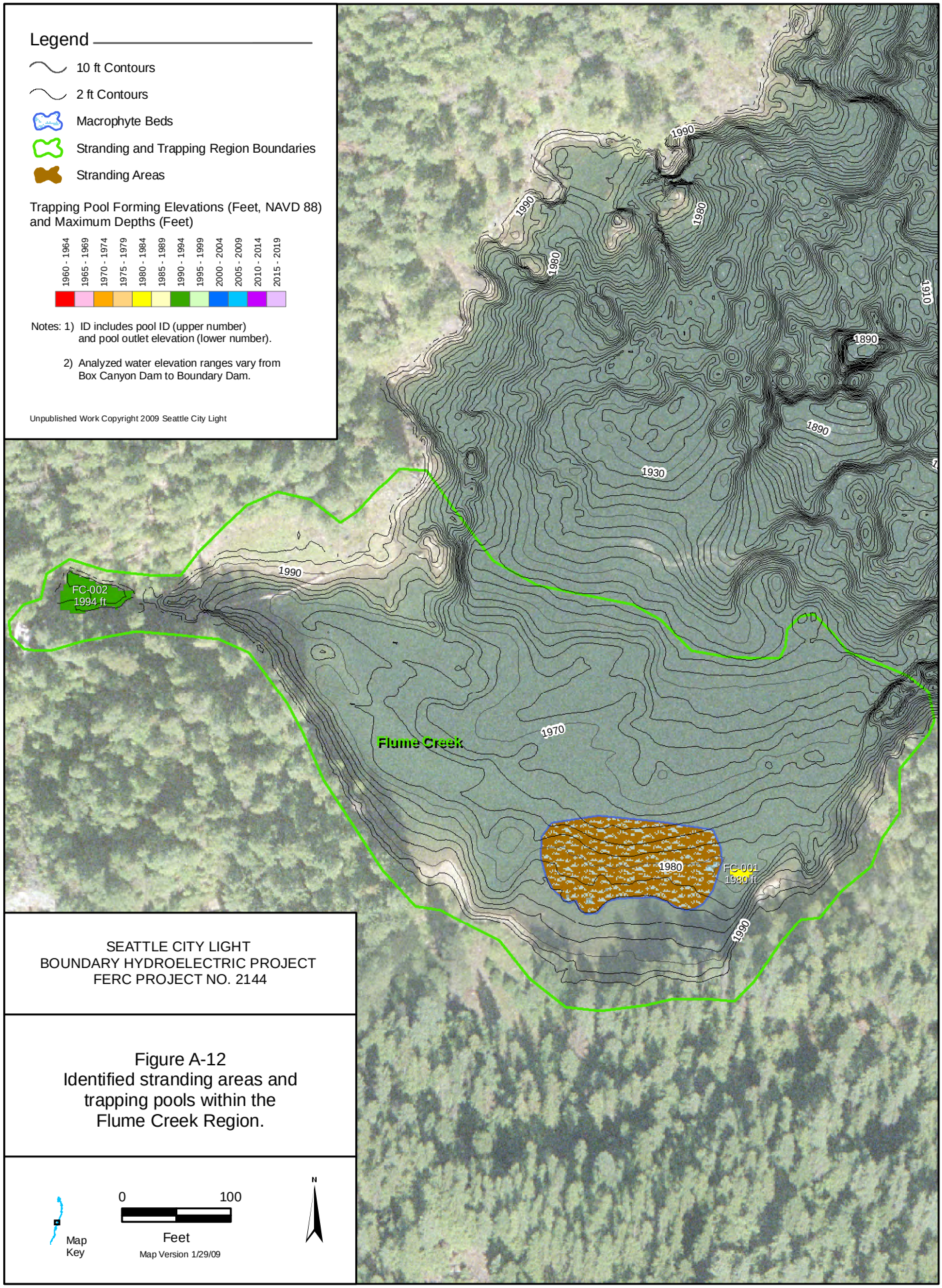


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Figure A-12
Identified stranding areas and trapping pools within the Flume Creek Region.

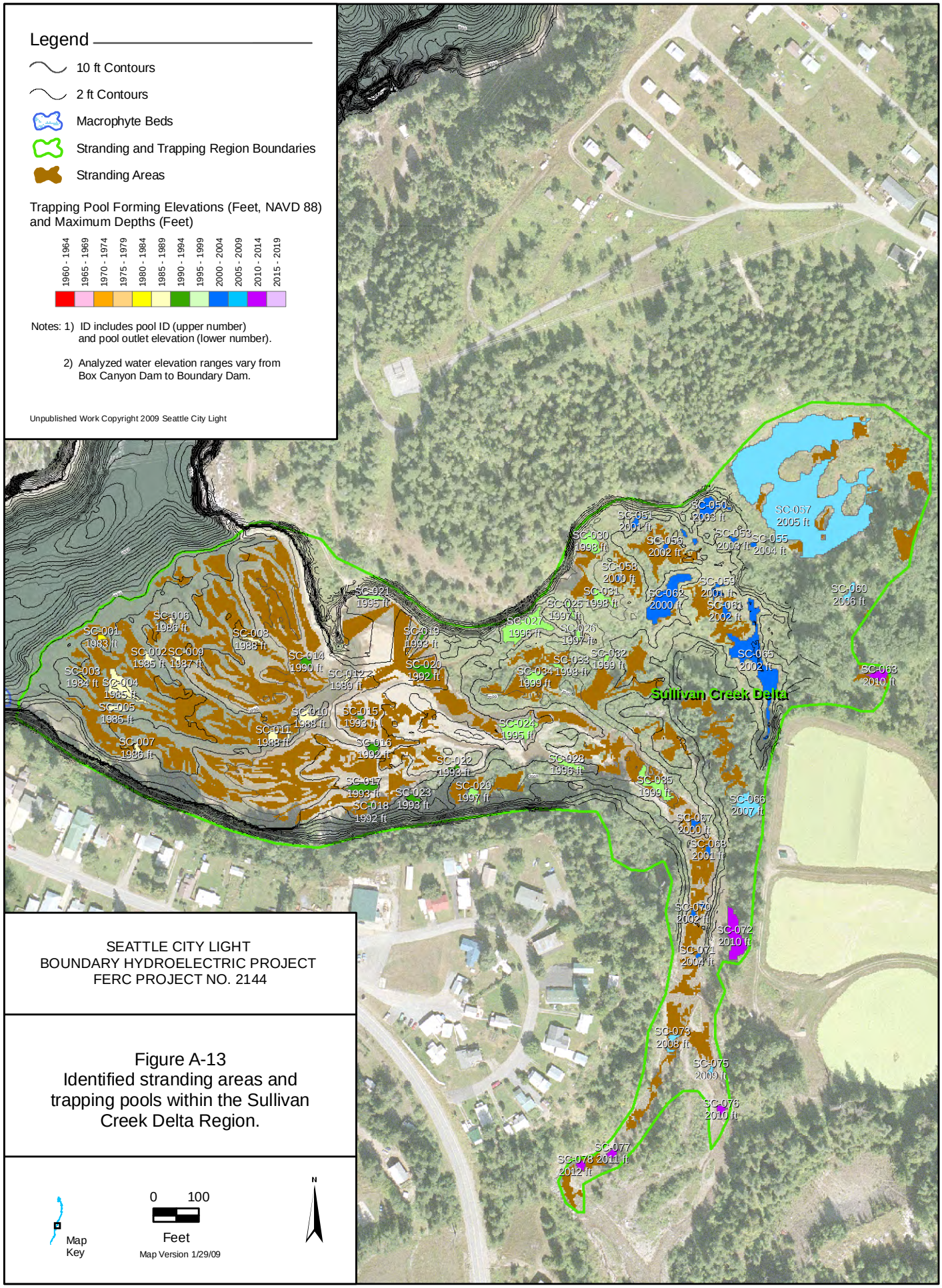


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Figure A-13
Identified stranding areas and trapping pools within the Sullivan Creek Delta Region.

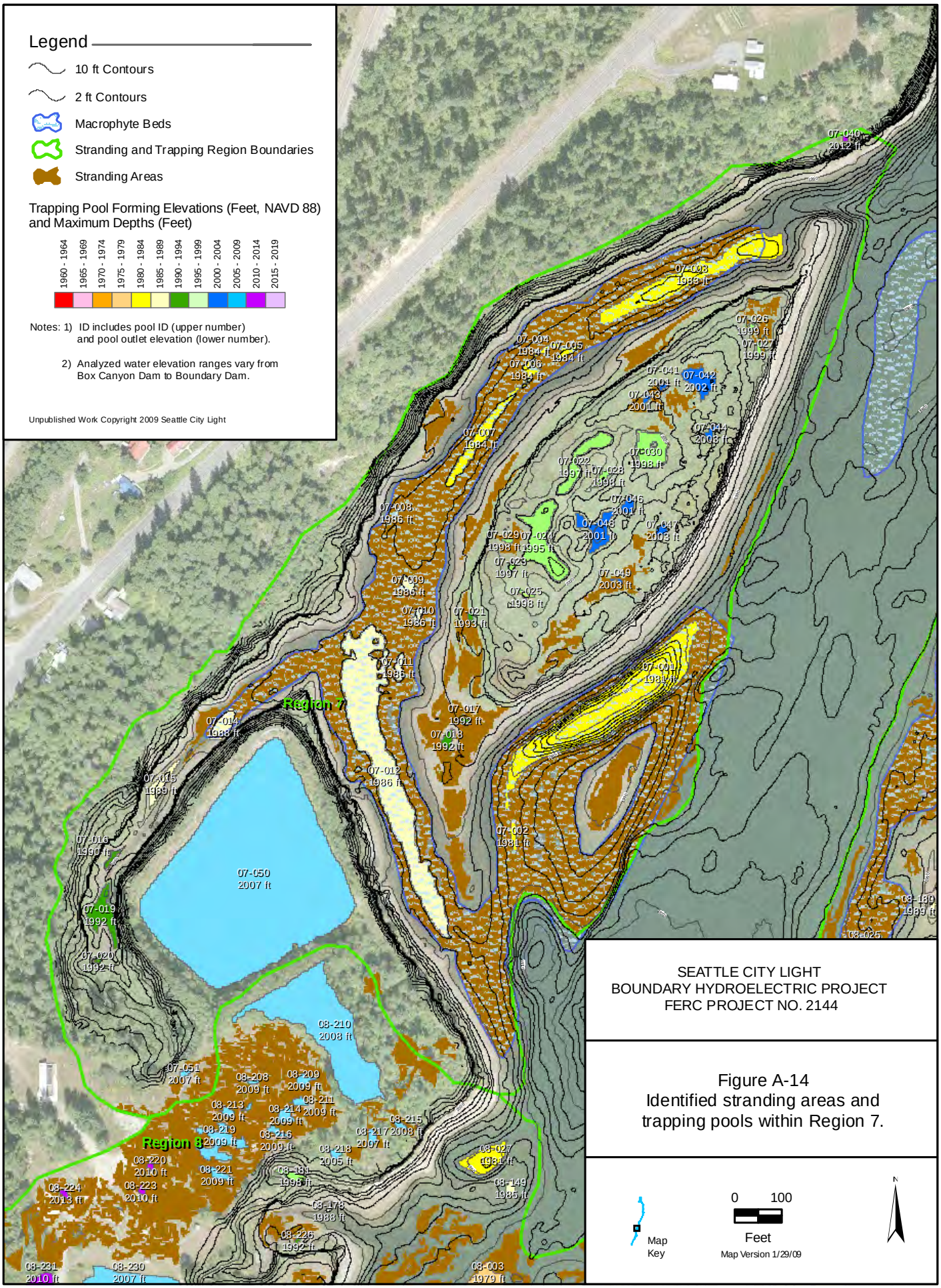


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Figure A-14
Identified stranding areas and trapping pools within Region 7.

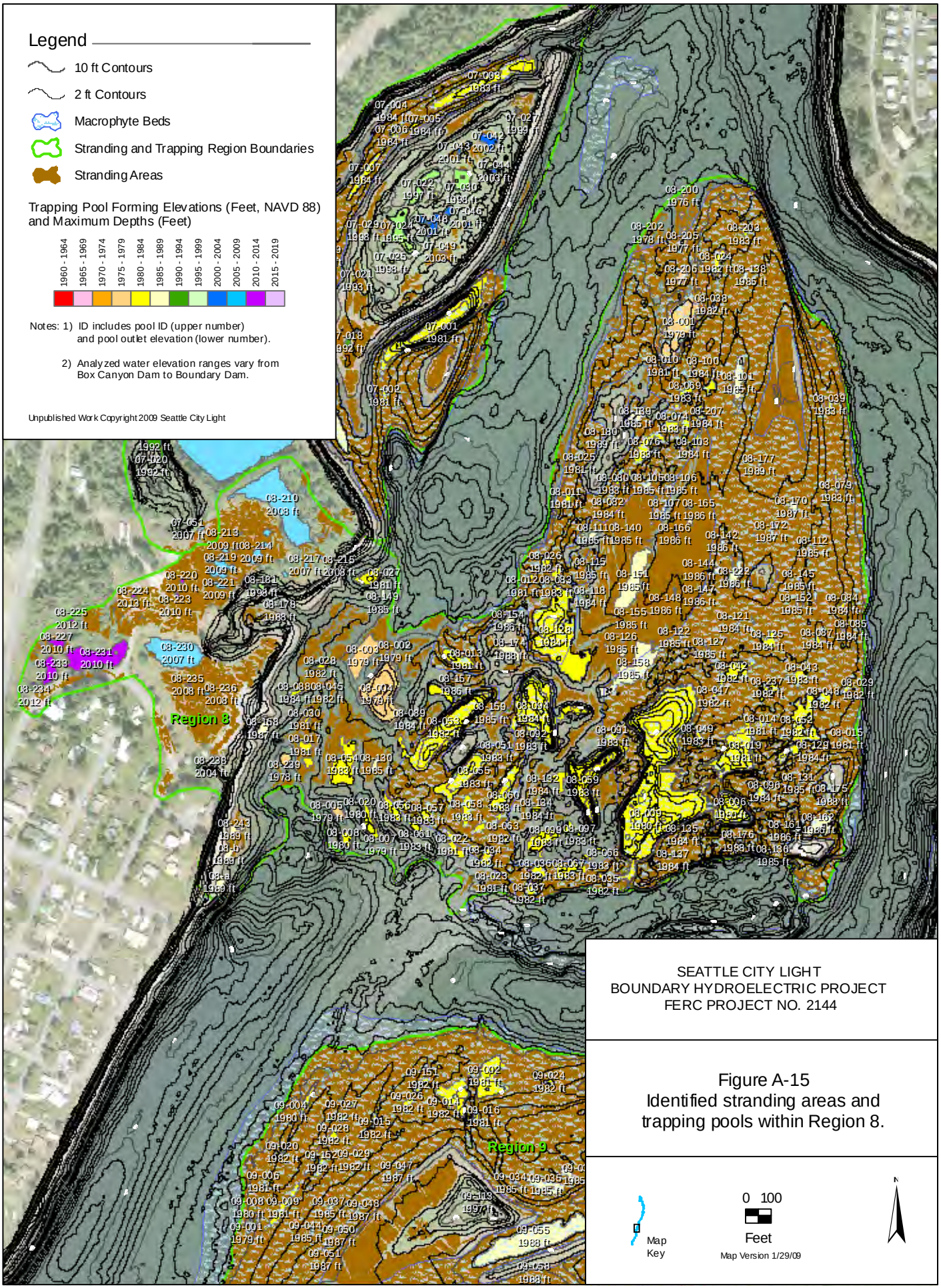


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Figure A-15
Identified stranding areas and trapping pools within Region 8.

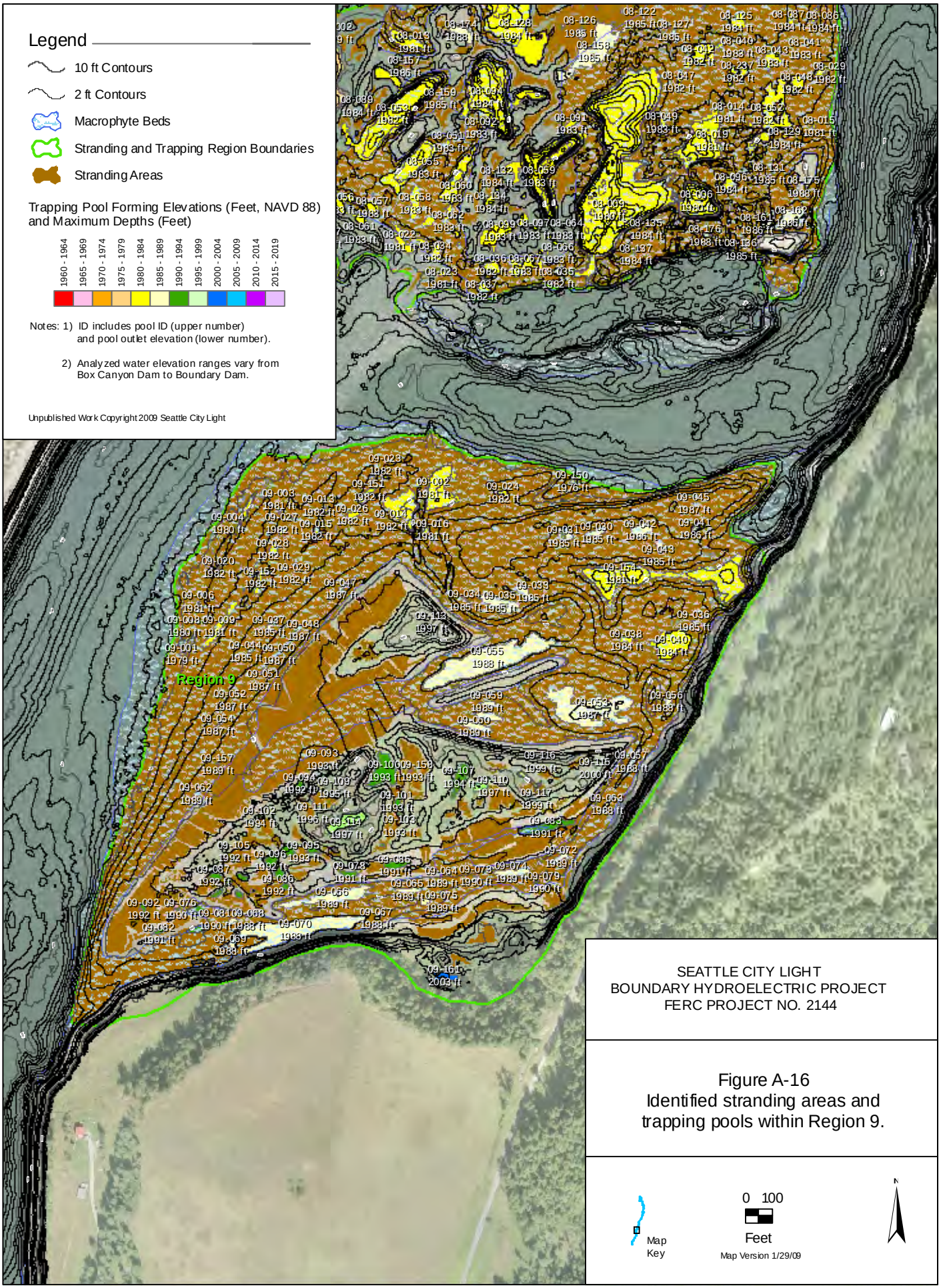


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Figure A-16
Identified stranding areas and trapping pools within Region 9.

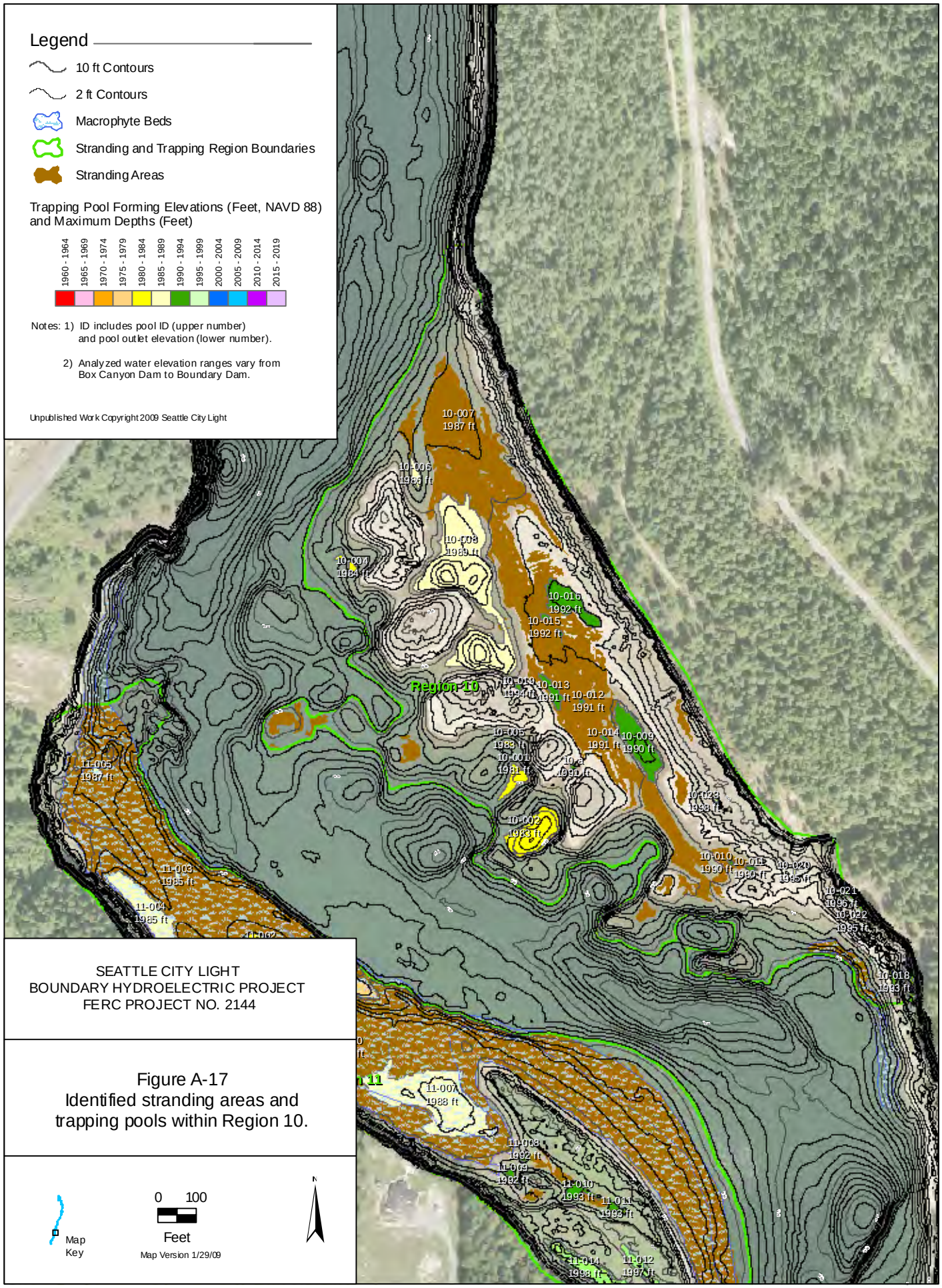


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Figure A-17
Identified stranding areas and trapping pools within Region 10.

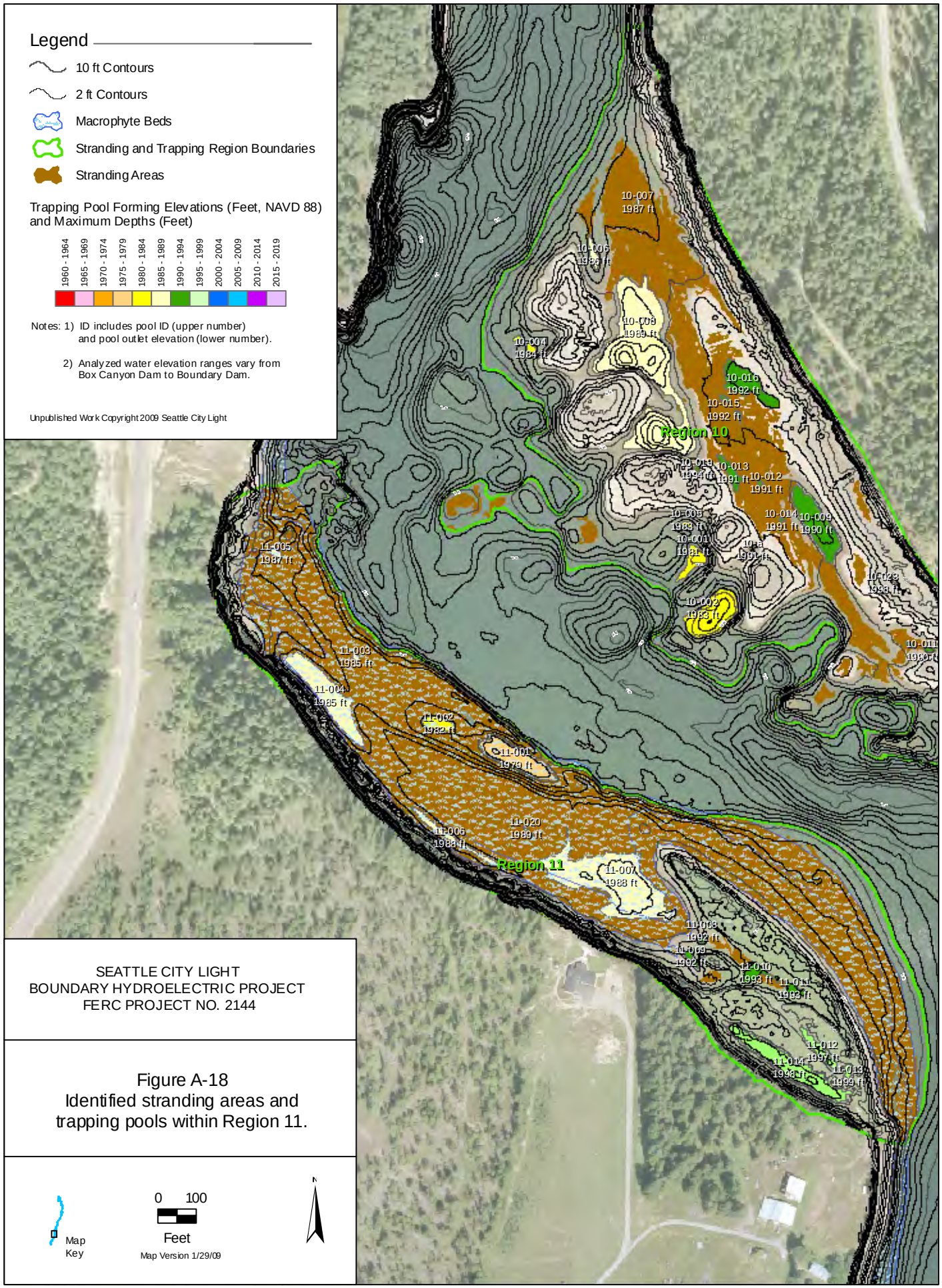


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Figure A-18
Identified stranding areas and trapping pools within Region 11.

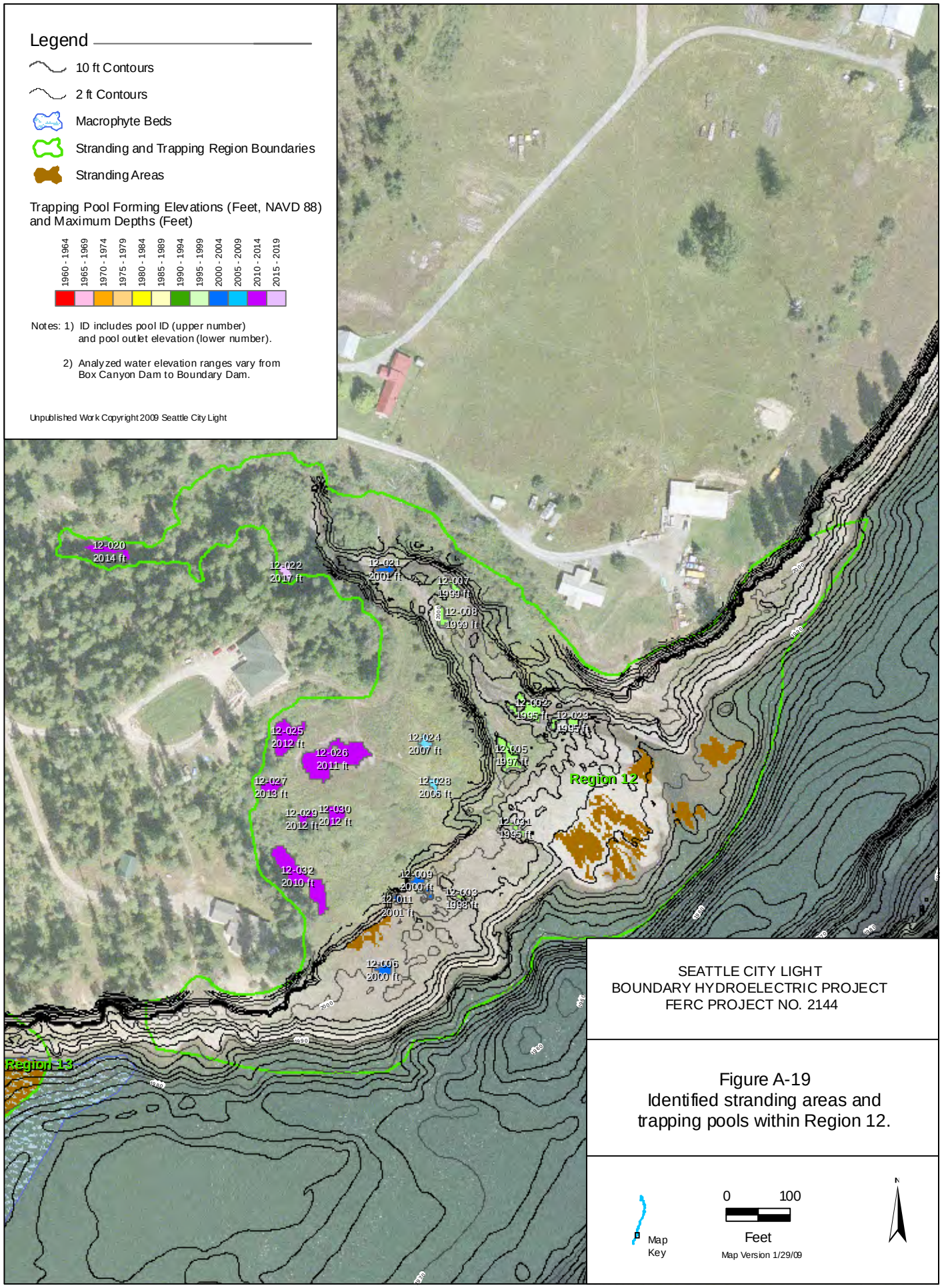


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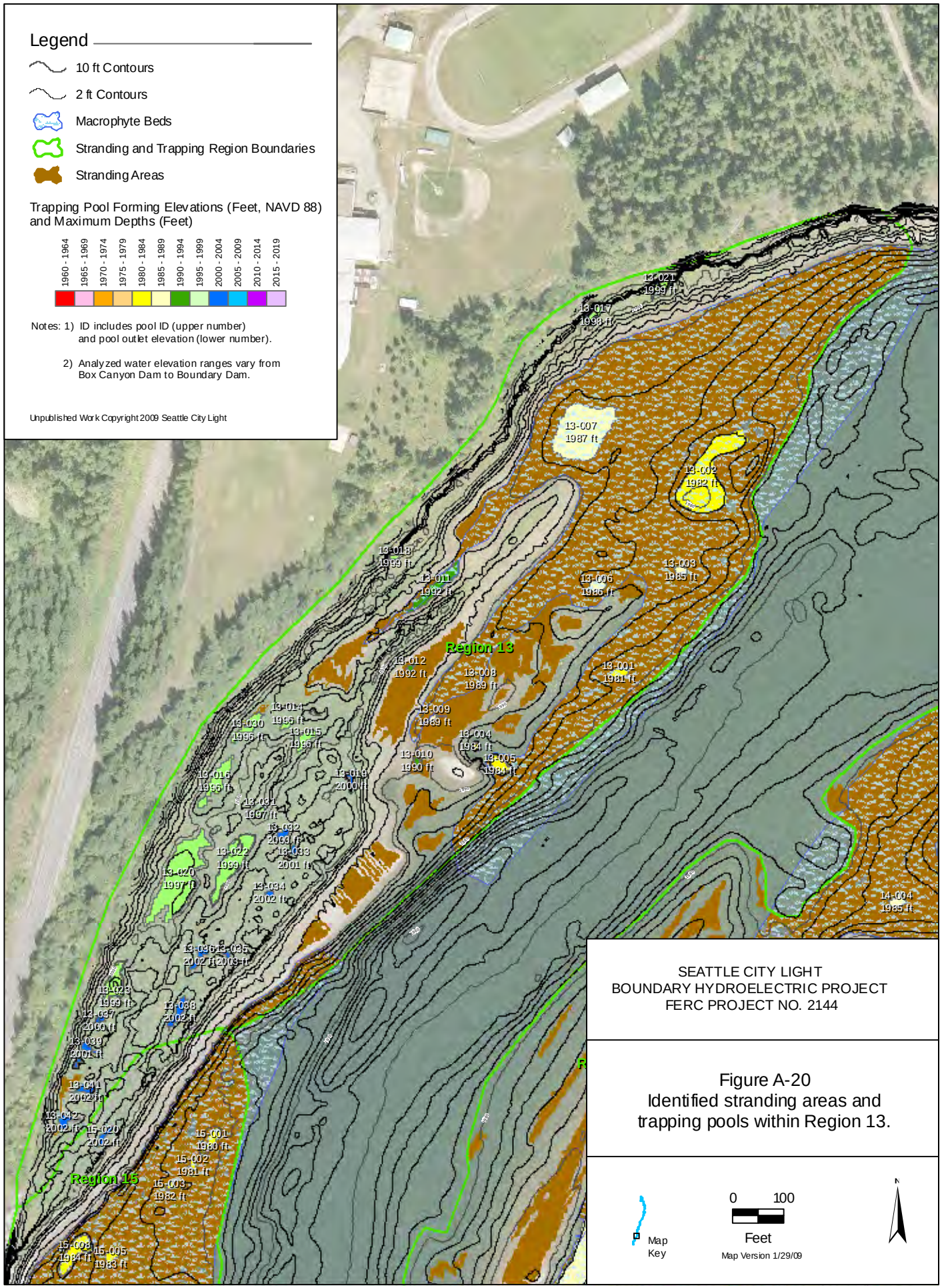
Figure A-19
Identified stranding areas and trapping pools within Region 12.


Legend
10 ft Contours
2 ft Contours
Macrophyte Beds
Stranding and Trapping Region Boundaries
Stranding Areas
Trapping Pool Forming Elevations (Feet, NAVD 88) and Maximum Depths (Feet)
1960 - 1964
1965 - 1969
1970 - 1974
1975 - 1979
1980 - 1984
1985 - 1989
1990 - 1994
1995 - 1999
2000 - 2004
2005 - 2009
2010 - 2014
2015 - 2019
Notes: 1) ID includes pool ID (upper number) and pool outlet elevation (lower number).
2) Analyzed water elevation ranges vary from Box Canyon Dam to Boundary Dam.
Unpublished Work Copyright 2009 Seattle City Light
13-021 1999 ft
13-017 1998 ft
13-007 1987 ft
13-002 1992 ft
13-018 1999 ft
13-011 1992 ft
13-003 1985 ft
13-006 1986 ft
Region 13
13-012 1992 ft
13-008 1989 ft
13-001 1981 ft
13-014 1996 ft
13-030 1996 ft
13-015 1996 ft
13-009 1989 ft
13-004 1984 ft
13-010 1990 ft
13-005 1984 ft
13-016 1996 ft
13-019 2000 ft
13-031 1997 ft
13-032 2000 ft
13-022 1999 ft
13-033 2001 ft
13-020 1997 ft
13-034 2002 ft
14-004 1985 ft
13-036 2002 ft
13-035 2003 ft
13-023 1999 ft
13-037 2000 ft
13-038 2002 ft
13-039 2001 ft
13-041 2002 ft
13-042 2002 ft
15-020 2002 ft
15-001 1980 ft
15-002 1981 ft
Region 15
15-003 1982 ft
15-008 1984 ft
15-005 1983 ft
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FERC PROJECT NO. 2144
Figure A-20
Identified stranding areas and trapping pools within Region 13.
Map Key
0 100
Feet
Map Version 1/29/09
N

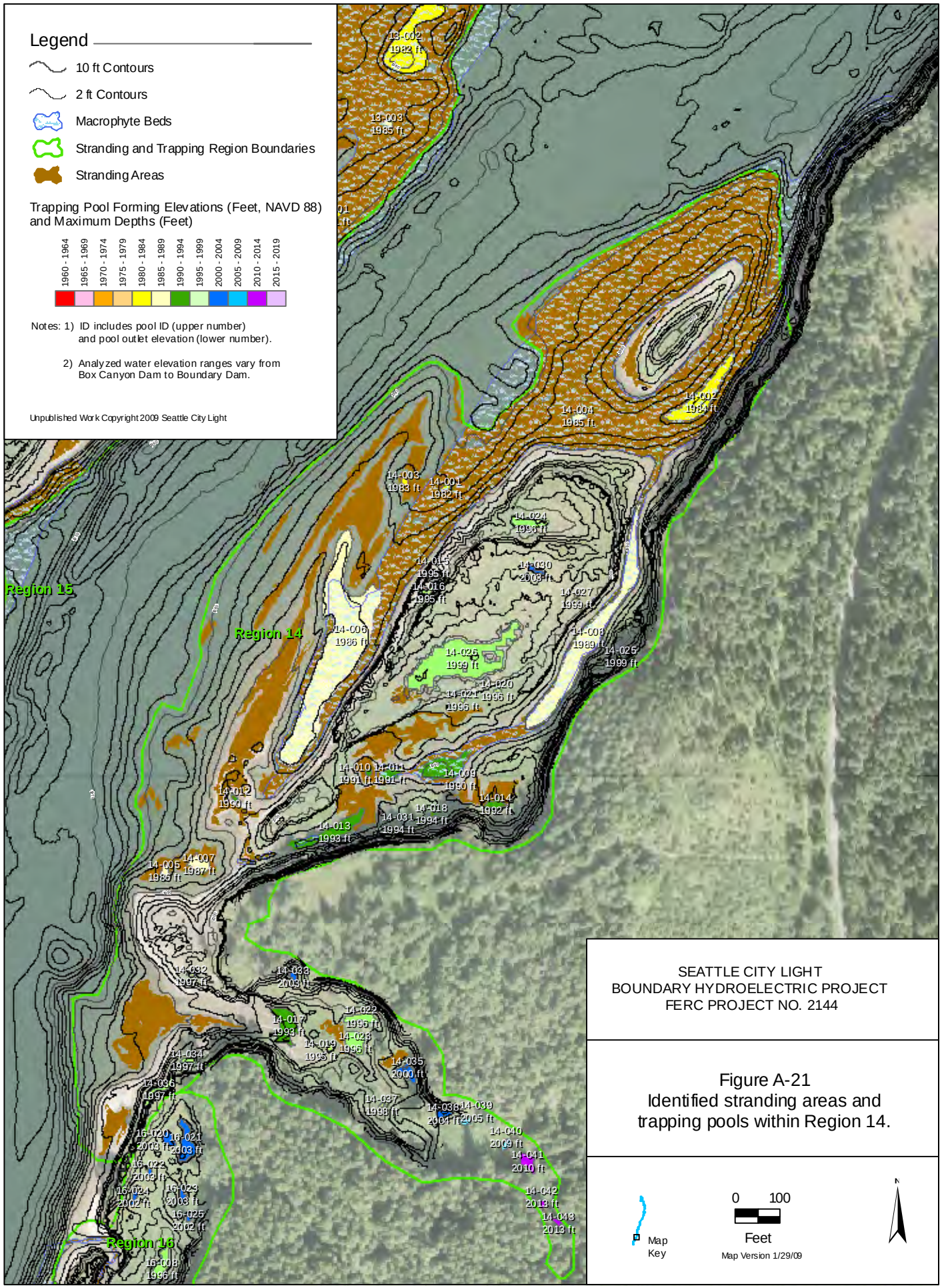


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Figure A-21
Identified stranding areas and trapping pools within Region 14.

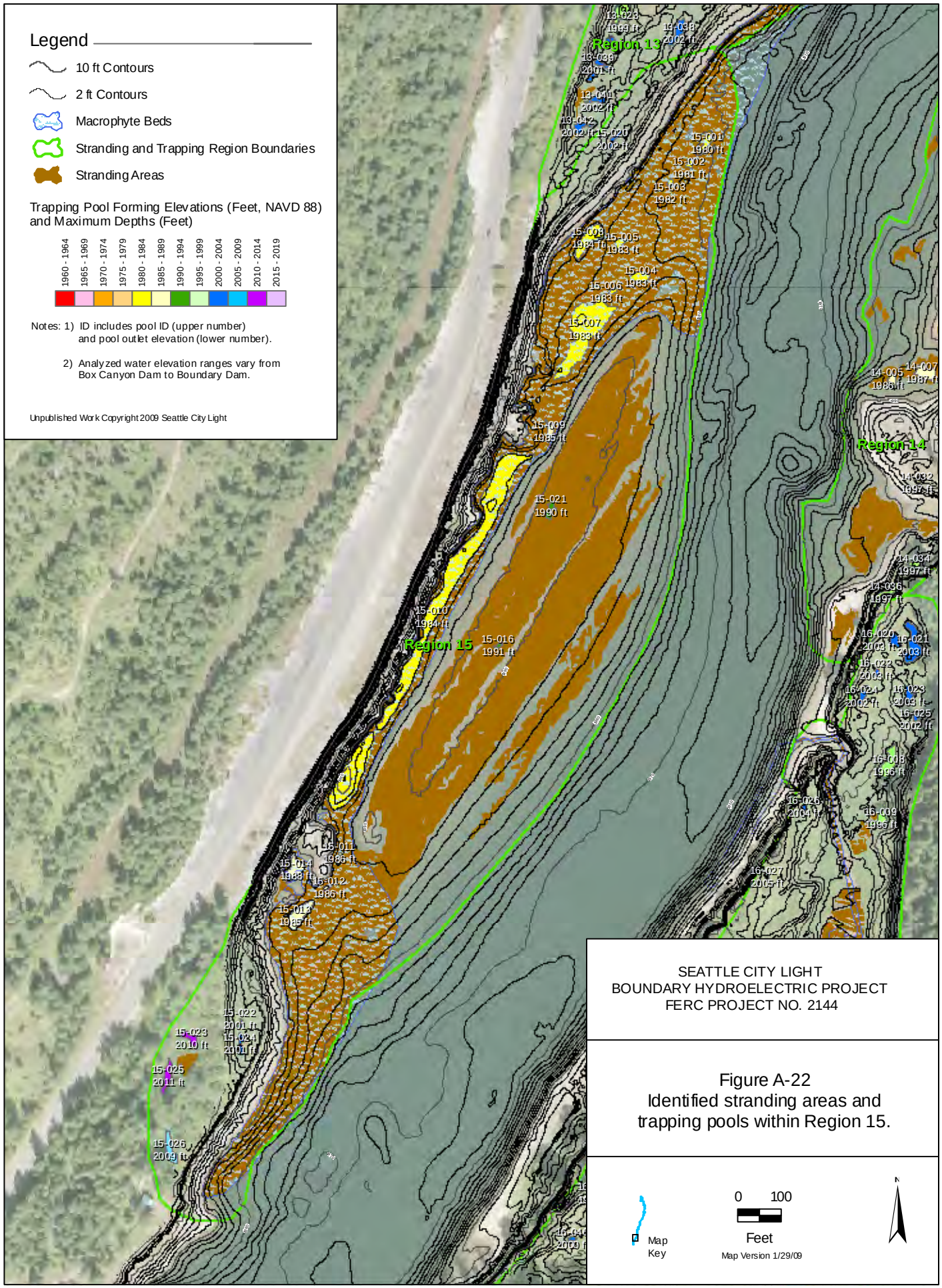


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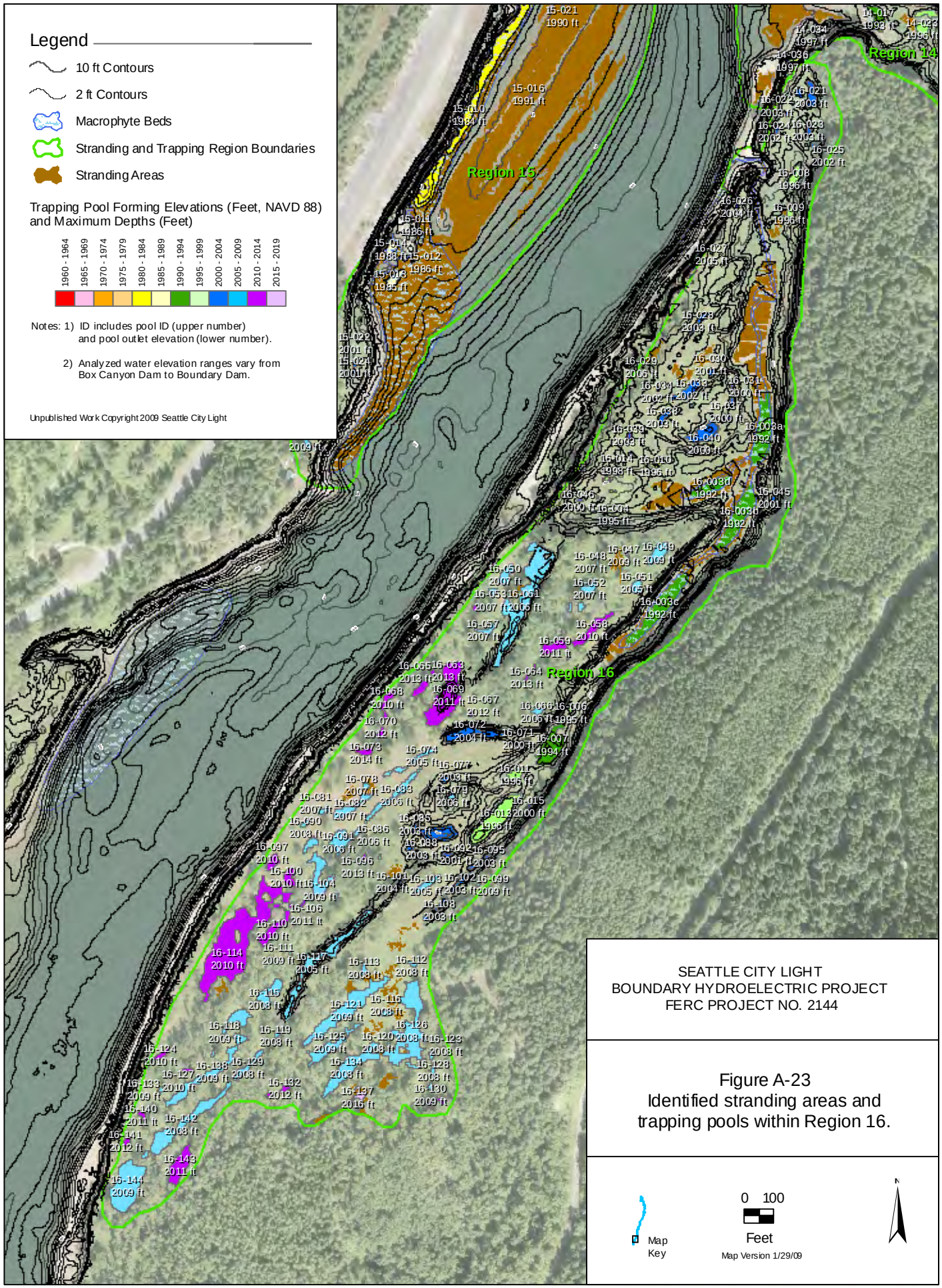
Figure A-22
Identified stranding areas and trapping pools within Region 15.

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FERC PROJECT NO. 2144

Figure A-23
Identified stranding areas and trapping pools within Region 16.

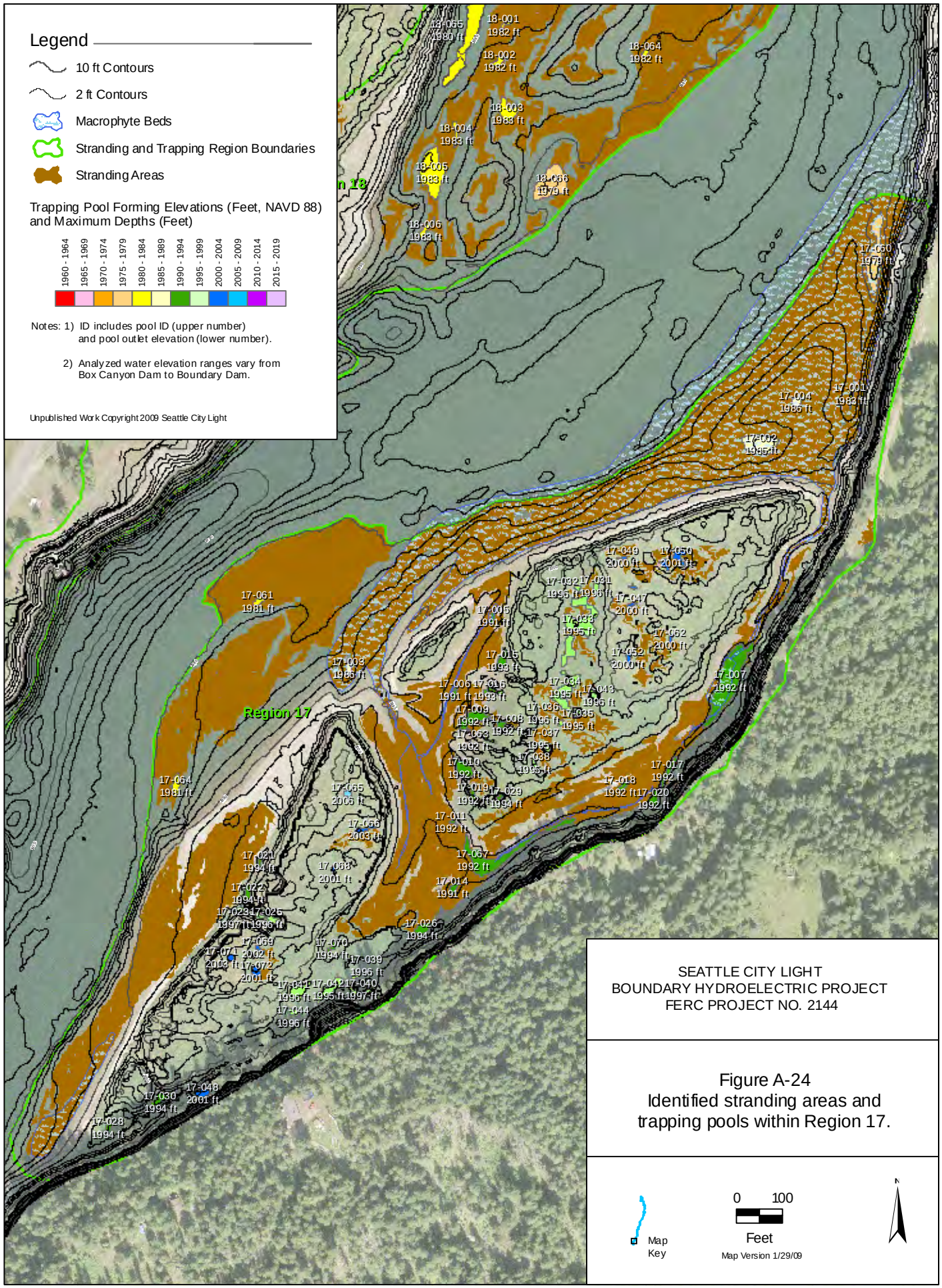


Figure A-24
Identified stranding areas and trapping pools within Region 17.

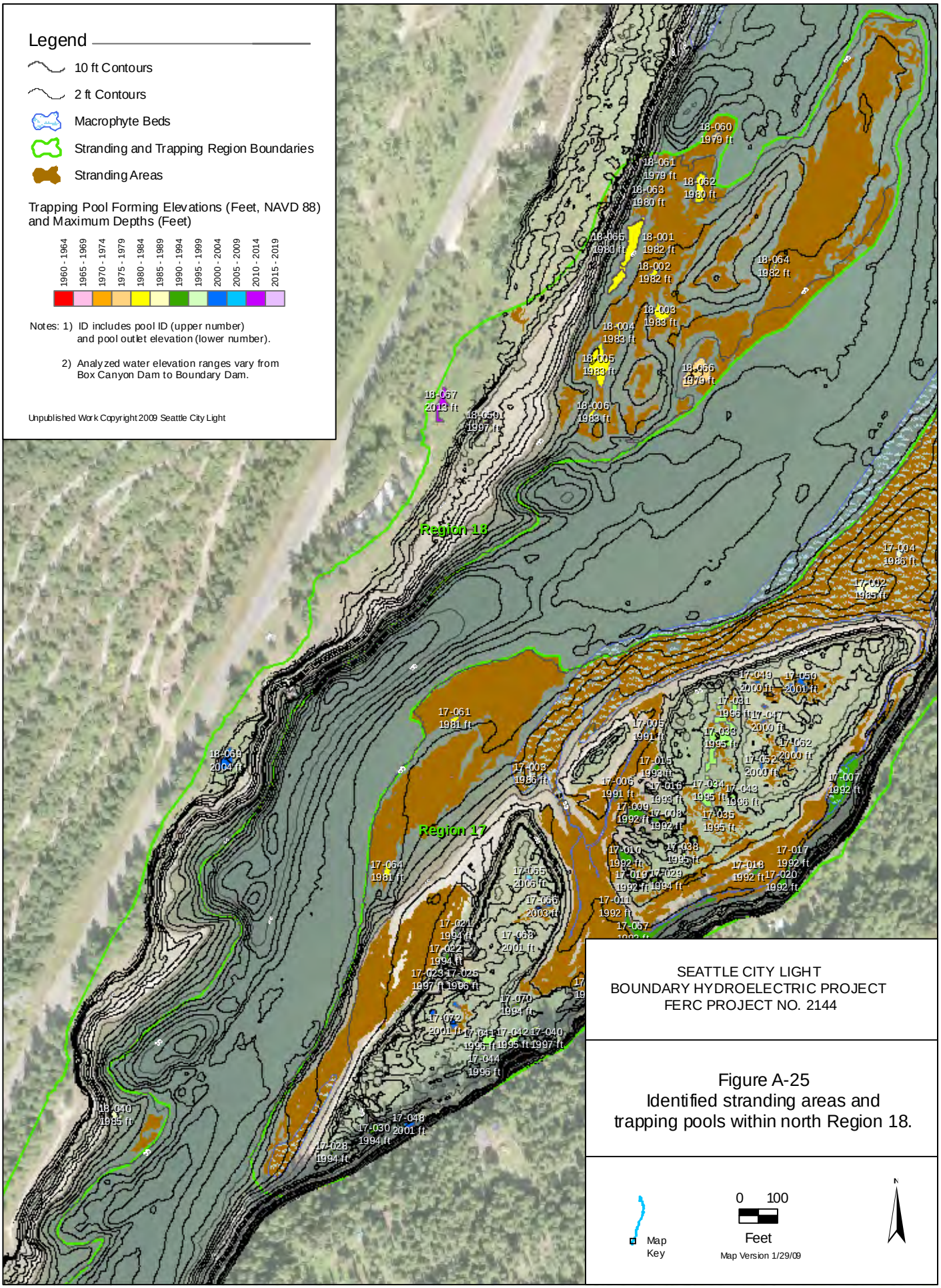


Figure A-25
Identified stranding areas and trapping pools within north Region 18.

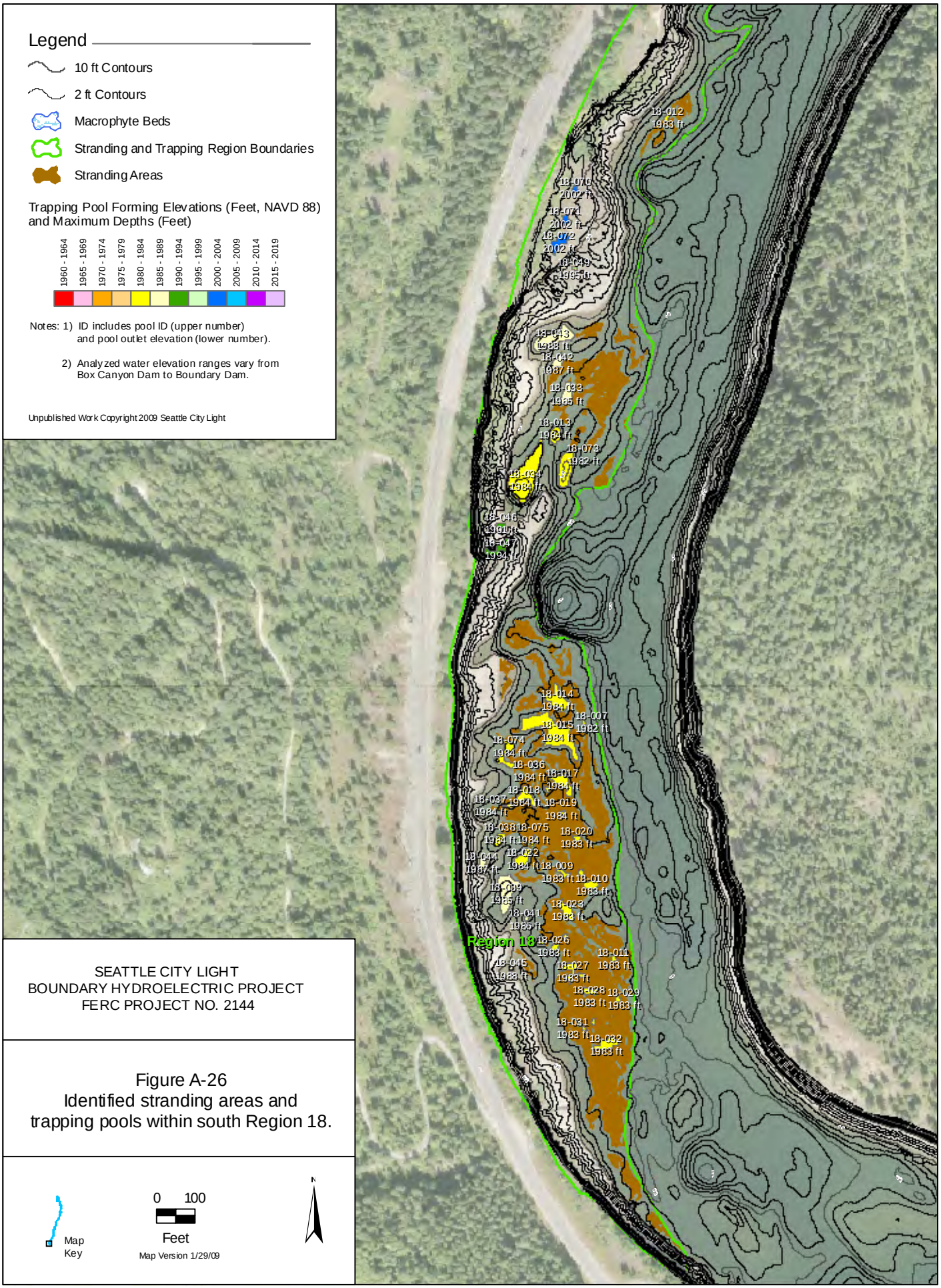


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Figure A-26
Identified stranding areas and trapping pools within south Region 18.

# Attachment B: Physical Characteristics of Stranding Areas

This attachment contains the following tables:

Table B-1. Summary of stranding area identified within the Forebay Launch Region.
Table B-2. Summary of stranding area identified within Region 1.
Table B-3. Summary of stranding area identified within Region 2.
Table B-4. Summary of stranding area identified within Region 3.
Table B-5. Summary of stranding area identified within Region 4.
Table B-6. Summary of stranding area identified within Region 5.
Table B-7. Summary of stranding area identified within Stump Farm Region.
Table B-8. Summary of stranding area identified within Region 6.
Table B-9. Summary of stranding area identified within Flume Creek Region.
Table B-10. Summary of stranding area identified within Sullivan Creek Delta Region.
Table B-11. Summary of stranding area identified within Region 7.
Table B-12. Summary of stranding area identified within Region 8.
Table B-13. Summary of stranding area identified within Region 9.
Table B-14. Summary of stranding area identified within Region 10.
Table B-15. Summary of stranding area identified within Region 11.
Table B-16. Summary of stranding area identified within Region 12.
Table B-17. Summary of stranding area identified within Region 13.
Table B-18. Summary of stranding area identified within Region 14.
Table B-19. Summary of stranding area identified within Region 15.
Table B-20. Summary of stranding area identified within Region 16.
Table B-21. Summary of stranding area identified within Region 17.
Table B-22. Summary of stranding area identified within Region 18.
Table B-23. Summary of stranding area identified within the Tailrace Region.
Table B-24. Summary of additional stranding area identified within Forebay Reach.
Table B-25. Summary of additional stranding area identified within Canyon Reach.
Table B-26. Summary of additional stranding area identified within Upper Reservoir Reach.
Table B-27. Summary of additional stranding area identified within Tailrace Reach.

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**Table B-1.** Summary of stranding area identified within the Forebay Launch Region.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,957 | --- | 756 | --- |
| 1,958 | --- | 3,123 | --- |
| 1,959 | --- | 225 | --- |
| 1,964 | --- | 189 | --- |
| 1,965 | --- | 2,196 | --- |
| 1,966 | --- | 684 | --- |
| 1,968 | --- | --- | 8 |
| 1,969 | --- | --- | 5 |
| 1,970 | --- | --- | 323 |
| 1,971 | --- | --- | 1,488 |
| 1,972 | --- | --- | 4,132 |
| 1,973 | 1,953 | --- | 4,675 |
| 1,974 | 1,080 | --- | 6,033 |
| 1,975 | 1,647 | --- | 6,140 |
| 1,976 | 8,109 | --- | 9,754 |
| 1,977 | 30,717 | --- | 14,629 |
| 1,978 | 5,553 | --- | 10,247 |
| 1,979 | --- | --- | 6,249 |
| 1,980 | --- | --- | 4,786 |
| 1,981 | 1,044 | --- | 5,735 |
| 1,982 | 943 | 20 | 6,615 |
| 1,983 | 711 | 18 | 3,658 |
| 1,984 | 63 | --- | 3,433 |
| 1,985 | --- | --- | 1,387 |
| 1,986 | --- | --- | 376 |
| 1,987 | --- | 27 | 187 |
| 1,988 | --- | 1,692 | 189 |

**Table B-2.** Summary of stranding area identified within Region 1.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,964 | --- | --- | 1 |
| 1,965 | --- | --- | 6 |
| 1,966 | --- | --- | 17 |
| 1,967 | --- | --- | 16 |
| 1,968 | --- | --- | 77 |
| 1,969 | --- | --- | 184 |
| 1,970 | --- | --- | 608 |
| 1,971 | --- | --- | 1,402 |
| 1,972 | --- | --- | 1,785 |
| 1,973 | --- | --- | 1,972 |
| 1,974 | --- | --- | 2,029 |
| 1,975 | --- | --- | 2,226 |
| 1,976 | --- | --- | 2,730 |
| 1,977 | --- | --- | 4,474 |
| 1,978 | --- | --- | 5,117 |
| 1,979 | --- | --- | 6,011 |
| 1,980 | --- | --- | 4,989 |
| 1,981 | --- | --- | 4,968 |
| 1,982 | --- | --- | 5,618 |
| 1,983 | --- | --- | 6,042 |
| 1,984 | --- | --- | 4,077 |
| 1,985 | --- | --- | 3,523 |
| 1,986 | --- | --- | 4,221 |
| 1,987 | --- | --- | 544 |
| 1,988 | --- | --- | 4 |

**Table B-3.** Summary of stranding area identified within Region 2.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,967 | --- | --- | 11 |
| 1,968 | --- | --- | 79 |
| 1,969 | --- | --- | 105 |
| 1,970 | --- | --- | 374 |
| 1,971 | --- | --- | 747 |
| 1,972 | --- | --- | 837 |
| 1,973 | --- | --- | 880 |
| 1,974 | --- | --- | 842 |
| 1,975 | --- | --- | 1,136 |
| 1,976 | --- | --- | 1,376 |
| 1,977 | --- | --- | 2,822 |
| 1,978 | --- | --- | 6,581 |
| 1,979 | --- | --- | 11,493 |
| 1,980 | 54 | --- | 16,922 |
| 1,981 | 1,575 | --- | 22,146 |
| 1,982 | 1,656 | --- | 25,072 |
| 1,983 | 216 | --- | 28,520 |
| 1,984 | 999 | --- | 33,479 |
| 1,985 | 7,343 | --- | 36,736 |
| 1,986 | 5,587 | 13 | 31,104 |
| 1,987 | 29 | 2,770 | 6,384 |
| 1,988 | --- | 198 | 268 |
| 1,989 | --- | --- | 7 |

**Table B-4.** Summary of stranding area identified within Region 3.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,968 | --- | --- | 4 |
| 1,969 | --- | --- | 7 |
| 1,970 | --- | --- | 47 |
| 1,971 | --- | --- | 83 |
| 1,972 | --- | --- | 121 |
| 1,973 | --- | --- | 197 |
| 1,974 | --- | --- | 164 |
| 1,975 | --- | --- | 225 |
| 1,976 | --- | --- | 354 |
| 1,977 | --- | --- | 407 |
| 1,978 | --- | --- | 490 |
| 1,979 | --- | --- | 882 |
| 1,980 | --- | --- | 1,272 |
| 1,981 | --- | --- | 1,438 |
| 1,982 | --- | --- | 1,208 |
| 1,983 | --- | --- | 1,099 |
| 1,984 | --- | 711 | 1,326 |
| 1,985 | --- | 2,115 | 925 |
| 1,986 | --- | 126 | 573 |
| 1,987 | --- | --- | 447 |
| 1,988 | --- | 4,086 | 100 |

**Table B-5.** Summary of stranding area identified within Region 4.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,971 | --- | --- | 118 |
| 1,972 | --- | --- | 107 |
| 1,973 | --- | --- | 88 |
| 1,974 | --- | --- | 171 |
| 1,975 | --- | --- | 221 |
| 1,976 | --- | --- | 240 |
| 1,977 | --- | --- | 425 |
| 1,978 | --- | --- | 544 |
| 1,979 | --- | --- | 527 |
| 1,980 | --- | --- | 724 |
| 1,981 | --- | --- | 1,260 |
| 1,982 | --- | --- | 1,875 |
| 1,983 | --- | --- | 1,481 |
| 1,984 | --- | --- | 1,317 |
| 1,985 | --- | --- | 1,232 |
| 1,986 | 174 | 69 | 1,441 |
| 1,987 | 133 | 812 | 595 |
| 1,988 | --- | --- | 73 |

**Table B-6.** Summary of stranding area identified within Region 5.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,965 | --- | --- | 2 |
| 1,966 | --- | --- | 9 |
| 1,967 | --- | --- | 17 |
| 1,968 | --- | --- | 77 |
| 1,969 | --- | --- | 144 |
| 1,970 | --- | --- | 789 |
| 1,971 | --- | --- | 1,583 |
| 1,972 | --- | --- | 1,646 |
| 1,973 | --- | --- | 1,946 |
| 1,974 | --- | --- | 2,552 |
| 1,975 | --- | --- | 2,628 |
| 1,976 | --- | --- | 2,583 |
| 1,977 | --- | --- | 2,817 |
| 1,978 | --- | --- | 2,767 |
| 1,979 | --- | --- | 2,830 |
| 1,980 | --- | --- | 2,884 |
| 1,981 | --- | --- | 2,400 |
| 1,982 | --- | --- | 2,771 |
| 1,983 | --- | --- | 2,757 |
| 1,984 | --- | --- | 2,899 |
| 1,985 | --- | --- | 3,214 |
| 1,986 | --- | --- | 3,016 |
| 1,987 | --- | --- | 513 |
| 1,988 | --- | --- | 1 |

**Table B-7.** Summary of stranding area identified within Stump Farm Region.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,970 | --- | --- | 3 |
| 1,971 | --- | --- | 37 |
| 1,972 | --- | --- | 100 |
| 1,973 | --- | --- | 181 |
| 1,974 | --- | --- | 398 |
| 1,975 | --- | --- | 628 |
| 1,976 | --- | --- | 1,012 |
| 1,977 | --- | --- | 1,011 |
| 1,978 | --- | --- | 1,203 |
| 1,979 | --- | --- | 1,388 |
| 1,980 | --- | --- | 1,957 |
| 1,981 | --- | --- | 1,948 |
| 1,982 | --- | --- | 1,745 |
| 1,983 | --- | --- | 1,258 |
| 1,984 | --- | --- | 2,223 |
| 1,985 | --- | --- | 3,746 |
| 1,986 | --- | --- | 3,212 |
| 1,987 | --- | --- | 3,679 |
| 1,988 | --- | --- | 2,368 |
| 1,989 | --- | --- | 224 |

**Table B-8.** Summary of stranding area identified within Region 6.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,965 | --- | --- | 86 |
| 1,966 | --- | --- | 389 |
| 1,967 | --- | --- | 258 |
| 1,968 | --- | --- | 264 |
| 1,969 | --- | --- | 180 |
| 1,970 | --- | --- | 155 |
| 1,971 | --- | --- | 151 |
| 1,972 | --- | --- | 146 |
| 1,973 | --- | --- | 122 |
| 1,974 | --- | --- | 142 |
| 1,975 | --- | --- | 186 |
| 1,976 | --- | --- | 153 |
| 1,977 | --- | --- | 220 |
| 1,978 | --- | --- | 288 |
| 1,979 | --- | --- | 180 |
| 1,980 | --- | --- | 81 |
| 1,981 | --- | --- | 74 |
| 1,982 | --- | --- | 149 |
| 1,983 | --- | --- | 133 |
| 1,984 | --- | --- | 87 |
| 1,985 | --- | --- | 465 |
| 1,986 | --- | --- | 320 |
| 1,987 | --- | --- | 350 |

**Table B-9.** Summary of stranding area identified within Flume Creek Region.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,973 | --- | --- | 187 |
| 1,974 | --- | --- | 583 |
| 1,975 | --- | --- | 698 |
| 1,976 | --- | --- | 882 |
| 1,977 | --- | --- | 926 |
| 1,978 | --- | --- | 800 |
| 1,979 | --- | --- | 864 |
| 1,980 | --- | --- | 1,138 |
| 1,981 | --- | --- | 1,467 |
| 1,982 | --- | --- | 1,360 |
| 1,983 | --- | --- | 1,498 |
| 1,984 | --- | --- | 1,107 |
| 1,985 | --- | --- | 47 |

**Table B-10.** Summary of stranding area identified within Sullivan Creek Delta Region.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,983 | --- | 459 | --- |
| 1,984 | --- | 2,610 | --- |
| 1,985 | --- | 12,069 | --- |
| 1,986 | --- | 14,310 | --- |
| 1,987 | --- | 11,970 | --- |
| 1,988 | --- | 19,332 | --- |
| 1,989 | --- | 9,855 | --- |
| 1,990 | --- | 18,702 | --- |
| 1,991 | --- | 15,849 | --- |
| 1,992 | --- | 11,673 | --- |
| 1,993 | --- | 6,840 | --- |
| 1,994 | --- | 18,117 | --- |
| 1,995 | --- | 8,523 | --- |
| 1,996 | --- | 4,311 | --- |
| 1,997 | --- | 3,834 | --- |
| 1,998 | --- | 1,341 | --- |
| 1,999 | --- | 5,310 | --- |
| 2,000 | --- | 14,607 | --- |
| 2,001 | --- | 5,868 | --- |
| 2,002 | --- | 6,867 | --- |
| 2,003 | --- | 8,640 | --- |
| 2,004 | --- | 9,756 | --- |
| 2,005 | --- | 4,401 | --- |
| 2,006 | --- | 2,241 | --- |
| 2,007 | --- | 2,673 | --- |
| 2,008 | --- | 1,476 | --- |
| 2,009 | --- | 5,670 | --- |
| 2,010 | --- | 7,794 | --- |
| 2,011 | --- | 4,871 | --- |
| 2,012 | --- | 1,577 | --- |
| 2,013 | --- | 258 | --- |
| 2,014 | --- | 2,147 | --- |
| 2,015 | --- | 157 | --- |
| 2,016 | --- | 29 | --- |

**Table B-11.** Summary of stranding area identified within Region 7.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,974 | 178 | --- | 179 |
| 1,975 | 11 | --- | 478 |
| 1,976 | --- | --- | 620 |
| 1,977 | --- | --- | 802 |
| 1,978 | 110 | 387 | 1,191 |
| 1,979 | 1,236 | 837 | 3,896 |
| 1,980 | 179 | 1,972 | 6,442 |
| 1,981 | 714 | 222 | 9,370 |
| 1,982 | 4,581 | --- | 15,522 |
| 1,983 | --- | --- | 15,526 |
| 1,984 | 1,260 | 747 | 22,520 |
| 1,985 | 15,073 | 1,325 | 31,158 |
| 1,986 | 10,962 | --- | 34,829 |
| 1,987 | 36,835 | 111 | 50,963 |
| 1,988 | 6,086 | 106 | 35,467 |
| 1,989 | 909 | 2,655 | 8,729 |
| 1,990 | 46 | 5,345 | 1,857 |
| 1,991 | --- | 10,764 | 498 |
| 1,992 | --- | 12,528 | --- |
| 1,993 | --- | 12,006 | --- |
| 1,994 | --- | 9,198 | --- |
| 1,995 | --- | 3,699 | --- |
| 1,999 | --- | 207 | --- |
| 2,000 | --- | 1,971 | --- |
| 2,001 | --- | 2,979 | --- |
| 2,002 | --- | 2,952 | --- |
| 2,003 | --- | 4,149 | --- |
| 2,004 | --- | 1,971 | --- |
| 2,005 | --- | 4,356 | --- |
| 2,006 | --- | 459 | --- |
| 2,009 | --- | 1,143 | --- |
| 2,010 | --- | 3,566 | --- |
| 2,011 | --- | 1,310 | --- |
| 2,012 | --- | 469 | --- |
| 2,013 | --- | 1,129 | --- |
| 2,014 | --- | 653 | --- |
| 2,015 | --- | 551 | --- |

**Table B-12.** Summary of stranding area identified within Region 8.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,974 | --- | --- | 1 |
| 1,975 | --- | --- | 34 |
| 1,976 | --- | --- | 305 |
| 1,977 | 3,321 | 6,529 | 4,279 |
| 1,978 | 6,334 | 3,790 | 13,806 |
| 1,979 | 4,598 | 12,557 | 24,925 |
| 1,980 | 9,340 | 12,557 | 51,964 |
| 1,981 | 11,272 | 13,713 | 81,575 |
| 1,982 | 35,456 | 17,590 | 114,689 |
| 1,983 | 110,056 | 28,922 | 162,791 |
| 1,984 | 79,558 | 25,922 | 168,734 |
| 1,985 | 127,928 | 52,054 | 177,166 |
| 1,986 | 169,071 | 104,872 | 119,386 |
| 1,987 | 93,236 | 106,735 | 70,378 |
| 1,988 | 76,965 | 15,690 | 42,556 |
| 1,989 | 33,812 | 10,766 | 23,646 |
| 1,990 | 27,360 | 30,946 | 5,537 |
| 1,991 | 9 | 9,837 | 99 |
| 1,992 | --- | 2,565 | --- |
| 1,993 | --- | 918 | --- |
| 2,006 | --- | 1,098 | --- |
| 2,007 | --- | 1,647 | --- |
| 2,008 | --- | 13,374 | --- |
| 2,009 | --- | 21,447 | --- |
| 2,010 | --- | 74,078 | --- |
| 2,011 | --- | 41,201 | --- |
| 2,012 | --- | 17,860 | --- |
| 2,013 | --- | 13,220 | --- |
| 2,014 | --- | 8,797 | --- |
| 2,015 | --- | 7,747 | --- |
| 2,016 | --- | 6,165 | --- |
| 2,017 | --- | 4,020 | --- |
| 2,018 | --- | 4,104 | --- |
| 2,019 | --- | 515 | --- |

**Table B-13.** Summary of stranding area identified within Region 9.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,976 | 949 | --- | 569 |
| 1,977 | 1,052 | --- | 3,574 |
| 1,978 | 257 | --- | 6,630 |
| 1,979 | 4,597 | --- | 25,692 |
| 1,980 | 12,753 | --- | 47,842 |
| 1,981 | 49,725 | --- | 65,429 |
| 1,982 | 78,525 | --- | 78,379 |
| 1,983 | 103,050 | --- | 76,861 |
| 1,984 | 44,505 | --- | 67,314 |
| 1,985 | 91,467 | --- | 69,365 |
| 1,986 | 86,931 | --- | 78,518 |
| 1,987 | 96,018 | 13 | 74,330 |
| 1,988 | 85,108 | 77 | 78,124 |
| 1,989 | 92,194 | 282 | 98,158 |
| 1,990 | 55,363 | 21,642 | 98,043 |
| 1,991 | 23,881 | 40,191 | 49,099 |
| 1,992 | 39,975 | 120,595 | 17,165 |
| 1,993 | 16,262 | 80,858 | 4,111 |
| 1,994 | 18,307 | 55,233 | 532 |
| 1,995 | 1,169 | 30,124 | --- |
| 1,996 | --- | 12,303 | --- |
| 1,997 | --- | 9,711 | --- |
| 1,998 | --- | 4,365 | --- |
| 1,999 | --- | 486 | --- |
| 2,000 | --- | 1,998 | --- |
| 2,001 | --- | 4,221 | --- |
| 2,002 | --- | 1,773 | --- |
| 2,003 | --- | 756 | --- |
| 2,004 | --- | 36 | --- |
| 2,005 | --- | 1,350 | --- |

**Table B-14.** Summary of stranding area identified within Region 10.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,978 | --- | --- | 1 |
| 1,979 | --- | 1,384 | 757 |
| 1,980 | --- | 1,179 | 1,660 |
| 1,981 | --- | 1,647 | 1,545 |
| 1,982 | --- | 1,134 | 1,324 |
| 1,983 | --- | --- | 1,084 |
| 1,984 | --- | --- | 1,384 |
| 1,985 | --- | 747 | 1,613 |
| 1,986 | --- | 5,544 | 1,093 |
| 1,987 | --- | 8,667 | 112 |
| 1,988 | --- | 15,525 | --- |
| 1,989 | --- | 22,734 | --- |
| 1,990 | --- | 27,486 | --- |
| 1,991 | --- | 22,545 | --- |
| 1,992 | --- | 43,893 | --- |
| 1,993 | --- | 27,864 | --- |
| 1,994 | --- | 1,107 | --- |
| 2,001 | --- | 9 | --- |
| 2,002 | --- | 1,737 | --- |

**Table B-15.** Summary of stranding area identified within Region 11.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,978 | --- | --- | 223 |
| 1,979 | --- | --- | 6,845 |
| 1,980 | --- | --- | 18,076 |
| 1,981 | 680 | 380 | 22,085 |
| 1,982 | 6,206 | 290 | 28,701 |
| 1,983 | 5,126 | 479 | 43,146 |
| 1,984 | 10,373 | 79 | 51,718 |
| 1,985 | 48,004 | --- | 50,912 |
| 1,986 | 48,267 | --- | 48,488 |
| 1,987 | 31,708 | --- | 41,841 |
| 1,988 | 19,422 | --- | 44,568 |
| 1,989 | 103,440 | --- | 53,307 |
| 1,990 | 105,564 | 592 | 32,901 |
| 1,991 | 2,485 | 26 | 11,966 |
| 1,992 | 567 | 36 | 3,889 |
| 1,993 | --- | 738 | 638 |
| 1,994 | --- | 1,737 | 3 |
| 1,995 | --- | 2,367 | 11 |

**Table B-16.** Summary of stranding area identified within Region 12.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,988 | --- | 315 | --- |
| 1,989 | --- | 1,620 | --- |
| 1,990 | --- | 828 | --- |
| 1,991 | --- | 369 | --- |
| 1,992 | --- | 1,611 | --- |
| 1,993 | --- | 3,942 | --- |
| 1,994 | --- | 2,403 | --- |
| 2,002 | --- | 1,089 | --- |

**Table B-17.** Summary of stranding area identified within Region 13.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,977 | --- | --- | 12 |
| 1,978 | --- | --- | 927 |
| 1,979 | --- | --- | 4,834 |
| 1,980 | --- | --- | 11,201 |
| 1,981 | 2,916 | --- | 13,649 |
| 1,982 | 5,679 | --- | 16,057 |
| 1,983 | 1,548 | --- | 22,884 |
| 1,984 | 297 | --- | 24,453 |
| 1,985 | 8,091 | --- | 22,396 |
| 1,986 | 23,867 | 2,053 | 16,576 |
| 1,987 | 12,348 | 1,530 | 18,542 |
| 1,988 | 33,680 | 8,710 | 14,307 |
| 1,989 | 18,312 | 8,616 | 14,268 |
| 1,990 | 12,794 | 10,777 | 14,091 |
| 1,991 | 3,175 | 1,361 | 8,172 |
| 1,992 | 2,236 | 9,851 | 2,110 |
| 1,993 | 117 | 13,806 | 124 |
| 1,994 | --- | 3,213 | --- |
| 1,995 | --- | 198 | --- |
| 1,997 | --- | 180 | --- |
| 1,998 | --- | 81 | --- |
| 2,000 | --- | 9 | --- |
| 2,003 | --- | 153 | --- |
| 2,004 | --- | 810 | --- |

**Table B-18.** Summary of stranding area identified within Region 14.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,977 | --- | --- | 35 |
| 1,978 | 4 | --- | 577 |
| 1,979 | --- | 935 | 3,955 |
| 1,980 | 170 | 2,706 | 9,629 |
| 1,981 | 4,923 | 1,395 | 11,591 |
| 1,982 | 6,677 | 442 | 14,737 |
| 1,983 | 5,159 | 1,681 | 16,617 |
| 1,984 | 11,299 | 3,048 | 17,479 |
| 1,985 | 17,492 | 2,713 | 20,534 |
| 1,986 | 11,565 | 5,427 | 21,170 |
| 1,987 | 5,401 | 14,696 | 24,081 |
| 1,988 | 1,030 | 15,692 | 21,123 |
| 1,989 | 790 | 10,478 | 14,406 |
| 1,990 | 104 | 6,808 | 14,149 |
| 1,991 | 1,353 | 8,214 | 6,906 |
| 1,992 | 441 | 18,990 | 3,618 |
| 1,993 | 35 | 9,415 | 194 |
| 1,994 | --- | 7,506 | --- |
| 1,995 | --- | 5,868 | --- |
| 1,996 | --- | 1,575 | --- |
| 1,997 | --- | 1,323 | --- |
| 1,998 | --- | 1,260 | --- |
| 1,999 | --- | 45 | --- |
| 2,000 | --- | 360 | --- |
| 2,001 | --- | 909 | --- |
| 2,002 | --- | 45 | --- |
| 2,003 | --- | 1,062 | --- |

**Table B-19.** Summary of stranding area identified within Region 15.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,978 | --- | --- | 60 |
| 1,979 | 616 | --- | 2,966 |
| 1,980 | 3,631 | 39 | 11,084 |
| 1,981 | 9,639 | --- | 15,869 |
| 1,982 | 13,905 | --- | 15,467 |
| 1,983 | 8,064 | --- | 18,299 |
| 1,984 | 15,759 | 594 | 27,339 |
| 1,985 | 11,970 | 2,763 | 33,643 |
| 1,986 | 10,359 | 14,823 | 29,002 |
| 1,987 | 18,781 | 12,467 | 23,664 |
| 1,988 | 2,784 | 9,258 | 13,585 |
| 1,989 | 484 | 53,795 | 9,470 |
| 1,990 | --- | 72,909 | 5,743 |
| 1,991 | --- | 87,300 | 2,886 |
| 1,992 | --- | 8,811 | 711 |
| 1,993 | --- | --- | 134 |
| 1,994 | --- | --- | 57 |
| 1,995 | --- | --- | 7 |
| 2,014 | --- | 1,107 | --- |
| 2,015 | --- | 144 | --- |

**Table B-20.** Summary of stranding area identified within Region 16.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,989 | | | 30 |
| 1,990 | --- | --- | 321 |
| 1,991 | --- | --- | 206 |
| 1,992 | --- | --- | 322 |
| 1,993 | 252 | 2,637 | 193 |
| 1,994 | 6,411 | 23,585 | 3,072 |
| 1,995 | 5,714 | 18,359 | 3,758 |
| 1,996 | 159 | 737 | 917 |
| 1,997 | --- | 18 | 84 |
| 1,998 | --- | 1,521 | 4 |
| 2,003 | --- | 504 | --- |
| 2,004 | --- | 2,160 | --- |
| 2,005 | --- | 747 | --- |
| 2,006 | --- | 261 | --- |
| 2,007 | --- | 1,548 | --- |
| 2,008 | --- | 3,717 | --- |
| 2,009 | --- | 1,022 | --- |
| 2,010 | --- | 4,248 | --- |
| 2,011 | --- | 3,249 | --- |
| 2,012 | --- | 1,494 | --- |
| 2,013 | --- | 972 | --- |
| 2,014 | --- | 9 | --- |
| 2,015 | --- | 531 | --- |
| 2,016 | --- | 747 | --- |
| 2,017 | --- | 307 | --- |
| 2,018 | --- | 1,011 | --- |
| 2,020 | --- | 583 | --- |

**Table B-21.** Summary of stranding area identified within Region 17.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,979 | --- | --- | 675 |
| 1,980 | 1,011 | 2,764 | 7,099 |
| 1,981 | 2,098 | 45,021 | 13,605 |
| 1,982 | 2,061 | 21,762 | 16,293 |
| 1,983 | 3,780 | 15,120 | 19,123 |
| 1,984 | 3,186 | 21,150 | 19,406 |
| 1,985 | 4,637 | 1,456 | 20,558 |
| 1,986 | 6,003 | 972 | 25,795 |
| 1,987 | 23,514 | 3,441 | 22,321 |
| 1,988 | 6,494 | 4,009 | 16,975 |
| 1,989 | 3,947 | 3,091 | 11,535 |
| 1,990 | 1,749 | 4,974 | 6,123 |
| 1,991 | 1,335 | 17,853 | 1,672 |
| 1,992 | 1,967 | 56,084 | 1,892 |
| 1,993 | 763 | 59,168 | 842 |
| 1,994 | --- | 37,962 | 160 |
| 1,995 | --- | 13,896 | --- |
| 1,996 | --- | 1,530 | --- |
| 1,997 | --- | 8,289 | --- |
| 1,998 | --- | 3,699 | --- |
| 2,001 | --- | 846 | --- |
| 2,002 | --- | 7,020 | --- |
| 2,003 | --- | 4,563 | --- |
| 2,004 | --- | 297 | --- |
| 2,005 | --- | 1,089 | --- |
| 2,006 | --- | 306 | --- |
| 2,019 | --- | 640 | --- |
| 2,020 | --- | 260 | --- |
| 2,021 | --- | 8 | --- |
| 2,023 | --- | 2 | --- |
| 2,024 | --- | 16 | --- |

**Table B-22.** Summary of stranding area identified within Region 18.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,979 | --- | 2,845 | --- |
| 1,980 | --- | 31,379 | --- |
| 1,981 | --- | 38,475 | --- |
| 1,982 | --- | 43,671 | --- |
| 1,983 | --- | 80,967 | --- |
| 1,984 | --- | 155,335 | --- |
| 1,985 | --- | 45,774 | --- |
| 1,986 | --- | 18,450 | --- |
| 1,987 | --- | 9,774 | --- |
| 1,988 | --- | 7,983 | --- |
| 1,989 | --- | 1,080 | --- |
| 1,990 | --- | 45 | --- |
| 1,991 | --- | 1,647 | --- |
| 2,005 | --- | 1,012 | --- |
| 2,006 | --- | 362 | --- |
| 2,007 | --- | 74 | --- |

**Table B-23.** Summary of stranding area identified within the Tailrace Region.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,712 | --- | 153 | --- |
| 1,713 | --- | 1,170 | --- |
| 1,714 | --- | 2,178 | --- |
| 1,715 | --- | 2,304 | --- |
| 1,716 | --- | 1,629 | --- |
| 1,717 | --- | 1,008 | --- |
| 1,718 | --- | 252 | --- |
| 1,719 | --- | 1,161 | --- |
| 1,720 | --- | 2,106 | --- |
| 1,721 | --- | 7,596 | --- |
| 1,722 | --- | 13,554 | --- |
| 1,723 | --- | 12,789 | --- |
| 1,724 | --- | 9,855 | --- |
| 1,725 | --- | 3,222 | --- |
| 1,726 | --- | 774 | --- |
| 1,727 | --- | 1,773 | --- |
| 1,728 | --- | 8,019 | --- |
| 1,729 | --- | 12,654 | --- |
| 1,730 | --- | 13,676 | --- |
| 1,731 | --- | 4,615 | --- |
| 1,732 | --- | 1,027 | --- |
| 1,733 | --- | 1,885 | --- |
| 1,734 | --- | 496 | --- |
| 1,735 | --- | 512 | --- |
| 1,736 | --- | 1,912 | --- |
| 1,737 | --- | 10,158 | --- |
| 1,738 | --- | 3,546 | --- |
| 1,739 | --- | 7,740 | --- |
| 1,740 | --- | 108 | --- |

**Table B-24.** Summary of additional stranding area identified within Forebay Reach.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1959 | --- | --- | --- |
| 1960 | --- | --- | 12 |
| 1961 | --- | --- | 157 |
| 1962 | --- | --- | 251 |
| 1963 | --- | --- | 258 |
| 1964 | --- | --- | 388 |
| 1965 | --- | --- | 540 |
| 1966 | --- | --- | 516 |
| 1967 | --- | --- | 413 |
| 1968 | --- | --- | 602 |
| 1969 | --- | --- | 789 |
| 1970 | --- | --- | 1046 |
| 1971 | --- | --- | 1577 |
| 1972 | --- | --- | 2101 |
| 1973 | --- | --- | 2946 |
| 1974 | --- | --- | 3377 |
| 1975 | --- | --- | 4400 |
| 1976 | --- | --- | 4290 |
| 1977 | --- | --- | 4737 |
| 1978 | --- | --- | 4146 |
| 1979 | --- | --- | 4865 |
| 1980 | --- | --- | 4528 |
| 1981 | --- | --- | 4097 |
| 1982 | --- | --- | 4361 |
| 1983 | --- | --- | 4546 |
| 1984 | --- | --- | 4820 |
| 1985 | --- | --- | 4240 |
| 1986 | --- | --- | 3237 |
| 1987 | --- | --- | 482 |
| 1988 | --- | --- | 9 |
| 1989 | --- | --- | --- |

**Table B-25.** Summary of additional stranding area identified within Canyon Reach.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,953 | --- | --- | --- |
| 1,954 | --- | 1548 | --- |
| 1,955 | --- | 1008 | --- |
| 1,956 | --- | --- | --- |
| 1,957 | --- | --- | --- |
| 1,958 | --- | --- | --- |
| 1,959 | --- | --- | 3 |
| 1,960 | --- | --- | 3 |
| 1,961 | --- | --- | 62 |
| 1,962 | --- | --- | 43 |
| 1,963 | --- | --- | 54 |
| 1,964 | --- | --- | 68 |
| 1,965 | --- | 648 | 111 |
| 1,966 | --- | 711 | 152 |
| 1,967 | --- | --- | 165 |
| 1,968 | --- | --- | 216 |
| 1,969 | --- | --- | 445 |
| 1,970 | --- | --- | 1029 |
| 1,971 | --- | --- | 2464 |
| 1,972 | --- | --- | 3144 |
| 1,973 | --- | --- | 4106 |
| 1,974 | --- | --- | 5384 |
| 1,975 | --- | 207 | 6613 |
| 1,976 | --- | 801 | 8096 |
| 1,977 | --- | 54 | 9177 |
| 1,978 | --- | --- | 10859 |
| 1,979 | --- | --- | 12432 |
| 1,980 | --- | --- | 13347 |
| 1,981 | --- | --- | 12091 |
| 1,982 | --- | --- | 11304 |
| 1,983 | --- | 63 | 12924 |
| 1,984 | --- | 4455 | 11287 |
| 1,985 | --- | 4527 | 10899 |
| 1,986 | --- | 2097 | 10476 |
| 1,987 | --- | --- | 2713 |
| 1,988 | --- | 1458 | 1030 |

**Table B-25, continued…**

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,989 | --- | --- | 1087 |
| 1,990 | --- | --- | 80 |
| 1,991 | --- | --- | 12 |
| 1,992 | --- | --- | 6 |
| 1,993 | --- | --- | --- |
| 1,994 | --- | --- | --- |
| 1,995 | --- | --- | --- |
| 1,996 | --- | --- | --- |
| 1,997 | --- | --- | --- |
| 1,998 | --- | --- | --- |
| 1,999 | --- | --- | --- |
| 2,000 | --- | --- | --- |
| 2,001 | --- | --- | --- |
| 2,002 | --- | --- | --- |
| 2,003 | --- | --- | --- |
| 2,004 | --- | 882 | --- |
| 2,005 | --- | 126 | --- |
| 2,006 | --- | --- | --- |

**Table B-26.** Summary of additional stranding area identified within Upper Reservoir Reach.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,968 | --- | --- | --- |
| 1,969 | --- | --- | 28 |
| 1,970 | --- | --- | 739 |
| 1,971 | --- | 3141 | 1641 |
| 1,972 | --- | 15957 | 3689 |
| 1,973 | --- | 37098 | 6527 |
| 1,974 | 8 | 62867 | 9542 |
| 1,975 | 1775 | 72115 | 23328 |
| 1,976 | 15735 | 209916 | 71904 |
| 1,977 | 9869 | 273080 | 123564 |
| 1,978 | 15184 | 257130 | 148592 |
| 1,979 | 14890 | 201808 | 138932 |
| 1,980 | 19367 | 118314 | 97381 |
| 1,981 | 10404 | 68343 | 79900 |
| 1,982 | 22905 | 38839 | 60416 |
| 1,983 | 468 | 41905 | 55783 |
| 1,984 | --- | 37606 | 54444 |
| 1,985 | 1125 | 31203 | 54153 |
| 1,986 | 23940 | 19386 | 54712 |
| 1,987 | 9144 | 16096 | 50405 |
| 1,988 | 1570 | 5406 | 42485 |
| 1,989 | 1053 | 9333 | 25051 |
| 1,990 | --- | 2187 | 15985 |
| 1,991 | 1 | 3221 | 6541 |
| 1,992 | --- | 513 | 1007 |
| 1,993 | --- | 27 | 476 |
| 1,994 | --- | 9 | 81 |
| 1,995 | --- | 126 | --- |
| 1,996 | --- | 846 | --- |
| 1,997 | --- | 378 | --- |
| 1,998 | --- | 657 | --- |
| 1,999 | --- | 612 | --- |
| 2,000 | --- | --- | --- |
| 2,001 | --- | --- | --- |
| 2,002 | --- | --- | --- |
| 2,003 | --- | 270 | --- |
| 2,004 | --- | 1755 | --- |
| 2,005 | --- | 1103 | --- |
| 2,006 | --- | 2446 | --- |

**Table B-26, continued…**

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 2,007 | --- | 862 | --- |
| 2,008 | --- | 4878 | --- |
| 2,009 | --- | 3528 | --- |
| 2,010 | --- | 2538 | --- |
| 2,011 | --- | 3686 | --- |
| 2,012 | --- | 5556 | --- |
| 2,013 | --- | 4866 | --- |
| 2,014 | --- | 3168 | --- |
| 2,015 | --- | 3078 | --- |
| 2,016 | --- | 2934 | --- |
| 2,017 | --- | 2258 | --- |
| 2,018 | --- | 1473 | --- |
| 2,019 | --- | 26271 | --- |
| 2,020 | --- | 32583 | --- |
| 2,021 | --- | 35921 | --- |
| 2,022 | --- | 20394 | --- |
| 2,023 | --- | 12915 | --- |
| 2,024 | --- | 1252 | --- |

**Table B-27.** Summary of additional stranding area identified within Tailrace Reach.

| Elevation (ft NAVD 88) | Area of Stranding ($ft^2$) | | |
|---|---|---|---|
| | Slopes 4 Percent or Less with Macrophytes | Slopes 4 Percent or Less w/out Macrophytes | Slopes greater than 4 Percent with Macrophytes |
| 1,711 | --- | --- | --- |
| 1,712 | --- | 18 | --- |
| 1,713 | --- | 1530 | --- |
| 1,714 | --- | 225 | --- |
| 1,715 | --- | --- | --- |
| 1,716 | --- | --- | --- |
| 1,717 | --- | 4839 | --- |
| 1,718 | --- | 396 | --- |
| 1,719 | --- | 3150 | --- |
| 1,720 | --- | 17028 | --- |
| 1,721 | --- | 10476 | --- |
| 1,722 | --- | 19188 | --- |
| 1,723 | --- | 8550 | --- |
| 1,724 | --- | 54 | --- |
| 1,725 | --- | --- | --- |
| 1,726 | --- | --- | --- |
| 1,727 | --- | --- | --- |
| 1,728 | --- | --- | --- |
| 1,729 | --- | --- | --- |
| 1,730 | --- | --- | --- |
| 1,731 | --- | --- | --- |
| 1,732 | --- | 4878 | --- |
| 1,733 | --- | 41526 | --- |
| 1,734 | --- | 25596 | --- |
| 1,735 | --- | 954 | --- |
| 1,736 | --- | 45 | --- |
| 1,737 | --- | 18 | --- |
| 1,738 | --- | 1782 | --- |
| 1,739 | --- | 5868 | --- |
| 1,740 | --- | 2853 | --- |
| 1,741 | --- | 5868 | --- |
| 1,742 | --- | 1305 | --- |
| 1,743 | --- | 1323 | --- |
| 1,744 | --- | --- | --- |

# Attachment C: Physical Characteristics of Trapping Pools

This attachment contains the following tables:

Table C-1. Summary of physical characteristics of trapping pools identified within the stranding and trapping regions.
Table C-2. Summary of physical characteristics of additional trapping pools identified within the study area.

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**Table C-1.** Summary of physical characteristics of trapping pools identified within the stranding and trapping regions.

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| Forebay Launch | FL-001 | 441 | F | Yes | 8 | 1 | 1,975.51 | 0.28 |
| | FL-002 | 315 | F | Yes | 8 | 1 | 1,975.97 | 0.15 |
| | FL-003 | 10,278 | F | Yes | 8 | 1 | 1,976.10 | 2.28 |
| | FL-004 | 108 | F | Yes | 8 | 1 | 1,980.65 | 0.30 |
| Region 1 | 01-001 | 189 | F | Yes | 8 | 1 | 1,984.73 | 1.04 |
| Region 2 | 02-001 | 171 | F | Yes | 8 | 1 | 1,977.42 | 1.30 |
| | 02-002 | 1,458 | F | Yes | 8 | 1 | 1,977.42 | 2.71 |
| | 02-003 | 684 | F | Yes | 8 | 1 | 1,977.42 | 1.73 |
| | 02-004 | 153 | F | Yes | 8 | 1 | 1,977.42 | 1.16 |
| | 02-005 | 108 | F | Yes | 8 | 1 | 1,978.23 | 1.28 |
| | 02-006 | 1,350 | F | Yes | 8 | 1 | 1,978.23 | 2.31 |
| | 02-007 | 747 | F | Yes | 8 | 1 | 1,979.41 | 2.23 |
| | 02-008 | 144 | F | Yes | 8 | 1 | 1,978.78 | 1.41 |
| | 02-009 | 171 | F | Yes | 8 | 1 | 1,979.71 | 0.34 |
| | 02-010 | 945 | F | Yes | 8 | 1 | 1,979.92 | 2.55 |
| | 02-011 | 8,551 | F | Yes | 8 | 1 | 1,981.21 | 1.70 |
| | 02-012 | 135 | F | Yes | 8 | 1 | 1,981.46 | 0.90 |
| | 02-013 | 180 | F | Yes | 8 | 1 | 1,981.15 | 3.34 |
| | 02-014 | 5,877 | F | Yes | 8 | 1 | 1,981.15 | 7.71 |
| | 02-015 | 252 | F | Yes | 8 | 1 | 1,981.69 | 0.86 |
| | 02-016 | 2,547 | F | Yes | 8 | 1 | 1,981.71 | 2.04 |
| | 02-017 | 369 | F | Yes | 8 | 1 | 1,982.39 | 2.11 |
| | 02-018 | 1,818 | F | Yes | 8 | 1 | 1,981.91 | 2.85 |
| | 02-019 | 50,375 | F | Yes | 8 | 1 | 1,982.67 | 6.80 |
| | 02-026 | 5,634 | F | Yes | 8 | 1 | 1,984.20 | 4.01 |
| Region 3 | 03-010 | 108 | F | Yes | 8 | 1 | 1,978.23 | 4.17 |
| Region 4 | 04-001 | 1,062 | FG | No | 1 | 1 | 1,985.63 | 2.49 |
| | 04-010 | 108 | FG | No | 1 | 1 | 1,993.11 | 1.71 |
| | 04-011 | 999 | FG | No | 1 | 1 | 1,960.83 | 2.00 |
| Region 5 | 05-010 | 135 | FG | No | 1 | 1 | 1,986.41 | 1.66 |
| Stump Farm | SF-001 | 153 | FG | No | 1 | 1 | 1,988.53 | 1.29 |
| Region 6 | 06-001 | 225 | FG | No | 1 | 1 | 1,989.45 | 2.30 |
| | 06-002 | 1,143 | FG | No | 1 | 1 | 1,989.45 | 2.99 |
| | 06-003 | 378 | FG | No | 1 | 1 | 1,990.16 | 2.33 |
| | 06-010 | 117 | FG | No | 1 | 1 | 1,962.80 | 0.71 |
| | 06-011 | 117 | FG | No | 1 | 1 | 1,998.62 | 0.48 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| Flume Creek | FC-001 | 216 | FG | No | 1 | 1 | 1,979.08 | 0.61 |
| | FC-002 | 1,593 | FG | No | 1 | 1 | 1,993.37 | 5.13 |
| Sullivan Creek Delta | SC-001 | 189 | FG | No | 1 | 1 | 1,982.91 | 0.15 |
| | SC-002 | 387 | FG | No | 1 | 1 | 1,984.35 | 0.79 |
| | SC-003 | 117 | FG | No | 1 | 1 | 1,983.92 | 0.96 |
| | SC-004 | 2,772 | FG | No | 1 | 1 | 1,984.07 | 1.02 |
| | SC-005 | 405 | FG | No | 1 | 1 | 1,984.11 | 0.49 |
| | SC-006 | 144 | FG | No | 1 | 1 | 1,985.42 | 0.22 |
| | SC-007 | 216 | FG | No | 1 | 1 | 1,985.57 | 0.26 |
| | SC-008 | 306 | FG | No | 1 | 1 | 1,987.45 | 0.16 |
| | SC-009 | 162 | FG | No | 1 | 1 | 1,986.86 | 0.14 |
| | SC-010 | 900 | FG | No | 1 | 1 | 1,987.38 | 1.16 |
| | SC-011 | 540 | FG | No | 1 | 1 | 1,987.09 | 0.24 |
| | SC-012 | 351 | FG | No | 1 | 1 | 1,988.14 | 0.74 |
| | SC-014 | 432 | FG | No | 1 | 1 | 1,989.78 | 0.35 |
| | SC-015 | 117 | FG | No | 1 | 1 | 1,992.34 | 0.27 |
| | SC-016 | 504 | FG | No | 1 | 1 | 1,991.60 | 0.37 |
| | SC-017 | 954 | FG | No | 1 | 1 | 1,992.02 | 0.68 |
| | SC-018 | 144 | FG | No | 1 | 1 | 1,991.27 | 0.54 |
| | SC-019 | 216 | FG | No | 1 | 1 | 1,992.15 | 0.61 |
| | SC-020 | 1,062 | FG | No | 1 | 1 | 1,991.90 | 0.30 |
| | SC-021 | 504 | FG | No | 1 | 1 | 1,994.20 | 0.69 |
| | SC-022 | 180 | FG | No | 1 | 1 | 1,992.73 | 0.59 |
| | SC-023 | 351 | FG | No | 1 | 1 | 1,992.51 | 0.76 |
| | SC-024 | 2,970 | FG | No | 1 | 1 | 1,994.02 | 0.83 |
| | SC-025 | 243 | FG | No | 1 | 1 | 1,996.26 | 0.64 |
| | SC-026 | 189 | FG | No | 1 | 1 | 1,996.26 | 0.31 |
| | SC-027 | 3,816 | FG | No | 1 | 1 | 1,995.99 | 1.38 |
| | SC-028 | 774 | FG | No | 1 | 1 | 1,995.83 | 0.84 |
| | SC-029 | 486 | FG | No | 1 | 1 | 1,996.91 | 0.41 |
| | SC-030 | 1,395 | FG | No | 1 | 1 | 1,997.56 | 0.93 |
| | SC-031 | 909 | FG | No | 1 | 1 | 1,997.52 | 0.52 |
| | SC-032 | 171 | FG | No | 1 | 1 | 1,998.20 | 0.66 |
| | SC-033 | 279 | FG | No | 1 | 1 | 1,997.52 | 0.28 |
| | SC-034 | 936 | FG | No | 1 | 1 | 1,998.15 | 0.69 |
| | SC-035 | 1,881 | FG | No | 1 | 1 | 1,998.16 | 0.52 |
| | SC-050 | 1,467 | FG | No | 1 | 1 | 2,002.03 | 1.67 |
| | SC-051 | 396 | FG | No | 1 | 1 | 2,000.01 | 0.69 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | SC-052 | 126 | FG | No | 1 | 1 | 2,001.32 | 0.94 |
| | SC-053 | 189 | FG | No | 1 | 1 | 2,002.90 | 0.50 |
| | SC-054 | 117 | FG | No | 1 | 1 | 2,001.52 | 0.34 |
| | SC-055 | 117 | FG | No | 1 | 1 | 2,003.69 | 0.94 |
| | SC-056 | 144 | FG | No | 1 | 1 | 2,001.69 | 0.43 |
| | SC-057 | 50,247 | FG | No | 1 | 1 | 2,004.26 | 2.00 |
| | SC-058 | 108 | FG | No | 1 | 1 | 1,999.16 | 0.46 |
| | SC-059 | 477 | FG | No | 1 | 1 | 2,000.81 | 0.95 |
| | SC-060 | 513 | FG | No | 1 | 1 | 2,005.55 | 0.74 |
| | SC-061 | 495 | FG | No | 1 | 1 | 2,001.05 | 0.50 |
| | SC-062 | 4,419 | FG | No | 1 | 1 | 1,999.47 | 1.17 |
| | SC-063 | 801 | FG | No | 1 | 1 | 2,009.14 | 0.55 |
| | SC-064 | 180 | FG | No | 1 | 1 | 1,987.09 | 0.32 |
| | SC-065 | 7,569 | FG | No | 1 | 1 | 2,001.40 | 1.47 |
| | SC-066 | 1,872 | FG | No | 1 | 1 | 2,006.23 | 2.36 |
| | SC-067 | 252 | FG | No | 1 | 1 | 1,999.54 | 0.22 |
| | SC-068 | 234 | FG | No | 1 | 1 | 2,000.78 | 0.29 |
| | SC-069 | 117 | FG | No | 1 | 1 | 2,001.68 | 0.53 |
| | SC-070 | 162 | FG | No | 1 | 1 | 2,001.70 | 0.29 |
| | SC-071 | 117 | FG | No | 1 | 1 | 2,003.33 | 0.35 |
| | SC-072 | 2,916 | FG | No | 1 | 1 | 2,009.62 | 1.67 |
| | SC-073 | 261 | FG | No | 1 | 1 | 2,007.29 | 0.25 |
| | SC-074 | 135 | FG | No | 1 | 1 | 2,007.37 | 0.30 |
| | SC-075 | 189 | FG | No | 1 | 1 | 2,008.46 | 0.55 |
| | SC-076 | 342 | FG | No | 1 | 1 | 2,009.66 | 0.64 |
| | SC-077 | 369 | FG | No | 1 | 1 | 2,010.12 | 0.40 |
| | SC-078 | 324 | FG | No | 1 | 1 | 2,011.81 | 0.51 |
| Region 7 | 07-001 | 35,181 | F | Yes | 8 | 1 | 1,980.59 | 13.03 |
| | 07-002 | 720 | F | Yes | 8 | 1 | 1,980.78 | 0.40 |
| | 07-003 | 16,047 | F | Yes | 8 | 1 | 1,982.92 | 2.46 |
| | 07-004 | 387 | F | Yes | 8 | 1 | 1,983.66 | 1.06 |
| | 07-005 | 693 | F | Yes | 8 | 1 | 1,983.66 | 1.06 |
| | 07-006 | 972 | F | Yes | 8 | 1 | 1,983.66 | 1.06 |
| | 07-007 | 4,455 | F | Yes | 8 | 1 | 1,983.66 | 1.06 |
| | 07-008 | 153 | F | Yes | 8 | 1 | 1,985.09 | 0.24 |
| | 07-009 | 891 | F | Yes | 8 | 1 | 1,985.72 | 0.66 |
| | 07-010 | 531 | F | Yes | 8 | 1 | 1,985.98 | 0.90 |
| | 07-011 | 819 | F | Yes | 8 | 1 | 1,985.56 | 0.22 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 07-012 | 35,559 | F | Yes | 8 | 1 | 1,985.04 | 0.54 |
| | 07-014 | 2,178 | F | Yes | 8 | 1 | 1,987.98 | 1.67 |
| | 07-015 | 1,890 | FG | No | 1 | 1 | 1,988.99 | 2.45 |
| | 07-016 | 423 | FG | No | 1 | 1 | 1,989.89 | 1.29 |
| | 07-017 | 153 | FG | No | 1 | 1 | 1,991.49 | 0.17 |
| | 07-018 | 675 | FG | No | 1 | 1 | 1,991.06 | 0.18 |
| | 07-019 | 3,798 | FG | No | 1 | 1 | 1,991.44 | 0.12 |
| | 07-020 | 153 | FG | No | 1 | 1 | 1,991.65 | 0.72 |
| | 07-021 | 180 | FG | No | 1 | 1 | 1,992.69 | 0.17 |
| | 07-023 | 297 | FG | No | 1 | 1 | 1,996.74 | 0.80 |
| | 07-024 | 7,695 | FG | No | 1 | 1 | 1,994.93 | 1.07 |
| | 07-025 | 423 | FG | No | 1 | 1 | 1,997.02 | 0.95 |
| | 07-026 | 126 | FG | No | 1 | 1 | 1,998.25 | 0.39 |
| | 07-027 | 270 | FG | No | 1 | 1 | 1,998.18 | 0.41 |
| | 07-028 | 450 | FG | No | 1 | 1 | 1,997.89 | 1.65 |
| | 07-029 | 162 | FG | No | 1 | 1 | 1,997.34 | 0.16 |
| | 07-030 | 3,933 | FG | No | 1 | 1 | 1,997.71 | 2.43 |
| | 07-040 | 108 | FG | No | 1 | 1 | 2,011.90 | 1.07 |
| | 07-041 | 162 | FG | No | 1 | 1 | 2,000.29 | 0.51 |
| | 07-042 | 2,754 | FG | No | 1 | 1 | 2,001.11 | 0.93 |
| | 07-043 | 243 | FG | No | 1 | 1 | 2,000.09 | 0.44 |
| | 07-044 | 414 | FG | No | 1 | 1 | 2,002.23 | 0.67 |
| | 07-022 | 3,438 | FG | No | 1 | 1 | 1,996.04 | 2.27 |
| | 07-046 | 720 | FG | No | 1 | 1 | 2,000.21 | 1.16 |
| | 07-047 | 414 | FG | No | 1 | 1 | 2,002.77 | 1.20 |
| | 07-048 | 3,033 | FG | No | 1 | 1 | 2,000.02 | 2.75 |
| | 07-049 | 144 | FG | No | 1 | 1 | 2,002.61 | 0.21 |
| | 07-050 | 138,843 | FG | No | 1 | 1 | 2,006.06 | 12.72 |
| | 07-051 | 306 | FG | No | 1 | 1 | 2,006.80 | 0.33 |
| Region 8 | 08-001 | 18,378 | F | Yes | 8 | 1 | 1,978.65 | 2.93 |
| | 08-002 | 144 | FG | No | 1 | 1 | 1,978.96 | 0.30 |
| | 08-003 | 9,234 | FG | No | 1 | 1 | 1,978.69 | 1.17 |
| | 08-004 | 23,814 | FG | No | 1 | 1 | 1,978.92 | 6.02 |
| | 08-005 | 2,025 | FG | No | 1 | 1 | 1,978.94 | 1.22 |
| | 08-006 | 11,664 | F | Yes | 8 | 1 | 1,979.43 | 8.97 |
| | 08-007 | 693 | FG | No | 1 | 1 | 1,978.92 | 1.65 |
| | 08-008 | 1,809 | FG | No | 1 | 1 | 1,979.34 | 2.24 |
| | 08-009 | 120,789 | F | Yes | 8 | 1 | 1,979.43 | 11.15 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-010 | 117 | F | Yes | 8 | 1 | 1,980.09 | 1.14 |
| | 08-011 | 891 | F | Yes | 8 | 1 | 1,980.20 | 0.70 |
| | 08-012 | 441 | F | Yes | 8 | 1 | 1,980.02 | 1.46 |
| | 08-013 | 5,076 | F | Yes | 8 | 1 | 1,980.39 | 3.52 |
| | 08-014 | 630 | F | Yes | 8 | 1 | 1,980.47 | 0.34 |
| | 08-015 | 162 | F | Yes | 8 | 1 | 1,980.46 | 0.26 |
| | 08-016 | 315 | FG | No | 1 | 1 | 1,980.02 | 4.69 |
| | 08-017 | 1,764 | FG | No | 1 | 1 | 1,980.16 | 0.43 |
| | 08-018 | 1,188 | FG | No | 1 | 1 | 1,980.13 | 0.59 |
| | 08-019 | 20,025 | F | Yes | 8 | 1 | 1,980.38 | 6.73 |
| | 08-020 | 3,717 | FG | No | 1 | 1 | 1,979.64 | 3.24 |
| | 08-021 | 207 | FG | No | 1 | 1 | 1,980.09 | 0.88 |
| | 08-022 | 3,420 | F | Yes | 8 | 1 | 1,980.49 | 1.03 |
| | 08-023 | 405 | FG | No | 1 | 1 | 1,980.26 | 0.41 |
| | 08-024 | 2,466 | F | Yes | 8 | 1 | 1,981.21 | 0.82 |
| | 08-025 | 153 | F | Yes | 8 | 1 | 1,980.90 | 0.77 |
| | 08-026 | 1,278 | F | Yes | 8 | 1 | 1,981.41 | 2.83 |
| | 08-027 | 3,969 | FG | No | 1 | 1 | 1,980.93 | 3.80 |
| | 08-028 | 603 | FG | No | 1 | 1 | 1,981.37 | 0.30 |
| | 08-029 | 810 | F | Yes | 8 | 1 | 1,981.34 | 0.41 |
| | 08-030 | 333 | FG | No | 1 | 1 | 1,980.77 | 0.24 |
| | 08-031 | 243 | F | Yes | 8 | 1 | 1,980.82 | 0.36 |
| | 08-032 | 144 | F | Yes | 8 | 1 | 1,981.20 | 1.41 |
| | 08-033 | 405 | F | Yes | 8 | 1 | 1,980.77 | 0.76 |
| | 08-034 | 2,043 | F | Yes | 8 | 1 | 1,981.20 | 1.43 |
| | 08-035 | 297 | F | Yes | 8 | 1 | 1,981.41 | 0.94 |
| | 08-036 | 1,809 | F | Yes | 8 | 1 | 1,981.45 | 0.90 |
| | 08-037 | 1,251 | F | Yes | 8 | 1 | 1,981.45 | 0.93 |
| | 08-038 | 144 | F | Yes | 8 | 1 | 1,981.70 | 0.43 |
| | 08-039 | 423 | F | Yes | 8 | 1 | 1,982.23 | 0.27 |
| | 08-040 | 234 | F | Yes | 8 | 1 | 1,982.05 | 0.23 |
| | 08-041 | 117 | F | Yes | 8 | 1 | 1,982.22 | 0.16 |
| | 08-042 | 6,426 | F | Yes | 8 | 1 | 1,981.94 | 1.13 |
| | 08-043 | 2,394 | F | Yes | 8 | 1 | 1,982.07 | 0.71 |
| | 08-045 | 261 | FG | No | 1 | 1 | 1,981.94 | 0.68 |
| | 08-046 | 306 | F | Yes | 8 | 1 | 1,981.58 | 0.27 |
| | 08-047 | 846 | F | Yes | 8 | 1 | 1,981.82 | 0.36 |
| | 08-048 | 2,187 | F | Yes | 8 | 1 | 1,981.61 | 0.61 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-049 | 477 | F | Yes | 8 | 1 | 1,982.08 | 0.49 |
| | 08-050 | 252 | F | Yes | 8 | 1 | 1,981.91 | 0.29 |
| | 08-051 | 306 | F | Yes | 8 | 1 | 1,982.44 | 0.26 |
| | 08-052 | 13,716 | F | Yes | 8 | 1 | 1,981.61 | 3.03 |
| | 08-053 | 36,153 | F | Yes | 8 | 1 | 1,981.98 | 10.29 |
| | 08-054 | 12,123 | FG | No | 1 | 1 | 1,982.09 | 1.90 |
| | 08-055 | 13,887 | F | Yes | 8 | 1 | 1,982.06 | 4.86 |
| | 08-056 | 5,157 | F | Yes | 8 | 1 | 1,982.46 | 2.23 |
| | 08-057 | 2,502 | F | Yes | 8 | 1 | 1,982.34 | 1.82 |
| | 08-058 | 3,861 | F | Yes | 8 | 1 | 1,982.11 | 0.34 |
| | 08-059 | 34,893 | F | Yes | 8 | 1 | 1,982.30 | 14.98 |
| | 08-060 | 9,351 | F | Yes | 8 | 1 | 1,982.04 | 4.26 |
| | 08-061 | 1,521 | F | Yes | 8 | 1 | 1,982.48 | 1.98 |
| | 08-062 | 1,260 | F | Yes | 8 | 1 | 1,982.02 | 0.33 |
| | 08-063 | 522 | F | Yes | 8 | 1 | 1,981.65 | 0.32 |
| | 08-064 | 333 | FG | No | 1 | 1 | 1,982.13 | 1.17 |
| | 08-065 | 117 | F | Yes | 8 | 1 | 1,981.72 | 0.12 |
| | 08-066 | 522 | FG | No | 1 | 1 | 1,982.13 | 1.17 |
| | 08-067 | 6,345 | F | Yes | 8 | 1 | 1,982.26 | 1.63 |
| | 08-069 | 1,593 | F | Yes | 8 | 1 | 1,982.53 | 1.34 |
| | 08-070 | 288 | F | Yes | 8 | 1 | 1,982.53 | 0.79 |
| | 08-071 | 153 | F | Yes | 8 | 1 | 1,982.55 | 0.34 |
| | 08-073 | 1,035 | F | Yes | 8 | 1 | 1,982.70 | 1.07 |
| | 08-074 | 2,781 | F | Yes | 8 | 1 | 1,982.70 | 1.82 |
| | 08-075 | 180 | F | Yes | 8 | 1 | 1,983.24 | 1.34 |
| | 08-076 | 4,770 | F | Yes | 8 | 1 | 1,982.83 | 1.34 |
| | 08-077 | 252 | F | Yes | 8 | 1 | 1,982.99 | 0.43 |
| | 08-078 | 297 | F | Yes | 8 | 1 | 1,982.99 | 0.80 |
| | 08-079 | 504 | F | Yes | 8 | 1 | 1,982.50 | 0.11 |
| | 08-080 | 396 | F | Yes | 8 | 1 | 1,982.99 | 0.41 |
| | 08-082 | 396 | F | Yes | 8 | 1 | 1,983.05 | 0.33 |
| | 08-083 | 1,188 | F | Yes | 8 | 1 | 1,982.78 | 1.34 |
| | 08-084 | 432 | F | Yes | 8 | 1 | 1,983.18 | 0.10 |
| | 08-085 | 189 | F | Yes | 8 | 1 | 1,983.37 | 0.06 |
| | 08-086 | 162 | F | Yes | 8 | 1 | 1,983.26 | 0.06 |
| | 08-087 | 585 | F | Yes | 8 | 1 | 1,983.19 | 0.16 |
| | 08-088 | 756 | FG | No | 1 | 1 | 1,983.01 | 0.60 |
| | 08-089 | 549 | FG | No | 1 | 1 | 1,983.39 | 0.47 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-090 | 153 | FG | No | 1 | 1 | 1,983.46 | 1.54 |
| | 08-091 | 963 | F | Yes | 8 | 1 | 1,982.59 | 1.19 |
| | 08-092 | 189 | F | Yes | 8 | 1 | 1,982.77 | 1.74 |
| | 08-093 | 144 | F | Yes | 8 | 1 | 1,983.03 | 0.38 |
| | 08-094 | 36,234 | F | Yes | 8 | 1 | 1,983.26 | 13.59 |
| | 08-095 | 126 | FG | No | 1 | 1 | 1,983.42 | 0.39 |
| | 08-096 | 1,323 | F | Yes | 8 | 1 | 1,983.40 | 0.90 |
| | 08-097 | 567 | FG | No | 1 | 1 | 1,982.51 | 3.15 |
| | 08-098 | 180 | FG | No | 1 | 1 | 1,982.86 | 0.96 |
| | 08-099 | 8,280 | FG | No | 1 | 1 | 1,982.51 | 3.15 |
| | 08-100 | 1,584 | F | Yes | 8 | 1 | 1,983.52 | 0.51 |
| | 08-101 | 5,913 | F | Yes | 8 | 1 | 1,984.25 | 0.90 |
| | 08-102 | 198 | F | Yes | 8 | 1 | 1,983.93 | 0.69 |
| | 08-103 | 1,071 | F | Yes | 8 | 1 | 1,983.93 | 0.69 |
| | 08-104 | 270 | F | Yes | 8 | 1 | 1,984.16 | 0.33 |
| | 08-105 | 963 | F | Yes | 8 | 1 | 1,984.00 | 0.31 |
| | 08-106 | 405 | F | Yes | 8 | 1 | 1,984.16 | 0.29 |
| | 08-107 | 540 | F | Yes | 8 | 1 | 1,984.21 | 0.50 |
| | 08-108 | 135 | F | Yes | 8 | 1 | 1,984.49 | 0.26 |
| | 08-109 | 108 | FG | No | 1 | 1 | 1,984.47 | 0.05 |
| | 08-110 | 135 | FG | No | 1 | 1 | 1,984.11 | 0.22 |
| | 08-111 | 765 | FG | No | 1 | 1 | 1,984.43 | 0.76 |
| | 08-112 | 135 | F | Yes | 8 | 1 | 1,984.25 | 0.05 |
| | 08-113 | 126 | F | Yes | 8 | 1 | 1,983.70 | 0.29 |
| | 08-114 | 207 | F | Yes | 8 | 1 | 1,983.70 | 0.37 |
| | 08-115 | 774 | F | Yes | 8 | 1 | 1,984.06 | 0.75 |
| | 08-116 | 135 | F | Yes | 8 | 1 | 1,983.55 | 0.19 |
| | 08-118 | 324 | FG | No | 1 | 1 | 1,983.83 | 0.41 |
| | 08-119 | 225 | F | Yes | 8 | 1 | 1,984.06 | 0.08 |
| | 08-120 | 225 | F | Yes | 8 | 1 | 1,983.93 | 0.23 |
| | 08-121 | 243 | F | Yes | 8 | 1 | 1,983.93 | 0.30 |
| | 08-122 | 144 | F | Yes | 8 | 1 | 1,984.29 | 0.18 |
| | 08-123 | 117 | F | Yes | 8 | 1 | 1,984.03 | 0.21 |
| | 08-124 | 117 | FG | No | 1 | 1 | 1,984.01 | 0.12 |
| | 08-125 | 2,700 | F | Yes | 8 | 1 | 1,983.93 | 0.58 |
| | 08-126 | 783 | FG | No | 1 | 1 | 1,984.44 | 0.21 |
| | 08-127 | 585 | F | Yes | 8 | 1 | 1,984.02 | 0.33 |
| | 08-128 | 39,699 | F | Yes | 8 | 1 | 1,983.54 | 5.21 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-129 | 495 | F | Yes | 8 | 1 | 1,983.89 | 0.96 |
| | 08-130 | 954 | FG | No | 1 | 1 | 1,984.30 | 0.46 |
| | 08-131 | 207 | F | Yes | 8 | 1 | 1,984.40 | 0.54 |
| | 08-132 | 504 | FG | No | 1 | 1 | 1,983.80 | 0.71 |
| | 08-133 | 144 | FG | No | 1 | 1 | 1,983.74 | 0.85 |
| | 08-134 | 1,458 | FG | No | 1 | 1 | 1,983.86 | 0.55 |
| | 08-135 | 270 | F | Yes | 8 | 1 | 1,983.93 | 0.65 |
| | 08-136 | 225 | F | Yes | 8 | 1 | 1,984.28 | 0.33 |
| | 08-137 | 180 | F | Yes | 8 | 1 | 1,983.75 | 0.37 |
| | 08-138 | 630 | F | Yes | 8 | 1 | 1,984.66 | 0.13 |
| | 08-139 | 2,601 | F | Yes | 8 | 1 | 1,984.53 | 1.46 |
| | 08-140 | 171 | FG | No | 1 | 1 | 1,984.58 | 0.16 |
| | 08-141 | 171 | FG | No | 1 | 1 | 1,984.82 | 0.25 |
| | 08-142 | 378 | F | Yes | 8 | 1 | 1,985.34 | 0.09 |
| | 08-143 | 126 | F | Yes | 8 | 1 | 1,985.26 | 0.06 |
| | 08-144 | 405 | F | Yes | 8 | 1 | 1,985.32 | 0.11 |
| | 08-145 | 279 | F | Yes | 8 | 1 | 1,984.92 | 0.24 |
| | 08-147 | 342 | F | Yes | 8 | 1 | 1,985.25 | 0.21 |
| | 08-148 | 225 | FG | No | 1 | 1 | 1,985.16 | 0.10 |
| | 08-149 | 477 | FG | No | 1 | 1 | 1,984.99 | 1.38 |
| | 08-150 | 297 | F | Yes | 8 | 1 | 1,984.92 | 0.23 |
| | 08-151 | 12,816 | FG | No | 1 | 1 | 1,984.96 | 0.58 |
| | 08-152 | 297 | F | Yes | 8 | 1 | 1,984.91 | 0.15 |
| | 08-154 | 1,071 | FG | No | 1 | 1 | 1,985.25 | 1.05 |
| | 08-155 | 108 | FG | No | 1 | 1 | 1,984.50 | 0.08 |
| | 08-156 | 135 | FG | No | 1 | 1 | 1,984.60 | 0.13 |
| | 08-157 | 243 | FG | No | 1 | 1 | 1,985.14 | 0.39 |
| | 08-158 | 15,390 | F | Yes | 8 | 1 | 1,984.50 | 2.27 |
| | 08-159 | 279 | FG | No | 1 | 1 | 1,984.95 | 0.48 |
| | 08-161 | 1,125 | F | Yes | 8 | 1 | 1,985.21 | 4.69 |
| | 08-162 | 5,004 | F | Yes | 8 | 1 | 1,985.33 | 2.07 |
| | 08-163 | 207 | FG | No | 1 | 1 | 1,985.87 | 0.06 |
| | 08-165 | 360 | FG | No | 1 | 1 | 1,985.88 | 0.08 |
| | 08-166 | 432 | FG | No | 1 | 1 | 1,985.53 | 0.06 |
| | 08-167 | 171 | FG | No | 1 | 1 | 1,985.62 | 0.31 |
| | 08-168 | 1,944 | FG | No | 1 | 1 | 1,986.17 | 2.24 |
| | 08-169 | 162 | F | Yes | 8 | 1 | 1,985.94 | 2.73 |
| | 08-170 | 1,098 | F | Yes | 8 | 1 | 1,986.62 | 0.25 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-171 | 117 | F | Yes | 8 | 1 | 1,986.82 | 0.06 |
| | 08-172 | 756 | F | Yes | 8 | 1 | 1,986.79 | 0.11 |
| | 08-174 | 2,583 | FG | No | 1 | 1 | 1,987.12 | 0.78 |
| | 08-175 | 153 | F | Yes | 8 | 1 | 1,987.00 | 0.46 |
| | 08-176 | 162 | F | Yes | 8 | 1 | 1,987.27 | 1.19 |
| | 08-177 | 189 | F | Yes | 8 | 1 | 1,988.49 | 0.08 |
| | 08-178 | 144 | FG | No | 1 | 1 | 1,987.88 | 0.46 |
| | 08-179 | 261 | FG | No | 1 | 1 | 1,987.69 | 0.56 |
| | 08-180 | 468 | FG | No | 1 | 1 | 1,988.64 | 1.62 |
| | 08-181 | 972 | FG | No | 1 | 1 | 1,997.00 | 0.26 |
| | 08-a | 1,800 | FG | No | 1 | 1 | 1,988.72 | 1.30 |
| | 08-b | 1,200 | FG | No | 1 | 1 | 1,988.58 | 1.10 |
| | 08-200 | 459 | FG | No | 1 | 1 | 1,975.73 | 0.23 |
| | 08-201 | 243 | FG | No | 1 | 1 | 1,976.14 | 0.20 |
| | 08-202 | 252 | FG | No | 1 | 1 | 1,977.64 | 0.42 |
| | 08-203 | 522 | F | Yes | 8 | 1 | 1,982.53 | 0.23 |
| | 08-204 | 108 | FG | No | 1 | 1 | 1,977.81 | 0.43 |
| | 08-205 | 1,917 | F | Yes | 8 | 1 | 1,976.15 | 0.72 |
| | 08-206 | 1,764 | F | Yes | 8 | 1 | 1,976.36 | 0.53 |
| | 08-207 | 621 | F | Yes | 8 | 1 | 1,983.27 | 0.76 |
| | 08-208 | 189 | FG | No | 1 | 1 | 2,008.16 | 0.40 |
| | 08-209 | 612 | FG | No | 1 | 1 | 2,008.02 | 0.39 |
| | 08-210 | 30,618 | FG | No | 1 | 1 | 2,007.09 | 8.43 |
| | 08-211 | 450 | FG | No | 1 | 1 | 2,008.04 | 0.22 |
| | 08-212 | 153 | FG | No | 1 | 1 | 2,008.18 | 0.19 |
| | 08-213 | 369 | FG | No | 1 | 1 | 2,008.18 | 0.32 |
| | 08-214 | 873 | FG | No | 1 | 1 | 2,008.04 | 0.30 |
| | 08-215 | 342 | FG | No | 1 | 1 | 2,007.96 | 0.04 |
| | 08-216 | 486 | FG | No | 1 | 1 | 2,008.04 | 0.39 |
| | 08-217 | 513 | FG | No | 1 | 1 | 2,006.09 | 0.08 |
| | 08-218 | 387 | FG | No | 1 | 1 | 2,004.86 | 0.72 |
| | 08-219 | 3,843 | FG | No | 1 | 1 | 2,008.18 | 0.66 |
| | 08-220 | 207 | FG | No | 1 | 1 | 2,009.40 | 0.25 |
| | 08-221 | 882 | FG | No | 1 | 1 | 2,008.16 | 0.41 |
| | 08-222 | 2,889 | F | Yes | 8 | 1 | 1,985.26 | 0.23 |
| | 08-223 | 198 | FG | No | 1 | 1 | 2,009.41 | 0.21 |
| | 08-224 | 279 | FG | No | 1 | 1 | 2,012.46 | 0.25 |
| | 08-225 | 153 | FG | No | 1 | 1 | 2,011.99 | 0.56 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 08-226 | 108 | FG | No | 1 | 1 | 1,991.11 | 0.30 |
| | 08-227 | 1,422 | FG | No | 1 | 1 | 2,009.86 | 0.48 |
| | 08-228 | 189 | F | Yes | 8 | 1 | 1,984.02 | 0.19 |
| | 08-229 | 117 | F | Yes | 8 | 1 | 1,983.10 | 0.17 |
| | 08-230 | 17,910 | FG | No | 1 | 1 | 2,006.31 | 4.35 |
| | 08-231 | 15,399 | FG | No | 1 | 1 | 2,009.52 | 2.31 |
| | 08-232 | 117 | F | Yes | 8 | 1 | 1,982.33 | 0.32 |
| | 08-233 | 3,924 | FG | No | 1 | 1 | 2,009.98 | 2.13 |
| | 08-234 | 108 | FG | No | 1 | 1 | 2,011.52 | 0.36 |
| | 08-235 | 171 | FG | No | 1 | 1 | 2,007.36 | 0.19 |
| | 08-236 | 144 | FG | No | 1 | 1 | 2,007.32 | 0.27 |
| | 08-237 | 1,566 | F | Yes | 8 | 1 | 1,981.58 | 0.71 |
| | 08-238 | 180 | FG | No | 1 | 1 | 2,003.04 | 0.98 |
| | 08-239 | 1,620 | FG | No | 1 | 1 | 1,977.83 | 1.55 |
| | 08-240 | 450 | FG | No | 1 | 1 | 1,977.83 | 0.50 |
| | 08-241 | 333 | FG | No | 1 | 1 | 1,977.92 | 1.23 |
| | 08-242 | 117 | F | Yes | 8 | 1 | 1,984.67 | 0.63 |
| | 08-243 | 1,125 | FG | No | 1 | 1 | 1,988.35 | 0.59 |
| Region 9 | 09-001 | 189 | F | Yes | 8 | 1 | 1,978.89 | 0.41 |
| | 09-002 | 12,024 | F | Yes | 8 | 1 | 1,980.04 | 2.73 |
| | 09-003 | 108 | F | Yes | 8 | 1 | 1,980.41 | 0.22 |
| | 09-004 | 1,278 | F | Yes | 8 | 1 | 1,979.60 | 1.60 |
| | 09-005 | 117 | F | Yes | 8 | 1 | 1,980.48 | 0.23 |
| | 09-006 | 225 | F | Yes | 8 | 1 | 1,980.19 | 0.77 |
| | 09-008 | 171 | F | Yes | 8 | 1 | 1,979.88 | 0.32 |
| | 09-009 | 3,627 | F | Yes | 8 | 1 | 1,980.48 | 0.61 |
| | 09-010 | 189 | F | Yes | 8 | 1 | 1,981.34 | 0.15 |
| | 09-011 | 279 | F | Yes | 8 | 1 | 1,980.88 | 0.82 |
| | 09-013 | 180 | F | Yes | 8 | 1 | 1,981.39 | 0.16 |
| | 09-014 | 9,297 | F | Yes | 8 | 1 | 1,981.16 | 3.32 |
| | 09-015 | 270 | F | Yes | 8 | 1 | 1,981.47 | 0.19 |
| | 09-016 | 648 | F | Yes | 8 | 1 | 1,980.95 | 2.09 |
| | 09-017 | 207 | F | Yes | 8 | 1 | 1,981.13 | 0.52 |
| | 09-018 | 126 | F | Yes | 8 | 1 | 1,981.49 | 0.11 |
| | 09-019 | 189 | F | Yes | 8 | 1 | 1,980.69 | 0.27 |
| | 09-020 | 117 | F | Yes | 8 | 1 | 1,981.23 | 0.85 |
| | 09-021 | 189 | F | Yes | 8 | 1 | 1,980.69 | 0.28 |
| | 09-023 | 243 | F | Yes | 8 | 1 | 1,981.56 | 0.11 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 09-024 | 540 | F | Yes | 8 | 1 | 1,981.62 | 0.39 |
| | 09-025 | 144 | F | Yes | 8 | 1 | 1,981.76 | 0.08 |
| | 09-026 | 1,071 | F | Yes | 8 | 1 | 1,981.94 | 0.30 |
| | 09-027 | 423 | F | Yes | 8 | 1 | 1,981.91 | 0.11 |
| | 09-028 | 756 | F | Yes | 8 | 1 | 1,981.76 | 0.20 |
| | 09-029 | 126 | F | Yes | 8 | 1 | 1,981.94 | 0.22 |
| | 09-030 | 1,359 | F | Yes | 8 | 1 | 1,984.49 | 0.15 |
| | 09-031 | 1,170 | F | Yes | 8 | 1 | 1,984.37 | 0.25 |
| | 09-033 | 1,566 | F | Yes | 8 | 1 | 1,984.36 | 0.47 |
| | 09-034 | 315 | F | Yes | 8 | 1 | 1,984.40 | 0.17 |
| | 09-035 | 4,698 | F | Yes | 8 | 1 | 1,984.36 | 0.45 |
| | 09-036 | 171 | F | Yes | 8 | 1 | 1,984.12 | 0.15 |
| | 09-037 | 576 | F | Yes | 8 | 1 | 1,984.37 | 0.14 |
| | 09-038 | 837 | F | Yes | 8 | 1 | 1,983.77 | 0.22 |
| | 09-040 | 11,070 | F | Yes | 8 | 1 | 1,983.83 | 1.59 |
| | 09-041 | 279 | F | Yes | 8 | 1 | 1,985.48 | 0.07 |
| | 09-042 | 2,655 | F | Yes | 8 | 1 | 1,985.00 | 0.42 |
| | 09-043 | 783 | F | Yes | 8 | 1 | 1,984.63 | 0.20 |
| | 09-044 | 234 | F | Yes | 8 | 1 | 1,984.51 | 0.08 |
| | 09-045 | 135 | F | Yes | 8 | 1 | 1,986.31 | 0.22 |
| | 09-047 | 1,053 | F | Yes | 8 | 1 | 1,986.39 | 0.22 |
| | 09-048 | 441 | F | Yes | 8 | 1 | 1,986.47 | 0.16 |
| | 09-049 | 153 | F | Yes | 8 | 1 | 1,986.47 | 0.16 |
| | 09-050 | 369 | F | Yes | 8 | 1 | 1,986.47 | 0.16 |
| | 09-051 | 297 | F | Yes | 8 | 1 | 1,986.47 | 0.14 |
| | 09-052 | 162 | F | Yes | 8 | 1 | 1,986.46 | 0.10 |
| | 09-053 | 25,308 | F | Yes | 8 | 1 | 1,986.11 | 0.93 |
| | 09-054 | 297 | F | Yes | 8 | 1 | 1,986.44 | 0.12 |
| | 09-055 | 30,969 | F | Yes | 8 | 1 | 1,987.11 | 1.07 |
| | 09-056 | 639 | F | Yes | 8 | 1 | 1,987.10 | 0.25 |
| | 09-057 | 1,332 | F | Yes | 8 | 1 | 1,987.49 | 0.35 |
| | 09-058 | 873 | F | Yes | 8 | 1 | 1,987.96 | 0.05 |
| | 09-059 | 2,106 | F | Yes | 8 | 1 | 1,988.06 | 0.16 |
| | 09-060 | 2,430 | F | Yes | 8 | 1 | 1,988.16 | 0.32 |
| | 09-062 | 387 | F | Yes | 8 | 1 | 1,988.12 | 0.28 |
| | 09-063 | 783 | F | Yes | 8 | 1 | 1,987.61 | 0.18 |
| | 09-064 | 189 | F | Yes | 8 | 1 | 1,988.42 | 0.11 |
| | 09-065 | 1,728 | F | Yes | 8 | 1 | 1,988.42 | 0.35 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 09-066 | 9,198 | F | Yes | 8 | 1 | 1,988.98 | 1.02 |
| | 09-067 | 198 | F | Yes | 8 | 1 | 1,987.66 | 0.32 |
| | 09-068 | 603 | F | Yes | 8 | 1 | 1,987.94 | 0.27 |
| | 09-069 | 1,035 | F | Yes | 8 | 1 | 1,987.49 | 0.67 |
| | 09-070 | 24,219 | F | Yes | 8 | 1 | 1,987.49 | 1.71 |
| | 09-071 | 117 | F | Yes | 8 | 1 | 1,988.72 | 0.39 |
| | 09-072 | 1,116 | F | Yes | 8 | 1 | 1,988.64 | 0.75 |
| | 09-073 | 117 | F | Yes | 8 | 1 | 1,989.09 | 0.16 |
| | 09-074 | 2,754 | F | Yes | 8 | 1 | 1,988.41 | 0.14 |
| | 09-075 | 639 | F | Yes | 8 | 1 | 1,988.65 | 0.24 |
| | 09-076 | 639 | F | Yes | 8 | 1 | 1,989.24 | 0.36 |
| | 09-077 | 315 | F | Yes | 8 | 1 | 1,988.71 | 0.14 |
| | 09-078 | 1,062 | FG | No | 1 | 1 | 1,990.34 | 0.36 |
| | 09-079 | 171 | F | Yes | 8 | 1 | 1,989.66 | 0.29 |
| | 09-080 | 108 | FG | No | 1 | 1 | 1,990.35 | 0.27 |
| | 09-081 | 774 | F | Yes | 8 | 1 | 1,989.51 | 0.31 |
| | 09-082 | 567 | FG | No | 1 | 1 | 1,990.07 | 0.48 |
| | 09-083 | 4,374 | F | Yes | 8 | 1 | 1,990.53 | 0.48 |
| | 09-084 | 171 | FG | No | 1 | 1 | 1,991.10 | 0.53 |
| | 09-085 | 2,070 | FG | No | 1 | 1 | 1,990.81 | 0.93 |
| | 09-086 | 1,008 | FG | No | 1 | 1 | 1,991.09 | 1.10 |
| | 09-087 | 954 | FG | No | 1 | 1 | 1,991.26 | 0.55 |
| | 09-088 | 180 | FG | No | 1 | 1 | 1,991.26 | 0.23 |
| | 09-089 | 522 | FG | No | 1 | 1 | 1,990.76 | 0.32 |
| | 09-090 | 630 | FG | No | 1 | 1 | 1,990.76 | 0.55 |
| | 09-091 | 513 | FG | No | 1 | 1 | 1,990.87 | 0.40 |
| | 09-092 | 675 | FG | No | 1 | 1 | 1,991.24 | 0.18 |
| | 09-093 | 126 | FG | No | 1 | 1 | 1,992.11 | 0.56 |
| | 09-094 | 702 | FG | No | 1 | 1 | 1,991.97 | 1.47 |
| | 09-095 | 1,296 | FG | No | 1 | 1 | 1,992.18 | 1.16 |
| | 09-096 | 1,377 | FG | No | 1 | 1 | 1,991.51 | 1.08 |
| | 09-097 | 765 | FG | No | 1 | 1 | 1,991.59 | 0.52 |
| | 09-098 | 171 | FG | No | 1 | 1 | 1,991.61 | 0.13 |
| | 09-100 | 6,939 | FG | No | 1 | 1 | 1,992.00 | 0.60 |
| | 09-101 | 828 | FG | No | 1 | 1 | 1,992.16 | 0.41 |
| | 09-102 | 117 | FG | No | 1 | 1 | 1,993.05 | 1.95 |
| | 09-103 | 279 | FG | No | 1 | 1 | 1,992.36 | 0.06 |
| | 09-104 | 774 | FG | No | 1 | 1 | 1,992.67 | 0.63 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 09-105 | 270 | FG | No | 1 | 1 | 1,991.80 | 0.30 |
| | 09-106 | 162 | FG | No | 1 | 1 | 1,992.93 | 0.22 |
| | 09-107 | 3,366 | FG | No | 1 | 1 | 1,993.84 | 0.78 |
| | 09-108 | 117 | FG | No | 1 | 1 | 1,994.28 | 0.19 |
| | 09-109 | 288 | FG | No | 1 | 1 | 1,994.69 | 0.51 |
| | 09-110 | 1,269 | FG | No | 1 | 1 | 1,996.45 | 1.87 |
| | 09-111 | 153 | FG | No | 1 | 1 | 1,995.21 | 0.28 |
| | 09-112 | 144 | FG | No | 1 | 1 | 1,995.21 | 0.31 |
| | 09-113 | 207 | FG | No | 1 | 1 | 1,996.84 | 2.01 |
| | 09-114 | 6,543 | FG | No | 1 | 1 | 1,996.66 | 2.97 |
| | 09-115 | 171 | FG | No | 1 | 1 | 1,999.09 | 0.78 |
| | 09-116 | 540 | FG | No | 1 | 1 | 1,998.39 | 0.66 |
| | 09-117 | 306 | FG | No | 1 | 1 | 1,998.39 | 0.25 |
| | 09-150 | 261 | F | Yes | 8 | 1 | 1,975.33 | 0.32 |
| | 09-151 | 828 | F | Yes | 8 | 1 | 1,981.35 | 0.26 |
| | 09-152 | 1,197 | F | Yes | 8 | 1 | 1,981.34 | 0.17 |
| | 09-153 | 108 | F | Yes | 8 | 1 | 1,981.40 | 0.11 |
| | 09-154 | 37,242 | F | Yes | 8 | 1 | 1,980.49 | 4.61 |
| | 09-155 | 108 | F | Yes | 8 | 1 | 1,984.37 | 0.14 |
| | 09-156 | 117 | F | Yes | 8 | 1 | 1,983.80 | 0.15 |
| | 09-157 | 108 | F | Yes | 8 | 1 | 1,988.26 | 0.04 |
| | 09-158 | 153 | FG | No | 1 | 1 | 1,992.62 | 0.21 |
| | 09-159 | 108 | FG | No | 1 | 1 | 1,994.40 | 0.33 |
| | 09-160 | 108 | FG | No | 1 | 1 | 1,995.51 | 0.42 |
| | 09-161 | 2,484 | FG | No | 1 | 1 | 2,002.92 | 1.33 |
| Region 10 | 10-001 | 2,808 | C | No | 6 | 6 | 1,980.88 | 2.77 |
| | 10-002 | 10,737 | C | No | 6 | 6 | 1,982.15 | 6.69 |
| | 10-003 | 171 | C | No | 6 | 6 | 1,982.48 | 0.59 |
| | 10-004 | 405 | C | No | 6 | 6 | 1,983.37 | 1.40 |
| | 10-005 | 270 | C | No | 6 | 6 | 1,982.72 | 1.19 |
| | 10-006 | 1,305 | C | No | 6 | 6 | 1,985.42 | 0.96 |
| | 10-007 | 144 | C | No | 6 | 6 | 1,986.62 | 0.19 |
| | 10-008 | 48,393 | C | No | 6 | 6 | 1,988.47 | 8.68 |
| | 10-009 | 9,783 | C | No | 6 | 6 | 1,989.08 | 2.44 |
| | 10-010 | 225 | C | No | 6 | 6 | 1,989.67 | 0.22 |
| | 10-011 | 297 | C | No | 6 | 6 | 1,989.87 | 0.77 |
| | 10-012 | 144 | C | No | 6 | 6 | 1,990.63 | 0.09 |
| | 10-013 | 1,890 | C | No | 6 | 6 | 1,990.79 | 0.44 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 10-014 | 144 | C | No | 6 | 6 | 1,990.61 | 0.18 |
| | 10-015 | 252 | C | No | 6 | 6 | 1,991.64 | 0.06 |
| | 10-016 | 7,326 | C | No | 6 | 6 | 1,991.75 | 1.01 |
| | 10-017 | 216 | C | No | 6 | 6 | 1,991.63 | 0.09 |
| | 10-018 | 666 | C | No | 6 | 6 | 1,992.27 | 1.31 |
| | 10-019 | 225 | C | No | 6 | 6 | 1,993.26 | 1.50 |
| | 10-020 | 108 | C | No | 6 | 6 | 1,994.50 | 0.58 |
| | 10-021 | 117 | C | No | 6 | 6 | 1,995.22 | 1.84 |
| | 10-022 | 135 | C | No | 6 | 6 | 1,994.46 | 1.96 |
| | 10-023 | 144 | C | No | 6 | 6 | 1,997.92 | 2.81 |
| | 10-a | 150 | C | No | 6 | 6 | 1,990.87 | 1.37 |
| Region 11 | 11-001 | 8,946 | F | Yes | 8 | 1 | 1,978.76 | 4.30 |
| | 11-002 | 2,115 | F | Yes | 8 | 1 | 1,981.46 | 0.44 |
| | 11-003 | 288 | F | Yes | 8 | 1 | 1,984.28 | 0.08 |
| | 11-004 | 13,986 | F | Yes | 8 | 1 | 1,984.71 | 1.23 |
| | 11-005 | 576 | F | Yes | 8 | 1 | 1,986.15 | 0.21 |
| | 11-006 | 3,258 | F | Yes | 8 | 1 | 1,987.50 | 0.04 |
| | 11-007 | 34,362 | F | Yes | 8 | 1 | 1,987.09 | 0.91 |
| | 11-008 | 180 | FG | No | 1 | 1 | 1,991.42 | 0.43 |
| | 11-009 | 540 | FG | No | 1 | 1 | 1,991.35 | 1.69 |
| | 11-010 | 2,106 | FG | No | 1 | 1 | 1,992.09 | 0.32 |
| | 11-011 | 1,116 | FG | No | 1 | 1 | 1,992.47 | 0.37 |
| | 11-012 | 2,412 | FG | No | 1 | 1 | 1,996.97 | 2.16 |
| | 11-013 | 558 | FG | No | 1 | 1 | 1,998.08 | 1.24 |
| | 11-014 | 13,311 | FG | No | 1 | 1 | 1,997.18 | 3.57 |
| | 11-020 | 117 | F | Yes | 8 | 1 | 1,988.31 | 0.01 |
| | 11-021 | 108 | F | Yes | 8 | 1 | 1,988.31 | 0.05 |
| Region 12 | 12-002 | 1,089 | FG | No | 1 | 1 | 1,994.93 | 2.26 |
| | 12-003 | 126 | FG | No | 1 | 1 | 1,997.35 | 2.08 |
| | 12-005 | 1,017 | FG | No | 1 | 1 | 1,996.59 | 1.94 |
| | 12-006 | 333 | FG | No | 1 | 1 | 1,999.14 | 1.13 |
| | 12-007 | 180 | FG | No | 1 | 1 | 1,998.79 | 1.00 |
| | 12-008 | 243 | FG | No | 1 | 1 | 1,998.40 | 1.53 |
| | 12-009 | 198 | FG | No | 1 | 1 | 1,999.73 | 1.83 |
| | 12-010 | 117 | FG | No | 1 | 1 | 1,999.73 | 0.78 |
| | 12-011 | 117 | FG | No | 1 | 1 | 2,000.04 | 3.44 |
| | 12-020 | 648 | FG | No | 1 | 1 | 2,013.66 | 1.98 |
| | 12-021 | 189 | FG | No | 1 | 1 | 2,000.27 | 1.06 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 12-022 | 315 | FG | No | 1 | 1 | 2,016.13 | 1.26 |
| | 12-023 | 360 | FG | No | 1 | 1 | 1,994.06 | 1.21 |
| | 12-024 | 288 | FG | No | 1 | 1 | 2,006.39 | 1.19 |
| | 12-025 | 1,701 | FG | No | 1 | 1 | 2,011.91 | 3.28 |
| | 12-026 | 3,726 | FG | No | 1 | 1 | 2,010.68 | 3.96 |
| | 12-027 | 504 | FG | No | 1 | 1 | 2,012.98 | 1.58 |
| | 12-028 | 288 | FG | No | 1 | 1 | 2,005.13 | 0.66 |
| | 12-029 | 252 | FG | No | 1 | 1 | 2,011.63 | 1.53 |
| | 12-030 | 738 | FG | No | 1 | 1 | 2,011.25 | 1.83 |
| | 12-031 | 189 | FG | No | 1 | 1 | 1,994.86 | 0.78 |
| | 12-032 | 2,799 | FG | No | 1 | 1 | 2,009.20 | 2.50 |
| Region 13 | 13-001 | 558 | F | Yes | 8 | 1 | 1,980.59 | 0.27 |
| | 13-002 | 10,179 | F | Yes | 8 | 1 | 1,981.95 | 3.34 |
| | 13-003 | 306 | F | Yes | 8 | 1 | 1,984.10 | 0.15 |
| | 13-004 | 171 | FG | No | 1 | 1 | 1,983.65 | 0.45 |
| | 13-005 | 828 | F | Yes | 8 | 1 | 1,983.53 | 0.90 |
| | 13-006 | 675 | F | Yes | 8 | 1 | 1,985.22 | 0.28 |
| | 13-007 | 9,819 | F | Yes | 8 | 1 | 1,986.51 | 0.45 |
| | 13-008 | 144 | F | Yes | 8 | 1 | 1,988.00 | 0.08 |
| | 13-009 | 225 | F | Yes | 8 | 1 | 1,988.51 | 0.11 |
| | 13-010 | 126 | FG | No | 1 | 1 | 1,989.47 | 0.27 |
| | 13-011 | 2,214 | F | Yes | 8 | 1 | 1,991.00 | 0.89 |
| | 13-012 | 153 | FG | No | 1 | 1 | 1,991.97 | 0.09 |
| | 13-014 | 342 | FG | No | 1 | 1 | 1,995.32 | 1.03 |
| | 13-015 | 774 | FG | No | 1 | 1 | 1,995.36 | 0.26 |
| | 13-016 | 2,025 | FG | No | 1 | 1 | 1,995.43 | 1.15 |
| | 13-017 | 477 | FG | No | 1 | 1 | 1,997.45 | 5.93 |
| | 13-018 | 126 | FG | No | 1 | 1 | 1,998.20 | 0.42 |
| | 13-019 | 198 | FG | No | 1 | 1 | 1,999.37 | 3.51 |
| | 13-020 | 9,243 | FG | No | 1 | 1 | 1,996.51 | 1.26 |
| | 13-021 | 522 | FG | No | 1 | 1 | 1,998.30 | 6.67 |
| | 13-022 | 3,627 | FG | No | 1 | 1 | 1,998.62 | 2.48 |
| | 13-023 | 1,647 | FG | No | 1 | 1 | 1,998.64 | 4.85 |
| | 13-030 | 1,089 | FG | No | 1 | 1 | 1,995.28 | 0.77 |
| | 13-031 | 198 | FG | No | 1 | 1 | 1,996.53 | 0.76 |
| | 13-032 | 288 | FG | No | 1 | 1 | 1,999.96 | 0.85 |
| | 13-033 | 153 | FG | No | 1 | 1 | 2,000.23 | 0.51 |
| | 13-034 | 135 | FG | No | 1 | 1 | 2,001.04 | 0.50 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 13-035 | 144 | FG | No | 1 | 1 | 2,002.06 | 0.79 |
| | 13-036 | 531 | FG | No | 1 | 1 | 2,001.71 | 0.70 |
| | 13-037 | 252 | FG | No | 1 | 1 | 1,999.24 | 1.43 |
| | 13-038 | 747 | FG | No | 1 | 1 | 2,001.94 | 1.08 |
| | 13-039 | 324 | FG | No | 1 | 1 | 2,000.11 | 0.88 |
| | 13-040 | 144 | FG | No | 1 | 1 | 2,000.43 | 0.54 |
| | 13-041 | 468 | FG | No | 1 | 1 | 2,001.31 | 2.18 |
| | 13-042 | 522 | FG | No | 1 | 1 | 2,001.56 | 0.73 |
| Region 14 | 14-001 | 162 | F | Yes | 8 | 1 | 1,981.40 | 0.52 |
| | 14-002 | 5,760 | F | Yes | 8 | 1 | 1,983.42 | 2.21 |
| | 14-003 | 270 | FG | No | 1 | 1 | 1,982.70 | 0.23 |
| | 14-004 | 522 | F | Yes | 8 | 1 | 1,984.29 | 0.11 |
| | 14-005 | 405 | FG | No | 1 | 1 | 1,985.30 | 0.34 |
| | 14-006 | 36,225 | F | Yes | 8 | 1 | 1,985.77 | 1.87 |
| | 14-007 | 1,197 | FG | No | 1 | 1 | 1,986.14 | 0.59 |
| | 14-008 | 16,263 | F | Yes | 8 | 1 | 1,988.32 | 0.72 |
| | 14-009 | 4,104 | F | Yes | 8 | 1 | 1,989.72 | 1.01 |
| | 14-010 | 180 | FG | No | 1 | 1 | 1,990.89 | 0.24 |
| | 14-011 | 783 | F | Yes | 8 | 1 | 1,990.53 | 0.66 |
| | 14-012 | 162 | FG | No | 1 | 1 | 1,989.50 | 0.57 |
| | 14-013 | 4,095 | F | Yes | 8 | 1 | 1,992.05 | 1.13 |
| | 14-014 | 738 | FG | No | 1 | 1 | 1,991.65 | 0.40 |
| | 14-015 | 144 | FG | No | 1 | 1 | 1,994.40 | 1.54 |
| | 14-016 | 234 | FG | No | 1 | 1 | 1,994.40 | 2.86 |
| | 14-017 | 3,105 | FG | No | 1 | 1 | 1,992.86 | 2.06 |
| | 14-018 | 135 | FG | No | 1 | 1 | 1,993.50 | 0.89 |
| | 14-019 | 144 | FG | No | 1 | 1 | 1,994.50 | 0.87 |
| | 14-020 | 135 | FG | No | 1 | 1 | 1,995.34 | 0.92 |
| | 14-021 | 117 | FG | No | 1 | 1 | 1,995.37 | 0.54 |
| | 14-022 | 1,251 | FG | No | 1 | 1 | 1,995.82 | 1.23 |
| | 14-023 | 1,692 | FG | No | 1 | 1 | 1,995.80 | 1.34 |
| | 14-024 | 1,233 | FG | No | 1 | 1 | 1,995.58 | 0.21 |
| | 14-025 | 108 | FG | No | 1 | 1 | 1,998.03 | 5.61 |
| | 14-026 | 14,247 | FG | No | 1 | 1 | 1,998.20 | 3.30 |
| | 14-027 | 180 | FG | No | 1 | 1 | 1,998.56 | 0.52 |
| | 14-030 | 270 | FG | No | 1 | 1 | 2,002.34 | 0.61 |
| | 14-031 | 117 | FG | No | 1 | 1 | 1,993.98 | 0.67 |
| | 14-032 | 108 | FG | No | 1 | 1 | 1,996.64 | 3.15 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 14-033 | 270 | FG | No | 1 | 1 | 2,002.30 | 0.73 |
| | 14-034 | 306 | FG | No | 1 | 1 | 1,996.95 | 2.21 |
| | 14-035 | 819 | FG | No | 1 | 1 | 1,999.79 | 1.76 |
| | 14-036 | 756 | FG | No | 1 | 1 | 1,996.95 | 3.60 |
| | 14-037 | 189 | FG | No | 1 | 1 | 1,997.31 | 0.37 |
| | 14-038 | 486 | FG | No | 1 | 1 | 2,003.34 | 4.36 |
| | 14-039 | 216 | FG | No | 1 | 1 | 2,004.77 | 1.21 |
| | 14-040 | 306 | FG | No | 1 | 1 | 2,008.41 | 1.18 |
| | 14-041 | 1,053 | FG | No | 1 | 1 | 2,009.88 | 1.75 |
| | 14-042 | 207 | FG | No | 1 | 1 | 2,012.83 | 3.18 |
| | 14-043 | 351 | FG | No | 1 | 1 | 2,012.83 | 1.00 |
| Region 15 | 15-001 | 657 | F | Yes | 8 | 1 | 1,979.35 | 0.55 |
| | 15-002 | 180 | F | Yes | 8 | 1 | 1,980.04 | 0.17 |
| | 15-003 | 153 | F | Yes | 8 | 1 | 1,981.10 | 0.51 |
| | 15-004 | 747 | F | Yes | 8 | 1 | 1,982.18 | 0.38 |
| | 15-005 | 405 | F | Yes | 8 | 1 | 1,982.57 | 0.27 |
| | 15-006 | 180 | F | Yes | 8 | 1 | 1,982.72 | 0.22 |
| | 15-007 | 9,756 | F | Yes | 8 | 1 | 1,982.72 | 1.63 |
| | 15-008 | 2,025 | F | Yes | 8 | 1 | 1,983.55 | 2.54 |
| | 15-009 | 513 | F | Yes | 8 | 1 | 1,984.30 | 0.43 |
| | 15-010 | 29,808 | F | Yes | 8 | 1 | 1,983.54 | 3.50 |
| | 15-011 | 144 | F | Yes | 8 | 1 | 1,985.34 | 0.38 |
| | 15-012 | 189 | F | Yes | 8 | 1 | 1,985.87 | 0.45 |
| | 15-013 | 1,845 | F | Yes | 8 | 1 | 1,984.69 | 1.22 |
| | 15-014 | 1,674 | F | Yes | 8 | 1 | 1,987.23 | 0.94 |
| | 15-016 | 108 | FG | No | 1 | 1 | 1,990.51 | 0.08 |
| | 15-020 | 360 | FG | No | 1 | 1 | 2,001.42 | 1.13 |
| | 15-021 | 441 | FG | No | 1 | 1 | 1,989.77 | 0.16 |
| | 15-022 | 108 | FG | No | 1 | 1 | 2,000.99 | 0.70 |
| | 15-023 | 576 | FG | No | 1 | 1 | 2,009.17 | 2.22 |
| | 15-024 | 414 | FG | No | 1 | 1 | 2,000.99 | 1.04 |
| | 15-025 | 801 | FG | No | 1 | 1 | 2,010.31 | 2.25 |
| | 15-026 | 1,098 | FG | No | 1 | 1 | 2,008.97 | 2.63 |
| Region 16 | 16-003a | 10,815 | F | Yes | 8 | 1 | 1,991.19 | 1.25 |
| | 16-003b | 9,731 | F | Yes | 8 | 1 | 1,991.03 | 1.03 |
| | 16-003c | 11,791 | F | Yes | 8 | 1 | 1,991.12 | 0.97 |
| | 16-003d | 4,436 | F | Yes | 8 | 1 | 1,991.34 | 0.51 |
| | 16-004 | 297 | FG | No | 1 | 1 | 1,994.33 | 0.69 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 16-006 | 432 | FG | No | 1 | 1 | 1,994.68 | 0.81 |
| | 16-007 | 7,191 | FG | No | 1 | 1 | 1,993.47 | 1.19 |
| | 16-008 | 1,503 | FG | No | 1 | 1 | 1,995.88 | 0.83 |
| | 16-009 | 747 | FG | No | 1 | 1 | 1,995.68 | 0.47 |
| | 16-010 | 594 | FG | No | 1 | 1 | 1,995.46 | 1.47 |
| | 16-011 | 1,386 | FG | No | 1 | 1 | 1,995.48 | 1.33 |
| | 16-013 | 9,972 | FG | No | 1 | 1 | 1,995.05 | 2.22 |
| | 16-014 | 351 | FG | No | 1 | 1 | 1,997.69 | 1.88 |
| | 16-015 | 270 | FG | No | 1 | 1 | 1,999.10 | 1.16 |
| | 16-020 | 576 | FG | No | 1 | 1 | 2,002.69 | 1.32 |
| | 16-021 | 1,917 | FG | No | 1 | 1 | 2,002.42 | 2.50 |
| | 16-022 | 144 | FG | No | 1 | 1 | 2,002.68 | 0.38 |
| | 16-023 | 324 | FG | No | 1 | 1 | 2,002.20 | 1.14 |
| | 16-024 | 288 | FG | No | 1 | 1 | 2,001.80 | 0.76 |
| | 16-025 | 144 | FG | No | 1 | 1 | 2,001.72 | 0.73 |
| | 16-026 | 108 | FG | No | 1 | 1 | 2,003.10 | 1.29 |
| | 16-027 | 117 | FG | No | 1 | 1 | 2,004.66 | 0.55 |
| | 16-028 | 846 | FG | No | 1 | 1 | 2,002.40 | 1.00 |
| | 16-029 | 108 | FG | No | 1 | 1 | 2,005.15 | 1.00 |
| | 16-030 | 315 | FG | No | 1 | 1 | 2,000.32 | 0.80 |
| | 16-031 | 153 | FG | No | 1 | 1 | 1,999.99 | 1.47 |
| | 16-032 | 198 | FG | No | 1 | 1 | 2,002.69 | 0.44 |
| | 16-033 | 1,890 | FG | No | 1 | 1 | 2,001.18 | 1.19 |
| | 16-034 | 315 | FG | No | 1 | 1 | 2,001.43 | 1.31 |
| | 16-035 | 216 | FG | No | 1 | 1 | 2,000.18 | 1.18 |
| | 16-036 | 117 | FG | No | 1 | 1 | 2,002.51 | 0.78 |
| | 16-037 | 243 | FG | No | 1 | 1 | 1,999.91 | 1.60 |
| | 16-038 | 909 | FG | No | 1 | 1 | 2,002.67 | 2.31 |
| | 16-039 | 135 | FG | No | 1 | 1 | 2,002.26 | 0.96 |
| | 16-040 | 4,473 | FG | No | 1 | 1 | 1,999.39 | 3.85 |
| | 16-041 | 144 | FG | No | 1 | 1 | 2,000.47 | 1.36 |
| | 16-042 | 216 | FG | No | 1 | 1 | 1,998.30 | 1.04 |
| | 16-043 | 153 | FG | No | 1 | 1 | 1,998.77 | 1.04 |
| | 16-044 | 108 | FG | No | 1 | 1 | 1,999.32 | 1.02 |
| | 16-045 | 126 | FG | No | 1 | 1 | 2,000.42 | 0.73 |
| | 16-046 | 153 | FG | No | 1 | 1 | 1,999.69 | 0.79 |
| | 16-047 | 171 | FG | No | 1 | 1 | 2,008.63 | 0.69 |
| | 16-048 | 117 | FG | No | 1 | 1 | 2,006.28 | 0.66 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 16-049 | 2,826 | FG | No | 1 | 1 | 2,008.46 | 6.13 |
| | 16-050 | 2,043 | FG | No | 1 | 1 | 2,006.32 | 3.33 |
| | 16-051 | 1,305 | FG | No | 1 | 1 | 2,004.22 | 2.53 |
| | 16-052 | 1,512 | FG | No | 1 | 1 | 2,006.69 | 2.61 |
| | 16-053 | 468 | FG | No | 1 | 1 | 2,006.51 | 1.48 |
| | 16-054 | 198 | FG | No | 1 | 1 | 2,009.20 | 2.20 |
| | 16-055 | 297 | FG | No | 1 | 1 | 2,008.67 | 1.28 |
| | 16-056 | 585 | FG | No | 1 | 1 | 2,008.84 | 1.72 |
| | 16-057 | 1,044 | FG | No | 1 | 1 | 2,006.62 | 3.13 |
| | 16-058 | 3,285 | FG | No | 1 | 1 | 2,009.40 | 4.39 |
| | 16-059 | 2,529 | FG | No | 1 | 1 | 2,010.36 | 3.25 |
| | 16-060 | 117 | FG | No | 1 | 1 | 2,010.92 | 1.17 |
| | 16-061 | 20,304 | FG | No | 1 | 1 | 2,005.13 | 4.91 |
| | 16-062 | 126 | FG | No | 1 | 1 | 2,011.44 | 1.44 |
| | 16-063 | 225 | FG | No | 1 | 1 | 2,012.87 | 1.41 |
| | 16-064 | 216 | FG | No | 1 | 1 | 2,012.36 | 1.02 |
| | 16-065 | 1,557 | FG | No | 1 | 1 | 2,012.99 | 3.06 |
| | 16-066 | 729 | FG | No | 1 | 1 | 2,005.66 | 3.48 |
| | 16-067 | 162 | FG | No | 1 | 1 | 2,011.12 | 1.84 |
| | 16-068 | 1,593 | FG | No | 1 | 1 | 2,009.93 | 3.48 |
| | 16-069 | 14,346 | FG | No | 1 | 1 | 2,010.88 | 11.97 |
| | 16-070 | 468 | FG | No | 1 | 1 | 2,011.43 | 1.31 |
| | 16-071 | 198 | FG | No | 1 | 1 | 1,999.05 | 0.94 |
| | 16-072 | 4,122 | FG | No | 1 | 1 | 2,003.78 | 3.89 |
| | 16-073 | 1,134 | FG | No | 1 | 1 | 2,013.04 | 2.54 |
| | 16-074 | 1,179 | FG | No | 1 | 1 | 2,004.59 | 1.44 |
| | 16-075 | 999 | FG | No | 1 | 1 | 2,004.59 | 1.12 |
| | 16-076 | 144 | FG | No | 1 | 1 | 2,000.47 | 0.79 |
| | 16-077 | 315 | FG | No | 1 | 1 | 2,002.36 | 0.95 |
| | 16-078 | 378 | FG | No | 1 | 1 | 2,006.08 | 0.92 |
| | 16-079 | 423 | FG | No | 1 | 1 | 2,005.43 | 2.85 |
| | 16-080 | 180 | FG | No | 1 | 1 | 2,003.25 | 1.16 |
| | 16-081 | 675 | FG | No | 1 | 1 | 2,006.49 | 1.28 |
| | 16-082 | 2,871 | FG | No | 1 | 1 | 2,006.08 | 2.96 |
| | 16-083 | 3,870 | FG | No | 1 | 1 | 2,005.18 | 2.95 |
| | 16-084 | 360 | FG | No | 1 | 1 | 2,007.53 | 1.52 |
| | 16-085 | 288 | FG | No | 1 | 1 | 2,002.52 | 1.28 |
| | 16-086 | 468 | FG | No | 1 | 1 | 2,005.39 | 3.92 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 16-087 | 117 | FG | No | 1 | 1 | 2,005.57 | 0.52 |
| | 16-088 | 4,617 | FG | No | 1 | 1 | 2,002.52 | 5.92 |
| | 16-089 | 432 | FG | No | 1 | 1 | 2,002.74 | 1.77 |
| | 16-090 | 1,332 | FG | No | 1 | 1 | 2,007.95 | 3.36 |
| | 16-091 | 3,186 | FG | No | 1 | 1 | 2,005.39 | 3.92 |
| | 16-092 | 378 | FG | No | 1 | 1 | 2,000.34 | 1.10 |
| | 16-093 | 171 | FG | No | 1 | 1 | 2,002.54 | 0.47 |
| | 16-094 | 126 | FG | No | 1 | 1 | 2,008.82 | 2.30 |
| | 16-095 | 297 | FG | No | 1 | 1 | 2,002.16 | 2.56 |
| | 16-096 | 306 | FG | No | 1 | 1 | 2,012.15 | 1.78 |
| | 16-097 | 1,467 | FG | No | 1 | 1 | 2,009.53 | 2.82 |
| | 16-098 | 243 | FG | No | 1 | 1 | 2,002.42 | 0.91 |
| | 16-099 | 171 | FG | No | 1 | 1 | 2,008.97 | 0.60 |
| | 16-100 | 1,791 | FG | No | 1 | 1 | 2,009.31 | 3.50 |
| | 16-101 | 522 | FG | No | 1 | 1 | 2,003.39 | 1.52 |
| | 16-102 | 630 | FG | No | 1 | 1 | 2,002.49 | 0.96 |
| | 16-103 | 1,584 | FG | No | 1 | 1 | 2,004.94 | 1.89 |
| | 16-104 | 5,058 | FG | No | 1 | 1 | 2,008.04 | 3.99 |
| | 16-105 | 180 | FG | No | 1 | 1 | 2,007.79 | 1.05 |
| | 16-106 | 252 | FG | No | 1 | 1 | 2,010.19 | 2.71 |
| | 16-107 | 135 | FG | No | 1 | 1 | 2,009.31 | 0.78 |
| | 16-108 | 810 | FG | No | 1 | 1 | 2,002.96 | 2.90 |
| | 16-109 | 297 | FG | No | 1 | 1 | 2,002.96 | 2.90 |
| | 16-110 | 3,690 | FG | No | 1 | 1 | 2,009.31 | 9.75 |
| | 16-111 | 117 | FG | No | 1 | 1 | 2,008.19 | 0.70 |
| | 16-112 | 396 | FG | No | 1 | 1 | 2,007.23 | 0.52 |
| | 16-113 | 621 | FG | No | 1 | 1 | 2,007.78 | 3.28 |
| | 16-114 | 35,523 | FG | No | 1 | 1 | 2,009.31 | 9.75 |
| | 16-115 | 3,537 | FG | No | 1 | 1 | 2,007.86 | 5.42 |
| | 16-116 | 693 | FG | No | 1 | 1 | 2,007.46 | 0.88 |
| | 16-117 | 10,701 | FG | No | 1 | 1 | 2,004.30 | 3.88 |
| | 16-118 | 405 | FG | No | 1 | 1 | 2,008.45 | 0.92 |
| | 16-119 | 342 | FG | No | 1 | 1 | 2,007.66 | 1.55 |
| | 16-120 | 117 | FG | No | 1 | 1 | 2,007.46 | 0.59 |
| | 16-121 | 12,483 | FG | No | 1 | 1 | 2,008.09 | 3.10 |
| | 16-122 | 333 | FG | No | 1 | 1 | 2,008.65 | 1.73 |
| | 16-123 | 243 | FG | No | 1 | 1 | 2,007.46 | 1.00 |
| | 16-124 | 819 | FG | No | 1 | 1 | 2,009.55 | 2.43 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 16-125 | 4,806 | FG | No | 1 | 1 | 2,008.09 | 3.10 |
| | 16-126 | 17,046 | FG | No | 1 | 1 | 2,007.46 | 2.41 |
| | 16-127 | 486 | FG | No | 1 | 1 | 2,009.21 | 2.08 |
| | 16-128 | 540 | FG | No | 1 | 1 | 2,007.96 | 1.01 |
| | 16-129 | 1,899 | FG | No | 1 | 1 | 2,007.66 | 5.79 |
| | 16-130 | 279 | FG | No | 1 | 1 | 2,008.81 | 0.97 |
| | 16-131 | 117 | FG | No | 1 | 1 | 2,015.25 | 0.34 |
| | 16-132 | 513 | FG | No | 1 | 1 | 2,011.07 | 1.44 |
| | 16-133 | 270 | FG | No | 1 | 1 | 2,008.44 | 0.96 |
| | 16-134 | 8,748 | FG | No | 1 | 1 | 2,007.46 | 2.94 |
| | 16-135 | 189 | FG | No | 1 | 1 | 2,013.26 | 0.72 |
| | 16-136 | 243 | FG | No | 1 | 1 | 2,009.48 | 0.38 |
| | 16-137 | 918 | FG | No | 1 | 1 | 2,015.27 | 0.78 |
| | 16-138 | 10,305 | FG | No | 1 | 1 | 2,008.44 | 3.80 |
| | 16-139 | 189 | FG | No | 1 | 1 | 2,009.53 | 0.28 |
| | 16-140 | 477 | FG | No | 1 | 1 | 2,010.37 | 2.60 |
| | 16-141 | 504 | FG | No | 1 | 1 | 2,011.25 | 1.49 |
| | 16-142 | 10,278 | FG | No | 1 | 1 | 2,007.66 | 5.79 |
| | 16-143 | 5,166 | FG | No | 1 | 1 | 2,010.25 | 6.61 |
| | 16-144 | 13,050 | FG | No | 1 | 1 | 2,008.82 | 9.18 |
| Region 17 | 17-001 | 315 | F | Yes | 8 | 1 | 1,982.11 | 0.67 |
| | 17-002 | 2,682 | F | Yes | 8 | 1 | 1,984.22 | 1.51 |
| | 17-003 | 342 | F | Yes | 8 | 1 | 1,985.07 | 0.69 |
| | 17-004 | 315 | F | Yes | 8 | 1 | 1,985.90 | 0.09 |
| | 17-005 | 216 | F | Yes | 8 | 1 | 1,990.81 | 0.12 |
| | 17-006 | 243 | FG | No | 1 | 1 | 1,990.62 | 0.16 |
| | 17-007 | 6,192 | F | Yes | 8 | 1 | 1,991.46 | 0.60 |
| | 17-008 | 216 | FG | No | 1 | 1 | 1,991.44 | 0.28 |
| | 17-009 | 1,251 | FG | No | 1 | 1 | 1,991.44 | 0.29 |
| | 17-010 | 936 | FG | No | 1 | 1 | 1,991.49 | 0.34 |
| | 17-011 | 135 | FG | No | 1 | 1 | 1,991.31 | 0.22 |
| | 17-014 | 306 | FG | No | 1 | 1 | 1,990.84 | 0.31 |
| | 17-015 | 675 | FG | No | 1 | 1 | 1,992.22 | 0.18 |
| | 17-016 | 288 | FG | No | 1 | 1 | 1,992.06 | 0.83 |
| | 17-017 | 540 | FG | No | 1 | 1 | 1,991.93 | 0.39 |
| | 17-018 | 252 | FG | No | 1 | 1 | 1,991.10 | 0.19 |
| | 17-019 | 351 | FG | No | 1 | 1 | 1,991.82 | 0.56 |
| | 17-020 | 549 | FG | No | 1 | 1 | 1,991.29 | 0.15 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 17-021 | 153 | FG | No | 1 | 1 | 1,993.33 | 1.35 |
| | 17-022 | 387 | FG | No | 1 | 1 | 1,993.33 | 1.93 |
| | 17-023 | 108 | FG | No | 1 | 1 | 1,996.65 | 0.49 |
| | 17-025 | 441 | FG | No | 1 | 1 | 1,995.96 | 0.62 |
| | 17-026 | 648 | FG | No | 1 | 1 | 1,993.57 | 0.20 |
| | 17-028 | 198 | FG | No | 1 | 1 | 1,993.35 | 0.59 |
| | 17-029 | 144 | FG | No | 1 | 1 | 1,993.43 | 3.08 |
| | 17-030 | 639 | FG | No | 1 | 1 | 1,993.35 | 0.97 |
| | 17-031 | 270 | FG | No | 1 | 1 | 1,995.13 | 0.65 |
| | 17-032 | 171 | FG | No | 1 | 1 | 1,995.06 | 0.50 |
| | 17-033 | 4,095 | FG | No | 1 | 1 | 1,994.44 | 0.12 |
| | 17-034 | 1,863 | FG | No | 1 | 1 | 1,994.95 | 0.85 |
| | 17-035 | 189 | FG | No | 1 | 1 | 1,994.95 | 2.92 |
| | 17-036 | 117 | FG | No | 1 | 1 | 1,995.18 | 0.91 |
| | 17-037 | 162 | FG | No | 1 | 1 | 1,994.78 | 3.18 |
| | 17-038 | 207 | FG | No | 1 | 1 | 1,994.53 | 0.33 |
| | 17-039 | 135 | FG | No | 1 | 1 | 1,995.07 | 0.77 |
| | 17-040 | 162 | FG | No | 1 | 1 | 1,996.27 | 2.84 |
| | 17-041 | 945 | FG | No | 1 | 1 | 1,995.14 | 2.30 |
| | 17-042 | 1,026 | FG | No | 1 | 1 | 1,994.17 | 0.63 |
| | 17-043 | 261 | FG | No | 1 | 1 | 1,995.76 | 3.72 |
| | 17-044 | 189 | FG | No | 1 | 1 | 1,995.34 | 0.65 |
| | 17-045 | 135 | FG | No | 1 | 1 | 1,997.57 | 3.91 |
| | 17-046 | 108 | FG | No | 1 | 1 | 1,999.29 | 0.59 |
| | 17-047 | 117 | FG | No | 1 | 1 | 1,999.13 | 0.45 |
| | 17-048 | 405 | FG | No | 1 | 1 | 2,000.06 | 4.31 |
| | 17-049 | 117 | FG | No | 1 | 1 | 1,999.55 | 0.50 |
| | 17-050 | 459 | FG | No | 1 | 1 | 2,000.13 | 0.65 |
| | 17-051 | 261 | FG | No | 1 | 1 | 2,000.01 | 0.60 |
| | 17-052 | 144 | FG | No | 1 | 1 | 1,999.41 | 0.60 |
| | 17-060 | 3,168 | F | Yes | 8 | 1 | 1,978.85 | 1.83 |
| | 17-061 | 270 | FG | No | 1 | 1 | 1,980.15 | 0.11 |
| | 17-062 | 117 | FG | No | 1 | 1 | 1,999.55 | 0.64 |
| | 17-063 | 171 | FG | No | 1 | 1 | 1,991.88 | 0.72 |
| | 17-064 | 621 | FG | No | 1 | 1 | 1,980.38 | 0.29 |
| | 17-065 | 261 | FG | No | 1 | 1 | 2,005.22 | 0.88 |
| | 17-066 | 288 | FG | No | 1 | 1 | 2,002.94 | 1.11 |
| | 17-067 | 4,239 | F | Yes | 8 | 1 | 1,991.31 | 0.42 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 17-068 | 126 | FG | No | 1 | 1 | 2,000.53 | 0.41 |
| | 17-069 | 135 | FG | No | 1 | 1 | 2,001.17 | 0.73 |
| | 17-070 | 234 | FG | No | 1 | 1 | 1,993.26 | 0.45 |
| | 17-071 | 189 | FG | No | 1 | 1 | 2,002.81 | 1.57 |
| | 17-072 | 369 | FG | No | 1 | 1 | 2,000.78 | 1.10 |
| Region 18 | 18-001 | 198 | C | No | 6 | 6 | 1,981.24 | 0.08 |
| | 18-002 | 315 | C | No | 6 | 6 | 1,981.69 | 0.10 |
| | 18-003 | 1,269 | C | No | 6 | 6 | 1,982.43 | 0.45 |
| | 18-004 | 306 | C | No | 6 | 6 | 1,982.15 | 0.18 |
| | 18-005 | 3,942 | C | No | 6 | 6 | 1,982.26 | 1.29 |
| | 18-006 | 441 | C | No | 6 | 6 | 1,982.36 | 0.45 |
| | 18-007 | 135 | C | No | 6 | 6 | 1,981.99 | 0.37 |
| | 18-008 | 198 | C | No | 6 | 6 | 1,982.34 | 0.14 |
| | 18-009 | 360 | C | No | 6 | 6 | 1,982.49 | 0.19 |
| | 18-010 | 639 | C | No | 6 | 6 | 1,982.23 | 0.12 |
| | 18-011 | 207 | C | No | 6 | 6 | 1,982.16 | 0.21 |
| | 18-012 | 270 | C | No | 6 | 6 | 1,982.57 | 0.45 |
| | 18-013 | 936 | C | No | 6 | 6 | 1,983.28 | 2.46 |
| | 18-014 | 2,007 | C | No | 6 | 6 | 1,983.23 | 0.50 |
| | 18-015 | 6,435 | C | No | 6 | 6 | 1,983.17 | 0.66 |
| | 18-016 | 198 | C | No | 6 | 6 | 1,983.42 | 0.27 |
| | 18-017 | 1,512 | C | No | 6 | 6 | 1,983.40 | 0.34 |
| | 18-018 | 1,125 | C | No | 6 | 6 | 1,983.44 | 0.50 |
| | 18-019 | 135 | C | No | 6 | 6 | 1,983.06 | 0.06 |
| | 18-020 | 234 | C | No | 6 | 6 | 1,982.86 | 0.13 |
| | 18-022 | 1,134 | C | No | 6 | 6 | 1,983.21 | 0.83 |
| | 18-023 | 1,260 | C | No | 6 | 6 | 1,982.54 | 0.22 |
| | 18-024 | 117 | C | No | 6 | 6 | 1,982.87 | 0.14 |
| | 18-025 | 126 | C | No | 6 | 6 | 1,983.24 | 0.34 |
| | 18-026 | 279 | C | No | 6 | 6 | 1,982.96 | 0.45 |
| | 18-027 | 1,161 | C | No | 6 | 6 | 1,982.54 | 0.28 |
| | 18-028 | 486 | C | No | 6 | 6 | 1,982.55 | 0.32 |
| | 18-029 | 225 | C | No | 6 | 6 | 1,982.51 | 0.23 |
| | 18-030 | 153 | C | No | 6 | 6 | 1,982.60 | 0.17 |
| | 18-031 | 180 | C | No | 6 | 6 | 1,982.67 | 0.23 |
| | 18-032 | 1,287 | C | No | 6 | 6 | 1,982.55 | 0.34 |
| | 18-033 | 1,170 | C | No | 6 | 6 | 1,984.50 | 0.72 |
| | 18-034 | 7,326 | C | No | 6 | 6 | 1,983.63 | 1.07 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | 18-036 | 207 | C | No | 6 | 6 | 1,983.90 | 0.43 |
| | 18-037 | 189 | C | No | 6 | 6 | 1,983.52 | 0.20 |
| | 18-038 | 702 | C | No | 6 | 6 | 1,983.97 | 1.06 |
| | 18-039 | 3,429 | C | No | 6 | 6 | 1,984.48 | 1.40 |
| | 18-040 | 558 | C | No | 6 | 6 | 1,984.69 | 1.88 |
| | 18-041 | 171 | C | No | 6 | 6 | 1,985.28 | 0.70 |
| | 18-042 | 900 | C | No | 6 | 6 | 1,986.58 | 0.52 |
| | 18-043 | 3,528 | C | No | 6 | 6 | 1,987.27 | 1.95 |
| | 18-044 | 477 | C | No | 6 | 6 | 1,986.91 | 0.58 |
| | 18-045 | 126 | C | No | 6 | 6 | 1,987.87 | 0.71 |
| | 18-046 | 306 | C | No | 6 | 6 | 1,990.54 | 0.79 |
| | 18-047 | 936 | C | No | 6 | 6 | 1,993.38 | 1.81 |
| | 18-049 | 108 | C | No | 6 | 6 | 1,994.65 | 0.94 |
| | 18-050 | 198 | C | No | 6 | 6 | 1,996.35 | 0.81 |
| | 18-060 | 360 | C | No | 6 | 6 | 1,978.89 | 0.09 |
| | 18-061 | 234 | C | No | 6 | 6 | 1,978.71 | 0.27 |
| | 18-062 | 1,404 | C | No | 6 | 6 | 1,979.54 | 0.39 |
| | 18-063 | 279 | C | No | 6 | 6 | 1,979.36 | 0.24 |
| | 18-064 | 180 | C | No | 6 | 6 | 1,981.37 | 0.07 |
| | 18-065 | 4,941 | C | No | 6 | 6 | 1,979.84 | 1.09 |
| | 18-066 | 3,717 | C | No | 6 | 6 | 1,978.13 | 0.79 |
| | 18-067 | 1,233 | C | No | 6 | 6 | 2,012.43 | 1.81 |
| | 18-068 | 108 | C | No | 6 | 6 | 1,996.35 | 1.41 |
| | 18-069 | 1,368 | C | No | 6 | 6 | 2,003.82 | 2.08 |
| | 18-070 | 288 | C | No | 6 | 6 | 2,001.52 | 0.48 |
| | 18-071 | 396 | C | No | 6 | 6 | 2,001.67 | 0.84 |
| | 18-072 | 1,215 | C | No | 6 | 6 | 2,001.34 | 1.02 |
| | 18-073 | 2,682 | C | No | 6 | 6 | 1,981.26 | 2.07 |
| | 18-074 | 1,593 | C | No | 6 | 6 | 1,983.90 | 0.96 |
| | 18-075 | 171 | C | No | 6 | 6 | 1,983.21 | 0.16 |
| Tailrace | TR-023 | 135 | C | No | 6 | 6 | 1,716.12 | 1.30 |
| | TR-029 | 990 | C | No | 6 | 6 | 1,721.45 | 1.56 |
| | TR-031 | 135 | C | No | 6 | 6 | 1,723.04 | 0.40 |
| | TR-020 | 2,853 | C | No | 6 | 6 | 1,713.46 | 3.55 |
| | TR-025 | 252 | C | No | 6 | 6 | 1,717.11 | 0.50 |
| | TR-035 | 2,016 | C | No | 6 | 6 | 1,728.81 | 1.48 |
| | TR-032 | 207 | C | No | 6 | 6 | 1,728.42 | 0.45 |
| | TR-036 | 1,197 | C | No | 6 | 6 | 1,729.10 | 1.30 |

**Table C-1, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | TR-033 | 756 | C | No | 6 | 6 | 1,728.38 | 0.37 |
| | TR-039 | 126 | C | No | 6 | 6 | 1,729.82 | 0.45 |
| | TR-030 | 414 | C | No | 6 | 6 | 1,722.27 | 0.40 |
| | TR-037 | 333 | C | No | 6 | 6 | 1,729.04 | 0.88 |
| | TR-034 | 216 | C | No | 6 | 6 | 1,727.90 | 0.83 |
| | TR-038 | 522 | C | No | 6 | 6 | 1,728.87 | 0.29 |
| | TR-050 | 108 | C | No | 6 | 6 | 1,727.30 | 0.21 |
| | TR-022 | 225 | C | No | 6 | 6 | 1,713.43 | 0.59 |
| | TR-051 | 144 | C | No | 6 | 6 | 1,743.09 | 0.89 |

Note:
1 Substrate type “F” = fines; substrate type “FG” = fines and/or gravels; substrate type “C” = cobble

**Table C-2.** Summary of physical characteristics of additional trapping pools identified within the study area.

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| Additional Canyon | CX-006 | 216 | FG | No | 1 | 1 | 1986.47 | 4.49 |
| | CX-025 | 5832 | FG | No | 1 | 1 | 1966.94 | 6.41 |
| | CX-034 | 162 | FG | No | 1 | 1 | 1953.54 | 0.24 |
| | CX-036 | 1665 | FG | No | 1 | 1 | 1972.13 | 1.80 |
| | CX-038 | 1458 | FG | No | 1 | 1 | 1962.99 | 3.50 |
| | CX-039 | 504 | FG | No | 1 | 1 | 1960.83 | 1.60 |
| | CX-040 | 126 | FG | No | 1 | 1 | 1957.95 | 1.59 |
| | CX-043 | 603 | C | No | 6 | 6 | 1964.33 | 4.64 |
| | CX-044 | 792 | C | No | 6 | 6 | 1979.36 | 2.90 |
| | CX-045 | 243 | C | No | 6 | 6 | 1982.96 | 0.68 |
| | CX-046 | 180 | C | No | 6 | 6 | 1982.96 | 1.71 |
| Additional Upper Reservoir | UX-055 | 162 | F | Yes | 8 | 1 | 1979.00 | 0.66 |
| | UX-057 | 6669 | F | Yes | 8 | 1 | 1979.18 | 0.47 |
| | UX-064 | 441 | F | Yes | 8 | 1 | 1977.85 | 0.34 |
| | UX-065 | 1287 | F | Yes | 8 | 1 | 1978.27 | 0.31 |
| | UX-066 | 234 | FG | No | 1 | 1 | 1977.96 | 0.33 |
| | UX-099 | 270 | F | Yes | 8 | 1 | 1980.78 | 0.13 |
| | UX-102 | 117 | F | Yes | 8 | 1 | 1979.42 | 0.19 |
| | UX-105 | 189 | FG | No | 1 | 1 | 2015.25 | 0.36 |
| | UX-107 | 162 | F | Yes | 8 | 1 | 1980.67 | 0.10 |
| | UX-110 | 2214 | FG | No | 1 | 1 | 2011.98 | 1.68 |
| | UX-205 | 1656 | FG | No | 1 | 1 | 2003.26 | 2.36 |
| | UX-206 | 117 | F | Yes | 8 | 1 | 1985.19 | 0.11 |
| | UX-207 | 1656 | F | Yes | 8 | 1 | 1985.00 | 0.37 |
| | UX-208 | 9189 | F | Yes | 8 | 1 | 1984.91 | 1.49 |
| | UX-223 | 738 | C | No | 6 | 6 | 1991.07 | 1.31 |
| | UX-225 | 117 | C | No | 6 | 6 | 1991.41 | 1.36 |
| | UX-235 | 180 | FG | No | 1 | 1 | 1985.86 | 0.48 |
| | UX-240 | 675 | FG | No | 1 | 1 | 1978.85 | 0.29 |
| | UX-254 | 486 | FG | No | 1 | 1 | 1991.26 | 1.36 |
| | UX-255 | 693 | FG | No | 1 | 1 | 1991.26 | 1.31 |
| | UX-256 | 432 | FG | No | 1 | 1 | 1991.85 | 1.89 |
| | UX-257 | 342 | FG | No | 1 | 1 | 1991.85 | 1.78 |
| | UX-258 | 261 | FG | No | 1 | 1 | 1991.85 | 1.69 |
| | UX-259 | 297 | FG | No | 1 | 1 | 1989.38 | 0.38 |
| | UX-261 | 387 | FG | No | 1 | 1 | 2008.63 | 1.77 |
| | UX-262 | 153 | FG | No | 1 | 1 | 2001.68 | 2.33 |
| | UX-264 | 270 | FG | No | 1 | 1 | 2012.96 | 1.35 |
| | UX-265 | 297 | FG | No | 1 | 1 | 2011.94 | 0.85 |
| | UX-266 | 252 | FG | No | 1 | 1 | 1996.69 | 0.90 |

**Table C-2, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | UX-267 | 126 | FG | No | 1 | 1 | 1994.73 | 0.69 |
| | UX-268 | 1017 | FG | No | 1 | 1 | 2011.93 | 1.01 |
| | UX-269 | 2457 | FG | No | 1 | 1 | 1994.53 | 1.21 |
| | UX-270 | 180 | FG | No | 1 | 1 | 2011.93 | 0.53 |
| | UX-271 | 288 | FG | No | 1 | 1 | 1994.53 | 0.98 |
| | UX-272 | 306 | FG | No | 1 | 1 | 1994.27 | 0.40 |
| | UX-273 | 243 | FG | No | 1 | 1 | 1991.66 | 0.36 |
| | UX-274 | 2268 | FG | No | 1 | 1 | 1991.47 | 1.11 |
| | UX-275 | 1485 | FG | No | 1 | 1 | 1985.84 | 0.34 |
| | UX-276 | 234 | FG | No | 1 | 1 | 2009.42 | 0.25 |
| | UX-277 | 18585 | FG | No | 1 | 1 | 2009.26 | 1.66 |
| | UX-278 | 171 | FG | No | 1 | 1 | 2005.02 | 2.13 |
| | UX-279 | 3681 | FG | No | 1 | 1 | 1984.34 | 0.69 |
| | UX-280 | 21411 | FG | No | 1 | 1 | 1983.48 | 7.17 |
| | UX-281 | 6210 | FG | No | 1 | 1 | 2008.63 | 4.76 |
| | UX-282 | 1953 | FG | No | 1 | 1 | 1986.12 | 1.09 |
| | UX-283 | 306 | FG | No | 1 | 1 | 2009.91 | 0.68 |
| | UX-284 | 126 | FG | No | 1 | 1 | 2015.09 | 1.05 |
| | UX-285 | 3519 | FG | No | 1 | 1 | 1982.54 | 1.16 |
| | UX-286 | 117 | FG | No | 1 | 1 | 2015.12 | 0.65 |
| | UX-287 | 261 | FG | No | 1 | 1 | 2016.35 | 0.80 |
| | UX-288 | 747 | FG | No | 1 | 1 | 2010.31 | 0.57 |
| | UX-289 | 3780 | FG | No | 1 | 1 | 2011.14 | 3.64 |
| | UX-290 | 585 | FG | No | 1 | 1 | 2015.05 | 1.28 |
| | UX-291 | 810 | FG | No | 1 | 1 | 2010.89 | 1.47 |
| | UX-292 | 351 | FG | No | 1 | 1 | 2015.05 | 0.81 |
| | UX-293 | 261 | FG | No | 1 | 1 | 2016.18 | 0.41 |
| | UX-294 | 1008 | FG | No | 1 | 1 | 2011.53 | 1.20 |
| | UX-295 | 135 | FG | No | 1 | 1 | 2014.58 | 0.94 |
| | UX-296 | 1800 | FG | No | 1 | 1 | 1982.59 | 0.69 |
| | UX-297 | 234 | FG | No | 1 | 1 | 2010.31 | 0.61 |
| | UX-298 | 810 | FG | No | 1 | 1 | 2016.18 | 1.57 |
| | UX-299 | 171 | FG | No | 1 | 1 | 2010.55 | 0.56 |
| | UX-300 | 558 | FG | No | 1 | 1 | 2010.31 | 0.64 |
| | UX-301 | 252 | FG | No | 1 | 1 | 2013.36 | 0.66 |
| | UX-302 | 468 | FG | No | 1 | 1 | 1998.88 | 1.21 |
| | UX-303 | 459 | FG | No | 1 | 1 | 2001.78 | 2.15 |
| | UX-304 | 117 | FG | No | 1 | 1 | 2014.96 | 0.53 |
| | UX-305 | 135 | FG | No | 1 | 1 | 2018.66 | 0.58 |
| | UX-306 | 648 | FG | No | 1 | 1 | 2014.63 | 0.89 |
| | UX-308 | 117 | FG | No | 1 | 1 | 2017.81 | 0.68 |
| | UX-309 | 2817 | FG | No | 1 | 1 | 1998.88 | 6.83 |
| | UX-310 | 351 | FG | No | 1 | 1 | 2017.79 | 0.73 |

**Table C-2, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | UX-311 | 1017 | FG | No | 1 | 1 | 2010.35 | 1.23 |
| | UX-312 | 243 | FG | No | 1 | 1 | 2017.45 | 0.66 |
| | UX-313 | 162 | FG | No | 1 | 1 | 2016.91 | 0.66 |
| | UX-314 | 639 | FG | No | 1 | 1 | 2013.13 | 0.60 |
| | UX-315 | 378 | FG | No | 1 | 1 | 2011.24 | 0.53 |
| | UX-316 | 117 | FG | No | 1 | 1 | 2016.66 | 0.29 |
| | UX-317 | 1773 | FG | No | 1 | 1 | 2017.79 | 2.25 |
| | UX-318 | 666 | FG | No | 1 | 1 | 2011.13 | 0.93 |
| | UX-319 | 144 | FG | No | 1 | 1 | 2018.47 | 0.13 |
| | UX-320 | 423 | FG | No | 1 | 1 | 2017.59 | 0.71 |
| | UX-321 | 603 | FG | No | 1 | 1 | 2017.52 | 0.78 |
| | UX-322 | 2088 | FG | No | 1 | 1 | 1982.80 | 0.56 |
| | UX-323 | 387 | FG | No | 1 | 1 | 2016.67 | 1.48 |
| | UX-324 | 189 | FG | No | 1 | 1 | 2012.56 | 0.48 |
| | UX-325 | 189 | FG | No | 1 | 1 | 2019.01 | 1.00 |
| | UX-326 | 261 | FG | No | 1 | 1 | 2012.54 | 0.71 |
| | UX-327 | 225 | FG | No | 1 | 1 | 2012.34 | 0.48 |
| | UX-328 | 324 | FG | No | 1 | 1 | 2017.12 | 0.97 |
| | UX-329 | 513 | FG | No | 1 | 1 | 2011.69 | 1.03 |
| | UX-330 | 198 | FG | No | 1 | 1 | 2019.67 | 0.68 |
| | UX-331 | 1719 | FG | No | 1 | 1 | 2016.63 | 2.15 |
| | UX-333 | 1188 | FG | No | 1 | 1 | 2002.18 | 2.80 |
| | UX-334 | 180 | FG | No | 1 | 1 | 2013.43 | 0.60 |
| | UX-335 | 198 | FG | No | 1 | 1 | 2019.28 | 0.41 |
| | UX-336 | 117 | FG | No | 1 | 1 | 2019.01 | 0.55 |
| | UX-337 | 972 | FG | No | 1 | 1 | 2019.28 | 1.43 |
| | UX-338 | 135 | FG | No | 1 | 1 | 2011.69 | 0.70 |
| | UX-339 | 7443 | FG | No | 1 | 1 | 2011.07 | 3.92 |
| | UX-340 | 342 | FG | No | 1 | 1 | 2017.49 | 0.18 |
| | UX-341 | 531 | FG | No | 1 | 1 | 2003.58 | 0.94 |
| | UX-342 | 126 | FG | No | 1 | 1 | 2019.53 | 0.77 |
| | UX-343 | 387 | FG | No | 1 | 1 | 2015.25 | 0.64 |
| | UX-344 | 1998 | FG | No | 1 | 1 | 2017.69 | 1.08 |
| | UX-345 | 162 | FG | No | 1 | 1 | 2019.07 | 0.36 |
| | UX-346 | 216 | FG | No | 1 | 1 | 2020.31 | 0.43 |
| | UX-347 | 234 | FG | No | 1 | 1 | 2020.04 | 0.74 |
| | UX-348 | 234 | FG | No | 1 | 1 | 2017.76 | 1.29 |
| | UX-349 | 9045 | FG | No | 1 | 1 | 2011.94 | 5.78 |
| | UX-350 | 990 | FG | No | 1 | 1 | 2020.59 | 0.61 |
| | UX-351 | 630 | FG | No | 1 | 1 | 2016.66 | 0.29 |
| | UX-352 | 78273 | FG | No | 1 | 1 | 2003.06 | 5.42 |
| | UX-353 | 171 | FG | No | 1 | 1 | 2015.43 | 0.65 |
| | UX-354 | 378 | FG | No | 1 | 1 | 2018.68 | 0.30 |

**Table C-2, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | UX-355 | 2565 | FG | No | 1 | 1 | 2019.14 | 2.86 |
| | UX-356 | 4149 | FG | No | 1 | 1 | 2018.76 | 0.85 |
| | UX-357 | 225 | FG | No | 1 | 1 | 2020.35 | 0.46 |
| | UX-358 | 270 | FG | No | 1 | 1 | 2016.74 | 1.21 |
| | UX-360 | 126 | FG | No | 1 | 1 | 2018.43 | 0.59 |
| | UX-361 | 297 | FG | No | 1 | 1 | 2019.29 | 0.68 |
| | UX-362 | 144 | FG | No | 1 | 1 | 2019.54 | 0.42 |
| | UX-363 | 216 | FG | No | 1 | 1 | 2011.07 | 1.43 |
| | UX-364 | 1980 | FG | No | 1 | 1 | 2016.35 | 1.08 |
| | UX-365 | 315 | FG | No | 1 | 1 | 2017.32 | 0.40 |
| | UX-366 | 621 | FG | No | 1 | 1 | 2016.49 | 0.86 |
| | UX-367 | 126 | FG | No | 1 | 1 | 2018.89 | 1.97 |
| | UX-368 | 639 | FG | No | 1 | 1 | 2011.26 | 1.05 |
| | UX-369 | 117 | FG | No | 1 | 1 | 2017.41 | 0.20 |
| | UX-370 | 297 | FG | No | 1 | 1 | 2019.63 | 1.05 |
| | UX-371 | 972 | FG | No | 1 | 1 | 2019.34 | 2.39 |
| | UX-372 | 549 | FG | No | 1 | 1 | 2011.37 | 0.86 |
| | UX-373 | 1215 | FG | No | 1 | 1 | 2016.77 | 0.91 |
| | UX-374 | 378 | FG | No | 1 | 1 | 2016.87 | 0.41 |
| | UX-375 | 1602 | FG | No | 1 | 1 | 2019.15 | 0.47 |
| | UX-376 | 93033 | FG | No | 1 | 1 | 2016.77 | 4.67 |
| | UX-377 | 576 | FG | No | 1 | 1 | 2018.69 | 0.69 |
| | UX-378 | 4005 | FG | No | 1 | 1 | 2013.25 | 3.79 |
| | UX-379 | 405 | FG | No | 1 | 1 | 2011.73 | 2.33 |
| | UX-381 | 144 | FG | No | 1 | 1 | 2017.31 | 0.64 |
| | UX-382 | 459 | FG | No | 1 | 1 | 2019.11 | 0.56 |
| | UX-383 | 378 | FG | No | 1 | 1 | 2016.77 | 0.64 |
| | UX-385 | 720 | FG | No | 1 | 1 | 2017.75 | 0.77 |
| | UX-386 | 1674 | FG | No | 1 | 1 | 2017.08 | 0.83 |
| | UX-387 | 918 | FG | No | 1 | 1 | 2017.15 | 1.61 |
| | UX-390 | 198 | FG | No | 1 | 1 | 2017.01 | 0.89 |
| | UX-394 | 1629 | FG | No | 1 | 1 | 2013.61 | 6.37 |
| | UX-395 | 1926 | FG | No | 1 | 1 | 2016.88 | 1.48 |
| | UX-398 | 1989 | FG | No | 1 | 1 | 2014.18 | 1.79 |
| | UX-399 | 909 | FG | No | 1 | 1 | 2013.39 | 3.01 |
| | UX-401 | 198 | FG | No | 1 | 1 | 2016.77 | 1.90 |
| | UX-403 | 684 | FG | No | 1 | 1 | 2016.95 | 0.88 |
| | UX-404 | 2205 | FG | No | 1 | 1 | 2016.90 | 1.70 |
| | UX-405 | 252 | FG | No | 1 | 1 | 2003.06 | 0.83 |
| | UX-408 | 432 | FG | No | 1 | 1 | 2003.26 | 0.77 |
| | UX-409 | 774 | FG | No | 1 | 1 | 2003.27 | 1.98 |
| | UX-411 | 216 | FG | No | 1 | 1 | 2003.52 | 1.19 |
| | UX-413 | 576 | FG | No | 1 | 1 | 2003.06 | 1.11 |

**Table C-2, continued…**

| Region | Pool ID | Area ($ft^2$) | Substrate Type[1] | Macrophyte Present | $C_T$ During Macrophyte Period | $C_T$ During Non-Macrophyte Period | Outlet Elevation (ft NAVD 88) | Depth of Pool (ft) |
|---|---|---|---|---|---|---|---|---|
| | UX-468 | 13833 | C | No | 6 | 6 | 2006.13 | 2.21 |
| | UX-469 | 306 | C | No | 6 | 6 | 2005.48 | 0.98 |
| | UX-470 | 2187 | C | No | 6 | 6 | 2005.53 | 0.66 |
| | UX-472 | 180 | C | No | 6 | 6 | 2006.22 | 0.83 |
| | UX-473 | 198 | C | No | 6 | 6 | 2007.14 | 0.51 |
| | UX-474 | 216 | C | No | 6 | 6 | 1987.75 | 0.31 |
| | UX-484 | 270 | C | No | 6 | 6 | 1985.28 | 0.65 |
| Additional Tailrace | TX-001 | 2061 | C | No | 6 | 6 | 1737.11 | 1.28 |
| | TX-002 | 630 | C | No | 6 | 6 | 1736.77 | 0.77 |
| | TX-003 | 423 | C | No | 6 | 6 | 1738.36 | 0.92 |
| | TX-004 | 252 | C | No | 6 | 6 | 1737.14 | 0.66 |
| | TX-005 | 117 | C | No | 6 | 6 | 1730.75 | 1.4 |
| | TX-006 | 216 | C | No | 6 | 6 | 1739.29 | 0.7 |
| | TX-007 | 144 | C | No | 6 | 6 | 1738.48 | 0.61 |
| | TX-008 | 351 | C | No | 6 | 6 | 1738.67 | 0.42 |
| | TX-009 | 729 | C | No | 6 | 6 | 1738.67 | 0.4 |
| | TX-011 | 477 | C | No | 6 | 6 | 1735.58 | 0.34 |
| | TX-012 | 2151 | C | No | 6 | 6 | 1735.58 | 0.95 |
| | TX-014 | 855 | C | No | 6 | 6 | 1732.78 | 2.89 |
| | TX-016 | 738 | C | No | 6 | 6 | 1719.32 | 1.08 |
| | TX-017 | 108 | C | No | 6 | 6 | 1720.69 | 0.15 |
| | TX-018 | 198 | C | No | 6 | 6 | 1720.67 | 1 |
| | TX-019 | 153 | C | No | 6 | 6 | 1720.91 | 0.35 |
| | TX-020 | 108 | C | No | 6 | 6 | 1722.39 | 0.39 |

# Appendix 2: Habitat Routing Model Development, Calibration, and Results Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 2*
## *Hydraulic Routing Model Development, Calibration, and Results*
## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Bill Fullerton, Jay Smith, and Adam Baines**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 2
# Hydraulic Routing Model Development, Calibration, and Results Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

This report provides documentation of the development and final calibration of the Hydraulic Routing Model (HRM) used to support analysis of the effects of historic Project operations on aquatic and terrestrial habitats in the Study 7, Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009a). The HRM will be utilized to support evaluation of operations scenarios during the Integrated Resource Analysis (IRA) and License Application (LA). This report also includes the analysis of the hydraulic influence of historic Project operations within the four reaches of the Project area. The HRM is an analytical tool used to support a multitude of study plan analyses; however, the primary use of the hydraulic routing model was to support Study 7, Mainstem Aquatic Habitat Modeling Study.

Study 7 is being conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by the FERC in its Study Plan Determination letter dated March 15, 2007.

Study 7 represents the integration of efforts being conducted to assess the changes in aquatic habitat of the Pend Oreille River resulting from historic Project operations. The HRM (Study 7.2) is a component study effort within the larger study.

This final report summarizes the study efforts of the HRM component of the Mainstem Aquatic Habitat Modeling Study, including documentation of the development and calibration of the HRM.

### 1.1. Background

The Project is operated in a load-following mode, generating power during peak-load hours and curtailing generation during off-peak hours. This operating regime allows SCL to meet continued service area load growth and provide regional system reliability. The Project capacity of the six turbines is about 55,000 cubic feet per second (cfs), which is more than double the average annual flow of the Pend Oreille River (SCL 2007). The reservoir's relatively small storage capacity in relation to inflow and the large turbine capacity means that existing Project operations can, at times, cause the water surface elevations in the Forebay and Tailrace reaches to fluctuate more than 10 feet in one day (see Section 3.0 for a description of the Project reaches).

Fluctuations in the water surface elevation of the Boundary Reservoir forebay occurs in response to in-flow fluctuations at Box Canyon Dam and the existing Project operations. The resulting water surface elevation fluctuations in the Project forebay propagate upstream as operationally

induced waves. These operationally induced waves attenuate, or dampen, as they travel from the Project forebay upstream through the entire 17.5-mile reservoir to Box Canyon Dam. Variations in channel morphology of the Pend Oreille River upstream of Boundary Dam affect the rate of travel and attenuation of the operationally induced waves. The most significant of these variations is the constriction and change in bed profile at the site of Metaline Falls, which significantly slows the translation and attenuation.

BC Hydro's Seven Mile Dam is located 11 miles downstream of Boundary Dam, and at full pool, the Seven Mile Dam backs water up to the tailwater of Boundary Dam. The Seven Mile Project creates forebay water surface fluctuations that result in operationally induced waves that can travel upstream to the Boundary Dam tailrace. Consequently, the effects of existing Project operations on aquatic habitats below Boundary Dam are also influenced by existing Seven Mile Project operations.

## 1.2. Study Description

A one-dimensional unsteady flow hydraulic routing software will be used to simulate the hydraulic conditions in the reach upstream of Boundary Dam between Box Canyon and Boundary Dam and in the reach downstream of Boundary Dam between Boundary Dam and Seven Mile Dam. Output from the hydraulic model will be used to support the analysis of existing Project effects and of operations scenarios on aquatic habitats in the Pend Oreille River between Box Canyon and Red Bird Creek. As is described in Section 4.4 of this report, the hydraulic model will be used to translate output from the Scenario Tool (ST) model to water surface elevations, flow rate, and mean column velocity at each of the transects in the mainstem aquatic habitat model on an hourly basis

The need for an unsteady flow hydraulic model is necessitated by existing Project operations. The process of energy production causes fluctuations in water surface elevation in the forebay of Boundary Reservoir and fluctuations in flow releases to the Boundary Tailrace. Slow moving waves originating in the forebay of the Project travel upstream through the Pend Oreille River to as far upstream as Box Canyon Dam. Daily flow fluctuations from the Project combined with daily fluctuations in water surface elevation in the forebay of Seven Mile Dam result in fluctuations in water surface elevations throughout the reach between the two dams. A one-dimensional unsteady flow hydraulic model will therefore be an essential tool to analyze the translation and attenuation of these waves and to quantify the spatial and temporal variability in the flow rate upstream and downstream of the Project.

Descriptions of the methods for developing and calibrating the hydraulic routing model are presented in Section 4. Development of the hydraulic routing model and the calibration results are presented in Section 5. Section 6 includes a brief summary of the calibration work effort. The method and the results for the analysis of Project operation influence on the hydraulic behavior of the Pend Oreille River within the study area are presented in Section 7. Section 8 includes the necessary references. Attachments A through C include supplemental graphics that support the model development and model calibration efforts. Attachment D includes the figures that graphically illustrate the Project operation influence on hydraulic behavior of the Pend Oreille River within the study area.

## 2 STUDY OBJECTIVES

The overall goal of the Mainstem Aquatic Habitat Modeling Study and its component study efforts was to provide quantitative indices of the effects of existing Project operations and operations scenarios on aquatic habitats. Within the context of this overall goal, the primary objective of the HRM component was to develop a calibrated hydraulic routing model that estimates water surface elevations, discharges, and cross section average water velocity at modeled habitat transects on an hourly basis for existing Project operations and operations scenarios.

The HRM was used within the context of the larger Mainstem Aquatic Habitat Modeling Study to produce a time series of data in support of quantifying a variety of biological metrics for existing Project operations and operations scenarios. These metrics included (but were not necessarily limited to):

- Water surface elevation and flow rates at selected locations in the reservoir and tailrace
- Characterization of the varial zone
- Frequency and duration of exposure and inundation of the varial zone at selected locations in the reservoir and tailrace
- Habitat area indices developed by applying the modeling results to the Habitat Suitability Indices (HSIs)

Output from the HRM was also used in conjunction with output from the Mainstem Aquatic Habitat Model to conduct a variety of post-processing comparative analyses for existing Project operations and operations scenarios. These comparative analyses included (but were not necessarily limited to):

- Downramping rate analysis
- Juvenile fish stranding and trapping analysis

Finally, output from the HRM was used to quantify the hydraulic influence of Project operations within the four reaches in the study area. Specifically, the influence of Project operations on water surface elevations and average cross section velocities was considered in this analysis.

## 3 STUDY AREA

Two levels of study area were defined for the Mainstem Aquatic Habitat Modeling Study: 1) a detailed study area for which the potential effects of operations scenarios on biological indices were evaluated, and 2) the larger study area required to conduct the hydraulic routing modeling effort to accurately model the water surface elevation and flow fluctuations resulting from various operations scenarios and upstream hydrologic conditions.

The detailed study area includes all of Boundary Reservoir and portions of the Pend Oreille River mainstem downstream of Boundary Dam that could potentially be affected by existing Project operations and operations scenarios and extends to the confluence with Red Bird Creek. The detailed study area is divided into the following four reaches (see Figure 3.0-1):

- Upper Reservoir Reach—Box Canyon Dam to Metaline Falls (Project river mile [PRM] 34.5–26.8)
- Canyon Reach—Metaline Falls to downstream end of Z Canyon (PRM 26.8–18.0)
- Forebay Reach—Downstream end of Z Canyon to Boundary Dam (PRM 18.0–17.0)
- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

The effects of existing Project operations on aquatic habitats below Boundary Dam are influenced by Seven Mile Project operations. Therefore, the downstream limit of the larger study area required to conduct the hydraulic routing modeling effort was extended approximately 7.1 miles downstream of the detailed study area to Seven Mile Dam at PRM 6.0. It was necessary to define the downstream limit of the hydraulic routing model at Seven Mile Dam so as to allow for the definition of a known boundary condition. This will therefore allow for the determination of Pend Oreille River water surface elevations, based on Seven Mile Project operations, at the downstream end of the detailed study area at PRM 13.9 (Red Bird Creek).

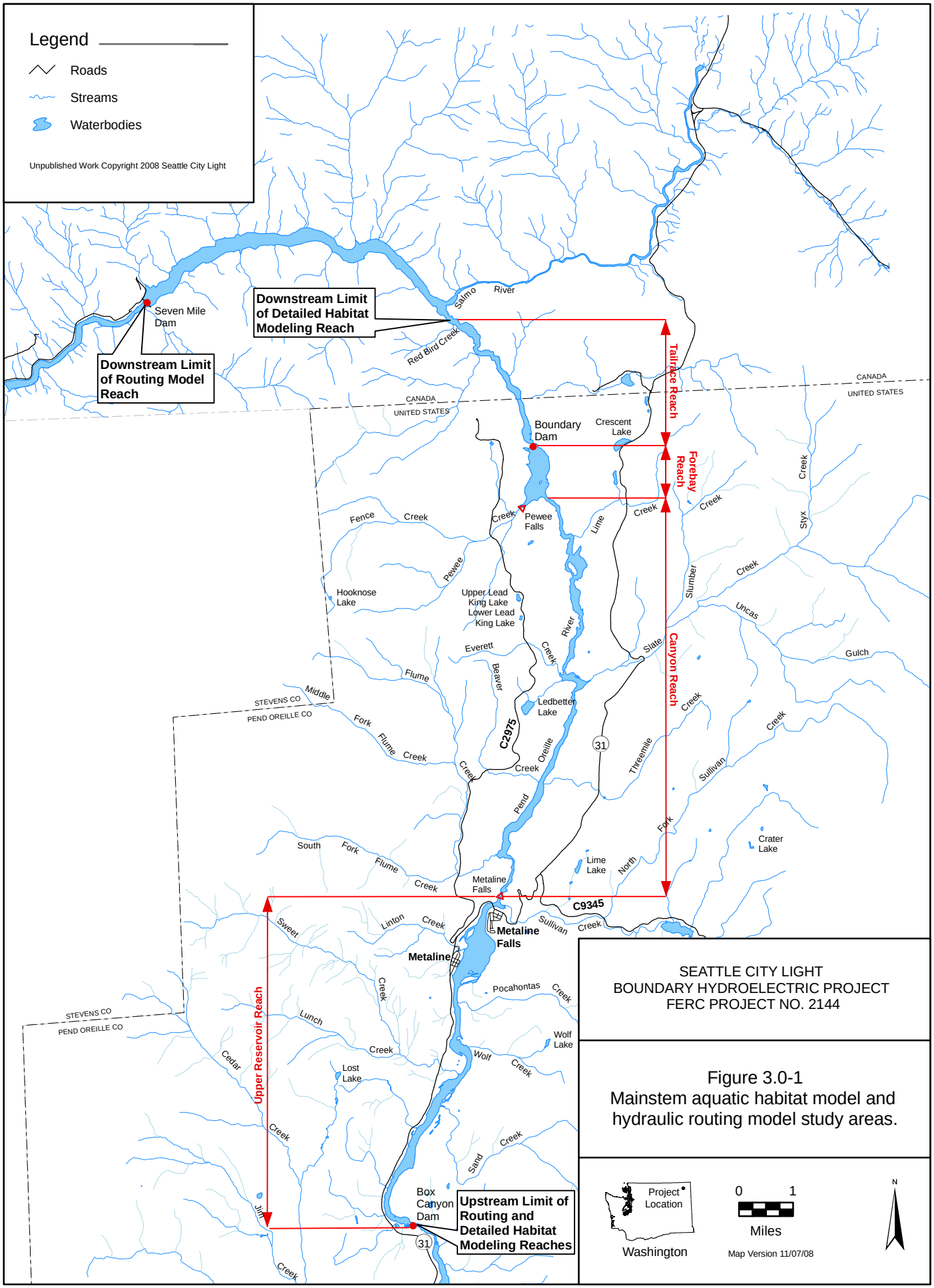


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Figure 3.0-1
Mainstem aquatic habitat model and hydraulic routing model study areas.

# 4 HRM DEVELOPMENT AND CALIBRATION METHODS

Section 4.1 describes the methods used to construct the hydraulic model and Section 4.2 presents the approach used for model calibration. The RSP (SCL 2007) identified that an evaluation of the need for separate seasonal-specific hydraulic routing models be conducted. The method used for this evaluation is described in Section 4.3. How the hydraulic model was integrated with the other models used in the Mainstem Aquatic Habitat Modeling effort is presented in Section 4.4.

The methods described in the following subsections were presented at the July 24, 2007, Fish and Aquatics Workgroup meeting and at the October 17, 2007, relicensing participants meeting. The methods were subsequently approved by the relicensing participants. At the July 24 meeting, the presentation included the data requirements for the HRM, the proposed calibration method, the cross section locations, and the relationship of the HRM to the other studies such as Study 2, Analysis of Peak Flood Flow Conditions above Metaline Falls (SCL 2009b); Study 7 (2009a), and Study 8, Sediment Transport and Boundary Reservoir Tributary Delta Habitats (SCL 2009c). At the October 17 meeting, the presentation primarily included a status report on the model calibration and preliminary results of the model calibration.

## 4.1. Hydraulic Routing Model Construction

Version 4.0 of the U.S. Army Corps of Engineers (USACE) HEC-RAS model, along with Version 4.1.1 of the USACE HEC-GeoRAS software, was chosen as the modeling software for use in the study. The HEC-RAS executable code and documentation are public domain software that was developed by the Hydrologic Engineering Center (HEC) for the USACE (USACE-HEC 2008).

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a dendritic network of natural and constructed channels. HEC-RAS computes the propagation of a floodwave with respect to the distance along the channel through the solution of the complete one-dimensional Saint-Venant equations of unsteady flow. The principles of conservation of mass and conservation of momentum form the basis of these equations. User input to HEC-RAS is primarily comprised of a series of cross sections spaced at intervals along the length of the river reach or reservoir reach; information that characterizes each of the cross section's resistance to flow; and definition of the boundary conditions at the upstream and downstream end of the modeling reach.

HEC-GeoRAS is an ArcGIS extension that provides the user with a set of procedures, tools, and utilities for the preparation of GIS-based information for import into HEC-RAS and generation of GIS-based information from HEC-RAS output. HEC-GeoRAS was used primarily in the creation of a geo-referenced cross section location database and for pre-processing of the geometric data for input into HEC-RAS. Version 4.1.1 of the HEC-GeoRAS is compatible with ArcGIS Version 9.1.

In support of the Mainstem Aquatic Habitat Modeling Study, it was necessary to develop and calibrate two separate hydraulic routing models. A hydraulic model of the reach upstream of Boundary Dam [Boundary Reservoir HRM] was used to analyze the translation and attenuation of waves generated by changes in the Boundary forebay. A second hydraulic model of the reach

downstream of Boundary Dam [Boundary Tailrace HRM] was used to analyze the translation and attenuation of operationally induced waves that are generated by the changing outflow from Boundary Dam. The need for two separate hydraulic models, instead of one continuous hydraulic model between Box Canyon Dam and Seven Mile Dam, was due to the presence of Boundary Dam. The HEC-RAS modeling software is strictly a hydraulic modeling tool that does not have the capabilities to model dam operations or spillway hydraulics. Therefore, a separate model or software is needed to provide the link between the two hydraulic models. The ST is designed specifically to optimize power operations of the Project. As such, the ST will produce a time series of Boundary forebay water surface elevations and Boundary outflows. These two time series will be used as boundary conditions in the HRMs. Therefore, the ST will function as the link between the two hydraulic models by providing boundary condition information to each model. Section 4.4 of this report describes in more detail the relationship between the two hydraulic routing models and ST.

The basic data and information necessary for the development of the hydraulic routing models are topographic data, boundary condition data, and local inflow data. The topographic data were used to develop the series of cross sections (oriented perpendicular to the flow) that represent the geometry of the river and reservoir system. The boundary condition data were used to define the hydraulic conditions at the open boundaries of the hydraulic models. For each model, the boundary condition at the upstream open boundary consists of a flow hydrograph of discharge versus time. The boundary condition at the downstream open boundary consists of stage hydrograph of water surface elevation versus time.

### 4.1.1. Boundary Reservoir Hydraulic Routing Model

The data and information that were used to specifically construct the Boundary Reservoir HRM included the following:

- Current bathymetric survey data of the reservoir between Box Canyon Dam and Boundary Dam
- Recent light detection and ranging (LiDAR)-based topographic survey data of the above-water portion of the banks of the reservoir between Box Canyon Dam and Boundary Dam
- Field surveyed cross section geometry at each habitat transect location (see Study 7 Final Report [SCL 2009a])
- Continuously recorded water surface elevation data obtained from pressure transducers deployed in the reservoir specifically in support of the relicensing effort.
- Continuously recorded water surface elevation data obtained from U.S. Geological Survey (USGS) gaging stations
- Flow rate data obtained from USGS gaging stations
- Synthesized flow records for the streams tributary to Boundary Reservoir between Box Canyon Dam and Boundary Dam (R2 Resource Consultants 2008)

Current bathymetric and topographic data were used as the basis for developing the cross section geometry for the Boundary Reservoir HRM. The bathymetric and LiDAR data were distinct products that were merged together to form a continuous digital terrain model (DTM) in the form of a triangulated irregular network (TIN). The bathymetric data represented the below water

portion of the reservoir topography. The LiDAR-based data represented the above water portion of reservoir and the upper banks of the reservoir. The LiDAR-based data set was derived from aerial flights conducted in August 2005 by Terrapoint (Terrapoint 2005).

Cross sections were cut through the DTM at specific locations along the profile of the reservoir using the HEC-GeoRAS software. Each cross section was then defined using a set of station (X) and elevation (Y) coordinate pairs. Two-hundred and twenty-five (225) cross sections were cut through the DTM to represent the geometry of the reservoir. The cross sections were then imported into the HEC-RAS software.

Transect bottom profile data were collected at each of the forty-nine (49) habitat transect locations in Boundary Reservoir as part of the overall velocity, depth, and substrate field data collection effort (see Study 7 Final Report [SCL 2009a]). The transect bottom profiles represent field surveyed cross section geometry for each habitat transect. This field surveyed cross section geometry was used in lieu of the DTM based cross section geometry at each of the habitat transect locations.

Continuously recorded 15-minute water surface elevation data and flow rate data were used to define the boundary conditions for the Boundary Reservoir HRM. Water surface elevation data were obtained from pressure transducers deployed in September 2006 at five locations in Boundary Reservoir. Each installation is comprised of a set of two identical Solinst Levelogger Gold units (model M10/F30) that provide redundancy in the event one of the transducers malfunctions. Table 4.1-1 summarizes the coordinate location of each pressure transducer installation in the reservoir as well as the abbreviated naming convention assigned to each pressure transducer installation. The location of each installation is shown in Figure 4.1-1.

**Table 4.1-1.** Boundary Reservoir pressure transducer installation locations and naming conventions.

| Pressure Transducer Installation Name | Description of Pressure Transducer Installation Location | Northing [1] (ft) | Easting[1] (ft) |
|---|---|---|---|
| BOX_TR | Box Canyon Tailrace. | 667964.68 | 2464743.08 |
| US_MET | Upstream of Metaline Falls. Transducer mounted on one of the piers of the Highway 31 bridge. | 698985.74 | 2473103.68 |
| DS_MET | Downstream of Metaline Falls. Transducer mounted on old powerhouse on east bank. | 700302.83 | 2474187.03 |
| CANYON | Mouth of Z Canyon. Transducer mounted on canyon wall on east bank. | 738667.89 | 2478253.01 |
| BND_LK | Boundary Dam forebay. | 743748.62 | 2476857.27 |

Note:
1 Northing and easting coordinates are relative to the Washington State Plane North Zone (4601) coordinate system and the NAD 1983 horizontal datum.

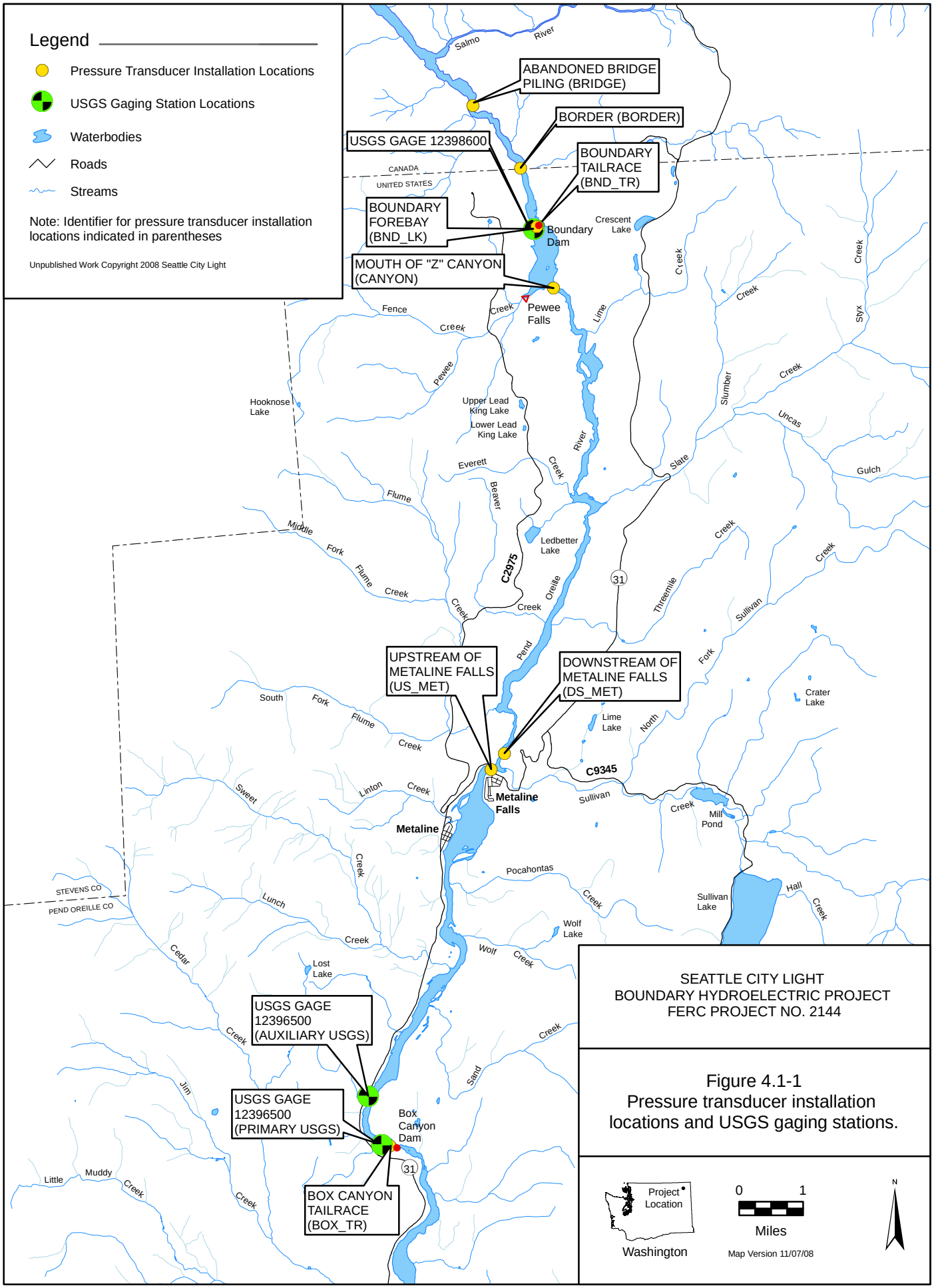


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Figure 4.1-1
Pressure transducer installation locations and USGS gaging stations.

Each pressure transducer provides continuous recording of the combined water pressure and barometric pressure above the transducer at 15-minute time intervals. The raw data collected by the pressure transducers were downloaded approximately every 3-months and were post-processed in Microsoft Excel®. The post-processing converted each recorded pressure value to a water surface elevation value. The data collected at the Boundary forebay (BND_LK) pressure transducer were used to represent the downstream boundary condition for the upstream hydraulic model.

USGS flow data for the main stem Pend Oreille River are available at one currently operating gaging station in the Project area as summarized in Table 4.1-2 and Figure 4.1-1. USGS gaging station 12398600 is a total dissolved gas (TDG) monitoring station and does not provide flow rate information other than daily average flows as supplied to the USGS by SCL. Raw 15-minute flow data from USGS gage 12396500 were used to define the upstream boundary condition of the Boundary Reservoir HRM.

**Table 4.1-2.** USGS gaging stations in Project area for main stem Pend Oreille River.

| Station Number | Station Name | Latitude | Longitude |
|---|---|---|---|
| 12398600 | Pend Oreille River at International Boundary | 48° 59’ 56” | 117° 21’ 09” |
| 12396500 | Pend Oreille River Below Box Canyon, near Ione, WA | 48° 46’ 52” | 117° 24’ 55” |

Notes:
1 USGS gaging station 12396500 comprises a primary station and an auxiliary station.
2 USGS gaging station 12398600 is a total dissolved gas (TDG) monitoring station and does not provide direct measurement of flow rate.

Total inflow to Boundary Reservoir consists of flows released by Box Canyon Dam plus the sum of all inflows from the streams tributary to Boundary Reservoir between Boundary Dam and Box Canyon Dam. Flow released by Box Canyon Dam are represented by the flow rate measured at USGS gage 12396500, which as previously mentioned, was used to represent the upstream boundary condition for the Boundary Reservoir HRM. To determine the inflows from the streams tributary to Boundary Reservoir, it was necessary to synthesize the inflow time series for each of the fifteen named tributaries and for the combined thirteen unnamed tributaries and the local hillslope drainage area. Synthesis of the tributary inflow time series was necessary because the only gaged tributary to the Boundary Reservoir is Sullivan Creek (USGS gage 12398000). The methodology used to synthesize these time series is described in R2 Resource Consultants, Inc. (2008).

### 4.1.2. Boundary Tailrace Hydraulic Routing Model

The data and information used to construct the Boundary Tailrace HRM included the following:

- Current bathymetric survey data of the Pend Oreille River between Boundary Dam and Seven Mile Dam
- Recent LiDAR based data of the upper banks of the Pend Oreille River between Boundary Dam and Seven Mile Dam

- Field surveyed cross section geometry at each habitat transect location (see Study 7 Final Report [SCL 2009a])
- Continuously recorded water surface elevation data obtained from pressure transducers deployed downstream of Boundary Dam specifically in support of the relicensing effort.
- Water surface elevation data in the Seven Mile Dam forebay
- Boundary Dam outflow data
- Salmo River flow data

As was the case for the Boundary Reservoir HRM, current bathymetric and topographic data were used as the basis for developing the cross section geometry for the Boundary Tailrace HRM. The bathymetric and LiDAR data were distinct products that were merged together to form a continuous DTM in the form of a three-foot regularly spaced gridded surface. The LiDAR-based data set was derived from aerial flights conducted in August 2005 by Terrapoint (Terrapoint 2005).

Cross sections of the Pend Oreille River between Boundary Dam and Seven Mile Dam were cut through the DTM at specific locations along the profile of the river using the HEC-GeoRAS software. Each cross section was then defined using a set of station (X) and elevation (Y) coordinate pairs. One-hundred and forty-one (141) cross sections were cut through the DTM to represent the geometry within the tailrace reach. The cross sections were then imported into the HEC-RAS software.

As was the case for the habitat transects upstream of Boundary Dam, transect bottom profile data were collected at each of the 14 habitat transects in the tailrace reach. These data represented field surveyed cross section geometry which was used in lieu of the DTM based cross section geometry at each of the habitat transect locations.

Average hourly water surface elevation data from the forebay of BC Hydro's Seven Mile Dam were obtained from SCL to represent the downstream boundary condition for the Boundary Tailrace HRM. The data were synthesized by R2 Resource Consultants, Inc., to a 15-minute instantaneous dataset for use in the calibration effort.

Average hourly Boundary outflow data were obtained from the SCL System Control Center (SCC) to represent the upstream boundary condition for the Boundary Tailrace HRM. The data were synthesized by R2 Resource Consultants, Inc., to a 15-minute instantaneous dataset for use in the calibration effort.

Average daily flow records for the Salmo River were provided by the Water Survey of Canada, which were then synthesized to a 15-minute instantaneous dataset (R2 Resource Consultants 2008).

Three pressure transducers were installed in the Pend Oreille River downstream of Boundary Dam specifically in support of the relicensing effort. The water surface elevation data from these three pressure transducers were not used in the development of the Boundary Tailrace HRM, but as will be described in a later section of this report, the data was used for the calibration. The

pressure transducer installations were identical to those described previously for the Boundary Reservoir installations. Table 4.1-3 summarizes the coordinate location of each pressure transducer installation as well as the abbreviated naming convention assigned to each pressure transducer installation. The location of each installation is shown in Figure 4.1-1.

**Table 4.1-3.** Boundary Tailrace pressure transducer installation locations and naming conventions.

| Pressure Transducer Installation Name | Description of Pressure Transducer Installation Location | Northing[1] (ft) | Easting[1] (ft) |
|---|---|---|---|
| BND_TR | Boundary Dam tailrace. | 743809.42 | 2476985.28 |
| BORDER | Pend Oreille River at International Border | 748590.61 | 2475525.29 |
| BRIDGE | Pend Oreille River at Abandoned Bridge Piling | 753733.24 | 2471582.29 |

Note:
1 Northing and easting coordinates are relative to the Washington State Plane North Zone (4601) coordinate system and the NAD 1983 horizontal datum.

## 4.2. Hydraulic Routing Model Calibration

Calibration of the Boundary Reservoir HRM used the post-processed water surface elevation data from the pressure transducer sites and water surface elevation data reported at the USGS gage station 12396500. Flow data from USGS gage 12396500 and Boundary Dam outflow data were used to support the calibration. All data were available in 15-minute resolution and were converted to Pacific Standard Time (PST). All water surface elevation data were either provided relative to the North American Vertical Datum of 1988 (NAVD 88) vertical datum or were converted from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the NAVD 88 datum.[1] Calibration of the Boundary Reservoir HRM was conducted using the collected data for the 19-month period between September 2006 and March 2008, inclusive. During this period, flow rates into the reservoir did not exceed the turbine capacity of the Project (approximately 55,000 cfs). Subsequent to March 2008, flows into the reservoir did exceed 55,000, ultimately attaining a peak flow magnitude of 104,000 cfs. However, since the influence of Project operations on upstream habitat is greatest during periods when flows are less than or equal to the turbine capacity, calibration of the Boundary Reservoir HRM was focused on the period when flows into the reservoir were less than 55,000 cfs. The separate hydraulic model of the Boundary Reservoir that was developed for Study 2 (SCL 2009b) was calibrated specifically flow conditions that were greater than the turbine capacity.

Calibration of the Boundary Tailrace HRM used the post processed water surface elevation data from the two pressure transducer sites downstream of Boundary Dam for the 23-month period between September 2006 and mid-July 2008, inclusive. Data from the supplemental pressure

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

transducer installed downstream of the international border in February 2008 was also used in the model calibration. Boundary Dam outflow data was used to support the calibration effort. The pressure transducer data were available in 15-minute resolution and was converted to PST. All water surface elevation data were either provided or converted to NAVD 88 vertical datum. Calibration of the Boundary Tailrace HRM was conducted using the collected data for the 23-month period between September 2006 and mid-July 2008, inclusive. Only during May, June and July of 2008 did flow rates through the Project exceed the turbine capacity (approximately 55,000 cfs). Since the influence of Project operations on downstream habitat is greatest during periods when flows are less than or equal to the turbine capacity, calibration of the Boundary Reservoir HRM was focused on the period when flows into the tailrace were less than 55,000 cfs.

Water surface elevation data surveyed at each of the habitat transects was also incorporated into the model calibration process for both the Boundary Reservoir HRM and the Boundary Tailrace HRM.

The calibration of the two models was conducted in three phases as summarized below:

- Phase One—Model calibration
- Phase Two—Verification of the model calibration
- Phase Three—Broad scale verification of the model calibration

In general, the objective of the model calibration was to adjust variables in the hydraulic model such that model output satisfies established criteria for representing observed conditions. The model verification process applies the calibrated model to time periods other than those used for the initial calibration to illustrate the validity of the calibration. The broad scale verification process provides further validity of the model calibration using the entire set of data (19-months in the case of the Boundary Reservoir HRM calibration and 21 months in the case of the Boundary Tailrace HRM calibration).

Work effort within Phase One included identification of the primary model parameters that were used as variables during calibration, initial selection of the magnitudes of the parameters, selection of the historical time periods for the calibration, determination of the criteria used to define a successful calibration, and finally execution of the calibration.

Work effort within Phase Two included selection of the historical time periods for the verification and execution of the calibrated model for the verification periods. Phase Two also included refinement of the calibration, using the verification time periods, in the event that the verification results did not satisfy the defined criteria for a successful model calibration.

Phase Three included execution of the verified model for the entire 19-month or 23-month data collection period and a reporting of the results.

### 4.2.1. Boundary Reservoir HRM Calibration—Phase One

The primary model parameters that were identified as variables for the calibration process included the following:

- Main channel hydraulic resistance (Manning's roughness) coefficient
- Overbank Manning's roughness coefficient
- Expansion and contraction coefficients
- Definition of ineffective flow areas

Both the Manning's roughness coefficients and the expansion and contraction coefficients are spatially variable, empirical parameters, the values of which are based upon local substrate conditions, channel and overbank vegetation, cross section geometry, and other localized conditions that affect the hydraulics of the system. Ineffective flow areas are not parameters but are locally defined portions of the cross section that do not "effectively" convey discharge. Ineffective flow areas are portions of the cross section where the downstream velocity is near zero. Eddy areas upstream and downstream of natural constrictions or constructed constrictions such as bridges can create ineffective flow areas in a cross section.

Prior to starting the calibration, it was necessary to develop initial estimates of the magnitudes of each parameter for each cross section. Estimates of main channel and overbank Manning's roughness coefficients were based on observations of the channel substrate and vegetative conditions made during the September 2007 drawdown period, and from the detailed characterization of substrate and aquatic vegetation at the habitat transect locations (see Study 7 Final Report [SCL 2009a]). Barnes (1967) and Arcement and Schneider (1989) were also used as guidance. Initial estimates of the contraction and expansion coefficients were based on guidance presented in the HEC-RAS user's manual (USACE-HEC 2008).

For the calibration of the Boundary Reservoir HRM, a sufficient portion of the 19-month record was identified so that the calibration procedure incorporated the entire range of Boundary forebay conditions and Box Canyon outflow conditions observed during the 19-month record. A matrix was developed using two pool conditions (high and low) and three flow conditions (high, moderate and low), and the 19-month record was reviewed to define six specific portions of the record representing each possible combination. The definitions for the two pool and three flow conditions were consistent with those used in defining the target pool and flow conditions for water surface and velocity measurements at the habitat transects (see Study 7 Final Report [SCL 2009a]) and are summarized as follows:

- *High pool conditions*—conditions during which the Boundary forebay elevation was generally greater than the 1,985-foot NAVD 88 (1,981-foot NGVD 29) elevation, thereby drowning out the hydraulic control at Metaline Falls.
- *Low pool conditions*—conditions during which the Boundary forebay elevation was allowed to drop below the 1,980-foot NAVD 88 (1,976 foot NGVD 29) elevation, thereby exposing the hydraulic control at Metaline Falls.
- *High flow conditions*—conditions during which outflow from Box Canyon Dam was greater than 40,000 cfs as recorded at USGS gage 12396500.

- *Moderate flow conditions*—conditions during which outflow from Box Canyon Dam was approximately 20,000 cfs.
- *Low flow conditions*—conditions during which outflow from Box Canyon Dam was less than 10,000 cfs.

Table 4.2-1 presents the matrix and summarizes the time periods identified from the 19-month record that included the combination of pool and flow conditions. Given the temporal variability in flow rate and forebay elevations, the time periods summarized in Table 4.2-1 were not exclusively composed of the particular combination of pool and flow condition, however, a sufficient portion of each time period was. This table also summarizes the naming convention that was used to identify each of the calibration time periods. The first half of the naming convention defines the Boundary forebay condition (Hi = high pool and Lo = low pool). The second half of the naming convention defines the Box Canyon outflow condition (Hi = high flow, Mod = moderate flow, and Lo = low flow). The six calibration periods represent a total of 92 days of the 19-month record. Figure 4.2-1 graphically presents the boundary condition hydrographs for the high pool_low flow (Hi_Lo) calibration period. The boundary condition hydrographs for all six of the calibration periods are included in Section 8 of this report.

**Table 4.2-1.** Calibration periods for Boundary Reservoir HRM.

| Pool Condition | Flow Condition | Identifier | Time Period | Number of Days in Time Period |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/19/06 | 17 |
| High | Moderate | Hi_Mod | 1/7/07 – 1/31/07 | 24 |
| High | High | Hi_Hi | 3/26/07 – 4/4/07 | 9 |
| Low | Low | Lo_Lo | 9/3/07 – 9/16/07 | 13 |
| Low | Moderate | Lo_Mod | 10/3/06 – 10/20/06 | 17 |
| Low | High | Lo_Hi | 5/11/07 – 5/23/07 | 12 |

Note:
All simulations start and end at noon on the specified days of the calibration time period.

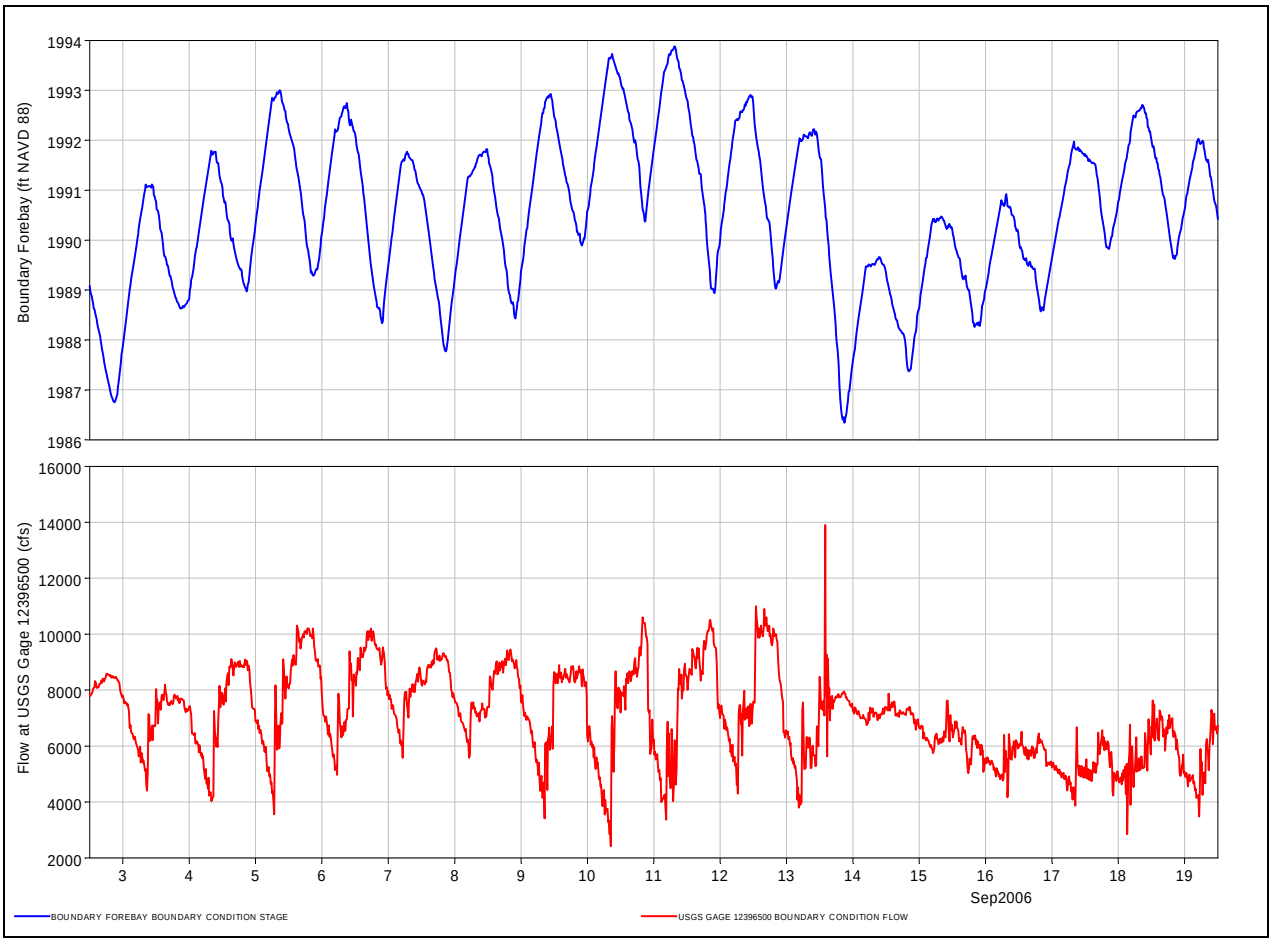


**Figure 4.2-1.** Hi_Lo calibration period boundary condition hydrographs for Boundary Reservoir HRM.

The Boundary Reservoir HRM was calibrated to observed water surface elevation hydrographs at six internal locations within the reach upstream of Boundary Dam. Stage hydrographs at four of the six locations were derived from data measured at the pressure transducer installations. Stage hydrographs at the remaining two locations were developed from raw 15-minute USGS gaging station data. The six locations are summarized in Table 4.2-2. Refer to Figure 4.1-1 for spatial illustration of these locations.

**Table 4.2-2.** Calibration locations for Boundary Reservoir HRM.

| Approximate Project River Mile[1] | HEC-RAS Cross Section ID | Source of Stage Hydrograph Data | Notes |
|---|---|---|---|
| 34.5 | 102198 | Box_TR pressure transducer | Data from pressure transducer installed in Box Canyon Tailrace |
| 34.2 | 101240 | USGS gaging station 12396500 (Primary) | USGS data |
| 33.1 | 96759 | USGS gaging station 12396500 (Auxiliary) | USGS data |
| 27.0 | 61170 | US_MET pressure transducer | Data from pressure transducer installed on Highway 31 Bridge |
| 26.7 | 59451 | DS_MET pressure transducer | Data from pressure transducer installed on old powerhouse on east bank |
| 18.0 | 12445 | CANYON pressure transducer | Data from pressure transducer installed at mouth of Z Canyon |

Notes:
1 Calibration locations are listed from upstream to downstream.
USGS – U.S. Geological Survey
US_MET – Upstream of Metaline Falls
DS_MET – Downstream of Metaline Falls
Box_TR – Box Canyon tailrace

During the iterative calibration process, model simulated stage hydrographs were compared in Microsoft Excel® to the observed stage hydrographs at each of the six calibration locations for each of the six calibration periods. The arithmetic difference between the simulated and observed was computed for each 15-minute time increment. The maximum difference was then computed at each location for each calibration period, thus providing quantitative feedback as to specific points in time, within a given calibration period, where the most significant deviation from observed conditions occurred. To provide a quantitative measure of the deviation from observed conditions at each calibration location for each calibration period, the root mean square error (RMSE) was evaluated as follows:

$$\text{Root Mean Square Error (RMSE)} = \left[ \sqrt{\frac{\sum_{i=1}^{n} \left( WSEL_{OBSi} - WSEL_{SIMi} \right)^2}{n}} \right]$$

Where:

$WSEL_{OBSi}$ = observed water surface elevation at time interval i
$WSEL_{OBSi}$ = simulated water surface elevation at time interval i
n = number of time intervals in simulation

At the onset of the calibration, criteria were established that were used to guide the calibration and to determine when a successful calibration had been attained. For each calibration location within each calibration period, the magnitudes of each calibration parameter were iteratively varied, within physically acceptable ranges, until the following criteria were met:

- Maximum absolute difference between the observed water surface elevation hydrograph and the model predicted water surface elevation hydrograph of less than 0.75 foot for each calibration location within each calibration period
- RMSE between observed and model predicted less than 0.50 foot for each calibration location within each calibration period

### 4.2.2. Boundary Reservoir HRM Calibration—Phases Two and Three

An independent verification of the model calibration was conducted using a separate set of time periods from the 19-month record than were used for calibration. Using a similar approach as was used to define the original calibration time periods, a matrix of five hydrologic conditions were defined as the verification periods, and the 19-month record was reviewed to find time periods representative of each hydrologic condition. Table 4.2-3 summarizes the time periods used for the model verification. As seen in Table 4.2-3, four of the five verification periods were inclusive of the time periods when velocity and depth measurements were taken at each of the habitat transects. The water surface elevations surveyed at each habitat transect during this data collection period provided additional data for verification of the hydraulic model at multiple locations in the reservoir.

**Table 4.2-3.** Verification periods for Boundary Reservoir HRM.

| Pool Condition | Flow Condition | Identifier | Time Period[1] | Number of Days in Time Period |
|---|---|---|---|---|
| High | High | Hi_Hi[2] | 5/22/07 – 5/29/07 | 7 |
| Variable | Variable | Var_Var | 2/1/07 – 2/28/07 | 27 |
| Low | Low | Lo_Lo[2] | 8/18/07 – 8/26/07 | 8 |
| Low | Moderate | Lo_Mod[2] | 7/6/07 – 7/13/07 | 7 |
| Low | High | Lo_Hi[2] | 5/28/07 – 6/2/07 | 5 |

Notes:
1 All simulations start and end at noon on the specified days of the verification time period.
2 The Hi_Hi, Lo_Lo, Lo_Mod, and Lo_Hi periods correspond with the time periods when water surface elevation and velocity measurements were conducted at the habitat transect locations.

A total of 54 days of the record were included in the model verification. The time period identified as Var_Var in Table 4.2-3 is representative of a wide range of pool and flow conditions and covers both a Hi_Mod and a Lo_Mod condition. Figure 4.2-2 presents the boundary condition hydrographs for the high pool_high flow (Hi_Hi) verification period. The boundary condition hydrographs for all five of the verification periods are included in Attachment B of this report.

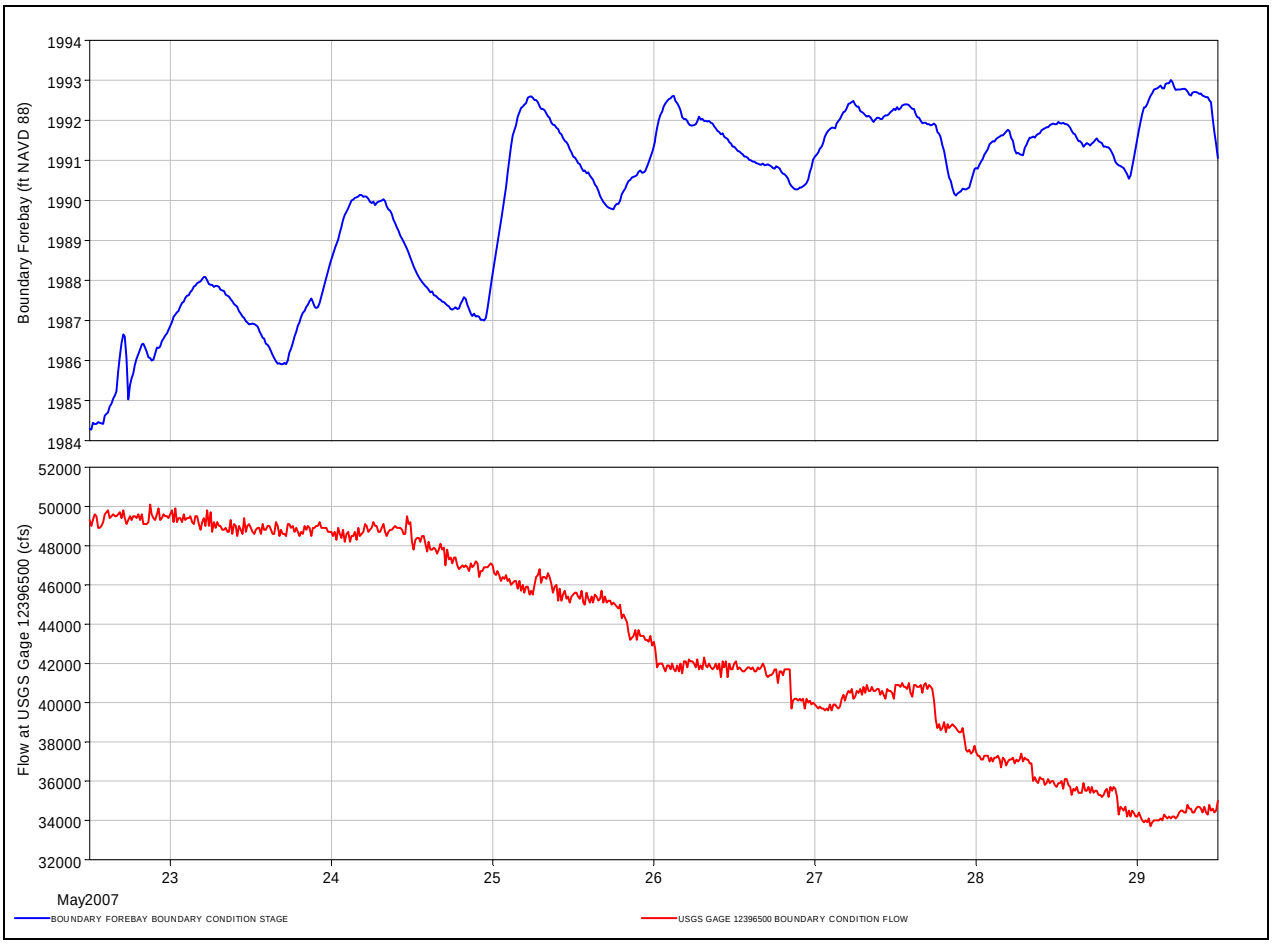


**Figure 4.2-2.** Hi_Hi verification period boundary condition hydrographs for Boundary Reservoir HRM.

The calibrated hydraulic model was then executed for each of the five verification periods. Simulated water surface elevation hydrographs were compared against the observed hydrographs at each of the six calibration locations. Absolute maximum error and RMSE were then computed. The verification was deemed unsuccessful if the verification model results were outside of the pre-defined error ranges defined originally for the calibration step. If this occurred, then the five verification periods were used as additional model calibration periods and adjustments were made to the model parameters until the model simulated results were within the pre-defined error ranges for all calibration and verification periods.

The final step in the calibration process (Phase Three) was to execute the verified model for the entire 19-month time period. The model results were then organized by month and the maximum error and RMSE were then computed per month at each calibration location.

### 4.2.3. Boundary Tailrace HRM Calibration—Phase One

Calibration and verification of the Boundary Tailrace HRM followed an identical procedure as was outlined in the previous sections for the calibration and verification of the Boundary Reservoir HRM.

The primary model parameters that were identified as variables for the calibration process included the following:

- Main channel hydraulic resistance (Manning's roughness) coefficient
- Overbank Manning's roughness coefficient
- Expansion and contraction coefficients
- Definition of ineffective flow areas

Estimates of main channel and overbank Manning's roughness coefficients were based on observations of the channel substrate and vegetative conditions made during site visits to the Project, and were supplemented with the detailed characterization of substrate and aquatic vegetation at the habitat transect locations (see Study 7 Final Report [SCL 2009a]). Barnes (1967) and Arcement and Schneider (1989) were also used as guidance. Initial estimates of the contraction and expansion coefficients were based on guidance presented in the HEC-RAS user's manual (USACE-HEC 2008).

For the calibration of the Boundary Tailrace HRM, a sufficient portion of the 23-month record was identified so that the calibration procedure incorporated the entire range of Seven Mile forebay conditions and Boundary Dam outflow conditions observed during the 23-month record. A matrix was developed using two pool conditions (high and low) and three flow conditions (high, moderate and low), and the 23-month record was reviewed to define specific portions of the record representing each possible combination. The definitions for the two pool and three flow conditions were consistent with those used in defining the target pool and flow conditions for water surface and velocity measurements at the habitat transects (see Study 7 Final Report [SCL 2009a]) and are summarized as follows:

- *High pool conditions*—conditions during which the Seven Mile Dam forebay elevation was generally greater than the 1,728-foot NAVD 88 (1,724-foot NGVD 29) elevation, thereby drowning out the hydraulic controls in the tailrace reach
- *Low pool conditions*—conditions during which the Seven Mile Dam forebay elevation was less than the 1,726-foot NAVD 88 (1,722 foot NGVD 29) elevation, thereby exposing the hydraulic controls in the tailrace reach. Preference was given to finding conditions when Seven Mile Dam forebay elevations were less than 1,713-foot NAVD 88 (1,709 foot NGVD 29) when the hydraulic controls in the tailrace are fully exposed.
- *High flow conditions*—conditions during which outflow from Boundary Dam was greater than 40,000 cfs.
- *Moderate flow conditions*—conditions during which outflow from Boundary Dam was approximately 20,000 cfs.
- *Low flow conditions*—conditions during which outflow from Boundary Dam was less than 10,000 cfs.

Table 4.2-4 presents the matrix and summarizes the time periods identified from the 23-month record that included the combination of pool and flow conditions. Given the daily variability in flow rate and forebay elevations, the time periods summarized in Table 4.2-4 were not exclusively comprised of the particular combination of pool and flow condition, however, a sufficient portion of each time period was. The naming convention in Table 4.2-4 is identical to that defined previously for the Boundary Reservoir HRM calibration procedure. The nine calibration periods represent a total of 217 days of the 23-month record. Figure 4.2-3 graphically presents the boundary condition hydrographs for the low pool_high flow (Lo_Hi) calibration period. The boundary condition hydrographs for all nine of the calibration periods are included in Attachment B of this report.

**Table 4.2-4.** Calibration periods for Boundary Tailrace HRM.

| Pool Condition | Flow Condition | Identifier | Time Period [1] | Number of Days in Time Period |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/30/06 | 28 |
| High | Moderate | Hi_Mod | 12/21/06 – 1/12/07 | 22 |
| High | High | Hi_Hi | 5/3/07 – 5/31/07 | 28 |
| High | High | Hi_Hi2 | 4/17/08 – 5/17/08 | 30 |
| Low | Low | Lo_Lo | 8/7/07 – 8/28/07 | 21 |
| Low | Moderate | Lo_Mod | 7/11/07 – 7/29/07 | 18 |
| Low | Moderate | Lo_Mod2 | 3/24/08 – 4/17/08 | 24 |
| Low | High | Lo_Hi | 3/31/07 – 4/19/07 | 19 |
| Var | Var | Var_Var | 2/26/08 – 3/24/08 | 27 |

Note:
1 All simulations start and end at noon on the specified days of the verification time period.

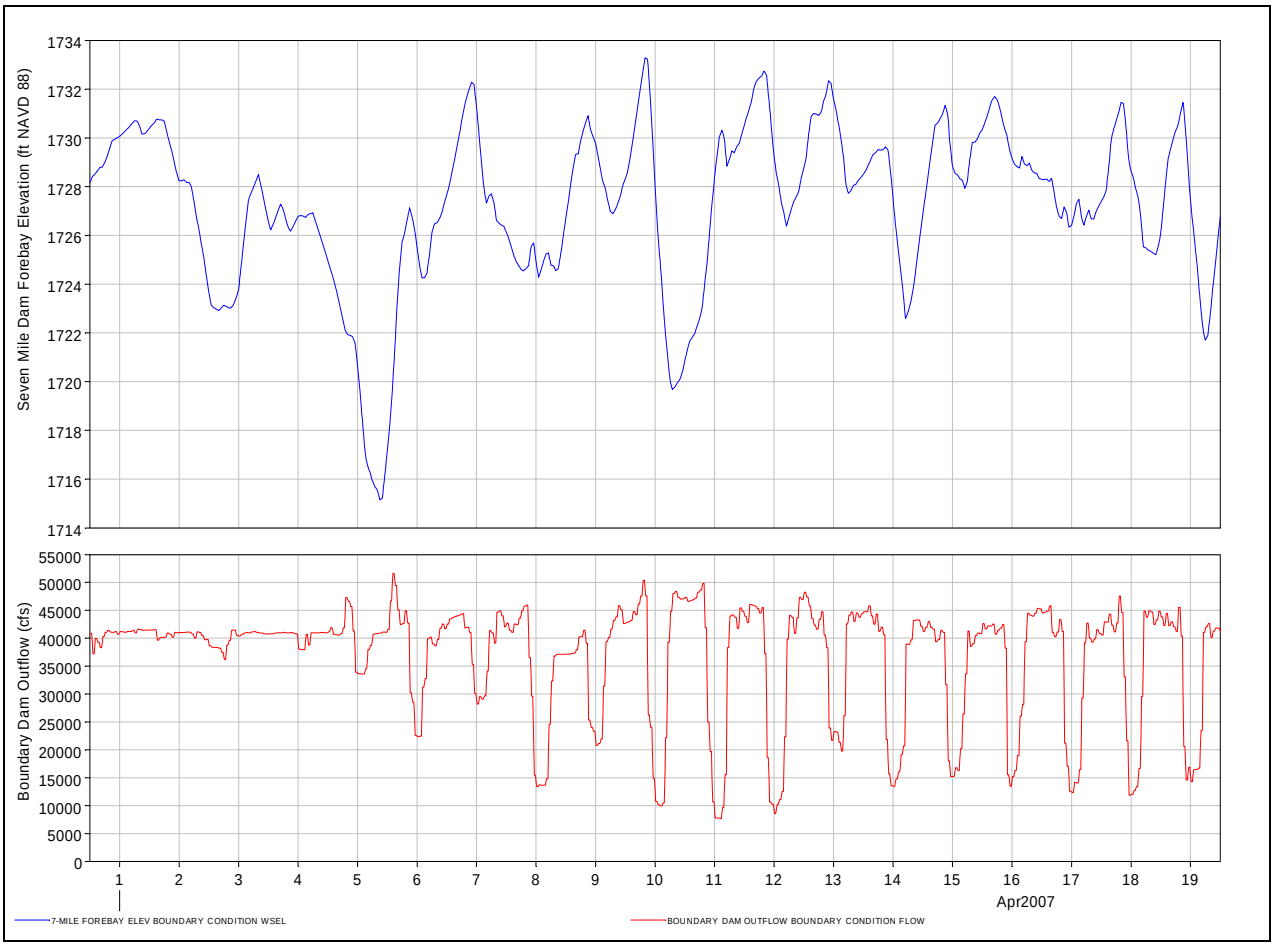


**Figure 4.2-3.** Lo_Hi calibration period boundary condition hydrographs for Boundary Tailrace HRM.

The Boundary Tailrace HRM was calibrated to observed water surface elevation hydrographs at three internal locations within the reach downstream of Boundary Dam. Stage hydrographs at all three locations were derived from the data measured at the pressure transducer installations. The three locations are summarized in Table 4.2-5. Refer to Figure 4.1-1 for spatial illustration of these locations.

**Table 4.2-5.** Calibration locations for Boundary Tailrace HRM.

| Approximate Project River Mile[1] | HEC-RAS Cross Section ID | Source of Stage Hydrograph Data | Notes |
|---|---|---|---|
| 17.0 | 53077 | BND_TR Pressure Transducer | Data from pressure transducer installed in Boundary Dam tailrace |
| 16.0 | 47677 | BORDER Pressure Transducer | Data from pressure transducer installed at the international border |
| 14.6 | 40245 | BRIDGE Pressure Transducer | Data from pressure transducer installed at the abandoned bridge piling |

Note:
1 Calibration locations are listed from upstream to downstream

The same calibration criteria as were used for the calibration of the Boundary Reservoir HRM were used to guide the Boundary Tailrace HRM calibration and to determine when a successful calibration had been attained. The magnitudes of each calibration parameter were iteratively varied, within physically acceptable ranges, until the following criteria were met at each calibration location within each calibration period:

- Maximum absolute difference between the observed water surface elevation hydrograph and the model predicted water surface elevation hydrograph of less than 0.75 foot for each calibration location within each calibration period
- RMSE between observed and model predicted less than 0.50 foot for each calibration location within each calibration period

### 4.2.4. Boundary Tailrace HRM Calibration—Phase Two

An independent verification of the model calibration was conducted using a separate set of time periods from the 23-month record than were used for calibration. Using a similar approach as was used to define the original calibration time periods, a matrix of six hydrologic conditions were defined as the verification periods, and the 19-month record was reviewed to find time periods representative of each hydrologic condition. Table 4.2-6 summarizes the time periods used for the model verification.

A total of 136 days of the record were included in the model verification. The time periods identified as Hi_Hi2 and Var_Var in Table 4.2-6 are the same time periods as were used in the calibration. However, these two time periods include the dates when water surface elevations were surveyed at the habitat transects and it was this additional data that was used in the verification. The boundary condition hydrographs for the six verification periods are included in Section 8 of this report.

**Table 4.2-6.** Verification periods for Boundary Tailrace HRM.

| Pool Condition | Flow Condition | Identifier | Time Period [1] | Number of Days in Time Period |
|---|---|---|---|---|
| High | Low | Hi_Lo | 9/2/06 – 9/30/06 | 28 |
| High | Moderate | Hi_Mod | 12/21/06 – 1/12/07 | 22 |
| High | High | Hi_Hi | 5/3/07 – 5/31/07 | 28 |
| High | High | Hi_Hi2 | 4/17/08 – 5/17/08 | N/A[2] |
| Low | Low | Lo_Lo | 8/7/07 – 8/28/07 | 21 |
| Low | Moderate | Lo_Mod | 7/11/07 – 7/29/07 | 18 |
| Low | High | Lo_Hi | 3/31/07 – 4/19/07 | 19 |
| Var | Var | Var_Var | 2/26/08 – 3/24/08 | N/A[2] |

Notes:
1 All simulations start and end at noon on the specified days of the verification time period.
2 The Hi_Hi2 and Var_Var periods are the original calibration periods and include the specific dates when water surface elevations were surveyed at the habitat transect locations. It is these additional observed data that were used in the verification. Neither period is officially considered a verification period.

The calibrated hydraulic model was then executed for each of the eight verification periods. Simulated water surface elevation hydrographs were compared against the observed hydrographs at each of the three calibration locations. Absolute maximum error and RMSE were then computed. The verification was deemed unsuccessful if the verification model results were outside of the pre-defined error ranges defined originally for the calibration step. If this occurred, then the six verification periods were used as additional model calibration periods and adjustments were made to the model parameters until the model simulated results were within the pre-defined error ranges for all calibration and verification periods.

## 4.3. Evaluation of the Need for Separate Seasonal Models

The RSP (SCL 2007) identified the need for an evaluation as to the necessity of developing a separate calibrated hydraulic routing model for the reservoir reach for the summer period. This need was based on the hypothesis that the seasonal presence of macrophytes (aquatic plants) in the Upper Reservoir Reach of the Boundary Reservoir during the summer months could be of sufficient density to contribute additional hydraulic roughness. If true, this would necessitate the need for a separate set of calibration parameters in the Boundary Reservoir HRM calibration, specific to the months of June through September when macrophyte growth is most robust.

To conduct this evaluation, the specific time periods that were selected for the Boundary Reservoir HRM were chosen to include time periods when macrophyte growth was expected to be most robust (June through September). Therefore, initial evaluation for the need to develop a separate set of calibration parameters for a separate seasonal model for the June to September time period was made during the model calibration effort. Calibration results were investigated to determine if there was a seasonal bias in results for equivalent flow conditions. The calibration model results were reviewed for two time periods with roughly similar flow conditions—one outside of the macrophyte growth period and one during the macrophyte growth period. The intent of the review was to determine if there was a consistent trend that the

calibration parameters determined for the entire 19-month calibration period were underpredicting water surface elevations during the June through September time period. The review was exclusive to only the pressure transducer and USGS gage locations located in the Upper Reservoir Reach within a mile of Box Canyon Dam.

If review of the calibration results found that the model was consistently underpredicting water surface elevations during the June through September time period, then the "Seasonal Roughness Change Factor" in HEC-RAS would be employed. Using the calibration results, an appropriate value for this factor would be estimated so as to increase the Manning's Roughness coefficient for the seasons (months) during which macrophyte growth is at its peak.

## 4.4. Model Documentation and Executable Model

The calibrated Boundary Reservoir and Boundary Tailrace HRMs will be used integrally with several other models in the evaluation of various operations scenarios. Figure 4.4-1 is a conceptual schematic illustration of the relationship between the models that will be used in support of the study.

The ST is an Excel®-based hydroelectric operations tool tailored to the requirements of relicensing for the Boundary Dam Project (CddHoward 2006). It will be used to optimize Project operations, under specific operational constraints, using three hydrologic periods corresponding to an average year, a wet year, and a dry year. As identified in R2 Resource Consultants (2008), the calendar year 2002 will be used to represent an average hydrologic year, and the calendar years 1997 and 2001 will be used to represent the wet and dry hydrologic years, respectively, based on average annual flows. Hydrologic data used to drive the ST consist of an hourly inflow hydrograph (as recorded at the USGS gage station 12396500) for each year. For each operations scenario, output from the Scenario Tool will consist of an hourly time series of Boundary outflow and Boundary forebay elevation for each of the three years.

The hourly Boundary forebay elevation time series from the ST will be used as the downstream boundary condition in the Boundary Reservoir HRM. The Boundary Reservoir HRM will route the operationally induced waves generated by the fluctuating water surface elevations in the forebay and will therefore provide detailed output regarding flow rate and water surface elevation throughout the reservoir between Boundary Dam and Box Canyon Dam. Output will be provided at hourly time steps for each of the three representative hydrologic years for each operations scenario. Similarly, the hourly Boundary Dam outflow time series produced by the ST will be used as the upstream boundary condition in the Boundary Tailrace HRM. The Boundary Tailrace HRM will be used to develop detailed output regarding flow rate and water surface elevation throughout the tailrace reach between Boundary Dam and Red Bird Creek.

The Mainstem Aquatic Habitat Model is the core model that will be used for assessing changes in aquatic habitat for operations scenarios. Hourly hydraulic routing model output at each of the habitat transects will be used as input to the mainstem aquatic habitat model.

As illustrated in Figure 4.4-1, output from the hydraulic routing models will also be used as necessary in supporting other study efforts in assessing changes in aquatic and terrestrial habitat for operations scenarios. For example, downramping information determined by the hydraulic

routing models was used to support Study 1, Erosion Study Final Report (SCL 2009d). Long-term water surface elevation hydrographs, using the 19-year hydrologic record, were generated by the hydraulic routing model and provided to Study 8 (SCL 2009c) to assist in determining whether Project operations have affected tributary delta morphology. Output from the hydraulic routing model, in the form of water surface elevation hydrographs, was used in Study 15, Waterfowl/Waterbird Study Final Report (SCL 2009e), to assess changes in terrestrial habitat conditions resulting from operations scenarios.

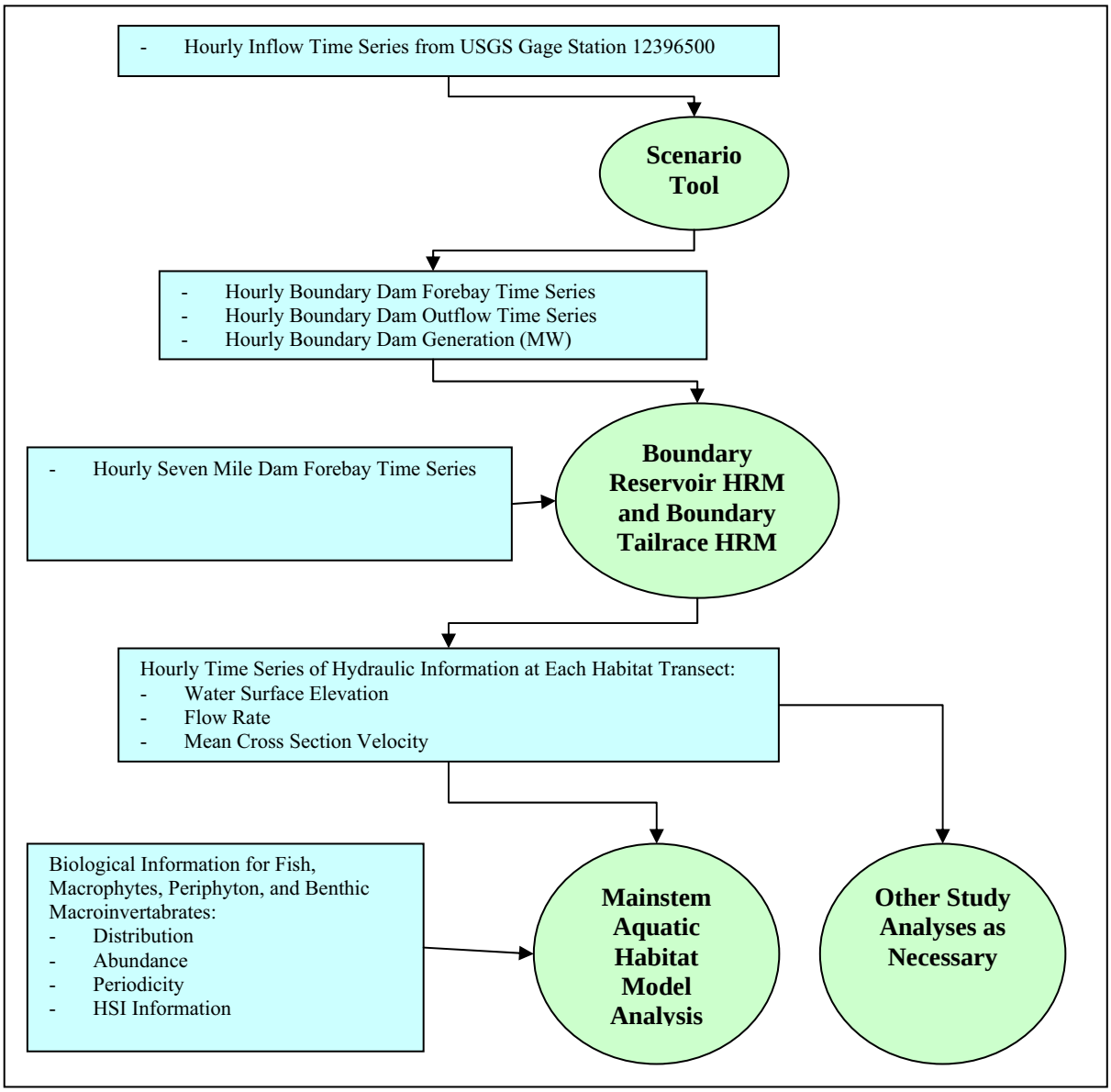


**Figure 4.4-1.** Conceptual model framework for Study 7.

# 5 HRM DEVELOPMENT AND CALIBRATION RESULTS

This section summarizes the development of the Boundary Reservoir and Boundary Tailrace HRMs and the results of the final calibration of both of these models. The calibration effort for the two models is considered final, meaning that all of the appropriate data for the September 2006 through May 2008 calibration period have been incorporated into the calibration and verification of the two models. Calibration of the two models to the data collected during this time period was inclusive of a wide range of flow and operational conditions in the Pend Oreille River between Box Canyon Dam and Seven Mile Dam.

## 5.1. Description of System and Need for Hydraulic Routing Models

Between Boundary Dam and Box Canyon Dam, the Pend Oreille River can be divided into three distinct reaches based on hydraulic conditions: the Forebay Reach, the Canyon Reach, and the Upper Reservoir Reach. The Forebay Reach is characterized as a very wide and deep pool area with near zero flow velocities caused by the backwater conditions from Boundary Dam. The Canyon Reach is characterized as a moderate gradient reach (0.6 percent average gradient) in terms of bed profile with localized areas of deep pools. However, flow velocities through the reach are quite low due to the backwater created by Boundary Dam. There are areas of rapidly expanding and contracting flow conditions due to localized constrictions from the canyon walls. In contrast to the Canyon Reach, the Upper Reservoir Reach is characterized as more of a riverine reach. Backwater effects from Boundary Dam are minimized or eliminated in the Upper Reservoir Reach during low Boundary forebay conditions by the hydraulic control at Metaline Falls. The Upper Reservoir Reach is a low gradient reach, with a reach average bed slope of approximately 0.07 percent. This reach is hydraulically separated from the Canyon Reach by Metaline Falls, when the water surface elevation of the Boundary forebay is low, and hence has areas of moderate flow velocity. Figure 5.1-1 shows a profile of the reach of the Pend Oreille River between Boundary Dam and Box Canyon Dam.

As seen in Figure 5.1-1, between Boundary Dam and Seven Mile Dam, the Pend Oreille River is characterized as a shallower gradient (0.3 percent average gradient) relative to the Canyon Reach. Water surface elevations in the forebay of Seven Mile Dam can be as high as 1,734 feet NAVD 88 (1,730 feet NGVD 29) and can therefore affect the hydraulic conditions all the way to Boundary Dam. Water surface fluctuations in the forebay of Seven Mile Dam are translated the 10.3-mile-long distance to Boundary Dam. The wave characteristics are attenuated as the wave travels upstream and are affected by the highly variable flow releases from Boundary Dam. The calibrated Boundary Tailrace HRM will provide specific information regarding wave travel time and wave attenuation throughout the 10.3-mile reach.

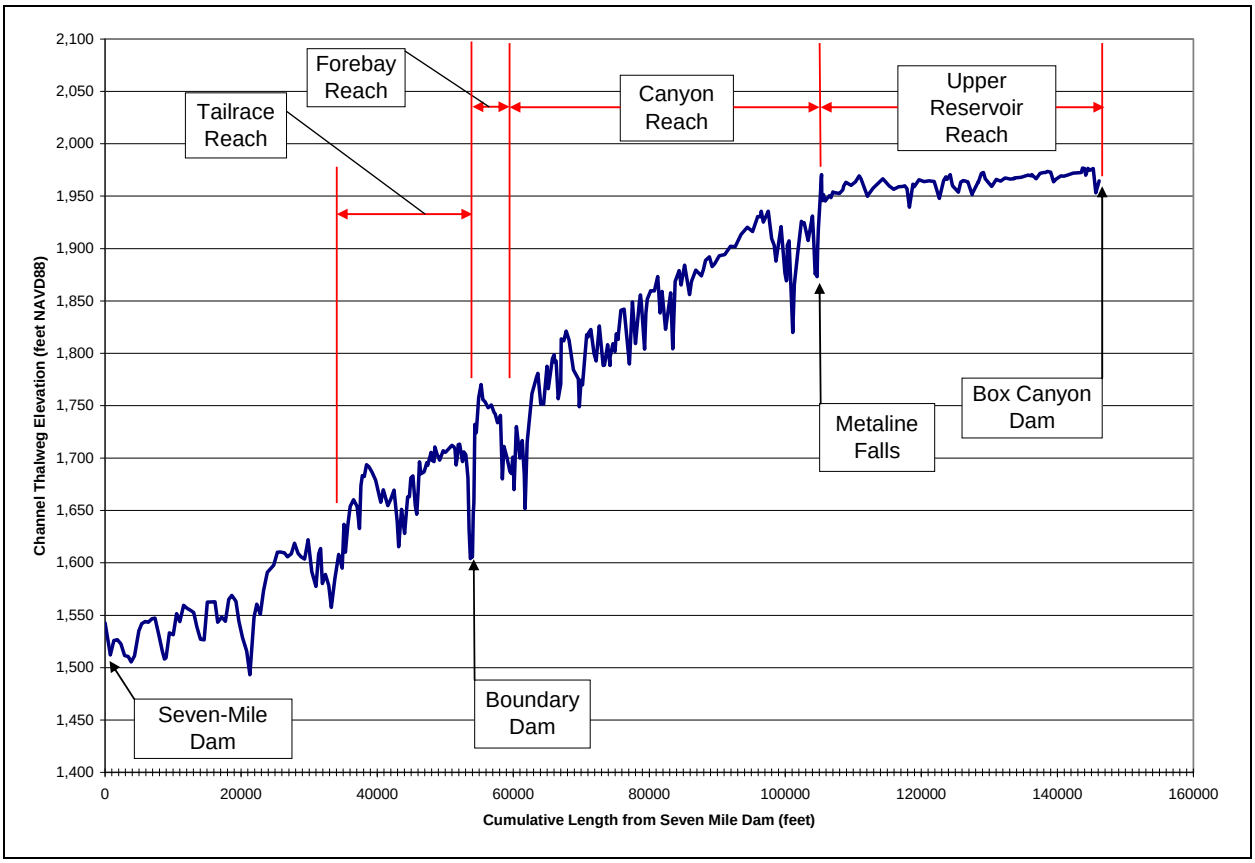


**Figure 5.1-1.** Combined thalweg profile for Pend Oreille River between Seven Mile Dam and Box Canyon Dam.

## 5.2. Data Used to Construct and Calibrate the Hydraulic Routing Models

This section will present various aspects of the development of the Boundary Reservoir and Boundary Tailrace HRMs, including:

- Bathymetry and topography used to develop the two hydraulic models
- Cross section location and development of cross section geometry
- Boundary conditions for the two hydraulic models
- Data and information specifically used for calibration

### 5.2.1. Bathymetry and Topography

A multibeam sonar bathymetric survey was conducted within Boundary Reservoir by Global Remote Sensing, LLC (GRS) in 2006. The data from this survey were supplemented and checked, within 11 priority areas, with a high resolution multibeam bathymetry and scanning survey by Tetra Tech in June/July 2007. GRS partially resurveyed the reservoir with a high resolution multibeam bathymetry system in October 2007. Tetra Tech conducted a concurrent shoreline scanning laser survey to provide full coverage of the shoreline below Metaline Falls.

A full coverage multi-beam survey was conducted between the U.S.-Canada border and the Salmo River and a combination of single beam transects and multibeam sonar surveys were collected in the remainder of the Seven Mile reservoir.

Pacific Geomatic Services (PGS) provided Global Positioning System (GPS) control support for the hydrographic and bathymetric survey. PGS verified the GPS coordinate positions for the existing control network in and around Metaline Falls up to the Canadian border and established new secondary GPS controls. PGS also established additional semi-permanent GPS control monuments along the Pend Oreille and Salmo Rivers immediately north of the Canadian border and within Canada (PGS 2007).

The bathymetric and scanning laser data were combined with topographic surveys conducted using LiDAR technology. The LiDAR data were collected from aerial flights in August 2005 by Terrapoint (Terrapoint 2005). The bathymetric data and the LiDAR data were merged together to form a continuous DTM in the form of a TIN for Boundary reservoir. For the Boundary tailrace and the Seven Mile reservoir, the bathymetric data and the LiDAR data were merged together to form a continuous DTM in the form of a three-foot regularly spaced gridded surface. The DTM is a digital representation of the ground surface topography. Figure 5.2-1 shows an example portion of the terrain model in the vicinity of Metaline Falls. Included in this figure are the hydraulic model cross sections (to be discussed in the next section) that are located through this region.

### 5.2.2. Cross Sections

The first step in the development of the hydraulic models was to identify locations for the cross sections. Each cross section is used to characterize the conveyance capacity of the river at a point in space but is also used in the hydraulic computations to represent the channel and floodplain geometry to the next downstream cross section.

Cross section locations were identified at locations along the river where changes in channel slope and channel shape were observed to occur and at locations where changes in the channel roughness conditions were observed during site visits. In locations where abrupt changes in geometry occur, such as at Metaline Falls, cross section spacing was intensified. Cross sections were also located at specific points where it was anticipated that hydraulic information will be required for input to other studies during the relicensing process. For example, cross sections were located through existing macrophyte beds (for Study 7.4.2 [Appendix 6 of Study 7]) and were located at the periphyton sampling locations (for Study 7.4.3 [Appendix 7 of Study 7]). Cross sections were also located at all habitat transect locations.

For the Boundary Reservoir HRM, 225 cross sections were ultimately included in the model. The average spacing between the cross sections was approximately 410 feet, although this value is skewed due to the closer spacing of the cross sections through Metaline Falls. The average spacing between cross sections through Metaline Falls is approximately 20 feet.

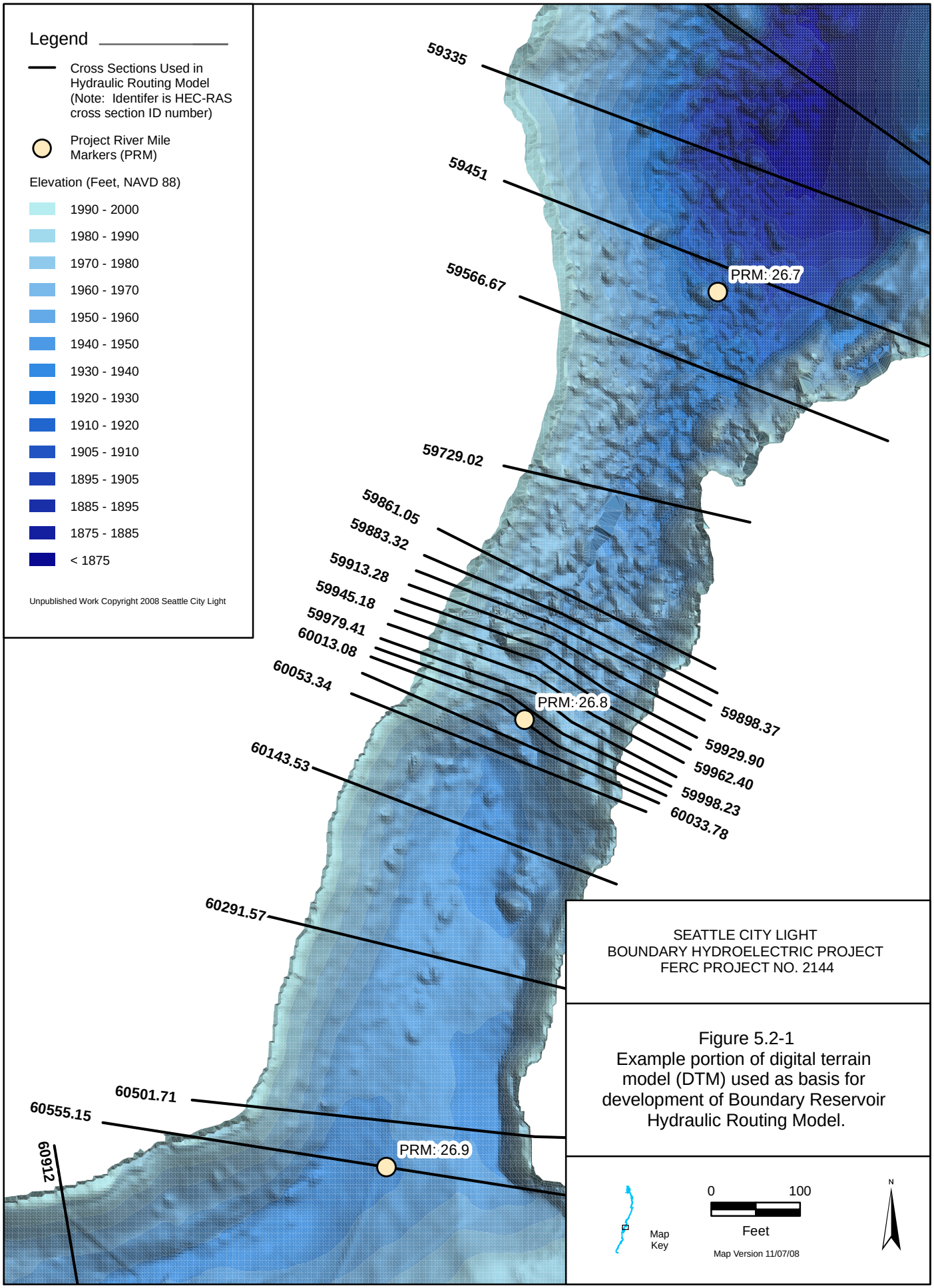


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Figure 5.2-1
Example portion of digital terrain model (DTM) used as basis for development of Boundary Reservoir Hydraulic Routing Model.

For the Boundary Tailrace HRM, 141 cross sections were ultimately included in the model. The average spacing between the cross sections is approximately 390 feet.

Figure 5.2-2 is an example figure showing the cross section locations for a portion of the Boundary Reservoir HRM. Similarly, Figure 5.2-3 is an example figure showing the cross section locations for a portion of the Boundary Tailrace HRM. A complete set of figures showing all cross section locations for each of the two models is included in Section 8 of this report.

Once the locations were identified, the cross sections were then cut through the DTM using the HEC-GeoRAS software and were imported into the HEC-RAS model. All cross sections were cut through the DTM with a downstream orientation (i.e., how the cross sections would look to an observer standing upstream looking downstream). Figures 5.2-4 and 5.2-5 are examples of the cross section geometry as input into the Boundary Reservoir HRM at two specific locations. Figure 5.2-4 is the cross section geometry for a cross section in the Canyon Reach (HEC-RAS cross section 15107). Figure 5.2-5 is the cross section geometry for a cross section in the Upper Reservoir Reach (HEC-RAS cross section 94743). Both cross sections are plotted using the same vertical scale so as to clearly show the variability in cross section depth through the Boundary Reservoir.

As mentioned in Section 4.1.1, the field surveyed cross section geometry for each of the 49 habitat transects located upstream of Boundary Dam was used instead of the DTM derived cross section geometry at each habitat transect location in the Boundary Reservoir HRM. Similarly, the field surveyed cross section geometry for each of the 14 habitat transects located downstream of Boundary Dam was used instead of the DTM-derived cross section geometry.

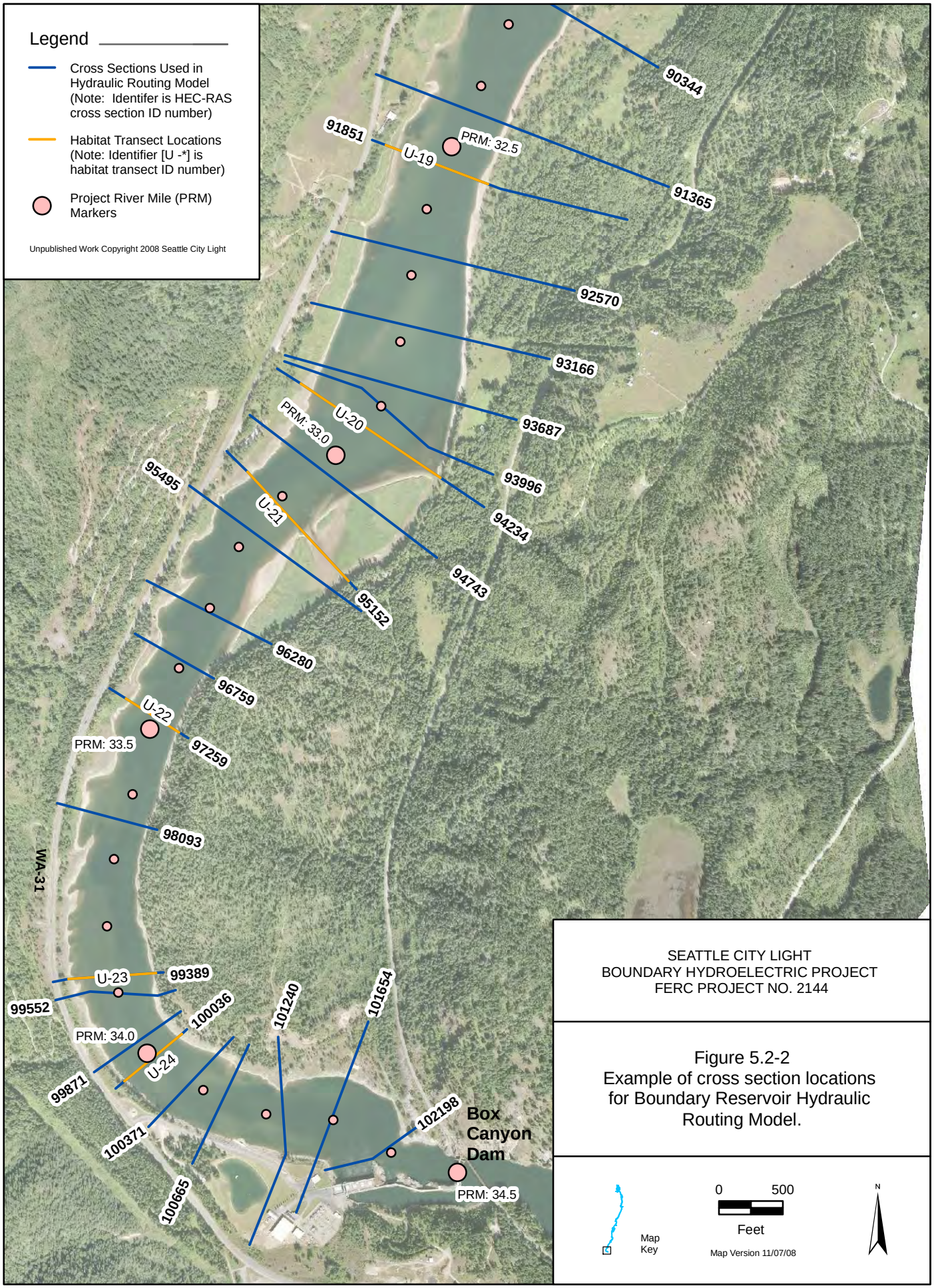


Figure 5.2-2
Example of cross section locations for Boundary Reservoir Hydraulic Routing Model.

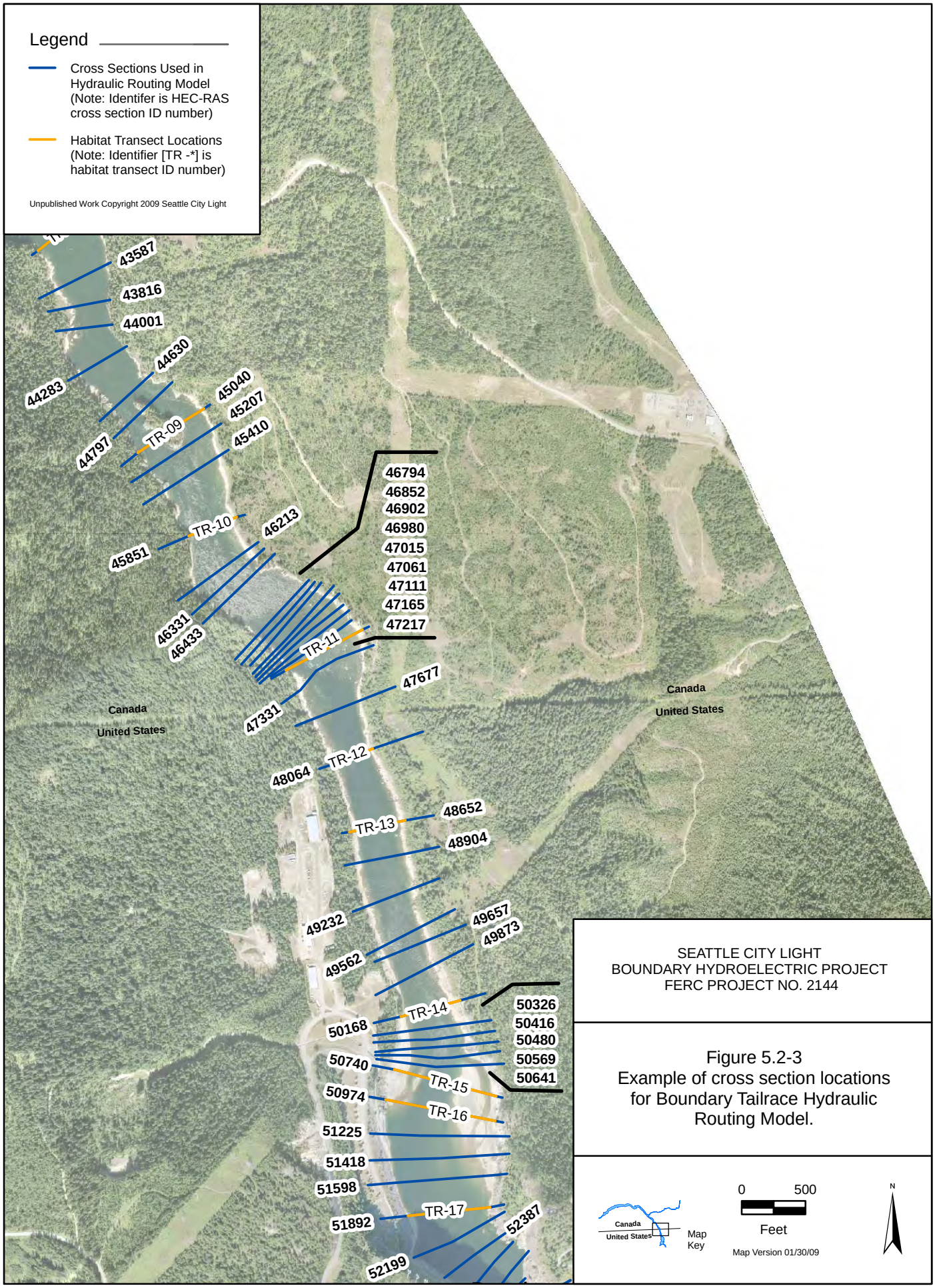


Figure 5.2-3
Example of cross section locations for Boundary Tailrace Hydraulic Routing Model.

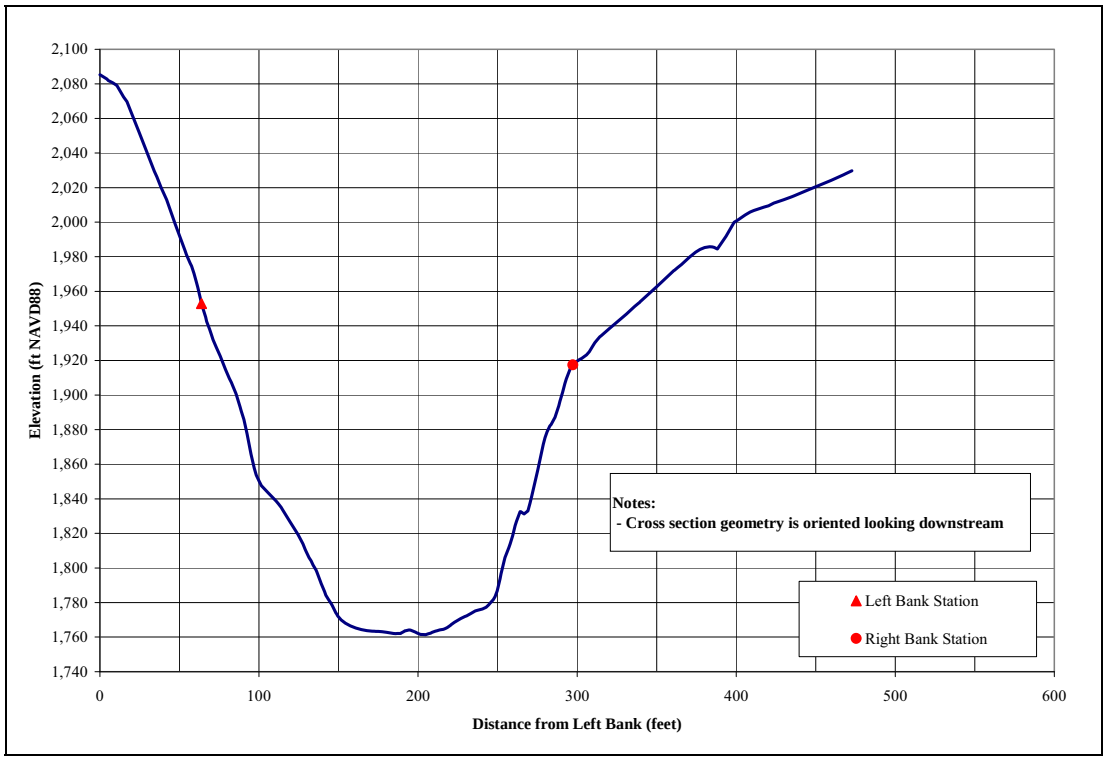


**Figure 5.2-4.** Example cross section in Boundary Reservoir HRM (HEC-RAS Station 15107).

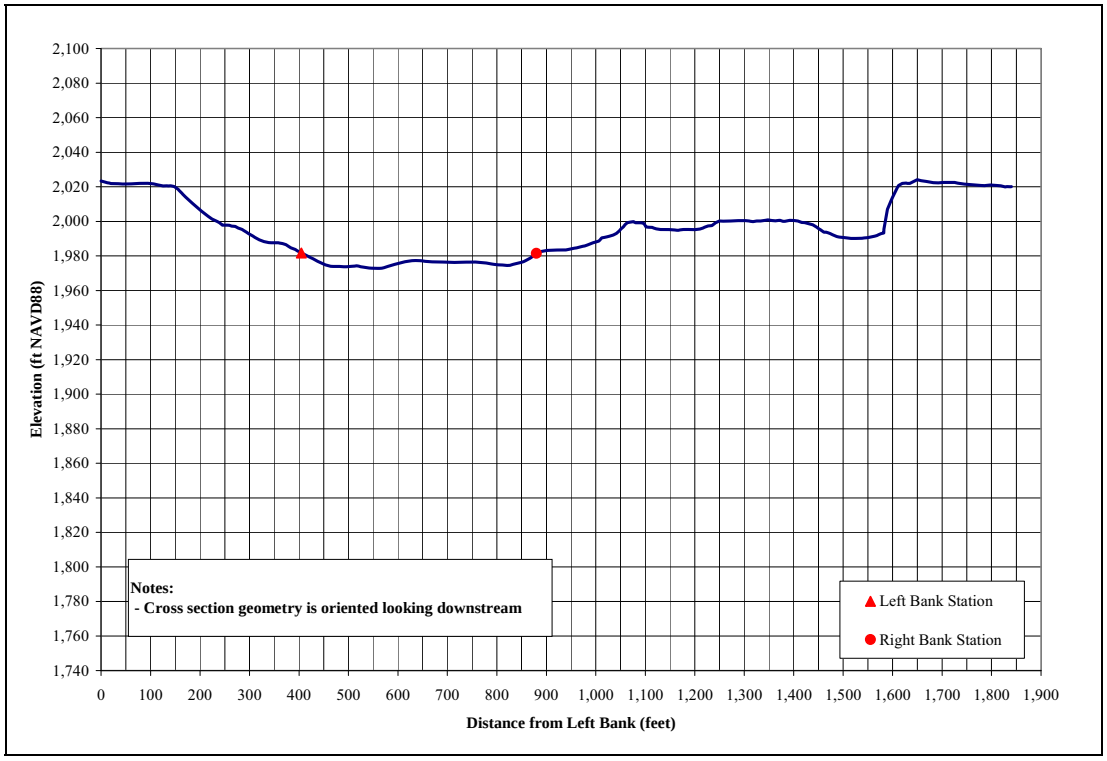


**Figure 5.2-5.** Example cross section in Boundary Reservoir HRM (HEC-RAS Station 94743).

The selection of the magnitude of the computational time step is a function of the spacing of the cross sections. The HEC-RAS user's manual (HEC-USACE 2008) provides guidance in selecting the time step that would result in optimum model stability and accuracy. The time step was selected in order to provide both model stability and also to provide a practical run time for execution of the model. The practical recommendation for the computational time step of the model is expressed in the following equation

$$t = \frac{T_r}{20}$$

Where:

$t$ = computational time step, hours
$T_r$ = time of rise of hydrograph to be routed, hours

Based on a review of the Boundary forebay water surface fluctuations, the shortest time of rise was found to be approximately 8 hours. Using this value in the above equation would result in a recommended computational time step of 0.4 hours or 24 minutes. This practical recommendation was then checked to see if it would satisfy the Courant condition, which is used to determine the computational time step as a function of cross section spacing and the velocity of the flood wave. Based on the check on the Courant condition, the computational time step was reduced to 1 minute. The same 1-minute computational time step was used for both the Boundary Reservoir and Boundary Tailrace HRMs.

### 5.2.3. Boundary Conditions

The boundary conditions for the calibration of the Boundary Reservoir HRM included a time series of Project forebay elevations (downstream boundary condition) and a time series of flow rates as measured at the USGS gaging station 12396500 (upstream boundary condition). Time series of tributary stream inflows to Boundary Reservoir were included in the model as an internal boundary conditions. With the exception of the tributary stream inflow time series, the boundary condition data were continuously recorded and were available at a 15-minute time interval. As discussed previously in this report, the tributary stream inflow time series were synthesized using Sullivan Creek (USGS gage 12396900) and Salmo River (Water Survey of Canada gage 08NE074) as reference stations.

The boundary conditions used for the calibration of the Boundary Tailrace HRM included a time series of Seven Mile Project forebay elevations (downstream boundary condition) and a time series of Boundary Project outflow data (upstream boundary condition). Both the Seven Mile forebay data and the Project outflow data was provided by SCL as average hourly values, which were synthesized into 15-minute instantaneous values.

For the evaluation of operations scenarios, the calibrated hydraulic routing models will use model output from the Scenario Tool optimization in combination with historical data as the boundary conditions. For example, the Boundary Reservoir HRM will use the hourly time series of Boundary forebay data determined by the Scenario Tool as the downstream boundary condition. The upstream boundary condition will be represented by the same historical hourly

flow data used in the ST. The source of this data is the USGS gage station 12396500 for the calendar years 1997, 2000, and 2002 and is average hourly data.

The Boundary Tailrace HRM will use an hourly time series of Seven Mile Dam forebay data based on the historical data from the calendar years of 1997, 2000, and 2001 as the downstream boundary condition. The upstream boundary condition will be represented by the Boundary Dam outflow as determined by the ST optimization.

### 5.2.4. Information for Calibration

Both the Boundary Reservoir and the Boundary Tailrace HRMs were calibrated to data collected between September 2006 and May 2008. This section documents the specific data used in the calibration of the two models.

#### *5.2.4.1. Boundary Reservoir HRM*

Data used to calibrate the Boundary Reservoir HRM included the following:

- USGS water surface elevation data from USGS gage station 12396500
- Water surface elevation data post-processed from water depth data collected at the five pressure transducer installations between Boundary Dam and Box Canyon Dam
- Water surface elevations field surveyed at the habitat transects for a range of target flow conditions and Boundary Dam forebay conditions
- Boundary Dam outflow data provided by SCL

The raw water surface elevation data from the USGS gage station 12396500 were available in 15-minute time increments. This USGS station actually comprises two recording stations: the primary station, which is located 1,000 feet downstream of Box Canyon Dam, and the auxiliary station, which is located 1.2 miles downstream of Box Canyon Dam. The provisional raw data from both stations, as provided by the USGS, were used for calibration.

The five pressure transducer installations provided continuous recording of water depth at 15-minute time increments. The data were downloaded and post-processed in approximately 3-month time periods. The time series of depth data were converted to a time series of water surface elevation data relative to the NAVD 88 datum. This conversion included subtracting out the influence of barometric pressure on the depth readings at each time step. The data were then reviewed to identify and eliminate erroneous instantaneous values. Since each installation included two pressure transducers, the review included identifying instances where the differential between two transducers was greater than a nominal value of 0.5 foot. The number of such instances was quite small, as seen in Table 5.2-1, thus providing additional confidence in the reliability of the data. The final step was to average the two post-processed water surface elevations at each time step so as to generate a continuous time series at each pressure transducer location.

**Table 5.2-1.** Number of instances where differential in pressure transducer readings exceeded nominal value of 0.5 foot for Boundary Reservoir transducer locations

| Time Period | Pressure Transducer Installation Identifier | | | | |
|---|---|---|---|---|---|
| | BOX_TR | US_MET[2] | DS_MET[3] | CANYON | BND_LK |
| Sept 06 – Dec 06 | 1 | 0 | 0 | 0 | N/A |
| Dec 06 – Mar 07 | 1 | 0 | 0 | 0 | N/A |
| Mar 07 – June 07 | 23 | 0 | 6 | 0 | 1 |
| June 07 – Oct 07 | 2 | 1 | 1 | 0 | 47[1] |
| Oct 07 – Mar 08 | 1 | 1 | 2 | 1 | 1 |

Notes:
1 Attributed to malfunction of one of the pressure transducers at the location.
2 US_MET = pressure transducer located upstream of Metaline Falls.
3 DS_MET = pressure transducer located downstream of Metaline Falls.
N/A – not applicable due to the fact that only one pressure transducer was installed at this location for this time period.

Water surface elevations that were surveyed at each habitat transect during specific target flow and Boundary forebay conditions in 2007 were used in the calibration of the Boundary Reservoir HRM. Table 5.2-2 summarizes the specific dates when these surveys were conducted. Each one of the sets of dates is included in one of the model verification periods described previously in Section 4.2.2 and were used to verify the calibration of the model attained in Phase One of the calibration. The water surface elevation data provided point-in-time calibration input at 5 locations in the Forebay Reach, 25 locations in the Canyon Reach, and 24 locations in the Upper Reservoir Reach. These data supplemented the continuously collected data available from the USGS gage and from the pressure transducer installations.

**Table 5.2-2.** Available periods for habitat transect water surface elevation data for Boundary Reservoir HRM.

| Dates | General Pool Condition | General Flow Condition | Reaches Included in Survey |
|---|---|---|---|
| May 24–29 , 2007 | High | High | Forebay, Canyon, Upper Reservoir |
| May 30–31, 2007 | Low | High | Upper Reservoir |
| July 11–12, 2007 | Low | Moderate | Upper Reservoir |
| August 22–23, 2007 | Low | Low | Upper Reservoir |

Finally, Boundary Dam outflow data were provided by SCL. The raw data were obtained from the SCL SCC and was expressed as average hourly flows which were subsequently synthesized into a dataset of instantaneous 15-minute flows. The Boundary Reservoir HRM was not calibrated to this data; however, comparison of model-predicted outflow versus the observed outflow was used as an internal verification of model continuity and stability.

### 5.2.4.2. Boundary Tailrace HRM

Data used to calibrate the Boundary Tailrace HRM included the following:

- Water surface elevation data post-processed from water depth data collected at the three pressure transducer installations between Boundary Dam and Seven Mile Dam
- Water surface elevations field surveyed at the habitat transects for a range of target flow conditions and Seven Mile Dam forebay conditions

The three pressure transducer installations provide continuous recording of water depth at 15-minute time increments. An identical post-processing and quality assurance review procedure was used for the Boundary tailrace transducer data as was used for the Boundary reservoir data. Table 5.2-3 provides a summary of the number of occurrences in the raw data when the differential in pressure transducer readings was greater than a nominal 0.5 foot value at each installation for each data download time period.

**Table 5.2-3.** Number of instances where differential in pressure transducer readings exceeded nominal value of 0.5 foot for Boundary Tailrace transducer locations

| Time Period | Pressure Transducer Installation Identifier | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** [3] |
| Sept 06 – Dec 06 | 1 | 3 | N/A |
| Dec 06 – Mar 07 | 6098[1] | 82 | N/A |
| Mar 07 – June 07 | 99 | 2 | N/A |
| June 07 – Oct 07 | 0 | 0 | N/A |
| Oct 07 – Mar 08 | 19 | 3 | 0 |
| Mar 08 – May 08 | 1148[2] | 13 | 0 |

Notes:
1 Attributed to malfunction of one of the pressure transducers at the location.
2 Attributed to opening of spillway gates at Boundary Dam starting approximately May 17, 2008.
3 The BRIDGE pressure transducer was installed and began operation on February 26,2008.
N/A – not applicable due to the fact that the BRIDGE transducer was not installed until February 26, 2008.

Water surface elevations that were surveyed at each habitat transect during specific target flow and Seven Mile forebay conditions in 2008 were used in the calibration of the Boundary Tailrace HRM. Table 5.2-4 summarizes the specific dates when these surveys were conducted. Each one of the sets of dates is included in one of the model calibration periods described previously in Section 4.2.3 and were used to verify the calibration of the model attained in Phase One of the calibration. The water surface elevation data provided point-in-time calibration input at 14 locations in the Tailrace Reach. These data supplemented the continuously collected data available from the pressure transducer installations.

**Table 5.2-4.** Available periods for habitat transect water surface elevation data for Boundary Tailrace HRM.

| Dates | General Pool Condition | General Flow Condition | Reaches Included in Survey |
|---|---|---|---|
| April 22, 2008 | High | High | U.S. portion of Tailrace Reach |
| April 23–24, 2008 | High | High | Canadian portion of Tailrace Reach |
| March 10, 2008 | Low | High | U.S portion of Tailrace Reach |
| March 7, 2008 | Low | Moderate | U.S portion of Tailrace Reach |
| March 9, 2008 | Low | Low | U.S portion of Tailrace Reach |

## 5.3. Boundary Reservoir HRM Calibration and Verification

This section presents a discussion of the initial magnitudes of the model calibration parameters, the tabular results of the model calibration, and observations made during the model calibration process for the Boundary Reservoir HRM.

### 5.3.1. Initial n-Value and Loss Coefficient Estimates

Initial estimates of the Manning's roughness coefficients and the expansion and contraction loss coefficients were based on observations made during the September 2007 site visit, the substrate and vegetation characterization at the habitat transects and guidance presented in USACE-HEC (2008), Barnes (1967), and Arcement and Schneider (1989). Table 5.3-1 summarizes the estimated initial values.

**Table 5.3-1.** Initial estimates of model calibration parameters for Boundary Reservoir HRM.

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | U/S Project River Mile[2] | D/S Project River Mile[2] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|---|---|
| | | | | Left Overbank | Channel | Right Overbank | | |
| 102198 | 100036 | 34.39 | 34.01 | 0.045 | 0.040 | 0.045 | 0.1 | 0.3 |
| 100036 | 96280 | 34.01 | 33.31 | 0.040 | 0.040 | 0.040 | 0.1 | 0.3 |
| 96280 | 94743 | 33.31 | 33.03 | 0.045 | 0.040 | 0.045 | 0.1 | 0.3 |
| 94743 | 90344 | 33.03 | 32.24 | 0.035 | 0.030 | 0.035 | 0.1 | 0.3 |
| 90344 | 83995 | 32.24 | 31.08 | 0.030 | 0.026 | 0.030 | 0.1 | 0.3 |
| 83995 | 71724 | 31.08 | 28.93 | 0.035 | 0.030 | 0.035 | 0.1 | 0.3 |
| 71724 | 64237 | 28.93 | 27.59 | 0.030 | 0.030 | 0.030 | 0.1 | 0.3 |
| 64237 | 60555.15 | 27.59 | 26.90 | 0.035 | 0.030 | 0.035 | 0.1 | 0.3 |
| 60555.15 | 60143.53 | 26.90 | 26.83 | 0.028 | 0.028 | 0.028 | 0.1 | 0.3 |
| 60143.53 | 59218 | 26.83 | 26.65 | 0.075 | 0.075 | 0.075 | 0.1 | 0.3 |
| 59218 | 9631 | 26.65 | 17.77 | 0.028 | 0.028 | 0.028 | 0.6 | 0.8 |
| 9631 | 5428 | 17.77 | 17.02 | 0.028 | 0.028 | 0.028 | 0.1 | 0.3 |

Notes:
1 Refer to figures in Attachment A for HEC-RAS cross section locations.
2 Project river miles were based on linear interpolation between Project river mile identifiers at 0.1 mile increments.
D/S – downstream
U/S – upstream

Observations of main channel substrate in the Upper Reservoir Reach (upstream of Metaline Falls) indicated predominantly cobble material upstream of PRM 33.0, small to large gravel between PRM 33.0 and PRM 29.0 and deposits of gravel, sand and silt between PRM 29.0 and PRM 27.0. Based on photographs presented in Barnes (1967) and Table 1 in Arcement and Schneider (1989), estimates of the Manning's roughness coefficient for the main channel could be expected to range between 0.026 and 0.050 within the Upper Reservoir Reach. Estimates of the main channel Manning's Roughness coefficient through Metaline Falls were based on estimates for boulder bed streams in Barnes (1967) and Arcement and Schneider (1989). Downstream of Metaline Falls, the channel is quite deep with steep limestone, slate, and dolomite canyon walls subject to rock fall, therefore resulting in substrate composition most closely resembling large diameter boulder material. However, due to the depth of the channel through this reach (up to 300 feet deep), a Manning's Roughness coefficient lower than typical for boulder bed channels was initially selected.

For the portion of the Pend Oreille River downstream of and including Metaline Falls, there is no discernable overbank area. This reach is essentially a deep, narrow canyon with near vertical walls. Therefore, while right and left bank stations were defined in HEC-RAS for the purposes of executing the model, they were not defined with the intent of delineating a change in roughness coefficient between the main channel and the overbank. As seen in Table 5.3-1, a single Manning's roughness coefficient value was used as a cross section averaged value for those cross sections within Metaline Falls and downstream of Metaline Falls.

Upstream of Metaline Falls, the overbank area is more physically definable. Therefore, left and right bank stations were defined at locations in each cross section at locations where change in Manning's roughness was expected or where a significant change in mean column velocity would be expected. For those cross sections where the overbank area was not physically discernable, the bank stations were defined at a nominal elevation of 1,985 feet NAVD 88 (1,981 feet NGVD 29).

Estimates of the contraction and expansion loss coefficients were based on guidance presented in the HEC-RAS User's Manual (USACE-HEC 2008) and observations of site conditions. According to USACE-HEC (2008), typical values of the empirical contraction and expansion coefficients where the change in the effective cross-sectional area is small and gradual are 0.1 and 0.3, respectively. These values were applied to all reaches, with the exception of the Canyon Reach downstream of Metaline Falls. In this reach, higher initial values for the contraction and expansion coefficients were assigned (0.6 and 0.8, respectively) based on the observations that the flow is repeatedly expanding and contracting through narrow bedrock outcroppings and through the irregularly shaped walls of the canyon.

### 5.3.2. Final Calibration and Verification

Phase One of the calibration of the Boundary Reservoir HRM was attained through an iterative process proceeding from the downstream end of the model (Boundary forebay) to the upstream end of the model (Box Canyon tailrace), using the six calibration periods defined previously in Section 4.2. Manning's roughness coefficients and the expansion and contraction loss coefficients were iteratively adjusted within physically acceptable ranges. The iterative process was continued until the model-predicted water surface elevations were within the calibration criteria established in Section 4.2. The calibration process also included defining ineffective flow areas within pertinent cross sections as appropriate so as to simulate flow expansion and contraction in a physically consistent manner. Flow was allowed to expand at a rate of no more than 1:4 (lateral: longitudinal). Flow was allowed to contract at a rate of no more than 1:1 (lateral: longitudinal).

Calibration of the model to the data upstream of Metaline Falls required ineffective flow definition at both low stage and high stage for the several cross sections through Metaline Falls. The high stage ineffective flow definition was used to model the eddy areas on the downstream side of several bedrock outcroppings as ineffective flow areas. The low stage ineffective flow definition was used to define the effective flow path through the falls during low flow and low pool conditions.

With the completion of Phase One of the calibration procedure, the model was executed for the five verification periods defined in Section 4.2 (Phase Two). Model predicted water surface elevations were compared to the continuous data from USGS gage 12396500 and from the pressure transducers. The model predicted water surface elevations were also compared to the water surface elevations surveyed during the habitat transect data collection periods. The results of the Phase Two verification indicated that the calibrated model was successfully able to predict water surface elevations within the defined calibration criteria for all of the continuous data collection stations and for a majority of the habitat transects as well. It was, however, found in Phase Two that the model was underpredicting water surface elevations by nearly one foot at one

of the habitat transects in the Canyon Reach (C-18) and that the model was overpredicting water surface elevations at several habitat transects in the Upper Reservoir Reach by up to 1.4 feet (U-20, U-21, U-22, U-23, and U-24). Using this additional insight, the verification periods were incorporated into the calibration procedure and the model calibration was refined until all model predicted water surface elevations were within the calibration goals for both the verification and calibration periods.

The final step in the calibration procedure (Phase Three) was to execute the calibrated model for the entire 19-month data collection period referred to as the broad verification period.

#### *5.3.2.1. Tabular Results for Calibration Periods*

Table 5.3-2 presents the final estimated values for the model calibration parameters. The higher than expected Manning's roughness values through the Canyon Reach are attributed to the irregularity of the limestone, dolomite, and slate canyon walls throughout this reach. The canyon walls are characterized with numerous caves and rock features that jut into the flow, thus providing local increase in hydraulic resistance. For similar reasons, the Manning's roughness values through Metaline Falls were higher than the initially assumed values. The bedrock outcroppings located within the wetted perimeter through Metaline Falls also contributed to the high Manning's roughness in this area.

Tables 5.3-3, 5.3-4, and 5.3-5 present tabular summaries of the results of the model calibration for each calibration period at each of the six calibration locations. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time ordinates at each calibration location for each calibration period. Since the calibration periods encompass a total of 92 days of observed conditions, nearly 8,800 time ordinate comparisons were made at each of the calibration locations.

**Table 5.3-2.** Final model calibration parameters for Boundary Reservoir HRM.

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | U/S Project River Mile[2] | D/S Project River Mile[2] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|---|---|
| | | | | Left Overbank | Channel | Right Overbank | | |
| 102198 | 101240 | 34.39 | 34.13 | 0.075 | 0.051 | 0.060 | 0.5 | 0.7 |
| 100665 | 99871 | 34.13 | 33.90 | 0.075 | 0.051 | 0.060 | 0.3 | 0.5 |
| 99552 | 98093 | 33.90 | 33.48 | 0.070 | 0.029 | 0.055 | 0.3 | 0.5 |
| 97259 | 95152 | 33.48 | 33.03 | 0.070 | 0.036 | 0.055 | 0.3 | 0.5 |
| 94743 | 91365 | 33.03 | 32.24 | 0.070 | 0.031 | 0.055 | 0.3 | 0.5 |
| 90344 | 84450 | 32.24 | 31.07 | 0.065 | 0.028 | 0.055 | 0.3 | 0.5 |
| 83968 | 81355 | 31.07 | 30.53 | 0.050 | 0.032 | 0.055 | 0.3 | 0.5 |
| 80958 | 77177 | 30.53 | 29.75 | 0.060 | 0.032 | 0.075 | 0.3 | 0.5 |
| 76404 | 72815 | 29.75 | 29.03 | 0.050 | 0.032 | 0.050 | 0.3 | 0.5 |
| 72527 | 69242 | 29.03 | 28.25 | 0.055 | 0.032 | 0.075 | 0.3 | 0.5 |
| 67659 | 63714 | 28.25 | 27.44 | 0.055 | 0.032 | 0.050 | 0.3 | 0.5 |
| 63373 | 60912 | 27.44 | 26.90 | 0.050 | 0.032 | 0.050 | 0.3 | 0.5 |
| 60555.15 | 60143.53 | 26.90 | 26.81 | 0.092 | 0.092 | 0.092 | 0.5 | 0.7 |
| 60053.34 | 59861.05 | 26.81 | 26.75 | 0.092 | 0.122 | 0.092 | 0.5 | 0.7 |
| 59729.02 | 59566.67 | 26.75 | 26.69 | 0.092 | 0.122 | 0.092 | 0.9 | 0.9 |
| 59451 | 58005 | 26.69 | 26.31 | 0.092 | 0.092 | 0.092 | 0.9 | 0.9 |
| 57424 | 12246 | 26.31 | 17.99 | 0.092 | 0.092 | 0.092 | 0.3 | 0.5 |
| 12044 | 5428 | 17.99 | 17.02 | 0.028 | 0.028 | 0.028 | 0.1 | 0.3 |

Notes:
1 Refer to figures in Section 8 for HEC-RAS cross section locations.
2 Project River Miles were based on linear interpolation between Project River Mile identifiers at 0.1 mile increments.
D/S – downstream
U/S – upstream

**Table 5.3-3.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all calibration periods – Boundary Reservoir HRM.

| Cumulative Range | Calibration Location | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| < 0.2 feet | 60.93 % | 53.30 % | 52.64 % | 67.47 % | 88.41 % | 99.76 % |
| < 0.4 feet | 93.12 % | 94.40 % | 86.65 % | 94.66 % | 99.44 % | 99.99 % |
| < 0.6 feet | 99.99 % | 100.00 % | 99.90 % | 99.99 % | 100.00 % | 100.00 % |
| < 0.75 feet | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % |

Notes:
1 There were a total of 92 calendar days represented in the calibration periods.
2 Model output and observed data were compared at 15-minute time intervals.
BOX TR – Box Canyon tailrace
USGS – U.S. Geological Survey
DS MET – Downstream of Metaline Falls
US MET – Upstream of Metaline Falls

**Table 5.3-4.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for each calibration period—Boundary Reservoir HRM.

| Calibration Period | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for each Calibration Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | **BOX_TR** | **Primary USGS** | **Auxiliary USGS** | **US_MET** | **DS_MET** | **CANYON** |
| | | **102198[1]** | **101240[1]** | **96759[1]** | **61170[1]** | **59451[1]** | **12445[1]** |
| Hi_Lo | Maximum Positive | + 0.5 | + 0.2 | + 0.3 | + 0.3 | + 0.3 | + 0.2 |
| | Maximum Negative | - 0.5 | - 0.6 | - 0.6 | - 0.2 | N/A | N/A |
| Hi_Mod | Maximum Positive | + 0.5 | N/A | + 0.2 | + 0.5 | + 0.3 | + 0.2 |
| | Maximum Negative | - 0.3 | - 0.6 | - 0.6 | - 0.2 | - 0.1 | N/A |
| Hi_Hi | Maximum Positive | + 0.5 | N/A | N/A | + 0.3 | + 0.2 | + 0.2 |
| | Maximum Negative | - 0.6 | - 0.5 | - 0.6 | - 0.1 | - 0.2 | N/A |
| Lo_Lo | Maximum Positive | + 0.6 | + 0.1 | + 0.5 | + 0.4 | + 0.5 | + 0.4 |
| | Maximum Negative | - 0.2 | - 0.4 | - 0.3 | - 0.4 | N/A | N/A |
| Lo_Mod | Maximum Positive | + 0.5 | + 0.5 | + 0.7 | + 0.6 | + 0.6 | + 0.2 |
| | Maximum Negative | - 0.3 | - 0.4 | - 0.4 | - 0.2 | N/A | N/A |
| Lo_Hi | Maximum Positive | + 0.5 | N/A | N/A | + 0.5 | + 0.4 | + 0.2 |
| | Maximum Negative | - 0.4 | - 0.5 | - 0.6 | - 0.3 | - 0.2 | N/A |

Notes:
N/A indicates that the computed difference at the location was either entirely positive or entirely negative for the entire period.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.
BOX TR – Box Canyon tailrace
DS MET – Downstream of Metaline Falls
N/A – not applicable
USGS – U.S. Geological Survey
US MET – Upstream of Metaline Falls

**Table 5.3-5.** Root mean square error (RMSE) at each calibration location for each calibration period—Boundary Reservoir HRM.

| Calibration Period | Root Mean Square Error (feet) at each Calibration Location for each Calibration Period | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| Hi_Lo | 0.18 | 0.20 | 0.16 | 0.08 | 0.14 | 0.08 |
| Hi_Mod | 0.20 | 0.28 | 0.29 | 0.20 | 0.06 | 0.09 |
| Hi_Hi | 0.21 | 0.32 | 0.40 | 0.10 | 0.05 | 0.15 |
| Lo_Lo | 0.25 | 0.22 | 0.26 | 0.19 | 0.18 | 0.09 |
| Lo_Mod | 0.30 | 0.14 | 0.18 | 0.26 | 0.20 | 0.09 |
| Lo_Hi | 0.12 | 0.18 | 0.23 | 0.27 | 0.10 | 0.07 |

Note:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.

The first table, Table 5.3-3, shows that for more than 99 percent of the time during the calibration periods, the model-predicted water surface elevations were within 0.6 foot of the observed water surface elevations at all of the calibration locations. Table 5.3-3 also shows that the model-predicted water surface elevations were within 0.4 feet of the observed water surface elevations more than 86 percent of the time at all calibration locations. As described previously in Section 4.2, an initial goal of a maximum absolute differential of 0.75 foot was established at the onset of the model calibration process. Table 5.3-3 clearly shows that this goal was attained at all of the calibration locations.

It should be noted that there were a few instances in certain of the calibration periods where the calibrated model was not able to replicate the exact timing of the stage hydrograph at the BOX_TR pressure transducer location. The model replicated the magnitude but not the exact timing. Figure 5.3-1 illustrates this phenomenon for the instance where it occurred during the Hi_Lo calibration period. The inability of the calibrated model to replicate the timing of the stage hydrograph at this location is likely attributed to the timing of the reported boundary condition data, namely the flow rate data provided by the USGS. Figure 5.3-1 clearly shows that water surface elevations changes resulting from the rapid change in flow rate as reported at USGS gage 12396500 were replicated by the model, but the hydrograph is shifted by approximately 15 minutes. The three instances where the issue of timing caused the calibrated model to produce results that were outside of the calibration criteria are not included in comparison reported in Tables 5.3-3 through 5.3-5.

Table 5.3-4 summarizes the maximum positive and maximum negative error at each calibration location within each calibration period. Positive values in this table indicate model-predicted water surface elevations greater than observed for the particular calibration location and calibration period. Negative values in this table indicate model-predicted water surface elevations less than observed. Those locations where the difference between the model predicted water surface elevation and the observed water surface elevation was greater than 0.75 foot are indicated as shaded boxes in the table. However, as explained in the previous paragraph, each of

these instances is attributed to the reported timing of the flow data input as the boundary condition and are not indicative of an unsuccessful model calibration.

Finally, Table 5.3-5 illustrates how well the calibrated model replicated observed conditions, using the RMSE as the objective evaluator. For example, this table indicates that the calibrated hydraulic model predicted water surface elevations for the entire Hi_Lo calibration period within an average error of less than 0.20 foot at each of the calibration location. The RMSE was less than or equal to 0.40 for all calibration locations within each of the calibration periods.

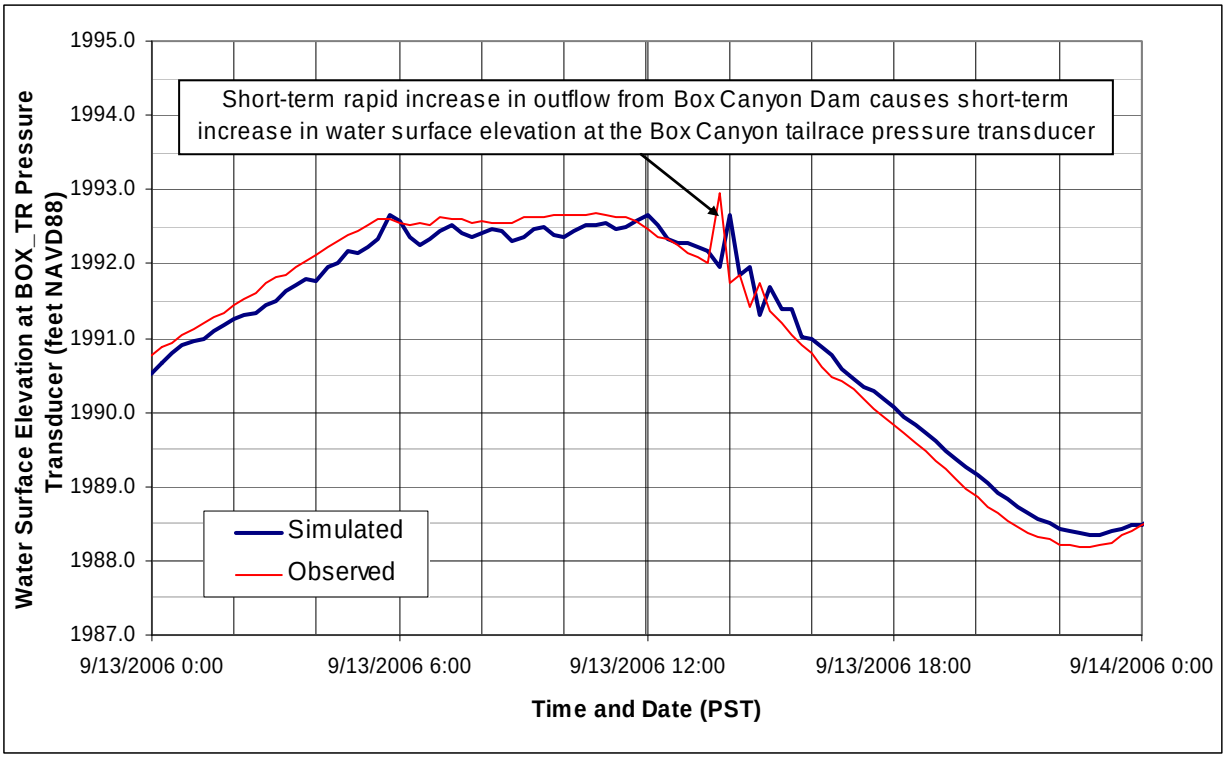


**Figure 5.3-1.** Example of timing issues encountered during calibration of Boundary Reservoir HRM.

### *5.3.2.2. Tabular Results for Verification Periods*

This section presents tabular results of the calibrated model predicted water surface elevations for the five verification periods at each of the six continuous data collection locations. Since the verification time periods were also inclusive of the time periods when water surface elevation data were collected at each of the habitat transects, this section also includes comparisons of the calibrated model predicted water surface elevations against the water surface elevations surveyed at the habitat transect locations.

Model predicted water surface elevations were compared against the water surface elevations surveyed at each habitat transect. For a given target flow and forebay condition, water surfaces were typically surveyed on each bank of the habitat transects. The differences between the

model predicted and field surveyed water surface elevations for the habitat transects were within the calibration criteria outline in Section 4.2 and are summarized, by reach, in Table 5.3-6.

Tables 5.3-7, 5.3-8, and 5.3-9 present tabular summaries of the results of the model verification for each verification period at each of the six calibration locations. These tables are the same format as those tables previously presented for the calibration results. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time ordinates at each calibration location for each verification period. As was done for the calibration periods, the few instance where anomalies in boundary condition data resulted in differences between observed and modeled water surface elevations that were greater than the calibration criteria were removed from the comparison and are therefore not included in Tables 5.3-7 through 5.3-9. Since the verification periods encompass a total of 54 days of observed conditions, approximately 5,100 time ordinate comparisons were made at each of the calibration locations.

**Table 5.3-6.** Cumulative percent of occurrences when model water surface elevation was within specified range of surveyed water surface elevation at habitat transects—Boundary Reservoir HRM.

| Range | Forebay Reach | Canyon Reach | Upper Reservoir Reach |
|---|---|---|---|
| < 0.2 feet | 80.00 % | 8.93 % | 51.27 % |
| < 0.4 feet | 100.00 % | 75.00 % | 75.65 % |
| < 0.6 feet | 100.00 % | 92.86 % | 94.92 % |
| < 0.75 feet | 100.00 % | 100.00 % | 99.49% |

Notes:
1 There were 10 data points for the Forebay Reach.
2 There were 56 data points for the Canyon Reach.
3 There were 197 data points for the Upper Reservoir Reach.

**Table 5.3-7.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all verification periods—Boundary Reservoir HRM.

| Cumulative Range | Calibration Location | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| < 0.2 feet | 58.71 % | 60.60 % | 49.84 % | 63.37 % | 93.92 % | 99.98 % |
| < 0.4 feet | 90.21 % | 94.13 % | 91.34 % | 92.36 % | 99.74 % | 100.00 % |
| < 0.6 feet | 99.98 % | 99.98 % | 99.98 % | 99.96 % | 100.00 % | 100.00 % |
| < 0.75 feet | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % |

Notes:
1 There were a total of 54 calendar days represented in the verification periods.
2 Model output and observed data were compared at 15-minute time intervals.

**Table 5.3-8.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for each verification period—Boundary Reservoir HRM.

| Verification Period | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for each Verification Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| Hi_Hi | Max Positive | + 0.3 | N/A | N/A | + 0.3 | + 0.2 | + 0.2 |
| | Max Negative | - 0.4 | - 0.4 | - 0.5 | - 0.2 | - 0.1 | N/A |
| Var_Var | Max Positive | + 0.6 | + 0.3 | + 0.4 | + 0.6 | + 0.5 | + 0.3 |
| | Max Negative | - 0.3 | - 0.6 | - 0.6 | - 0.2 | - 0.1 | - 0.1 |
| Lo_Lo | Max Positive | + 0.5 | + 0.1 | + 0.7 | + 0.4 | + 0.3 | + 0.1 |
| | Max Negative | - 0.4 | - 0.5 | - 0.4 | - 0.2 | N/A | N/A |
| Lo_Mod | Max Positive | + 0.5 | + 0.2 | + 0.4 | + 0.5 | + 0.6 | + 0.1 |
| | Max Negative | - 0.2 | - 0.3 | - 0.3 | - 0.3 | N/A | - 0.1 |
| Lo_Hi | Max Positive | + 0.3 | + 0.2 | + 0.4 | + 0.7 | + 0.4 | + 0.2 |
| | Max Negative | - 0.3 | - 0.4 | - 0.5 | - 0.3 | - 0.1 | N/A |

Notes:
N/A indicates that the computed difference at the location was either entirely positive or entirely negative for the entire period.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.3-9.** Root mean square error (RMSE) at each calibration location for each verification period—Boundary Reservoir HRM.

| Verification Period | Root Mean Square Error (feet) at Each Calibration Location for Each Verification Period | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| Hi_Hi | 0.09 | 0.22 | 0.28 | 0.12 | 0.06 | 0.10 |
| Var_Var | 0.28 | 0.24 | 0.25 | 0.24 | 0.10 | 0.10 |
| Lo_Lo | 0.22 | 0.20 | 0.26 | 0.16 | 0.13 | 0.09 |
| Lo_Mod | 0.22 | 0.13 | 0.18 | 0.19 | 0.15 | 0.05 |
| Lo_Hi | 0.18 | 0.16 | 0.19 | 0.28 | 0.12 | 0.08 |

Notes:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.
BOX TR – Box Canyon tailrace
DS MET – Downstream of Metaline Falls
USGS – U.S. Geological Survey
US MET – Upstream of Metaline Falls

Table 5.3-6 shows that the calibrated hydraulic model predicted water surface elevations at all habitat transects with a maximum absolute error of less than 0.75 foot for the range of flow conditions that were surveyed. These results are important because it illustrates that the model is accurately predicting water surface elevations along the entire length of the reservoir reach.

Table 5.3-7, shows that for more than 99 percent of the time during the verification periods, the model-predicted water surface elevations were within 0.6 foot of the observed water surface elevations at all of the calibration locations. Table 5.3-7 also shows that the model-predicted water surface elevations were within 0.4 foot of the observed water surface elevations more than 90 percent of the time. As described previously in Section 4.2, an initial goal of a maximum absolute difference of 0.75 foot was established as a calibration criterion. Table 5.3-7 clearly shows that this goal was attained at the all calibration locations for all of the verification periods.

Table 5.3-8 summarizes the maximum positive and maximum negative differences at each calibration location for each verification period. Those locations where the maximum difference between the model predicted water surface elevation and the observed water surface elevation was greater than 0.75 foot are indicated as shaded boxes in the table. Similar to the calibration period results, these anomalies were removed from the comparison and are not included in the results presented in Tables 5.3-7 through 5.3-9. The cause of these anomalies is again the result of the model not exactly replicating the timing of rapid changes in water surface elevation caused by rapid changes in the flow data provided by USGS. These rapidly changing conditions typically occurred over a period of less than 30 minutes and are considered unusual conditions that will not be encountered during the evaluation of operations scenarios.

Finally, Table 5.3-9 illustrates how well the calibrated model replicated observed conditions for the verification periods, using the RMSE as the objective evaluator. For example, this table indicates that the calibrated hydraulic model predicted water surface elevations for the Lo_Mod verification period within an average error of less than 0.22 foot at each of the calibration locations. The RMSE was less than or equal to 0.28 for all calibration locations within each of the verification periods.

The results presented in Tables 5.3-6 through 5.3-9 clearly validate and verify the calibration of the Boundary Reservoir HRM.

#### *5.3.2.3. Tabular Results for Broad Verification Period*

The final step of the calibration process was to execute the calibrated model for the entire 19-month period of pressure transducer data and USGS data for the Boundary Reservoir HRM. This 19-month run of the model included all of the calibration and verification periods. The time period for this model run was September 2006 through March 2008. This step is considered a broad verification of the calibrated model in that it provides verification of the model calibration using all of pressure transducer data and USGS data collected in the Boundary Reservoir. Tables 5.3-10, 5.3-11, and 5.3-12 present tabular summaries of the results of the model verification for the broad verification period at each of the six calibration locations. These tables are the same format as those tables previously presented, except that the model output is organized and presented by month. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time

ordinates at each calibration location for each calibration period. Anomalies in the boundary condition data that resulted in maximum differences between the model predicted water surface elevation and the observed water surface elevation that were greater than 0.75 foot were removed from the comparison and are not included in the following tables. Because the broad verification period included nearly 19 months of continuously collected data, there were more than 55,000 time ordinate comparisons made at each of the calibration locations.

**Table 5.3-10.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the broad verification period—Boundary Reservoir HRM.

| Cumulative Range | Calibration Location | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| < 0.2 feet | 56.22 % | 61.14 % | 55.67 % | 63.70 % | 92.62 % | 99.80 % |
| < 0.4 feet | 92.48 % | 95.43 % | 91.53 % | 95.41 % | 99.79 % | 99.99 % |
| < 0.6 feet | 99.97 % | 99.98 % | 99.89 % | 99.99 % | 100.00 % | 100.00 % |
| < 0.75 feet | 99.99 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % | 100.00 % |

Notes:
1 There were a total of 19 months represented in the broad verification period.
2 Model output and observed data were compared at 15-minute time intervals.

**Table 5.3-11.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for broad verification period—Boundary Reservoir HRM.

| Month | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for Broad Verification Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| September 2006 | Max Positive | + 0.6 | + 0.2 | + 0.5 | + 0.4 | + 0.4 | + 0.2 |
| | Max Negative | - 0.5 | - 0.6 | - 0.6 | - 0.2 | N/A | N/A |
| October 2006 | Max Positive | + 0.5 | + 0.5 | + 0.7 | + 0.6 | + 0.6 | + 0.4 |
| | Max Negative | - 0.3 | - 0.4 | - 0.4 | - 0.2 | N/A | N/A |
| November 2006 | Max Positive | + 0.6 | + 0.1 | + 0.3 | + 0.5 | + 0.5 | + 0.2 |
| | Max Negative | - 0.1 | - 0.4 | - 0.5 | - 0.1 | - 0.1 | N/A |
| December 2006 | Max Positive | + 0.6 | + 0.3 | + 0.4 | + 0.6 | + 0.4 | + 0.2 |
| | Max Negative | - 0.2 | - 0.5 | - 0.5 | - 0.1 | - 0.1 | - 0.1 |
| January 2007 | Max Positive | + 0.5 | + 0.1 | + 0.2 | + 0.5 | + 0.5 | + 0.3 |
| | Max Negative | - 0.3 | - 0.6 | - 0.6 | - 0.2 | - 0.1 | N/A |
| February 2007 | Max Positive | + 0.6 | + 0.3 | + 0.4 | + 0.6 | + 0.5 | + 0.3 |
| | Max Negative | - 0.3 | - 0.6 | - 0.6 | - 0.1 | - 0.1 | - 0.1 |
| March 2007 | Max Positive | + 0.6 | + 0.1 | + 0.3 | + 0.6 | + 0.5 | + 0.4 |
| | Max Negative | - 0.6 | - 0.7 | - 0.7 | - 0.2 | - 0.1 | - 0.1 |

**Table 5.3-11, continued…**

| Month | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for Broad Verification Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| April 2007 | Max Positive | + 0.6 | + 0.1 | + 0.1 | + 0.5 | + 0.5 | + 0.2 |
| | Max Negative | - 0.3 | - 0.6 | - 0.6 | - 0.2 | - 0.1 | N/A |
| May 2007 | Max Positive | + 0.5 | N/A | + 0.1 | + 0.5 | + 0.5 | + 0.2 |
| | Max Negative | - 0.4 | - 0.5 | - 0.7 | - 0.3 | - 0.3 | N/A |
| June 2007 | Max Positive | + 0.8 | + 0.5 | + 0.4 | + 0.7 | + 0.4 | + 0.2 |
| | Max Negative | - 0.4 | - 0.5 | - 0.6 | - 0.2 | - 0.1 | - 0.1 |
| July 2007 | Max Positive | + 0.5 | + 0.2 | + 0.4 | + 0.5 | + 0.6 | + 0.2 |
| | Max Negative | - 0.5 | - 0.4 | - 0.4 | - 0.2 | - 0.1 | - 0.1 |
| August 2007 | Max Positive | + 0.9 | + 0.2 | + 0.7 | + 0.5 | + 0.3 | + 0.2 |
| | Max Negative | - 0.4 | - 0.5 | - 0.4 | - 0.2 | N/A | N/A |
| September 2007 | Max Positive | + 0.6 | + 0.2 | + 0.5 | + 0.4 | + 0.5 | + 0.4 |
| | Max Negative | - 0.3 | - 0.4 | - 0.3 | - 0.3 | N/A | N/A |
| October 2007 | Max Positive | + 0.5 | + 0.2 | + 0.4 | + 0.5 | + 0.5 | + 0.2 |
| | Max Negative | - 0.2 | - 0.4 | - 0.4 | - 0.1 | N/A | N/A |
| November 2007 | Max Positive | + 0.5 | + 0.1 | + 0.5 | + 0.4 | + 0.4 | + 0.2 |
| | Max Negative | - 0.2 | - 0.4 | - 0.4 | - 0.1 | - 0.1 | N/A |
| December 2007 | Max Positive | + 0.7 | + 0.2 | + 0.4 | + 0.6 | + 0.5 | + 0.2 |
| | Max Negative | - 0.2 | - 0.5 | - 0.5 | - 0.1 | - 0.1 | N/A |
| January 2008 | Max Positive | + 0.5 | + 0.1 | + 0.3 | + 0.4 | + 0.4 | + 0.2 |
| | Max Negative | - 0.7 | - 0.6 | - 0.7 | - 0.2 | - 0.2 | - 0.2 |
| February 2008 | Max Positive | + 0.5 | + 0.1 | + 0.3 | + 0.5 | + 0.4 | + 0.3 |
| | Max Negative | - 0.4 | - 0.6 | - 0.6 | - 0.2 | - 0.1 | - 0.1 |
| March 2008 | Max Positive | + 0.6 | + 0.3 | + 0.5 | + 0.6 | + 0.4 | + 0.2 |
| | Max Negative | - 0.3 | - 0.5 | - 0.5 | - 0.1 | - 0.2 | - 0.1 |

Notes:
N/A indicates the computed difference at the location was either entirely positive or entirely negative for the entire period.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.3-12.** Root mean square error (RMSE) at each calibration location for broad verification period – Boundary Reservoir HRM.

| Month | Root Mean Square Error (feet) at Each Calibration Location for Broad Verification Period | | | | | |
|---|---|---|---|---|---|---|
| | BOX_TR | Primary USGS | Auxiliary USGS | US_MET | DS_MET | CANYON |
| | 102198[1] | 101240[1] | 96759[1] | 61170[1] | 59451[1] | 12445[1] |
| September 2006 | 0.20 | 0.18 | 0.17 | 0.12 | 0.16 | 0.08 |
| October 2006 | 0.26 | 0.16 | 0.18 | 0.22 | 0.17 | 0.09 |
| November 2006 | 0.23 | 0.17 | 0.20 | 0.21 | 0.12 | 0.09 |
| December 2006 | 0.30 | 0.18 | 0.20 | 0.26 | 0.11 | 0.07 |
| January 2007 | 0.20 | 0.27 | 0.28 | 0.20 | 0.07 | 0.09 |
| February 2007 | 0.27 | 0.24 | 0.25 | 0.24 | 0.10 | 0.10 |
| March 2007 | 0.22 | 0.27 | 0.31 | 0.20 | 0.07 | 0.12 |
| April 2007 | 0.18 | 0.25 | 0.30 | 0.22 | 0.10 | 0.12 |
| May 2007 | 0.13 | 0.21 | 0.27 | 0.23 | 0.09 | 0.09 |
| June 2007 | 0.14 | 0.19 | 0.22 | 0.19 | 0.09 | 0.09 |
| July 2007 | 0.19 | 0.15 | 0.16 | 0.16 | 0.13 | 0.07 |
| August 2007 | 0.18 | 0.21 | 0.20 | 0.13 | 0.12 | 0.09 |
| September 2007 | 0.23 | 0.18 | 0.20 | 0.16 | 0.16 | 0.09 |
| October 2007 | 0.27 | 0.14 | 0.18 | 0.23 | 0.15 | 0.10 |
| November 2007 | 0.23 | 0.17 | 0.18 | 0.18 | 0.14 | 0.11 |
| December 2007 | 0.29 | 0.17 | 0.20 | 0.26 | 0.13 | 0.11 |
| January 2008 | 0.25 | 0.22 | 0.27 | 0.20 | 0.11 | 0.10 |
| February 2008 | 0.20 | 0.30 | 0.31 | 0.17 | 0.10 | 0.10 |
| March 2008 | 0.28 | 0.18 | 0.21 | 0.22 | 0.12 | 0.08 |

Notes:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration location.
BOX TR – Box Canyon tailrace
DS MET – Downstream of Metaline Falls
USGS – U.S. Geological Survey
US MET – Upstream of Metaline Falls

### *5.3.2.4. Graphical Results of Boundary Reservoir HRM Calibration*

This section presents the final calibration results in the form of graphical output of the calibrated model to provide illustration of the success of the model calibration. Using the calibrated model as a tool, this section then also proceeds to present discussion illustrating the Boundary reservoir hydraulic characteristics, such as the point-in-time variability of the flow rate through the length of the Reservoir and the attenuation and translation of the operationally induced waves that originate in the Boundary forebay. Particular focus will be on the evaluation of the influence of Metaline Falls as a control and attenuating factor.

Figure 5.3-2 is a time series plot that compares the water surface elevations predicted by the calibrated Boundary Reservoir HRM to the observed water surface elevations. This figure is for the BOX_TR pressure transducer location for the Hi_Lo calibration period (High Pool and Low Flow). Attachment C of this report contains identical plots for each of the six calibration locations during each of the six calibration periods. Attachment C also contains these same types of plots for each of the six calibration locations during each of the five verification periods. The statistical summary of maximum absolute difference in Figure 5.3-2 (and all similar figures in Attachment C) includes the anomalies that were deleted from the model calibration tables in the previous sections of this report.

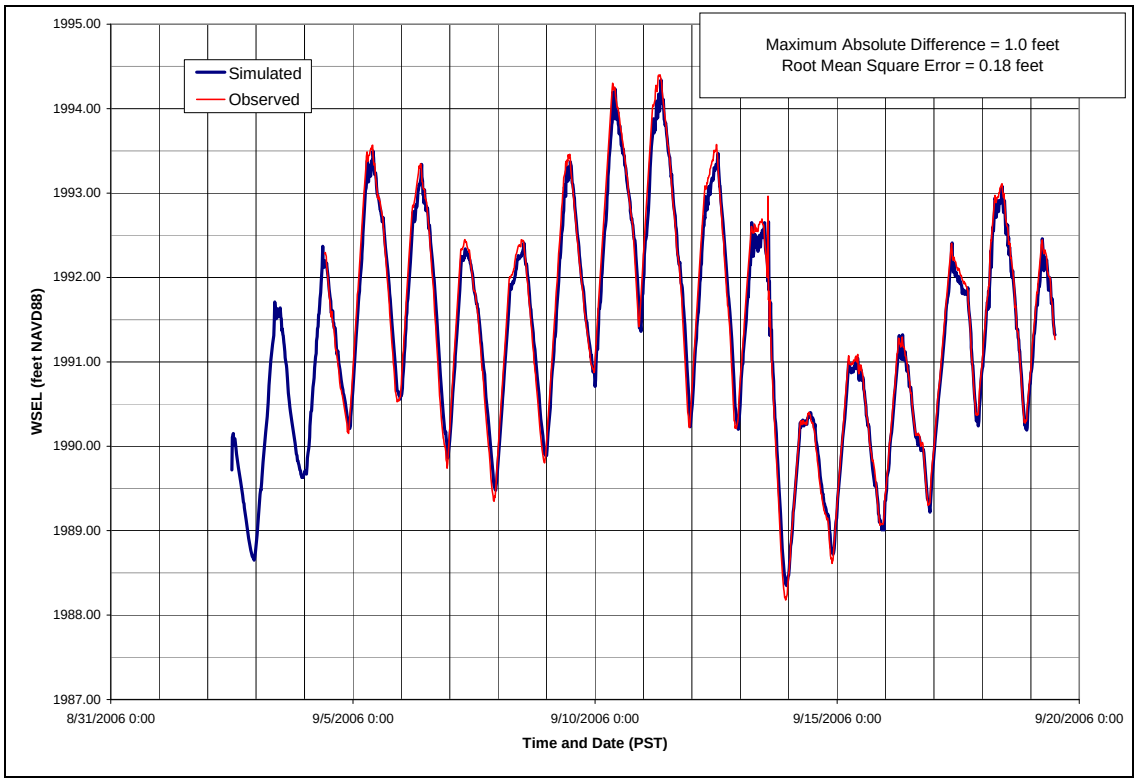


**Figure 5.3-2.** Model calibration results for Hi_Lo Calibration Period at BOX_TR Pressure Transducer Location for Boundary Reservoir HRM.

In addition to illustrating the success of the model calibration in replicating the rising and falling limbs of the operationally induced waves, it is seen in Figure 5.3-2 that the calibrated model resulted in very good replication of the timing of the peaks. These peaks are the by-product of existing Project operations. Quantitative analysis of the accuracy of the model's ability to predict peak timing was not conducted, but time series plots such as shown in Figure 5.3-2 provided the basis to state qualitatively that the model was accurately replicating the timing of fluctuating water surface elevations, and therefore the translation of the operationally induced wave, throughout the length of the reservoir.

Based on the tables presented in Section 5.3.2 and the comparative time series plots presented in Attachment C, it is concluded that the calibration of the Boundary Reservoir HRM was successfully completed. With only 15 exceptions, model-predicted water surface elevations were within 0.75 foot of the observed conditions at all calibration locations for the entire 19-month broad verification period. As mentioned in the previous sections, 13 of these instances are attributed to distinct occurrences where outflow from Box Canyon Dam (as recorded at the USGS gage 12396500) was apparently either rapidly reduced or rapidly increased for a brief period of time and the calibrated model did not exactly replicate the timing of the resulting downstream water surface elevation fluctuation.

The time period to which the Boundary Reservoir HRM was calibrated included flow rates (as measured at the USGS gage 12396500) that ranged between 2,400 cfs and 55,400 cfs and included Boundary Dam forebay elevations that ranged between 1,964.62 and 1,995.08 feet NAVD 88 (1,960.59 and 1,991.05 feet NGVD 29).

The calibrated Boundary Reservoir HRM can be used as a tool to qualitatively evaluate the hydraulic characteristics throughout the reach of the Pend Oreille River upstream of Boundary Dam. For instance, Figure 5.3-3 illustrates the attenuation and translation of the operationally induced waves using a 36-hour portion of the Lo_Mod calibration period. During this period, the outflow from Box Canyon was fairly constant at an average value of 25,100 cfs with only 1,500 cfs in flow variation above or below this average value. This figure illustrates the timing of the wave translation, showing a nearly 2-hour travel time from Boundary Dam to Box Canyon Dam for October 13, 2006, peak. The figure also shows the broadening, or attenuating, of the wave as it travels upstream. As seen in this figure, Metaline Falls plays an important factor in both the translation time and shape of the wave. This figure illustrates that fluctuations in water surface elevations are greatly reduced upstream of Metaline Falls. There is nearly 16 feet of water surface fluctuation in Boundary forebay; however, upstream of Metaline Falls, there is only 7 feet of water surface elevation fluctuation.

Existing Project operations, combined with fluctuations in outflow from Box Canyon Dam, also result in point-in-time variability in the magnitude of the flow rate throughout the entire reach between Box Canyon Dam and Boundary Dam. Certain conditions can magnify this variability more than others, such as extreme water surface elevation fluctuations in the Boundary forebay combined with outflow from Box Canyon that is on the rising or receding limb of the river's hydrograph. Figure 5.3-4 illustrates this point-in-time variability. The flow rate profile at 1300 hours on October 7, 2006, is at a time when the Project is generating power as seen by the 15,000 cfs outflow rate at the left side of the graph. At this point-in-time, the flow rate between Box Canyon Dam and Boundary Dam ranges between 15,000 cfs and 18,200 cfs. Twelve hours later (at 0100 hours on October 8, 2006) outflow from Box Canyon has increased from 18,200 cfs to 22,800 cfs, generation at Boundary Dam has been reduced, and Boundary Reservoir is in the process of being re-filled. The flow rate profile at this later point-in-time shows significantly greater flow variability on as a product of these changed conditions.

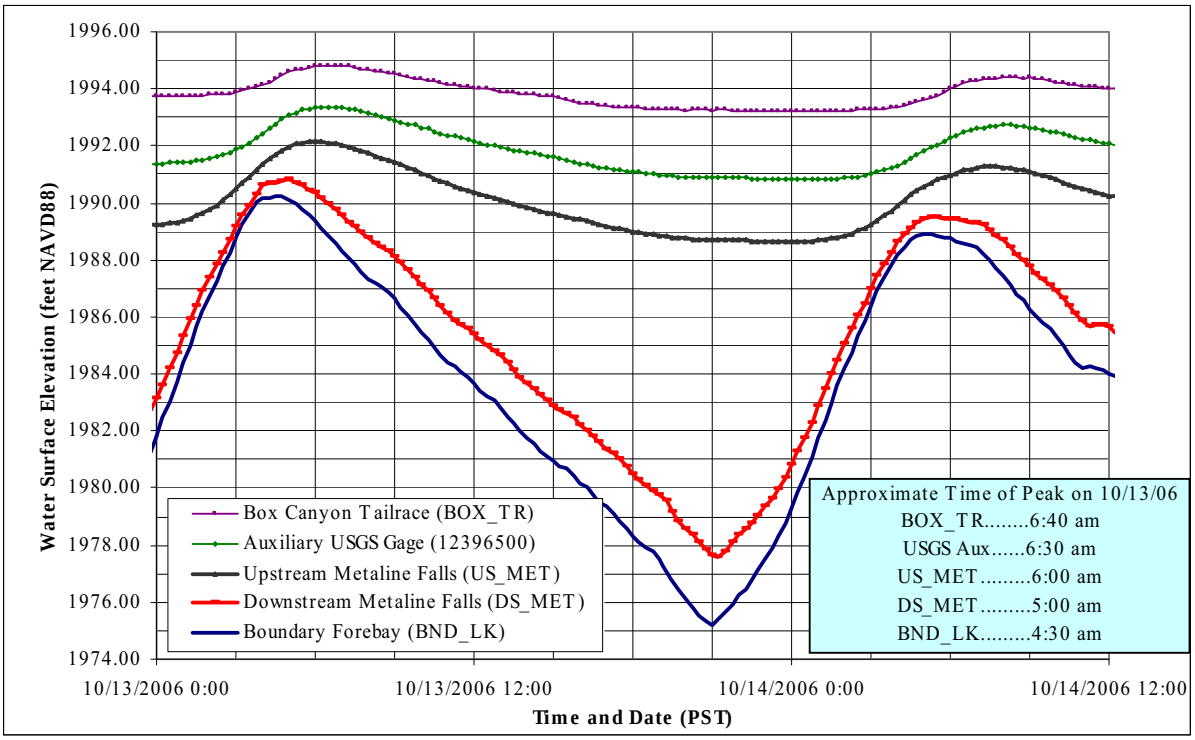


**Figure 5.3-3.** Illustration of flood wave attenuation upstream of Boundary Dam during low pool and moderate flow conditions.

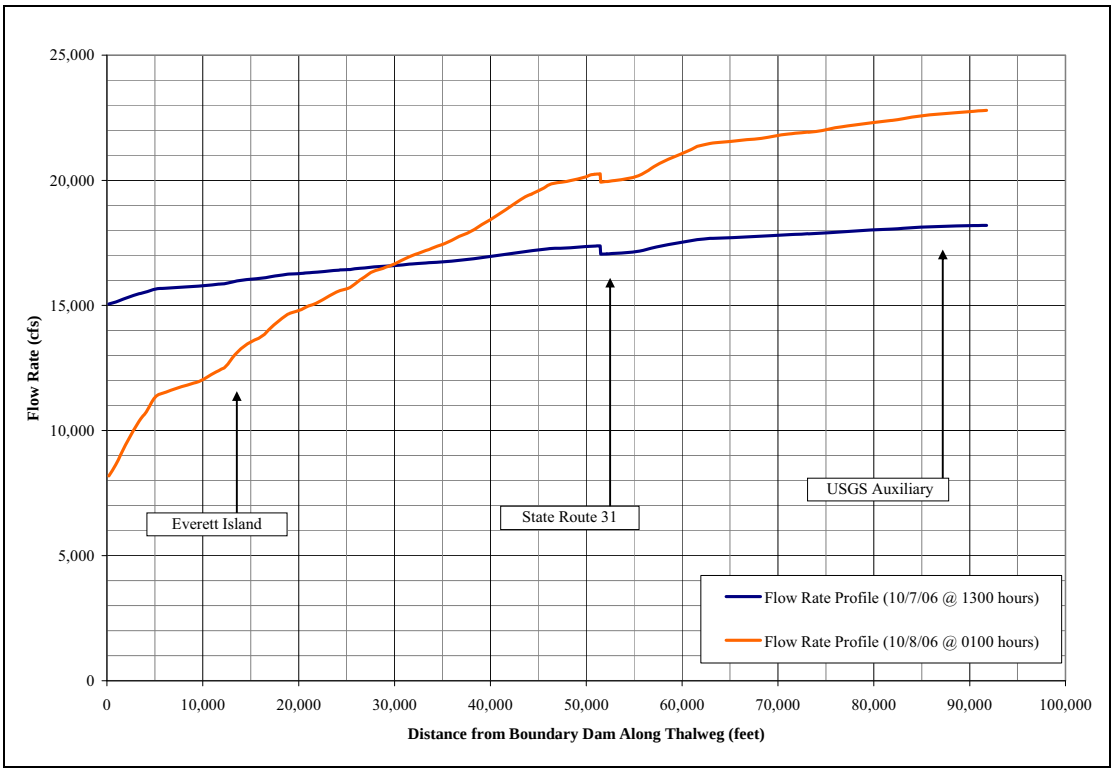


**Figure 5.3-4.** Illustration of point-in-time variability in flow rate magnitude upstream of Boundary Dam.

## 5.4. Boundary Tailrace HRM Calibration and Verification

This section presents a discussion of the initial magnitudes of the model calibration parameters, the tabular results of the model calibration, and observations made during the model calibration process for the Boundary Tailrace HRM.

### 5.4.1. Initial n-Value and Loss Coefficient Estimates

Initial estimates of the Manning's roughness coefficients and the expansion and contraction loss coefficients were based on site photos of the tailrace reach, the substrate and vegetation characterization at the habitat transects and guidance presented in USACE-HEC (2008), Barnes (1967), and Arcement and Schneider (1989). Table 5.4-1 summarizes the estimated initial values.

Left and right overbank Manning's roughness values in the tailrace reach were assigned from one of the five following categories:

- Dense trees, steep rock slopes ($0.093 < n < 0.115$)
- Dense trees, gentle rocky slopes ($0.079 < n < 0.101$)
- Dense trees, gentle slopes ($0.070 < n < 0.092$)
- Moderate to low density trees, gentle slopes ($0.051 < n < 0.073$)
- Low density trees and open meadow/grass ($0.041 < n < 0.063$)

**Table 5.4-1.** Initial estimates of model calibration parameters for Boundary Tailrace HRM.

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|
| | | Left Overbank | Channel | Right Overbank | | |
| 53077 | 50641 | 0.09 | 0.032 | 0.09 | 0.1 | 0.3 |
| 50569 | 49873 | 0.08 | 0.043 | 0.08 | 0.1 | 0.3 |
| 49657 | 47217 | 0.08 | 0.043 | 0.07 | 0.1 | 0.3 |
| 47165 | 46433 | 0.08 | 0.043 | 0.09 | 0.3 | 0.5 |
| 46331 | 46213 | 0.09 | 0.043 | 0.08 | 0.3 | 0.5 |
| 45851 | 44630 | 0.09 | 0.043 | 0.09 | 0.3 | 0.5 |
| 44283 | 43587 | 0.09 | 0.036 | 0.09 | 0.3 | 0.5 |
| 43200 | 42700 | 0.09 | 0.036 | 0.08 | 0.1 | 0.3 |
| 42358 | 41219 | 0.08 | 0.036 | 0.07 | 0.1 | 0.3 |
| 40792 | 36549 | 0.08 | 0.036 | 0.09 | 0.1 | 0.3 |
| 36085 | 35263 | 0.08 | 0.028 | 0.08 | 0.1 | 0.3 |
| 34886 | 34392 | 0.09 | 0.028 | 0.09 | 0.1 | 0.3 |
| 33876 | 30612 | 0.08 | 0.028 | 0.08 | 0.1 | 0.3 |
| 29988 | 28950 | 0.08 | 0.028 | 0.06 | 0.1 | 0.3 |
| 28416 | 27440 | 0.09 | 0.028 | 0.09 | 0.1 | 0.3 |
| 26960 | 25967 | 0.08 | 0.028 | 0.08 | 0.1 | 0.3 |
| 25374 | 22423 | 0.08 | 0.028 | 0.09 | 0.1 | 0.3 |

**Table 5.4-1, continued…**

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|
| | | Left Overbank | Channel | Right Overbank | | |
| 21942 | 20968 | 0.08 | 0.028 | 0.07 | 0.1 | 0.3 |
| 20497 | 14482 | 0.08 | 0.028 | 0.08 | 0.1 | 0.3 |
| 13939 | 8438 | 0.08 | 0.028 | 0.07 | 0.1 | 0.3 |
| 7968 | 7394 | 0.09 | 0.028 | 0.08 | 0.1 | 0.3 |
| 6953 | 126 | 0.08 | 0.028 | 0.06 | 0.1 | 0.3 |

Notes:
1 Refer to figures in Attachment A for HEC-RAS cross section locations.
D/S – downstream
U/S – upstream

### 5.4.2. Final Calibration and Verification

Similar to the calibration of the Boundary Reservoir HRM, Phase One of the calibration of the Boundary Tailrace HRM was attained through an iterative process proceeding from the downstream end of the model (Seven Mile forebay) to the upstream end of the model (Boundary tailrace), using the nine calibration periods defined previously in Section 4.2. The magnitudes of the Manning's roughness coefficients and the expansion and contraction loss coefficients were iteratively adjusted within physically acceptable ranges. The iterative process was continued until the model-predicted water surface elevations were within the calibration criteria established in Section 4.2. The calibration process also included defining ineffective flow areas within pertinent cross sections so as to simulate flow expansion and contraction in a physically consistent manner. Flow was allowed to expand at a rate of no more than 1:4 (lateral: longitudinal). Flow was allowed to contract at a rate of no more than 1:1 (lateral: longitudinal).

In the early stages of the Phase One calibration effort, it became apparent that there were going to be difficulties associated with calibrating the Boundary Tailrace HRM within the calibration criteria established in Section 4.2. The difficulties were primarily associated with matching the precise timing of the stage hydrographs at the transducer locations, which resulted in producing maximum differences in excess of the 0.75-foot calibration criteria. The root cause of this was the timing of the data provided for the boundary conditions. The raw Boundary outflow data (upstream boundary condition) were provided by SCL in the form of an average hourly flow dataset. These raw data were then synthesized by R2 Resource Consultants into a 15-minute instantaneous dataset so as to be consistent with the pressure transducer time intervals. Because the raw data were average hourly flows, any short-term spikes or changes in outflow within a given hour would be averaged out. It is also a possibility that the process of synthesizing the average hourly flows may not have resulted in exactly matching the actual timing of the Boundary outflow. Fluctuations in the Boundary outflow hydrograph are the primary driver in producing the water surface fluctuations downstream of the dam, so any timing discrepancies in the outflow hydrograph dataset will result in the model output not matching the precise timing of

the stage hydrographs at the pressure transducer locations. For this reason, the calibration criteria were redefined for the Boundary Tailrace HRM as follows:

- Maximum absolute difference between the observed water surface elevation hydrograph and the model predicted water surface elevation hydrograph of *less than 1.50 feet* for each calibration location within each calibration period
- RMSE between observed and model predicted less than 0.50 foot for each calibration location within each calibration period

With the completion of Phase One of the calibration procedure, the model was executed for the six verification periods defined in Section 4.2 (Phase Two). Model predicted water surface elevations were compared to the continuous data from the pressure transducers. The model predicted water surface elevations were also compared to the water surface elevations surveyed during the habitat transect data collection periods. The results of the Phase Two verification indicated that the calibrated model was successfully able to predict water surface elevations within the revised calibration criteria for all of the continuous data collection stations and for the habitat transects.

#### *5.4.2.1. Tabular Results for Calibration Periods*

Table 5.4-2 presents the final values for the model calibration parameters for the Boundary Tailrace HRM. The magnitudes of the calibrated Manning's roughness value for the main channel downstream of XS 40245 were higher than initially estimated. The driver for these high Manning's roughness values was the high flow condition. It was found that higher than expected Manning's roughness values were required to match the observed water surface elevations at the BRIDGE pressure transducer location for high flow conditions. Upstream of XS 40245, the magnitudes of the calibrated Manning's roughness value for the main channel were higher than initially estimated; however, the values are still within a physically acceptable range given the substrate characterization of the reach downstream of Boundary Dam.

The Manning's roughness values determined for the overbank areas were slightly higher than initially estimated; however, the values are not outside of the range expected for the conditions of the reach downstream of Boundary Dam.

**Table 5.4-2.** Final model calibration parameters for Boundary Tailrace HRM.

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|
| | | Left Overbank | Channel | Right Overbank | | |
| 53077 | 52199 | 0.104 | 0.05 | 0.104 | 0.5 | 0.7 |
| 51892 | 51892 | 0.072 | 0.05 | 0.104 | 0.5 | 0.7 |
| 51598 | 51598 | 0.072 | 0.05 | 0.077 | 0.5 | 0.7 |
| 51418 | 51225 | 0.072 | 0.058 | 0.077 | 0.5 | 0.7 |
| 50974 | 50641 | 0.077 | 0.058 | 0.077 | 0.5 | 0.7 |
| 50569 | 50326 | 0.077 | 0.06 | 0.083 | 0.5 | 0.7 |
| 50168 | 49652 | 0.091 | 0.06 | 0.083 | 0.5 | 0.7 |
| 49232 | 48652 | 0.091 | 0.06 | 0.083 | 0.3 | 0.5 |

**Table 5.4-2, continued…**

| U/S HEC-RAS Cross Section[1] | D/S HEC-RAS Cross Section[1] | Manning's Roughness | | | Contraction Coefficient | Expansion Coefficient |
|---|---|---|---|---|---|---|
| | | Left Overbank | Channel | Right Overbank | | |
| 48064 | 48064 | 0.091 | 0.06 | 0.083 | 0.5 | 0.7 |
| 47677 | 47217 | 0.101 | 0.055 / 0.09 | 0.10 | 0.5 | 0.7 |
| 47165 | 46794 | 0.101 | 0.055 / 0.09 | 0.115 | 0.5 | .07 |
| 46433 | 46433 | 0.101 | 0.075 / 0.085 | 0.115 | 0.5 | 0.7 |
| 46331 | 45410 | 0.115 | 0.075 / 0.085 | 0.10 | 0.5 | 0.7 |
| 45207 | 44630 | 0.115 | 0.066 / 0.075 | 0.115 | 0.5 | 0.7 |
| 44283 | 40792 | 0.115 | 0.066 | 0.115 | 0.3 | 0.5 |
| 40245 | 37323 | 0.10 | 0.088 | 0.11 | 0.5 | 0.7 |
| 37114 | 34650 | 0.125 | 0.083 | 0.11 | 0.5 | 0.7 |
| 34392 | 34392 | 0.125 | 0.074 | 0.11 | 0.5 | 0..7 |
| 33876 | 30612 | 0.125 | 0.074 | 0.125 | 0.1 | 0.3 |
| 29988 | 28950 | 0.125 | 0.074 | 0.09 | 0.1 | 0.3 |
| 28416 | 27964 | 0.125 | 0.074 | 0.11 | 0.1 | 0.3 |
| 27440 | 26412 | 0.1 | 0.074 | 0.11 | 0.1 | 0.3 |
| 25967 | 24388 | 0.1 | 0.074 | 0.1 | 0.1 | 0.3 |
| 23440 | 20497 | 0.1 | 0.074 | 0.09 | 0.1 | 0.3 |
| 19934 | 19934 | 0.1 | 0.074 | 0.11 | 0.1 | 0.3 |
| 19425 | 5426 | 0.125 | 0.074 | 0.11 | 0.1 | 0.3 |
| 5019 | 4385 | 0.125 | 0.074 | 0.075 | 0.1 | 0.3 |
| 3918 | 1397 | 0.125 | 0.074 | 0.1 | 0.1 | 0.3 |
| 888 | 126 | 0.075 | 0.074 | 0.075 | 0.1 | 0.3 |

Note:
1 Refer to figures in Section 8 for HEC-RAS cross section locations.

Tables 5.4-3, 5.4-4, and 5.4-5 present tabular summaries of the results of the model calibration for each calibration period at each of the three calibration locations. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time ordinates at each calibration location for each calibration period. Since the calibration periods encompass a total of 217 days of observed conditions, nearly 20,800 time ordinate comparisons were made at each of the calibration locations.

The first table, Table 5.4-3, shows that for more than 92 percent of the time during the calibration periods, the model-predicted water surface elevations were within 0.6 feet of the observed water surface elevations at all of the calibration locations. Table 5.4-3 also shows that the model-predicted water surface elevations were within 0.4 feet of the observed water surface elevations more than 77 percent of the time at all calibration locations.

There were instances where the calibrated model was not able to replicate observed conditions within the revised calibration criteria. Theses instances were attributed to incorrect timing of the

boundary condition data or erroneous boundary condition data, as was the case for the Lo_Mod2 calibration period. All such instances were reviewed to determine the exact cause and then were deleted from the comparisons and results reported in Tables 5.4-3 through 5.4-5. Shaded boxes in these tables indicate calibration periods during which short portions of the results were not included in the evaluation of the calibration success. Figure 5.4-1 illustrates the portion of the Lo_Lo calibration period where the model was unable to replicate the timing of the stage hydrograph at the BND_TR pressure transducer location on account of the timing of the boundary condition data. This figure shows that for a four hour time period, the model predicted water surface elevation was shifted relative to the observed condition, while for the remainder of the time shown in the figure, the model predicted water surface elevation matches the timing of the observed condition.

**Table 5.4-3.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all calibration periods – Boundary Tailrace HRM.

| Cumulative Range | Calibration Location | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| < 0.2 feet | 43.40 % | 56.97 % | 73.76 % |
| < 0.4 feet | 77.63 % | 84.11 % | 97.43 % |
| < 0.6 feet | 94.44 % | 92.31 % | 99.79 % |
| < 0.8 feet | 98.45 % | 96.13 % | 100.00 % |
| < 1.0 feet | 99.52 % | 98.54 % | 100.00 % |
| < 1.2 feet | 99.85 % | 99.69 % | 100.00 % |
| < 1.4 feet | 99.99 % | 99.95 % | 100.00 % |
| < 1.5 feet | 100.00 % | 99.99 % | 100.00 % |

Notes:
There were a total of 217 calendar days represented in the calibration periods.
Model output and observed data were compared at 15-minute intervals
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-4.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for each calibration period – Boundary Tailrace HRM.

| Calibration Period | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for each Calibration Period | | |
|---|---|---|---|---|
| | | **BND_TR** | **BORDER** | **BRIDGE** |
| | | **53077[1]** | **47677[1]** | **40245[1]** |
| Hi_Lo | Maximum Positive | + 0.8 | + 0.5 | n/a |
| | Maximum Negative | - 0.9 | - 0.9 | n/a |
| Hi_Mod | Maximum Positive | + 1.4 | + 0.7 | n/a |
| | Maximum Negative | - 0.8 | - 0.7 | n/a |
| Hi_Hi | Maximum Positive | + 1.1 | + 1.4 | n/a |
| | Maximum Negative | - 0.8 | - 1.4 | n/a |
| Hi_Hi2 | Maximum Positive | + 1.1 | + 0.7 | + 0.6 |
| | Maximum Negative | - 0.7 | - 0.8 | - 0.6 |
| Lo_Lo | Maximum Positive | + 1.4 | + 1.6 | n/a |
| | Maximum Negative | - 1.4 | - 1.5 | n/a |
| Lo_Mod | Maximum Positive | + 1.1 | + 1.5 | n/a |
| | Maximum Negative | - 1.3 | - 1.4 | n/a |
| Lo_Mod2 | Maximum Positive | + 1.3 | + 1.2 | + 0.6 |
| | Maximum Negative | - 1.0 | - 0.7 | - 0.5 |
| Lo_Hi | Maximum Positive | + 1.2 | + 0.8 | n/a |
| | Maximum Negative | - 0.4 | - 0.7 | n/a |
| Var_Var | Maximum Positive | + 1.5 | + 0.9 | + 0.7 |
| | Maximum Negative | - 0.8 | - 0.7 | - 0.4 |

Notes:
N/A indicates observed data not available for calibration period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-5.** Root mean square error (RMSE) at each calibration location for each calibration period – Boundary Tailrace HRM.

| Calibration Period | Root Mean Square Error (feet) at each Calibration Location for each Calibration Period | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| Hi_Lo | 0.18 | 0.29 | n/a |
| Hi_Mod | 0.35 | 0.15 | n/a |
| Hi_Hi | 0.37 | 0.38 | n/a |
| Hi_Hi2 | 0.30 | 0.25 | 0.17 |
| Lo_Lo | 0.34 | 0.48 | n/a |
| Lo_Mod | 0.37 | 0.66 | n/a |
| Lo_Mod2 | 0.32 | 0.25 | 0.15 |
| Lo_Hi | 0.43 | 0.21 | n/a |
| Var_Var | 0.30 | 0.17 | 0.21 |

Notes:
N/A indicates observed data not available for calibration period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.

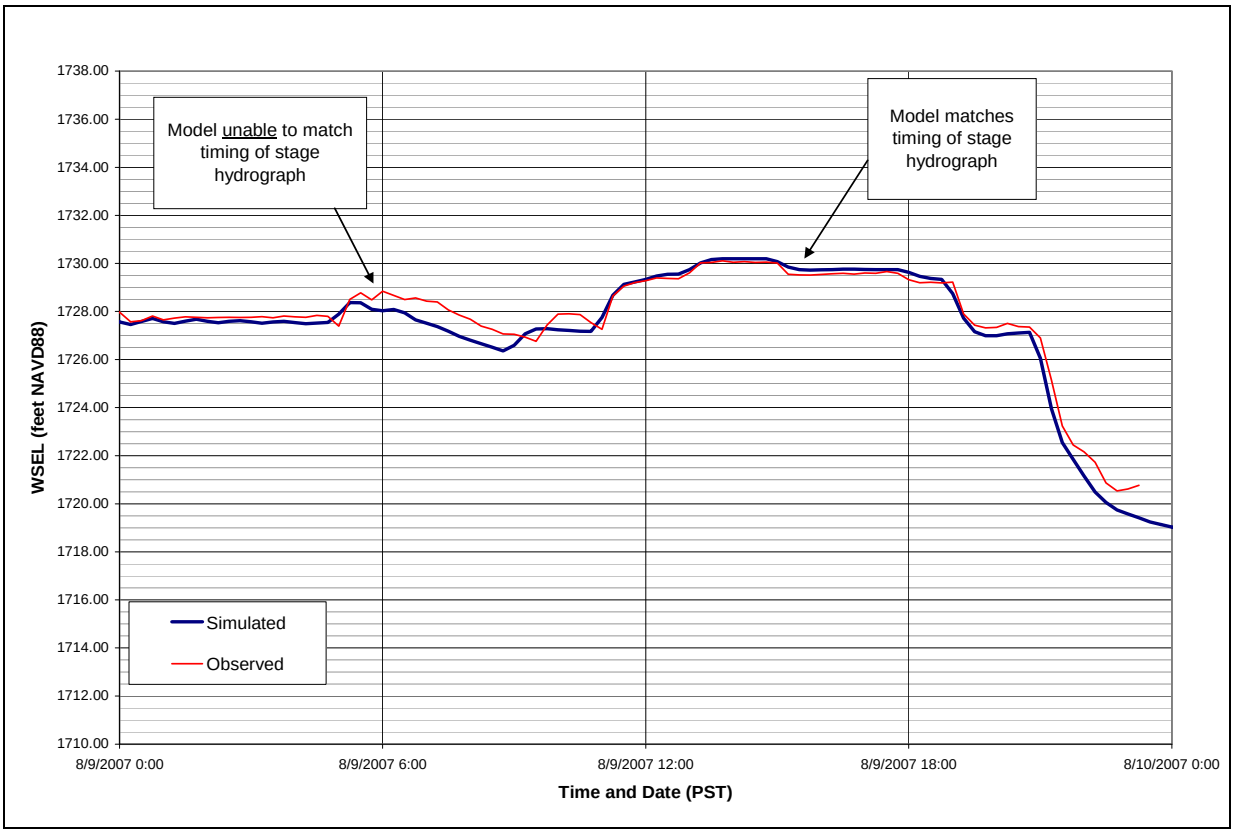


**Figure 5.4-1.** Example of timing issues encountered during calibration of Boundary Tailrace HRM.

Table 5.4-4 summarizes the maximum positive and maximum negative error at each calibration location within each calibration period. Positive values in this table indicate model-predicted water surface elevations that were greater than observed for the particular calibration location and calibration period. Negative values in this table indicate model-predicted water surface elevations less than observed. Those locations where the difference between the model-predicted water surface elevation and the observed water surface elevation was greater than 1.50 feet are indicated as shaded boxes in the table. However, as explained earlier, each of these instances is attributed to incorrect timing or magnitude of the boundary condition data and is not indicative of an unsuccessful model calibration.

Finally, Table 5.4-5 illustrates how well the calibrated model replicated observed conditions, using the RMSE as the objective evaluator. For example, this table indicates that the calibrated hydraulic model predicted water surface elevations for the entire Hi_Hi2 calibration period within an average error of less than 0.30 foot at each of the calibration locations. The RMSE was less than or equal to 0.48 for all calibration locations within each of the calibration periods, thus exceeding the calibration criteria.

#### 5.4.2.2. Tabular Results for Verification Periods

This section presents tabular results of the calibrated model predicted water surface elevations for the six verification periods at each of the three continuous data collection locations. Because the verification time periods were also inclusive of the time periods when water surface elevation data were collected at each of the habitat transects, this section also includes comparisons of the calibrated model predicted water surface elevations against the water surface elevations surveyed at the habitat transect locations.

Model predicted water surface elevations were compared against the water surface elevations surveyed at each habitat transect. For a given target flow and forebay condition, water surfaces were typically surveyed on each bank of the habitat transects. With only three exceptions, the difference between the model predicted and field surveyed water surface elevations at the habitat transects were within the original calibration criteria outline in Section 4.2. The model verification results at the habitat transect locations are summarized in Table 5.4-6. Model-predicted water surface elevations were greater than 0.75 foot for only three habitat transect water surface elevation measurements. All three of them were during the High Pool_High Flow condition at TR-09.

**Table 5.4-6.** Cumulative percent of occurrences when model water surface elevation was within specified range of surveyed water surface elevation at habitat transects – Boundary Tailrace HRM.

| Cumulative Range | Tailrace Reach |
|---|---|
| < 0.2 feet | 42.67 % |
| < 0.4 feet | 70.67 % |
| < 0.6 feet | 88.00 % |
| < 0.75 feet | 96.00 % |
| < 1.0 feet | 98.67 % |

Note:
1 There were 75 data points for the Tailrace Reach.

Tables 5.4-7, 5.4-8, and 5.4-9 present tabular summaries of the results of the model verification for each verification period at each of the three calibration locations. These tables are the same format as those tables previously presented for the calibration results. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time ordinates at each calibration location for each verification period. As was done for the calibration periods, the few instance where anomalies in boundary condition data resulted in differences between observed and modeled water surface elevations that were greater than the calibration criteria were removed from the comparison and are therefore not included in Tables 5.4-7 through 5.4-9. Because the verification periods encompass a total of 136 days of observed conditions, approximately 13,100 time ordinate comparisons were made at each of the calibration locations.

**Table 5.4-7.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for all verification periods—Boundary Tailrace HRM.

| Cumulative Range | Calibration Location | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077**[1] | **47677**[1] | **40245**[1] |
| < 0.2 feet | 45.08 % | 67.87 % | N/A |
| < 0.4 feet | 79.75 % | 87.57 % | N/A |
| < 0.6 feet | 93.71 % | 93.33 % | N/A |
| < 0.8 feet | 97.68 % | 96.60 % | N/A |
| < 1.0 feet | 99.24 % | 98.86 % | N/A |
| < 1.2 feet | 99.78 % | 99.68 % | N/A |
| < 1.4 feet | 99.97 % | 99.94 % | N/A |
| < 1.5 feet | 100.00 % | 100.00 % | N/A |

Notes:
There were a total of 136 calendar days represented in the verification periods.
Model output and observed data were compared at 15-minute intervals
N/A indicates that none of the verification periods included time periods when the BRIDGE pressure transducer was collecting data
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-8.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for each verification period—Boundary Tailrace HRM.

| Verification Period | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for each Verification Period | | |
|---|---|---|---|---|
| | | **BND_TR** | **BORDER** | **BRIDGE** |
| | | **53077[1]** | **47677[1]** | **40245[1]** |
| Hi_Lo | Maximum Positive | + 1.3 | +1.1 | N/A |
| | Maximum Negative | - 1.4 | - 1.5 | N/A |
| Hi_Mod | Maximum Positive | + 1.2 | + 0.7 | N/A |
| | Maximum Negative | - 0.7 | - 0.6 | N/A |
| Hi_Hi | Maximum Positive | +1.5 | + 1.2 | N/A |
| | Maximum Negative | - 0.5 | - 0.7 | N/A |
| Lo_Lo | Maximum Positive | +1.0 | + 1.5 | N/A |
| | Maximum Negative | -1.0 | - 0.7 | N/A |
| Lo_Mod | Maximum Positive | + 1.2 | +1.2 | N/A |
| | Maximum Negative | - 0.9 | - 0.6 | N/A |
| Lo_Hi | Maximum Positive | +1.1 | + 1.0 | N/A |
| | Maximum Negative | - 0.4 | - 0.5 | N/A |

Notes:
N/A indicates observed data not available for verification period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-9.** Root mean square error (RMSE) at each calibration location for each verification period—Boundary Tailrace HRM.

| Verification Period | Root Mean Square Error (feet) at each Calibration Location for each Verification Period | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| Hi_Lo | 0.36 | 0.44 | N/A |
| Hi_Mod | 0.28 | 0.16 | N/A |
| Hi_Hi | 0.42 | 0.17 | N/A |
| Lo_Lo | 0.31 | 0.51 | N/A |
| Lo_Mod | 0.27 | 0.28 | N/A |
| Lo_Hi | 0.33 | 0.19 | N/A |

Notes:
N/A indicates observed data not available for calibration period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.

Table 5.4-6 shows that the calibrated hydraulic model accurately predicted water surface elevations at all habitat transect locations. With only three exceptions (all at TR-09), the calibrated hydraulic model predicted water surface elevations within 0.75 feet of the measured water surface elevations. These results are important because it illustrates that the model is accurately predicting water surface elevations along the entire length of the tailrace reach.

Table 5.4-7 shows that for more than 93 percent of the time during the verification periods, the model-predicted water surface elevations were within 0.6 feet of the observed water surface elevations at all of the calibration locations. Table 5.3-7 also shows that the model-predicted water surface elevations were within 0.4 foot of the observed water surface elevations more than 79 percent of the time. As described previously in this section, a revised goal of a maximum absolute difference of 1.50 feet was established as a calibration criterion. Table 5.3-7 clearly shows that this goal was attained at the all calibration locations for all of the verification periods.

Table 5.4-8 summarizes the maximum positive and maximum negative differences at each calibration location for each verification period. Those locations where the maximum difference between the model-predicted water surface elevation and the observed water surface elevation was greater than 1.50 feet are indicated as shaded boxes in the table. Similar to the calibration period results, these anomalies were removed from the comparison and are not included in the results presented in Tables 5.4-6 through 5.4-9.

Finally, Table 5.4-9 illustrates how well the calibrated model replicated observed conditions for the verification periods, using the RMSE as the objective evaluator. For example, this table indicates that the calibrated hydraulic model predicted water surface elevations for the Lo_Mod verification period within an average error of less than 0.28 foot at each of the calibration

locations. The RMSE was less than or equal to 0.51 for all calibration locations within each of the verification periods.

The results presented in Tables 5.4-6 through 5.4-9 clearly validate and verify the calibration of the Boundary Tailrace HRM. This conclusion is substantiated by the fact that the accuracy of the Boundary Tailrace HRM for the verification periods equaled or exceeded that of the calibration periods, thereby verifying the calibrated model.

#### *5.4.2.3. Tabular Results for Broad Verification Period*

The final step of the calibration process was to execute the calibrated model for the entire 23-month period of pressure transducer data for the Boundary Tailrace HRM. This 23-month run of the model included all of the calibration and verification periods. The time period for this model run was September 2006 through mid-July 2008. This step is considered a broad verification of the calibrated model in that it provides verification of the model calibration using all of pressure transducer data collected in the Boundary Reservoir. Tables 5.4-10, 5.4-11, and 5.4-12 present tabular summaries of the results of the model verification for the broad verification period at each of the three calibration locations. These tables are the same format as those tables previously presented for the calibration and verification periods, except that the model output is organized and presented by month. For the development of these tables, the model-predicted water surface elevation was compared to the observed water surface elevation at each of the 15-minute time ordinates. Anomalies in the boundary condition data that resulted in maximum differences between the model predicted water surface elevation and the observed water surface elevation that were greater than 1.50 feet were removed from the comparison and are not included in the following tables. Because the broad verification period included nearly 23 months of continuously collected data, there were more than 58,000 time ordinate comparisons made at each of the BND_TR and BORDER pressure transducer locations and more than 13,000 time ordinate comparisons made at the BRIDGE pressure transducer location.

**Table 5.4-10.** Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the broad verification period – Boundary Tailrace HRM.

| Cumulative Range | Calibration Location | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| < 0.2 feet | 45.18 % | 56.73 % | 52.31 % |
| < 0.4 feet | 78.42 % | 79.90 % | 88.72 % |
| < 0.6 feet | 93.93 % | 89.26 % | 98.94 % |
| < 0.8 feet | 98.17 % | 95.14 % | 99.95 % |
| < 1.0 feet | 99.45 % | 98.47 % | 100.00 % |
| < 1.2 feet | 99.83 % | 99.61 % | 100.00 % |
| < 1.4 feet | 99.98 % | 99.92 % | 100.00 % |
| < 1.5 feet | 99.99 % | 99.98 % | 100.00 % |

Notes:
There were a total of 23 months represented in the broad verification period.
Model output and observed data were compared at 15-minute intervals.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-11.** Magnitude of maximum difference between observed and simulated water surface elevation at each calibration location for broad verification period – Boundary Tailrace HRM.

| Month | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for Broad Verification Period | | |
|---|---|---|---|---|
| | | **BND_TR** | **BORDER** | **BRIDGE** |
| | | **53077[1]** | **47677[1]** | **40245[1]** |
| September 2006 | Max Positive | + 0.8 | + 0.5 | N/A |
| | Max Negative | - 0.9 | - 0.9 | N/A |
| October 2006 | Max Positive | + 1.1 | + 1.5 | N/A |
| | Max Negative | - 1.0 | - 0.9 | N/A |
| November 2006 | Max Positive | + 1.5 | + 1.2 | N/A |
| | Max Negative | - 0.8 | - 0.9 | N/A |
| December 2006 | Max Positive | + 1.4 | + 0.8 | N/A |
| | Max Negative | - 0.8 | - 0.7 | N/A |
| January 2007 | Max Positive | + 1.4 | + 1.2 | N/A |
| | Max Negative | - 1.0 | - 0.6 | N/A |
| February 2007 | Max Positive | + 1.2 | + 1.2 | N/A |
| | Max Negative | - 1.2 | - 0.7 | N/A |
| March 2007 | Max Positive | + 1.5 | + 1.4 | N/A |
| | Max Negative | - 1.2 | - 1.0 | N/A |
| April 2007 | Max Positive | + 1.5 | + 0.9 | N/A |
| | Max Negative | - 0.5 | - 1.2 | N/A |

**Table 5.4-11, continued...**

| Month | | Magnitude of Maximum Difference (feet) between Model Predicted and Observed Conditions at each Calibration Location for Broad Verification Period | | |
|---|---|---|---|---|
| | | **BND_TR** | **BORDER** | **BRIDGE** |
| | | **53077[1]** | **47677[1]** | **40245[1]** |
| May 2007 | Max Positive | + 1.2 | + 1.4 | N/A |
| | Max Negative | - 1.1 | - 1.6 | N/A |
| June 2007 | Max Positive | + 1.3 | + 1.0 | N/A |
| | Max Negative | - 1.5 | - 1.5 | N/A |
| July 2007 | Max Positive | + 1.1 | + 1.5 | N/A |
| | Max Negative | - 1.3 | - 1.4 | N/A |
| August 2007 | Max Positive | + 1.4 | + 1.6 | N/A |
| | Max Negative | - 1.4 | - 1.5 | N/A |
| September 2007 | Max Positive | + 1.5 | + 1.3 | N/A |
| | Max Negative | - 1.4 | - 1.5 | N/A |
| October 2007 | Max Positive | + 1.2 | + 0.9 | N/A |
| | Max Negative | - 1.4 | - 1.5 | N/A |
| November 2007 | Max Positive | + 1.5 | + 0.7 | N/A |
| | Max Negative | - 1.0 | - 1.0 | N/A |
| December 2007 | Max Positive | + 1.3 | + 0.6 | N/A |
| | Max Negative | - 0.7 | - 0.7 | N/A |
| January 2008 | Max Positive | + 1.3 | + 0.8 | N/A |
| | Max Negative | - 1.2 | - 0.8 | N/A |
| February 2008 | Max Positive | + 1.2 | + 0.7 | + 0.4 |
| | Max Negative | - 0.8 | - 0.6 | - 0.3 |
| March 2008 | Max Positive | + 1.5 | + 0.9 | + 0.7 |
| | Max Negative | - 0.8 | - 0.7 | - 0.4 |
| April 2008 | Max Positive | + 1.3 | + 1.2 | + 0.6 |
| | Max Negative | - 1.0 | - 0.6 | - 0.5 |
| May 2008 | Max Positive | + 1.1 | + 1.4 | + 0.7 |
| | Max Negative | - 0.7 | - 1.6 | - 0.9 |
| June 2008 | Max Positive | N/A | + 1.0 | + 0.5 |
| | Max Negative | N/A | - 1.5 | - 0.9 |
| July 2008 | Max Positive | N/A | + 0.2 | + 0.2 |
| | Max Negative | N/A | - 1.3 | - 0.7 |

Notes:
N/A indicates observed data not available for calibration period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.
Difference computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where anomalies were removed from the comparison.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.

**Table 5.4-12.** Root mean square error (RMSE) at each calibration location for broad verification period – Boundary Tailrace HRM.

| Month | Root Mean Square Error (feet) at each Calibration Location for Broad Verification Period | | |
|---|---|---|---|
| | **BND_TR** | **BORDER** | **BRIDGE** |
| | **53077[1]** | **47677[1]** | **40245[1]** |
| September 2006 | 0.18 | 0.29 | N/A |
| October 2006 | 0.27 | 0.31 | N/A |
| November 2006 | 0.36 | 0.23 | N/A |
| December 2006 | 0.32 | 0.16 | N/A |
| January 2007 | 0.31 | 0.20 | N/A |
| February 2007 | 0.27 | 0.25 | N/A |
| March 2007 | 0.39 | 0.20 | N/A |
| April 2007 | 0.44 | 0.21 | N/A |
| May 2007 | 0.39 | 0.40 | N/A |
| June 2007 | 0.40 | 0.43 | N/A |
| July 2007 | 0.35 | 0.57 | N/A |
| August 2007 | 0.35 | 0.47 | N/A |
| September 2007 | 0.34 | 0.43 | N/A |
| October 2007 | 0.38 | 0.39 | N/A |
| November 2007 | 0.25 | 0.19 | N/A |
| December 2007 | 0.31 | 0.16 | N/A |
| January 2008 | 0.30 | 0.18 | N/A |
| February 2008 | 0.29 | 0.16 | 0.12 |
| March 2008 | 0.30 | 0.18 | 0.20 |
| April 2008 | 0.32 | 0.22 | 0.15 |
| May 2008 | 0.29 | 0.51 | 0.26 |
| June 2008 | --[2] | 0.71 | 0.35 |
| July 2008 | -- | 0.60 | 0.29 |

Note:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration location.
2 No data available
N/A indicates observed data not available for calibration period at BRIDGE pressure transducer location. The BRIDGE pressure transducer was installed on February 26, 2008.

### *5.4.2.4. Graphical Results of Boundary Tailrace HRM Calibration*

This section presents the final calibration results in the form of graphical output of the calibrated model to provide illustration of the success of the model calibration. Figures 5.4-2 is a time series plots that compares the water surface elevations predicted by the calibrated Boundary Tailrace HRM to the observed water surface elevations. This figure is for the BORDER pressure transducer location for the Lo_Hi calibration period (Low Pool and High Flow). Attachment C of this report contains identical plots for each of the three calibration locations during each of the

nine calibration periods. Section 8 also contains these same types of plots for each of the three calibration locations during each of the six verification periods. The statistical summary of maximum absolute difference in Figure 5.4-2 (and all similar figures in Attachment C) includes the anomalies that were deleted from the model calibration tables in the previous sections of this report.

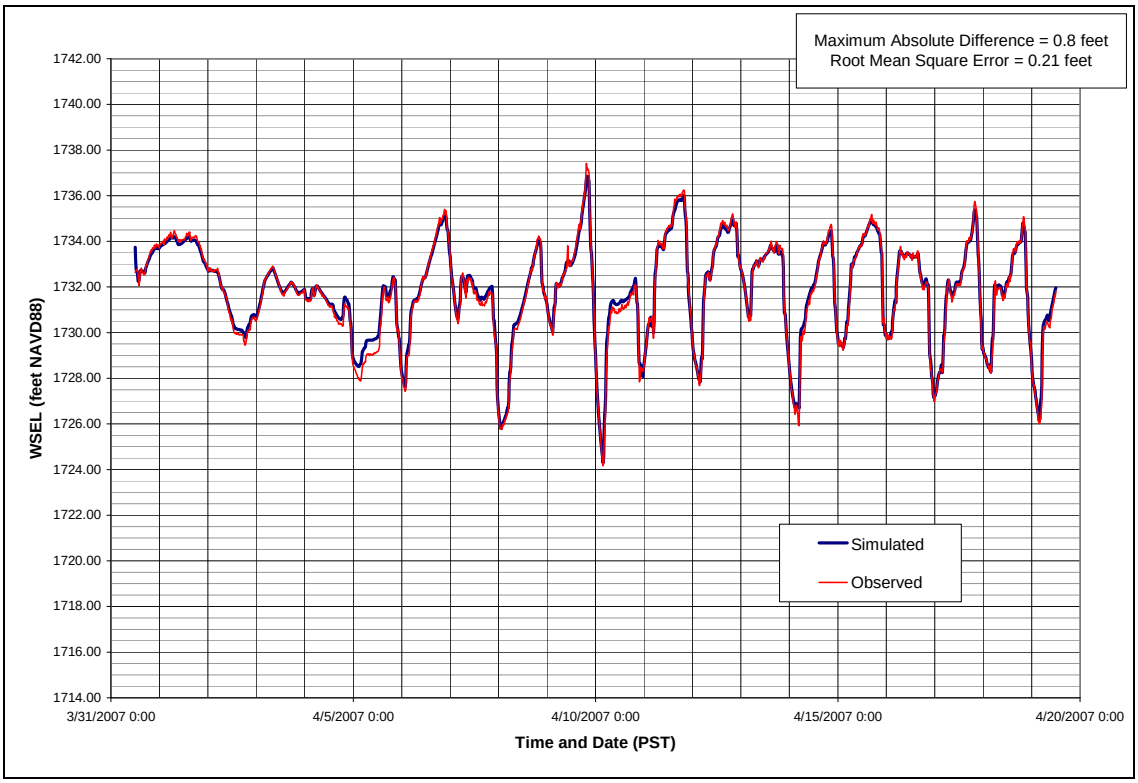


**Figure 5.4-2.** Model calibration results for Lo_Hi calibration period at BORDER pressure transducer location for Boundary Tailrace HRM.

In addition to illustrating the success of the model calibration in replicating the rising and falling limbs of the operationally induced waves, it is seen in Figure 5.4-2 that the calibrated model resulted in very good replication of the timing of the peaks. These peaks are the by-product of existing Project operations. Quantitative analysis of the accuracy of the model's ability to predict peak timing was not conducted, but time series plots such as shown in Figure 5.4-2 provided the basis to state qualitatively that the model was accurately replicating the timing of fluctuating water surface elevations, and therefore the translation of the operationally induced wave, throughout the length of the Tailrace Reach.

Based on the tables presented in Section 5.4.2 and the comparative time series plots presented in Attachment C, it is concluded that the calibration of the Boundary Tailrace HRM was successfully completed. The time period to which the Boundary Tailrace HRM was calibrated included flow rates (Boundary Dam outflow) that ranged between 0 cfs and 108,900 cfs and

included Seven Mile Dam forebay elevations that ranged between 1,702.43 and 1,736.16 feet NAVD 88 (1,698.40 and 1,732.13 feet NGVD 29).

## 5.5. Assessment of the Need for Separate Seasonal Hydraulic Models

Successful calibration and verification of the Boundary Reservoir HRM was attained for the 19-month data collection period without the need for using seasonal correction factors to account for the presumed increase in hydraulic resistance due to the presence of macrophytes. This led to the initial conclusion that the growth patterns of macrophytes in the Pend Oreille River have less influence on the hydraulic resistance in the Pend Oreille River than initially theorized. Macrophyte growth in the Pend Oreille River occurs primarily in shallow portions of the cross sections or in side channel areas where flow is not effectively conveyed or where average velocities are very low. There are instances where macrophytes were observed to occur within deeper portions adjacent to the main channel, such as adjacent to the large center bar near the Town of Metaline. However, this area is affected by backwater from Metaline Falls and average velocities are on the order of 1 foot per second, even during high flow conditions. Therefore, the initial conclusion that growth patterns of macrophytes in the Pend Oreille River likely have minimal influence on the hydraulic resistance is consistent with the physical conditions of macrophyte growth patterns in the Pend Oreille River.

To verify this initial conclusion, the results of the calibrated Boundary Reservoir HRM were reviewed to determine if the model was consistently underpredicting water surface elevations during the periods of peak macrophyte growth. This would be expected if the calibrated hydraulic roughness parameters were not accurately accounting for the increased hydraulic resistance contributed by the macrophyte growth.

Model results were reviewed for three hydrologic conditions related to Box Canyon outflow rate. For each hydrologic condition, a short time period (typically 12 hours in duration) was identified corresponding to a period of no macrophyte growth and an equivalent duration time period was chosen corresponding to when macrophytes would be expected to be present. To minimize the influence of other variables in this comparison, the two time periods were chosen so as to have roughly equivalent flow conditions and Boundary forebay conditions. Table 5.5-1 summarizes the periods that were selected for each hydrologic condition.

**Table 5.5-1.** Time periods used in review of calibrated model results to determine need for separate seasonal model.

| Hydrologic Condition | Time Period for Review of Calibrated Results (PST) | Flow Rate Range (cfs) | Boundary forebay Elevation Range (feet NAVD 88) |
|---|---|---|---|
| High Flow | 11/14/06 1400 hrs – 11/14/06 2000 hrs | 31,800 – 32,700 | 1,984.03 – 1,986.44 |
| | 6/19/07 1600 hrs – 6/19/07 2200 hrs | 32,200 – 32,600 | 1,983.66 – 1,986.22 |
| Moderate Flow | 10/15/06 0300 hrs – 10/15/06 1500 hrs | 23,800 – 25,300 | 1,987.73 – 1,991.71 |
| | 7/1/07 0100 hrs – 7/1/07 1300 hrs | 23,300 – 25,100 | 1,988.91 – 1,993.49 |
| Low Flow | 2/11/07 0900 hrs – 2/11/07 2000 hrs | 13,500 – 15,000 | 1,988.72 – 1,993.13 |
| | 7/29/07 1100 hrs – 7/29/07 2200 hrs | 13,600 – 14,900 | 1,988.76 – 1,991.18 |

Notes:
cfs – cubic feet per second
NAVD 88 – North American Vertical Datum of 1988
PST – Pacific Standard Time

For each period, the difference between the model predicted and observed water surface elevation during the macrophyte growth period was compared to that during the period absent of macrophyte growth to determine if the calibrated model was consistently underpredicting water surface elevations during the periods of peak macrophyte growth. The review was conclusive in finding that there was no consistent trend in the model results that would indicate that the model, as currently calibrated, was underpredicting water surface elevations during periods of macrophyte growth. Therefore, it was concluded that there was no need to develop a separate set of calibration parameters or a separate hydraulic model to account for the effect of macrophyte growth on the hydraulics of the system.

## 6 HRM CALIBRATION SUMMARY

Version 4.0 (Beta) of the USACE HEC-RAS model, along with Version 4.1.1 of the USACE HEC-GeoRAS software, was used to develop two hydraulic routing models of the Pend Oreille River in support of the Boundary Dam Relicensing effort. The first model was for the Pend Oreille River between Box Canyon Dam and Boundary Dam and is referred to as the Boundary Reservoir HRM. The second model was for the Pend Oreille River between Boundary Dam and Seven Mile Dam and is referred to as the Boundary Tailrace HRM.

Recently collected topographic data and bathymetric data, compiled into a DTM, were used to define the geometry of the cross sections for both the Boundary Reservoir HRM and the Boundary Tailrace HRM. A total of 225 cross sections were used to define the hydraulic characteristics of the 17.5-mile reach between Boundary Dam and Box Canyon Dam. The average cross section spacing was approximately 410 feet. A total of 141 cross sections were used to define the hydraulic characteristics of the 10.5-mile reach between Boundary Dam and Seven Mile Dam. The average cross section spacing was approximately 390 feet. For both models, cross section geometry that was field surveyed at each habitat transect location was incorporated into the model input files in lieu of the geometry from the DTM.

The Boundary Reservoir HRM was calibrated to water surface elevation data recorded at USGS gaging station 12396500 and to water surface elevation data collected with pressure transducers installed in September 2006 in the Boundary Reservoir specifically for the Boundary Dam relicensing effort. All data were continuously recorded at 15-minute time increments. The model calibration effort, which was described in this report, used the continuously collected data from September 2006 through March 2008.

Successful calibration of the Boundary Reservoir HRM was attained using specific portions of the 19-month record. Six distinct periods of the 19-month record, encompassing a total of 92 days, were identified and used for the calibration. The six periods were representative of the entire range of Boundary forebay elevations and USGS flow rates recorded during the 19-month period. The calibration of the model was successfully verified, using five additional periods of the 19-month record, encompassing a total of 54 days and using water surface elevations surveyed at each of the habitat transect locations. The calibrated model was then executed for the entire 19-month period as a broad verification of the model calibration.

The 19-month time period to which the Boundary Reservoir HRM was calibrated included a wide range of flows and Boundary forebay conditions, and therefore the model is considered a reliable tool in evaluating hydraulic conditions in the reservoir. The range of conditions to which the model was calibrated are summarized as follows:

- Flow rates (as measured at the USGS gage 12396500) that ranged between 2,400 cfs and 55,400 cfs
- Boundary forebay elevations that ranged between 1,964.62 and 1,995.08 feet NAVD 88 (1,960.59 and 1,991.05 feet NGVD 29).

The Boundary Tailrace HRM was calibrated to water surface elevation data collected with two pressure transducers installed in September 2006 and a supplemental pressure transducer installed in February 2008. All three were installed in Tailrace Reach between Boundary Dam and the Red Bird Creek specifically for the Boundary Dam relicensing effort. All data were continuously recorded at 15-minute time increments. The model calibration effort, which was described in this report, used the continuously collected data from September 2006 through mid-July 2008.

Successful calibration of the Boundary Tailrace HRM was attained using specific portions of the 23-month record. Nine distinct periods of the 23-month record, encompassing a total of 217 days, were identified and used for the calibration. The nine periods were representative of the entire range of Boundary Dam discharge rates and Seven Mile Dam forebay elevations recorded during the 23-month period. The calibration of the model was successfully verified, using six additional periods of the 23-month record, encompassing a total of 136 days and using water surface elevations surveyed at each of the habitat transect locations. The calibrated model was then executed for the entire 23-month period as a broad verification of the model calibration.

The 23-month time period to which the Boundary Tailrace HRM was calibrated included a wide range of flows and Seven Mile Dam forebay conditions, and therefore the model is considered a reliable tool in evaluating hydraulic conditions in the tailrace reach between Boundary Dam and

Red Bird Creek. The range of conditions to which the model was calibrated are summarized as follows:

- Synthesized 15-minute instantaneous Boundary Dam discharge rates that ranged between 0 cfs and 108,900 cfs
- Seven Mile Dam forebay elevations that ranged between 1,702.43 and 1,736.16 feet NAVD 88 (1,698.40 and 1,732.13 feet NGVD 29).

# 7 DETERMINATION OF HYDRAULIC INFLUENCE OF PROJECT OPERATIONS

The main purpose of the calibrated HRM is to provide the hourly water surface elevations and discharges at the habitat transects distributed throughout the study area that support evaluation of Project influences on various resources. The HRM primarily supports the habitat modeling for Study 7 as well as Study 8 (SCL 2009c) and to a lesser extent, provides information on water surface levels and fluctuations used in a variety of the other Boundary relicensing studies. In Study 7, the HRM provides the hourly water surface elevations and flow rates for the transects for the stranding and trapping analysis, downramping analysis and the weighted useable area (WUA) determinations for submerged aquatic macrophytes, benthic macroinvertebrates, periphyton and fish.

Section 5.2 of the Study 7 Final Report (SCL 2009a) presents the results of the HRM runs for the representative wet, dry, and average years. The resulting hourly water surface elevations and flow rates are post-processed by the routines developed for evaluation of habitat indices such as the WUA calculations and other indicators of project influences such as the downramping analysis. However, in addition to supporting the habitat analyses, the results of the HRM are useful in understanding the hydraulic conditions within the study area. A general understanding of these conditions and the influence of both the Project and natural riverine features on hydraulic conditions throughout the study area provides valuable insight for interpreting results of the habitat analyses. Section 5.2 of the Study 7 Final Report (SCL 2009a) provides the information necessary to understand the complex hydraulic behavior of the Pend Oreille River throughout the study area, including how Project operations influence these conditions.

Included in this section is the presentation of the results of the analysis conducted to quantify the hydraulic influence of Project operations. The analysis focused on the influence of Project operations on water surface elevations and average cross section velocities in the Boundary Reservoir and the Boundary tailrace, which are presented graphically. Examples of the graphs are included in this section; however, the complete set of graphs is included in Attachment D.

## 7.1. Hydraulic Influence of Project Operations in Boundary Reservoir

Some degree of hydraulic influence from Project operations can extend up to the Box Canyon Dam Tailrace. However, as discussed in Section 5.2 of the Study 7 Final Report (SCL 2009a), Metaline Falls functions as a localized hydraulic control that attenuates (or dampens) the magnitude of this influence in the Upper Reservoir Reach. It will be shown in this section that the magnitude of the hydraulic influence due to Project operations varies, depending upon the location in the reservoir, the water surface elevation in the Boundary forebay, and the flow rate through the Boundary Reservoir.

This section presents figures and tables that quantify the influence of Project operations on the hydraulic conditions in the Boundary reservoir. The intent of this analysis is to graphically illustrate the range of influence Project operations can have on water surface elevations and average cross section velocities between Boundary Dam and Box Canyon Dam.

The quantification of hydraulic influence was made relative to the hydraulic conditions associated with the Project operating at the lowest pool limit of the current license 1,954 feet NAVD 88 (1,950 feet NGVD 29). The Boundary Reservoir HRM was run for a set of discreet flow rates that ranged from 5,000 cfs to 80,000 cfs, coincident with this operating pool elevation. The specific flow rates that were included in the analysis were 5,000; 10,000; 19,500; 30,000; 40,000; 55,000; and 80,000 cfs. The significance of the 19,500 cfs rate is that it represents the median hourly flow rate for the 1987 through 2005 period of record (R2 Resource Consultants 2008). The 55,000 cfs flow rate represents the turbine capacity of the Project and the 80,000 cfs flow rate represents the upper limit of flow rate considered in the Mainstem Aquatic Habitat Model for WUA analysis.

The next step in the analysis was to run the Boundary Reservoir HRM for incrementally higher forebay elevations while still using the same set of flow rates that were run for the 1,954-foot NAVD 88 condition. The forebay elevations included in the analysis were 1,974, 1,979; 1,984; 1,989; and 1,994 feet NAVD 88 (1,970; 1,975; 1,980; 1,985; and 1,990 feet NGVD 29). The 1,994 foot-NAVD 88 (1,990-foot NGVD 29) elevation represents the maximum operating pool elevation.

Throughout this section, the term "influence" is used to indicate a change in a specific hydraulic parameter (such as water surface elevation) at a specific point in the Boundary Reservoir attributed to Project operation.

The method used to quantify the hydraulic influence is best explained using Figure 7.1-1. This figure shows water surface elevations determined from steady state model runs of the Boundary Reservoir HRM. The water surface profiles in this figure are for a 40,000 cfs flow rate for the six different Boundary Dam forebay elevations. The lowest elevation represents the lowest operating pool elevation. The other five profiles are for incrementally higher forebay elevations, up to the maximum operating pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29). For a 40,000 cfs flow rate condition, the hydraulic influence (in this case change in water surface elevation) attributed to Project operations is determined by comparing the model results for the forebay elevation to the model results for the lowest operating pool condition.

A similar approach was used to evaluate the hydraulic influence of Project operations in regards to average cross section velocities. Figure 7.1-2 plots average cross section velocities along the length of Boundary Reservoir for a 40,000 cfs flow rate and the range of Boundary forebay elevations. Similar to Figure 7.1-1, the Boundary forebay elevations that were included ranged from the lowest operating pool elevation of 1,954 feet NAVD 88 (1,950 feet NGVD 29) to the maximum operating pool elevation of 1,994 feet NAVD 88 (1,990 feet NGVD 29). For the 40,000 cfs flow rate, it is seen that Project operations generally result in producing reduced average cross section velocities as the forebay elevation increases. This is attributed to the backwater effect associated with incrementally increasing forebay elevations.

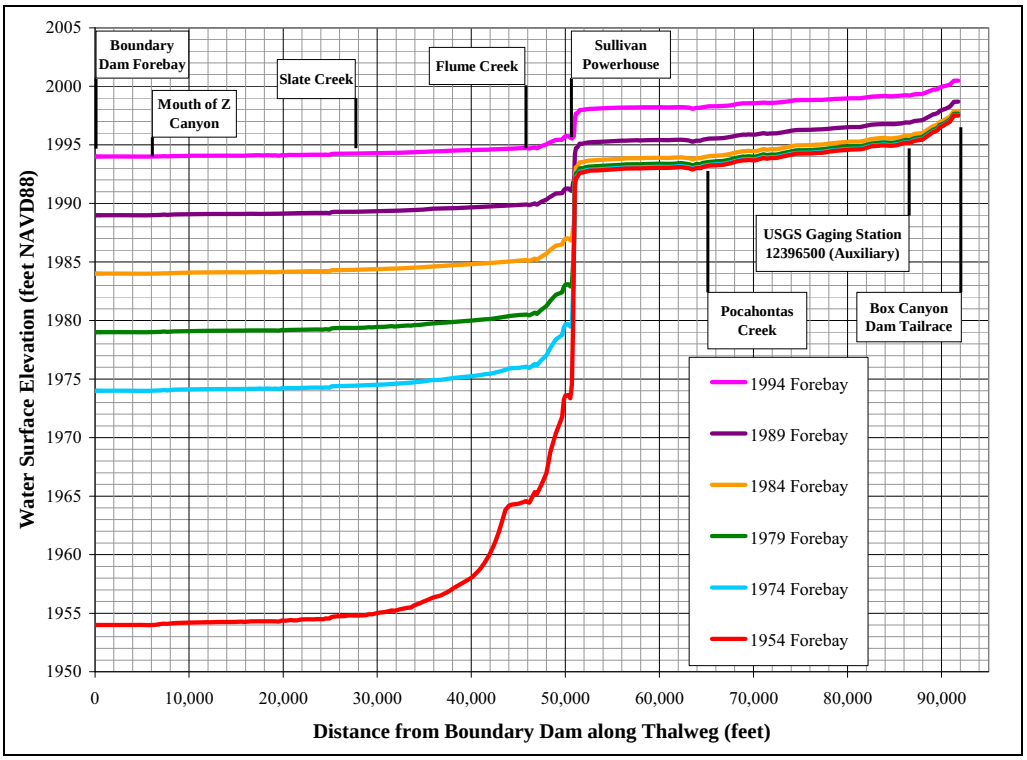


**Figure 7.1-1.** Boundary Reservoir HRM steady state water surface profiles for 40,000 cfs flow rate.

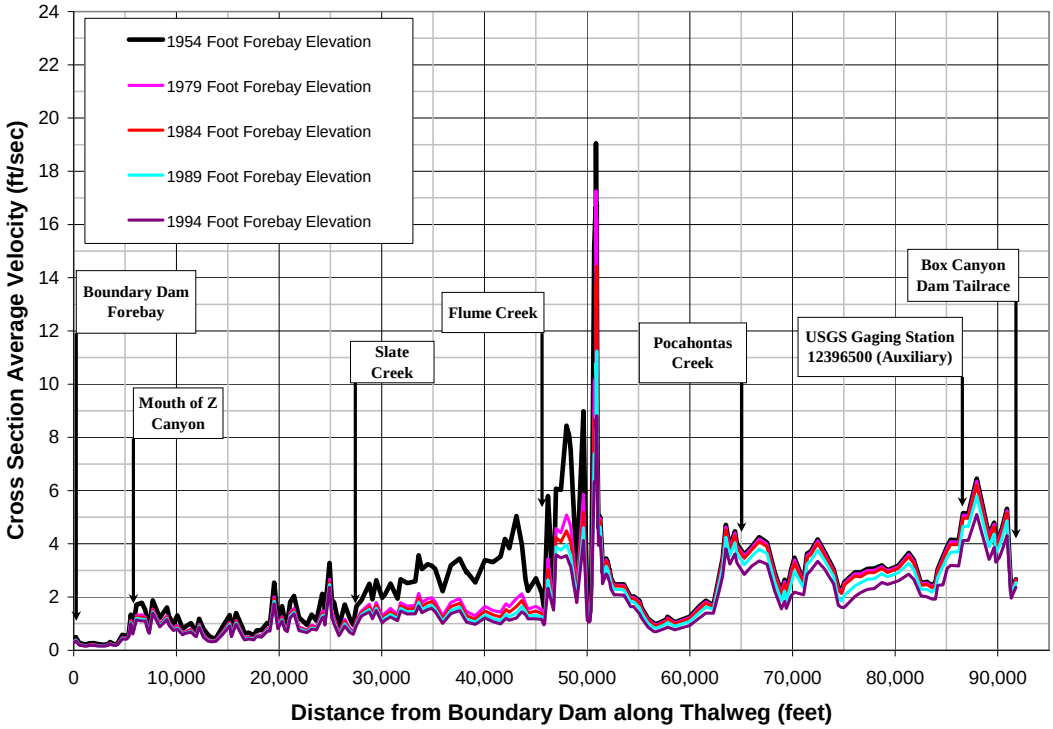


**Figure 7.1-2.** Upstream hydraulic influence of Project operations on average cross section velocity for 40,000 cfs flow rate.

The hydraulic influence of Project operations on upstream water surface elevations and velocities is a function of the three variables: 1) the distance from the Project, specifically whether the location being considered is upstream or downstream of Metaline Falls; 2) the Boundary Dam forebay elevation; and 3) the flow rate in the reservoir.

Figures 7.1-1 and 7.1-2 illustrate the first two variables. Incremental changes in forebay elevation (Project operations) are seen to result in larger changes in water surface elevation at locations downstream of Metaline Falls as compared to locations upstream of Metaline Falls. For this 40,000 cfs flow condition, it is not until the forebay elevation is increased above 1,974 feet NAVD 88 (1,970 feet NGVD 29) that any increase in water surface elevation is produced upstream of Metaline Falls. So, it can be said that for the 40,000 cfs flow condition, the Upper Reservoir Reach is essentially functioning without influence from Boundary Dam and is therefore hydraulically disconnected from the lower reaches when the Boundary forebay elevation is less than approximately 1,974 feet NAVD 88 (1,970 feet NGVD 29). At incrementally increasing forebay elevations, backwater conditions from the Project gradually extend upstream along the Upper Reservoir Reach, thereby incrementally reducing the free-flowing conditions in the reach.

A series of figures were developed to illustrate the magnitude of the hydraulic influence of Project operations on water surface elevations and on average cross section velocities. The figures were developed in such a manner as to present the results of the analysis as a function of the three variables (distance, forebay elevation, flow rate). Each figure therefore presents the hydraulic influence attributed to Project operations for a specific flow rate for the range of flows considered (5,000 cfs to 80,000 cfs). All of the figures are included in Attachment D. Only the figures for the 19,500 cfs flow condition are included in this section as examples. Figure 7.1-3 shows the magnitude of the hydraulic influence of Project operations on water surface elevations, and Figure 7.1-4 shows the magnitude of the hydraulic influence of Project operations on average cross section velocities.

In Figure 7.1-3, the change in water surface elevation attributed to Project operations is plotted on the y-axis. This change is measured relative to the condition associated with a 19,500 cfs flow rate and a forebay elevation of 1,954 feet NAVD 88 (1,950 feet NGVD 29). This figure is specifically for the 19,500 cfs flow rate and shows Project influence for five successively higher Boundary forebay elevations. Figures for all seven of the flow conditions included in the analysis are in Attachment D. The hydraulic influence due to Project operations varies depending not only upon the flow rate and the Boundary forebay elevation, but upon the distance from the Project. Therefore, the x-axis of Figure 7.1-3 is the upstream distance from Boundary Dam.

Figure 7.1-4 shows the average cross section velocity along the length of the Boundary Reservoir for the condition associated with a 19,500 cfs flow rate and a forebay elevation of 1954-feet NAVD 88 (1950-feet NGVD 29). Cross section average velocities are highest when the Boundary forebay is at the 1,954-foot NAVD 88 (1,950-foot NGVD 29) elevation. For incrementally increasing forebay elevations, backwater conditions reduce the cross section average velocities. Again, this figure is specifically for the 19,500 cfs flow condition. Figures for all seven of the flow conditions included in the analysis are in Attachment D.

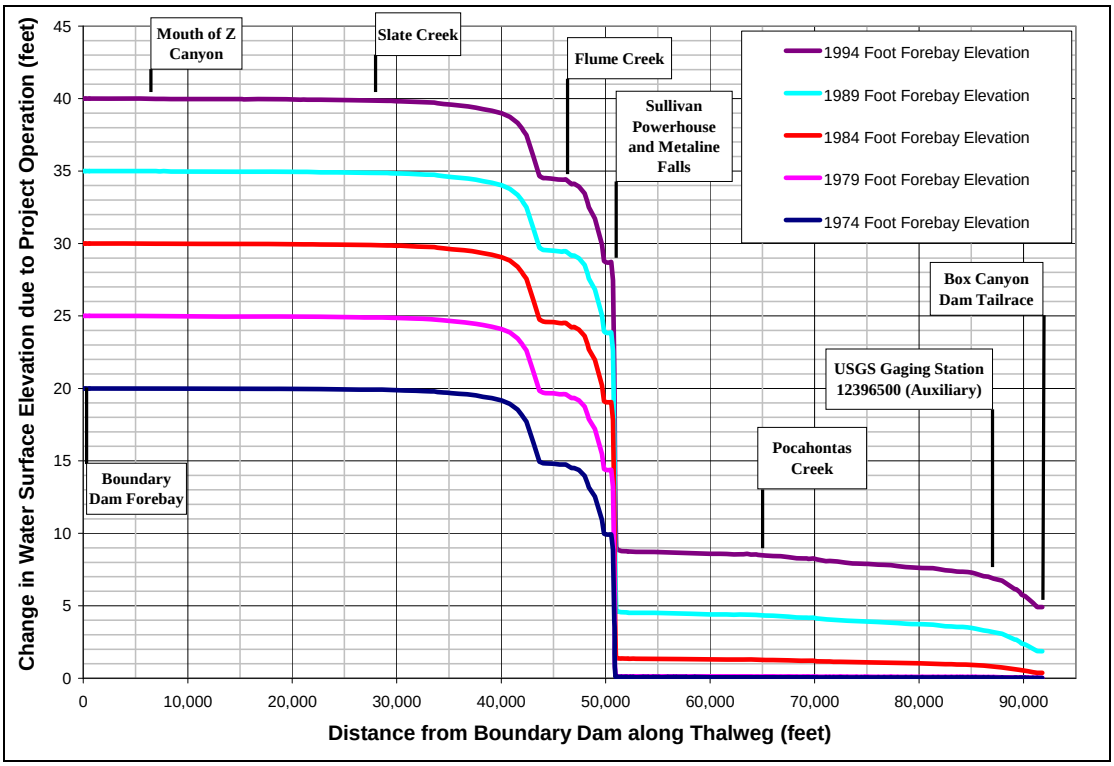


**Figure 7.1-3.** Upstream hydraulic influence of Project operations on water surface elevations for 19,500 cfs flow rate.

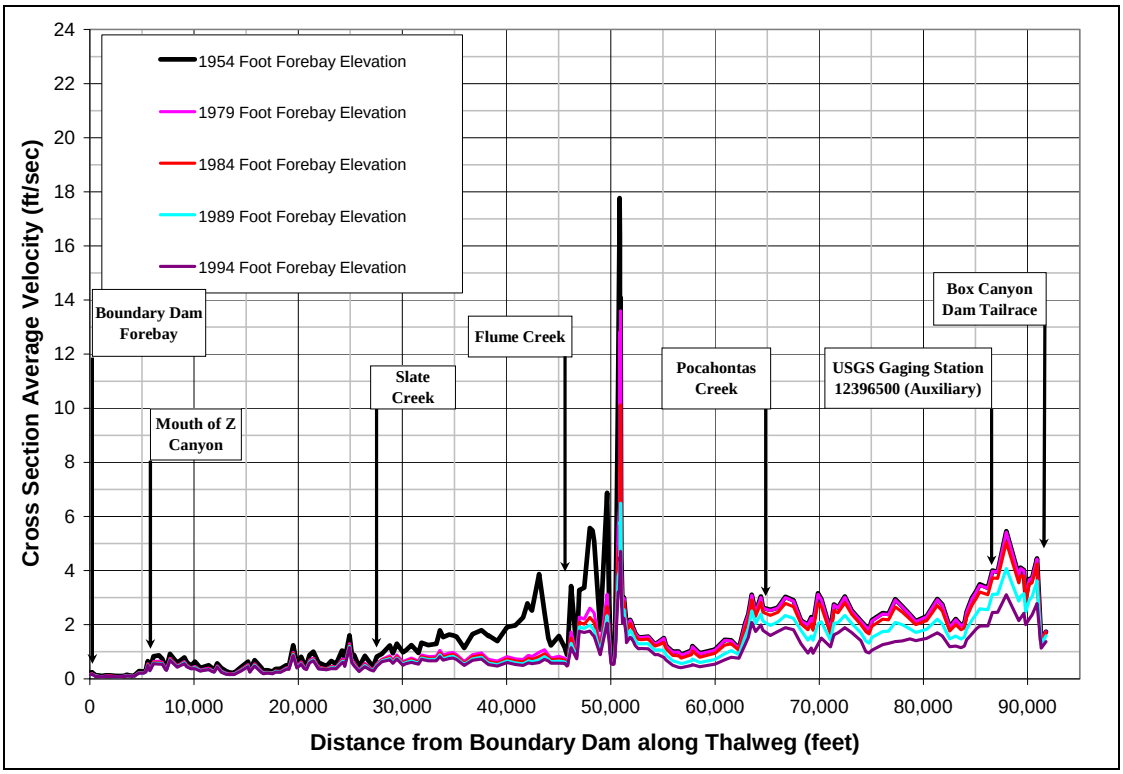


**Figure 7.1-4.** Upstream hydraulic influence of Project operations on average cross section velocities for 19,500 cfs flow rate.

## 7.2. Hydraulic Influence of Project Operations in Boundary Tailrace

An analysis was conducted to quantify the hydraulic influence of Project operations in the Tailrace Reach, between the Project and Red Bird Creek. The methodology was similar to that which was used for the analysis conducted for the Boundary reservoir (see Section 7.1). The results of this analysis are used to illustrate the range of influence Project operations can have on water surface elevations and average cross section velocities along the length of the Tailrace Reach. In the Boundary Reservoir, the hydraulic influence attributed to Project operations is due to water surface fluctuations in the forebay. However, in the Tailrace Reach, the hydraulic influence attributed to Project operations is due to flow releases from the powerhouse (project outflows) that are either greater than or less than the flow rate that is being conveyed in the Pend Oreille River upstream of Boundary Dam (project inflows).

Some degree of hydraulic influence from Project operations can extend from Boundary Dam down to the confluence with Red Bird Creek (i.e., the Tailrace Reach). As discussed in Section 5.2 of the Study 7 Final Report (SCL 2009a), Seven Mile Dam Project operations can also produce a hydraulic influence in the Tailrace Reach. As will be shown in this section, the magnitude of the hydraulic influence attributed to Project operations is a function of the following three factors:

- *Downstream distance from the Project*—Similar to the upstream hydraulic influence of Boundary Project operations, the downstream hydraulic influence of Boundary Project operations varies throughout the length of the Tailrace Reach and therefore is a function of increasing distance from Boundary Project.
- *Seven Mile Dam forebay elevation*—When Seven Mile Dam is operating at high pool elevations, it is possible for backwater conditions to extend up to the base of Boundary Dam, thereby affecting water surface elevations throughout the entire Tailrace Reach.
- *Magnitude of the Project discharge relative to the magnitude of the Pend Oreille River flow rate upstream of Boundary Dam*—When Project discharge is equal to the Pend Oreille River flow rate in the Boundary Reservoir (i.e., when Project outflow equals Project inflow), there is no influence of Project operations on the hydraulic conditions in the Tailrace Reach. It is only when outflows from the Project are greater than or less than the Pend Oreille River flow rate in the Boundary Reservoir that the Project begins to have downstream hydraulic influence.

Just as was the case for quantifying the upstream Project hydraulic influence, it was necessary to first establish the condition against which the results of Project operations are compared. To simplify the analysis, three unique Pend Oreille River flow conditions were combined with three unique Seven Mile Dam forebay elevation conditions to create nine unique conditions against which results associated with Project operations could be compared. The matrix of the nine conditions used in the quantification of Project influence in the Tailrace Reach is defined in Table 7.2-1.

**Table 7.2-1.** Matrix of boundary conditions used as basis for evaluating hydraulic influence in the Tailrace Reach due to Project operations.

| Seven Mile Dam Forebay Elevation Condition (ft NAVD 88) [2] | Pend Oreille River Flow Rate Condition Upstream of Boundary Dam (cfs) [1] | | |
|---|---|---|---|
| | 90% Exceedance Pend Oreille River Flow Rate (10,700 cfs) | 50% Exceedance Pend Oreille River Flow Rate (19,500 cfs) | 10% Exceedance Pend Oreille River Flow Rate (43,100 cfs) |
| 90% Exceedance Forebay Elevation (1715.68 feet) | √ | √ | √ |
| 50% Exceedance Forebay Elevation (1727.00 feet) | √ | √ | √ |
| 10% Exceedance Forebay Elevation (1732.28 feet) | √ | √ | √ |

Notes:
1 Pend Oreille River flow rates obtained from annual flow duration curve in Pend Oreille River based on total hourly inflow to Boundary Reservoir for 1987–2005 period of record.
2 Seven Mile Dam forebay conditions obtained from annual frequency of exceedance curves for 1987–2005 period of record.

The Boundary Tailrace HRM was run to define the water surface elevation profiles and the average cross section velocity profiles along the length of the Tailrace Reach for each of the nine conditions defined in Table 7.2-1. Steady state conditions were assumed for each of these nine runs.

The Boundary Tailrace HRM was then run for six hypothetical Boundary Project outflow conditions coincident with each of the three Seven Mile Dam forebay conditions defined in Table 7.2-1. The six hypothetical Boundary Project outflow conditions included 5,000; 15,000; 25,000; 35,000; 45,000; and 55,000 cfs. The 55,000 cfs condition is the approximate turbine capacity of the Project and represents the upper bound of conditions for which Boundary Project hydraulic influence was determined. When inflows to Boundary Reservoir exceed this magnitude, the Project generally ceases to operate in a load-following manner and begins to pass excess flows through the spillway. Hence, the downstream hydraulic influence of the Project is minimized since Project outflows approximately equal Project inflows.

The results of these hypothetical model runs were then compared to the results of the initial model runs defined in Table 7.2-1 to quantify the hydraulic influence attributed to Project operations. The comparison was organized using a series of figures that illustrate the magnitude of hydraulic influence of Project operations on water surface elevations and average cross section velocities. The figures were developed in such a manner as to present the results of the analysis as a function of the three factors (distance, Seven Mile Dam forebay elevation, ratio of Project outflow to Project inflow). Each figure therefore graphically summarizes the hydraulic influence attributed to Project operations relative to each of the nine conditions defined in Table 7.2-1.

All of the figures are included in Attachment D. Only select example figures are included in this section. Figure 7.2-1 shows the magnitude of the hydraulic influence of Project operations on water surface elevations and Figure 7.2-2 shows the magnitude of the hydraulic influence of Project operations on average cross section velocities. Both of these example figures illustrate Project hydraulic influence relative to the condition associated with a 1,727.00-foot NAVD 88 (1,723.00-foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value).

Figure 7.2-1 shows the change in water surface elevation in the Tailrace Reach relative to the condition associated with a 1,727.00 foot NAVD 88 (1,723.00 foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value). The change in water surface elevation is attributed to Project outflows being either greater than or less than the 10,700 cfs Project inflow condition. The change is plotted on the y-axis and the distance downstream of Boundary Dam is plotted on the x-axis. A positive value for the change in water surface elevation occurs when the Project is discharging at a flow rate that is greater than the inflow to the Project. Conversely, a negative value for the change in water surface elevation occurs when the Project is discharging at a rate that is less than the inflow to the Project. For example, when the Project outflow is greater than 10,700 cfs, Project operations result in increased water surface elevations in the Tailrace Reach.

Figure 7.2-2 shows the average cross section velocity in the Tailrace Reach relative to the condition associated with a 1,727.00-foot NAVD 88 (1,723.00-foot NGVD 29) Seven Mile Dam forebay elevation (90 percent exceedance value) with a coincident 10,700 cfs Project inflow condition (90 percent exceedance value). Average cross section velocity is plotted on the y-axis and the distance downstream of Boundary Dam is plotted on the x-axis. The seven average cross section velocity profiles shown in this figure are oriented such that the profile for the lowest flow rate (in this case 5,000 cfs) is at the bottom of the graph and the profile for the highest flow rate (in this case 55,000 cfs) is located at the top of the graph. These two conditions provide the lower and upper bounds, respectively, for the analysis of the hydraulic influence. The average cross section velocity profile for the 10,700 cfs Project inflow condition is shown in the heaviest line type.

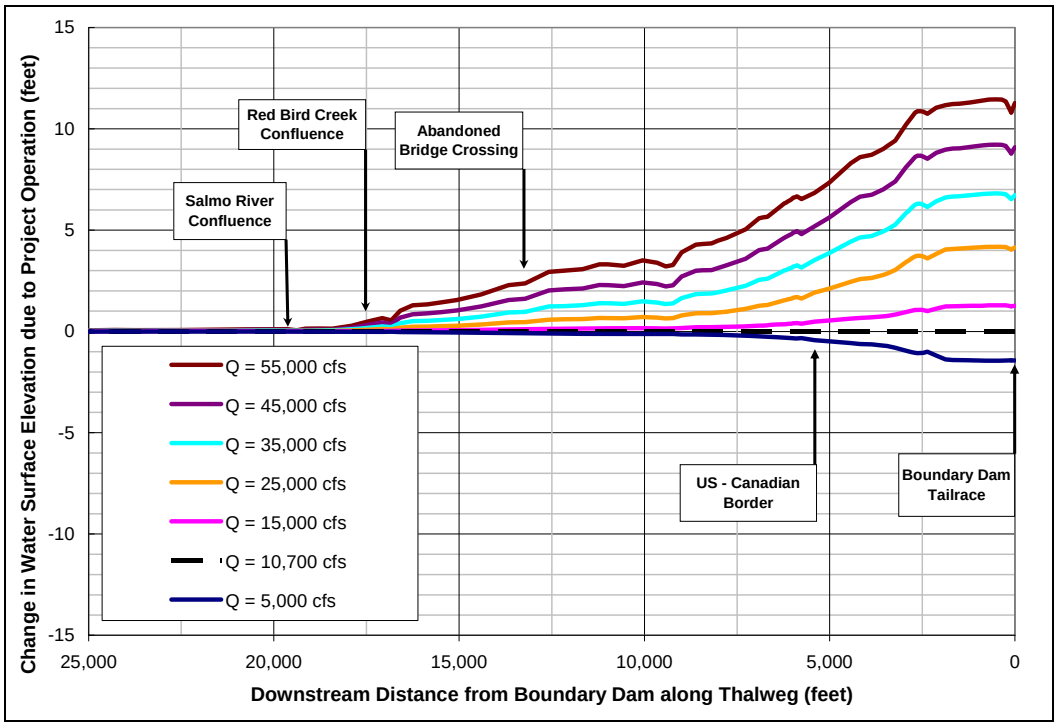


**Figure 7.2-1.** Downstream hydraulic influence of Project operations on water surface elevations relative to the condition associated with 1,727.00-foot NAVD 88 Seven Mile Dam forebay and 10,700 cfs Project inflow.

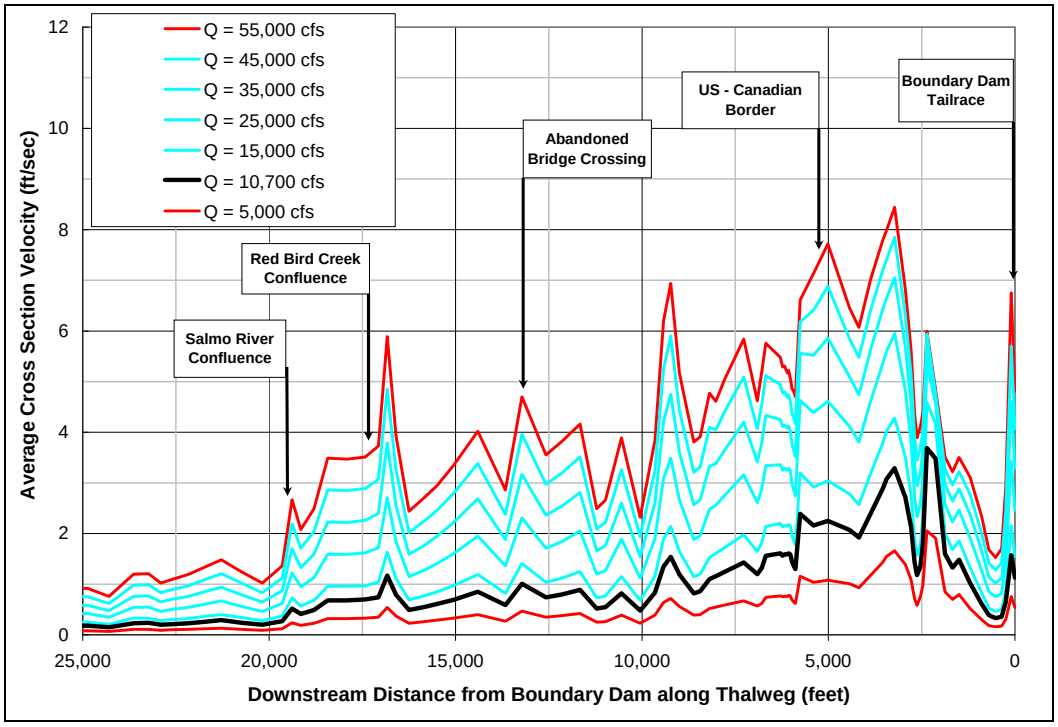


**Figure 7.2-2.** Downstream hydraulic influence of Project operations on average cross section velocities relative to the condition associated with 1,727.00-foot NAVD 88 Seven Mile Dam forebay and 10,700 cfs Project inflow.

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# Attachment A: Cross Section Location Figures

This attachment includes figures in support of the development and calibration of the Boundary Reservoir Hydraulic Routing Model (HRM) and the Boundary Tailrace HRM. The following figures are included in this attachment:

- Complete set of cross section location figures for Boundary Reservoir HRM (Figure A-1). This figure is a series of nine maps.
- Complete set of cross section location figures for Boundary Tailrace HRM (Figure A-2). This figure is a series of nine maps.

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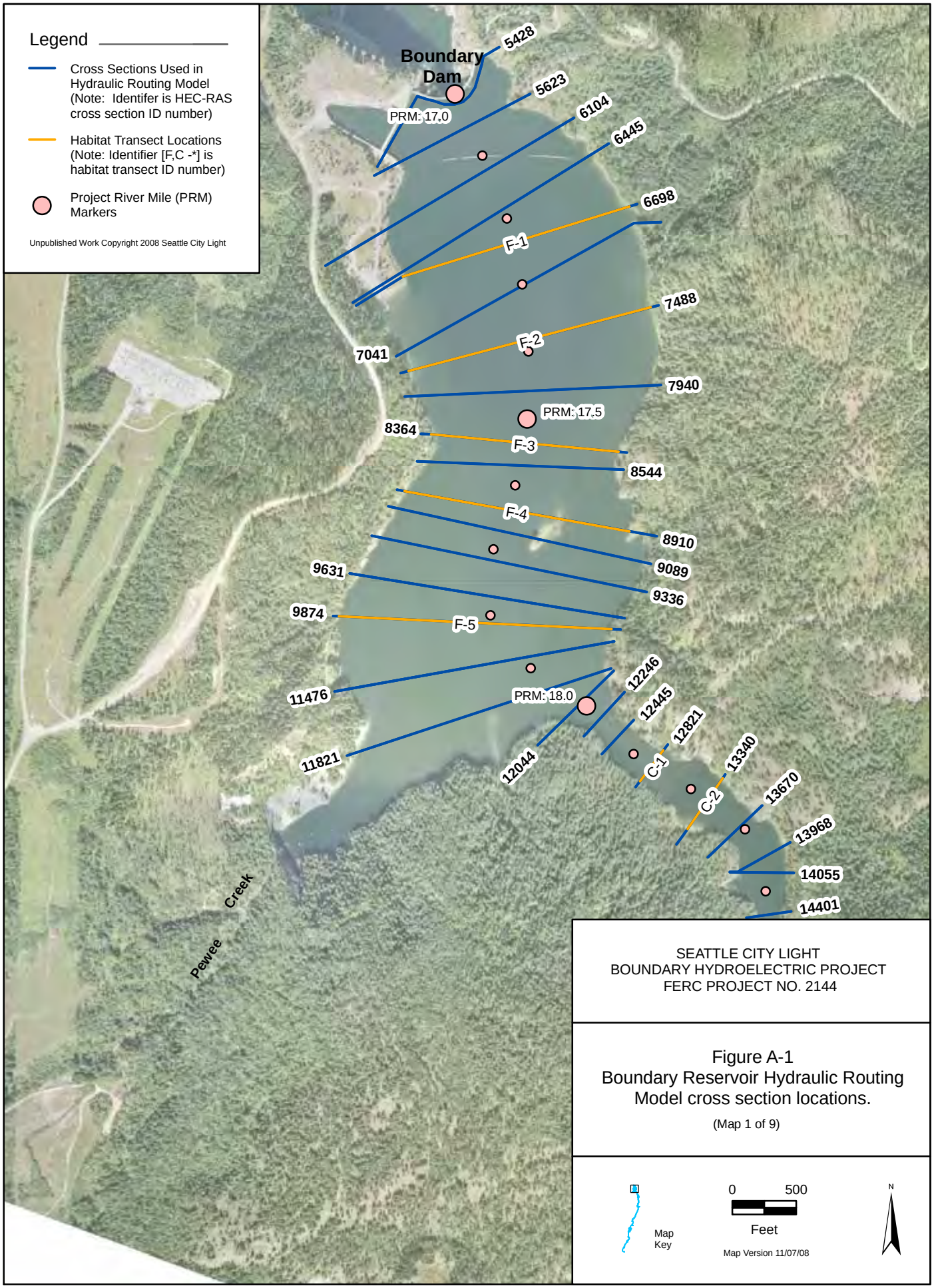
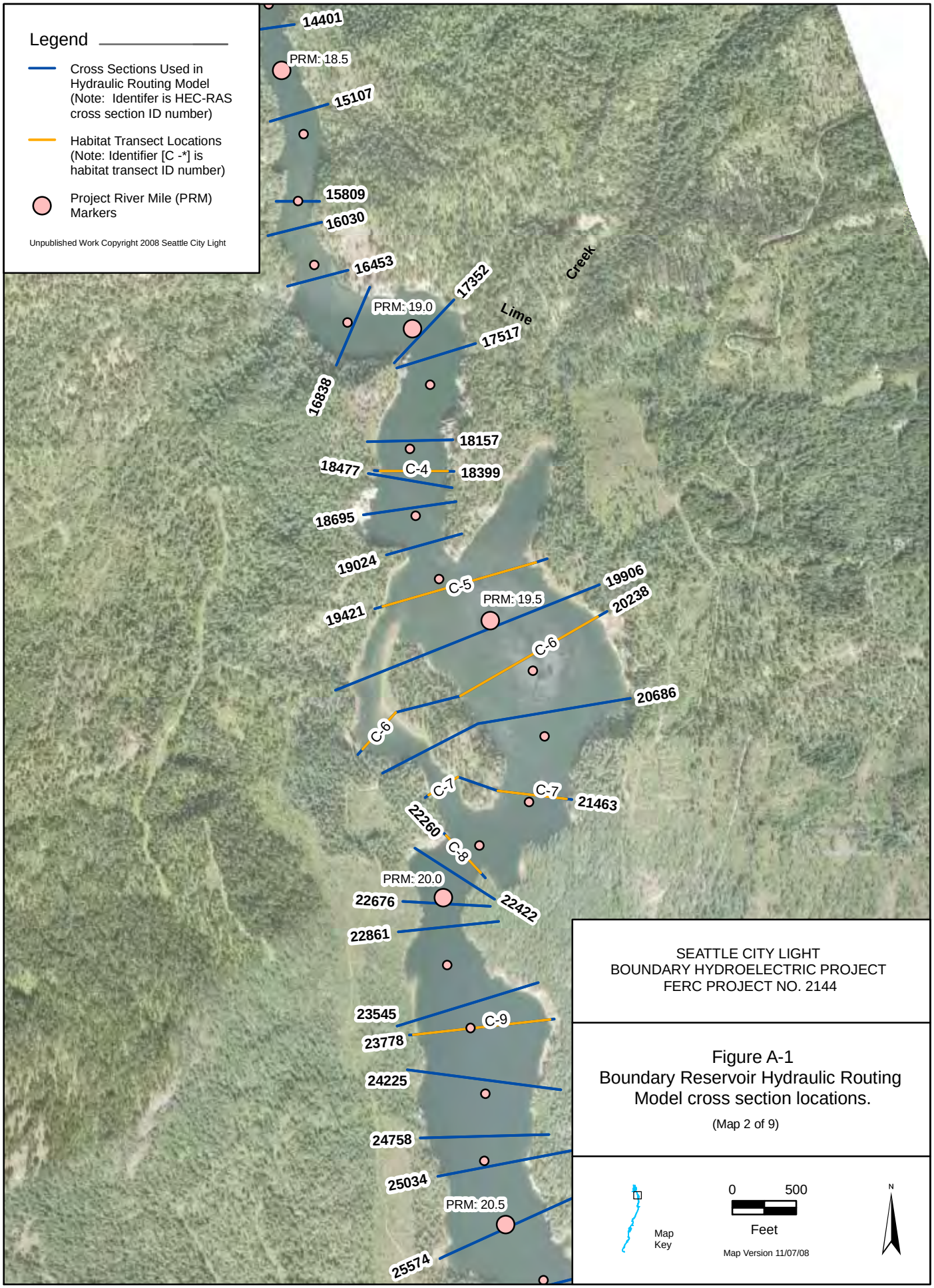


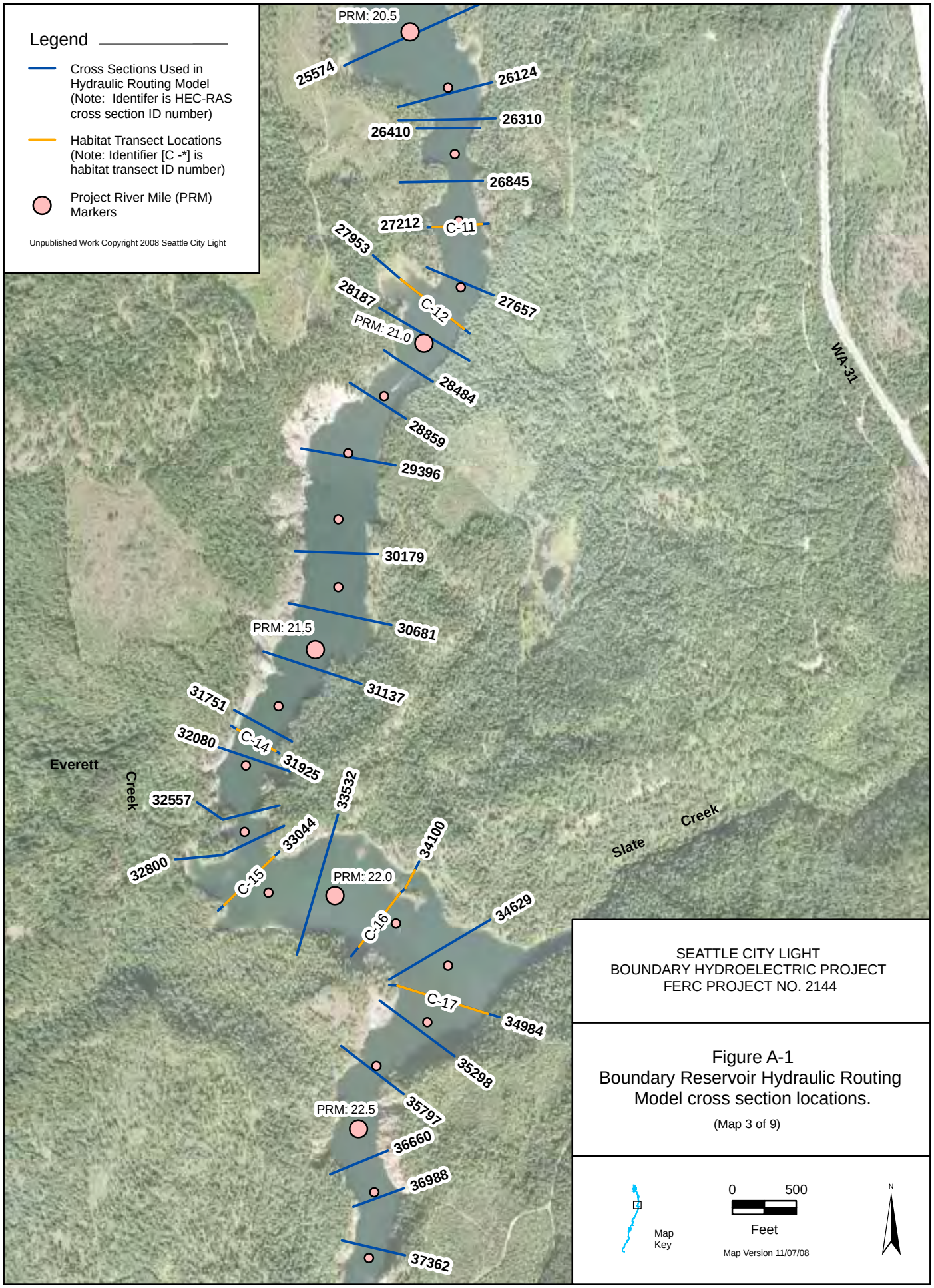

Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 1 of 9)




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.

(Map 2 of 9)


Legend
Cross Sections Used in Hydraulic Routing Model (Note: Identifer is HEC-RAS cross section ID number)
Habitat Transect Locations (Note: Identifier [C -*] is habitat transect ID number)
Project River Mile (PRM) Markers
Unpublished Work Copyright 2008 Seattle City Light
PRM: 20.5
25574
26124
26310
26410
26845
27212
C-11
27953
27657
28187
C-12
PRM: 21.0
28484
28859
29396
30179
30681
PRM: 21.5
31137
31751
C-14
32080
31925
Everett
Creek
32557
33532
33044
32800
C-15
PRM: 22.0
34100
C-16
34629
C-17
34984
35298
35797
PRM: 22.5
36660
36988
37362
WA-31
Slate
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 3 of 9)
Map Key
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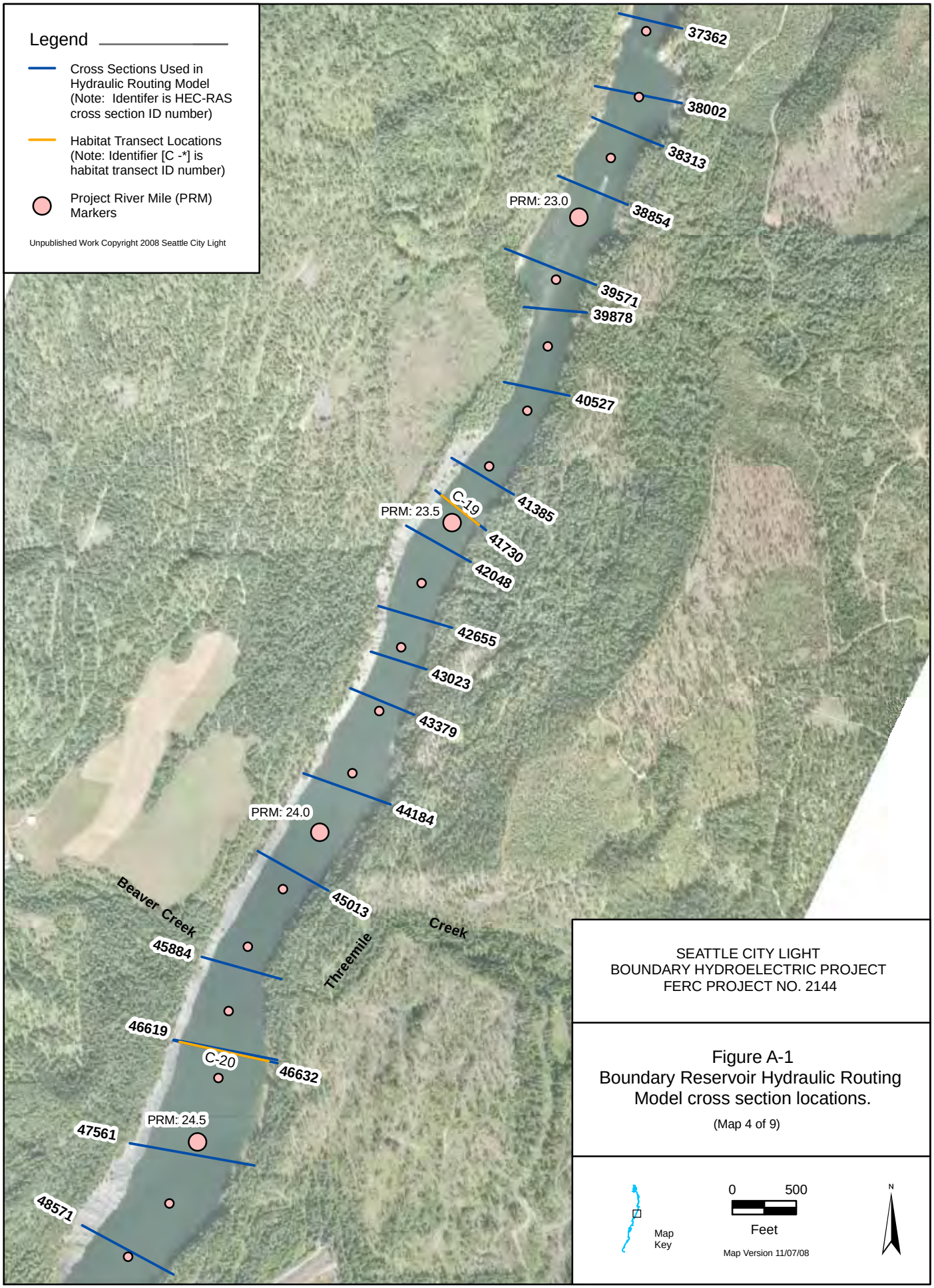
Feet
Map Version 11/07/08
N




SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.

(Map 4 of 9)

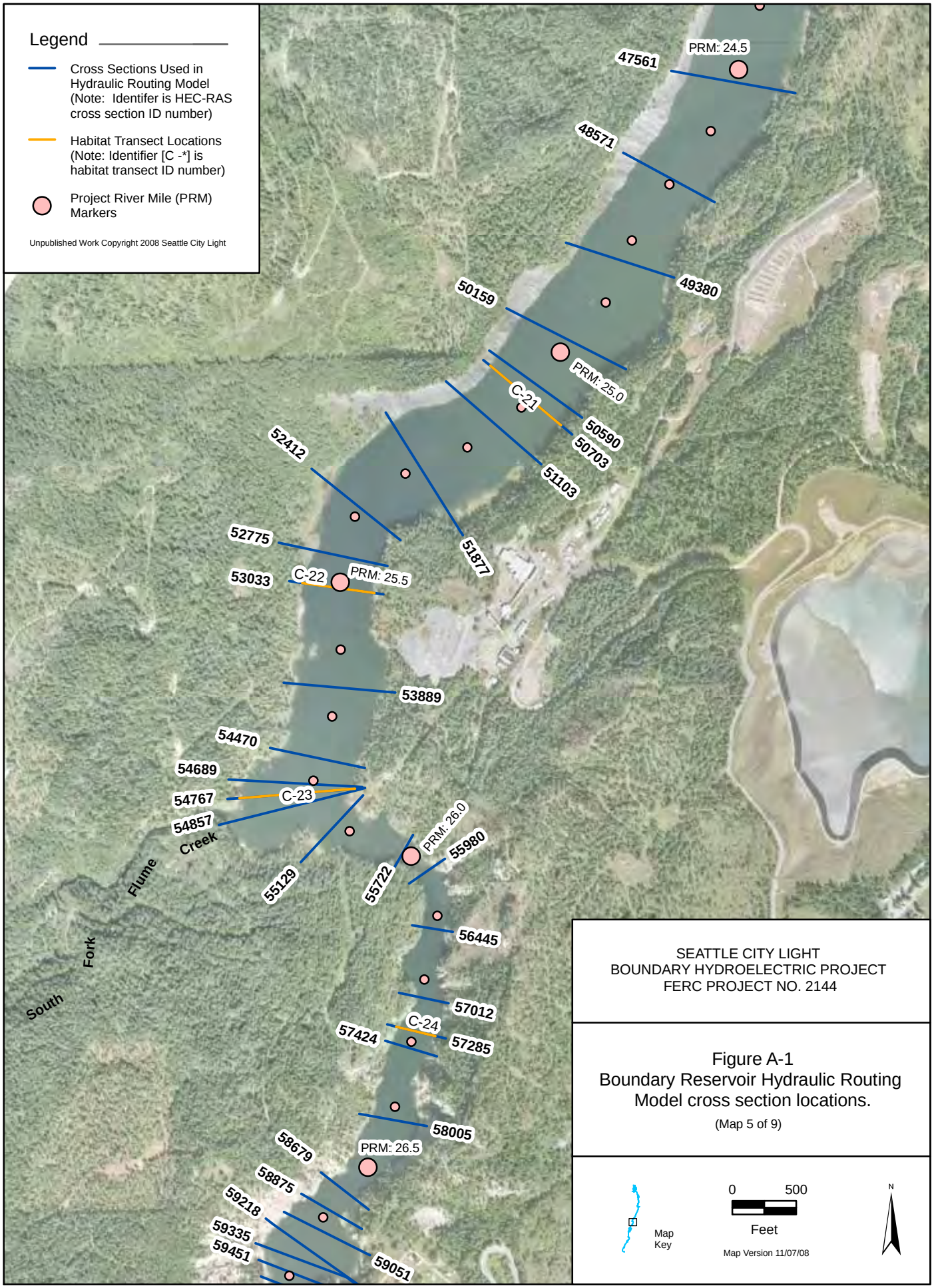
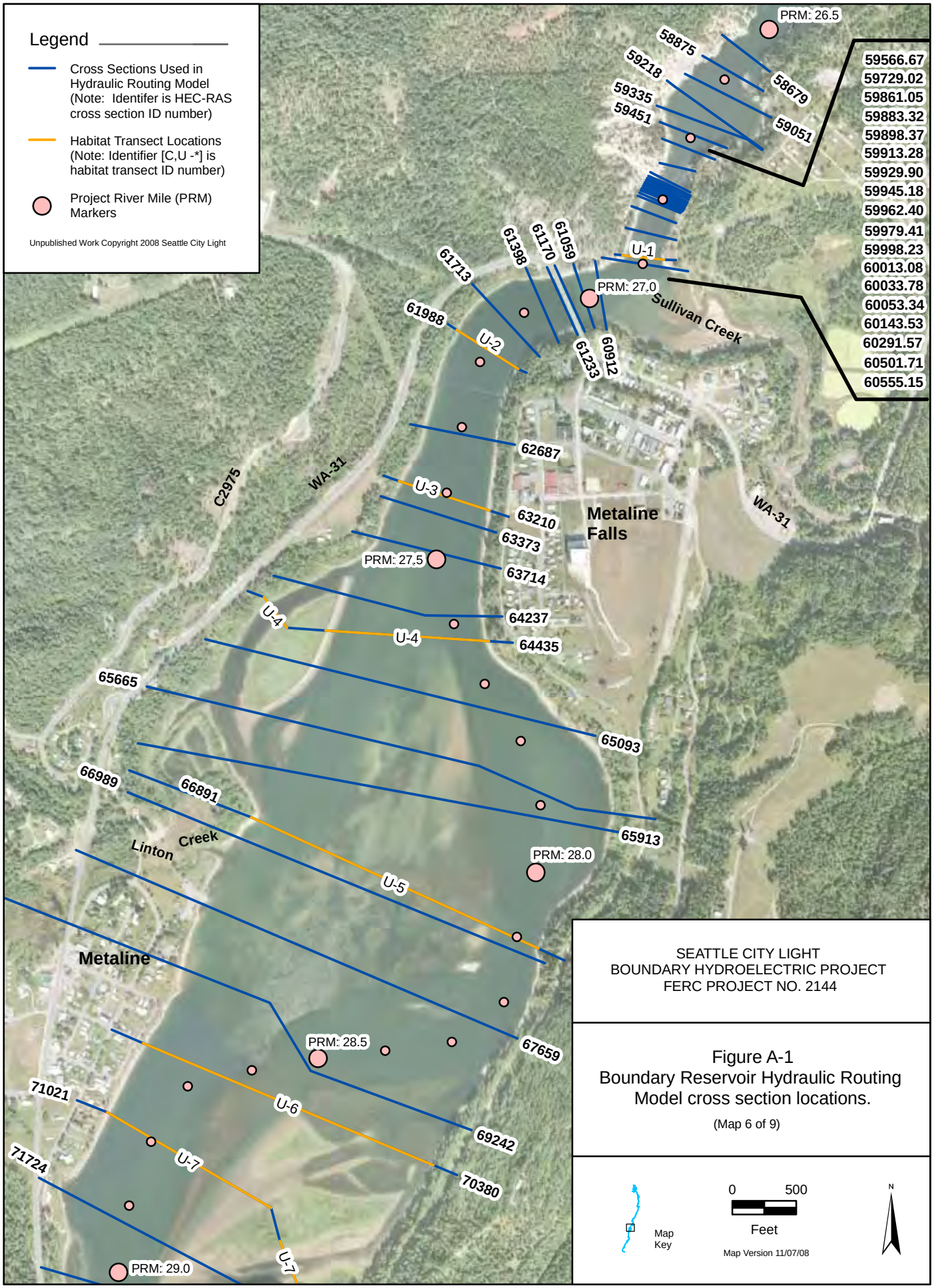



Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 5 of 9)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Habitat Transect Locations (Note: Identifier [C,U -*] is habitat transect ID number)
Project River Mile (PRM) Markers
Unpublished Work Copyright 2008 Seattle City Light
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58875
59218
59335
59451
58679
59051
59566.67
59729.02
59861.05
59883.32
59898.37
59913.28
59929.90
59945.18
59962.40
59979.41
59998.23
60013.08
60033.78
60053.34
60143.53
60291.57
60501.71
60555.15
U-1
PRM: 27.0
Sullivan Creek
61713
61398
61170
61059
61988
U-2
61233
60912
62687
C2975
WA-31
U-3
63210
63373
Metaline Falls
WA-31
PRM: 27.5
63714
64237
U-4
U-4
64435
65665
65093
66989
66891
65913
Linton Creek
PRM: 28.0
U-5
Metaline
67659
PRM: 28.5
71021
U-6
69242
71724
U-7
70380
U-7
PRM: 29.0
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 6 of 9)
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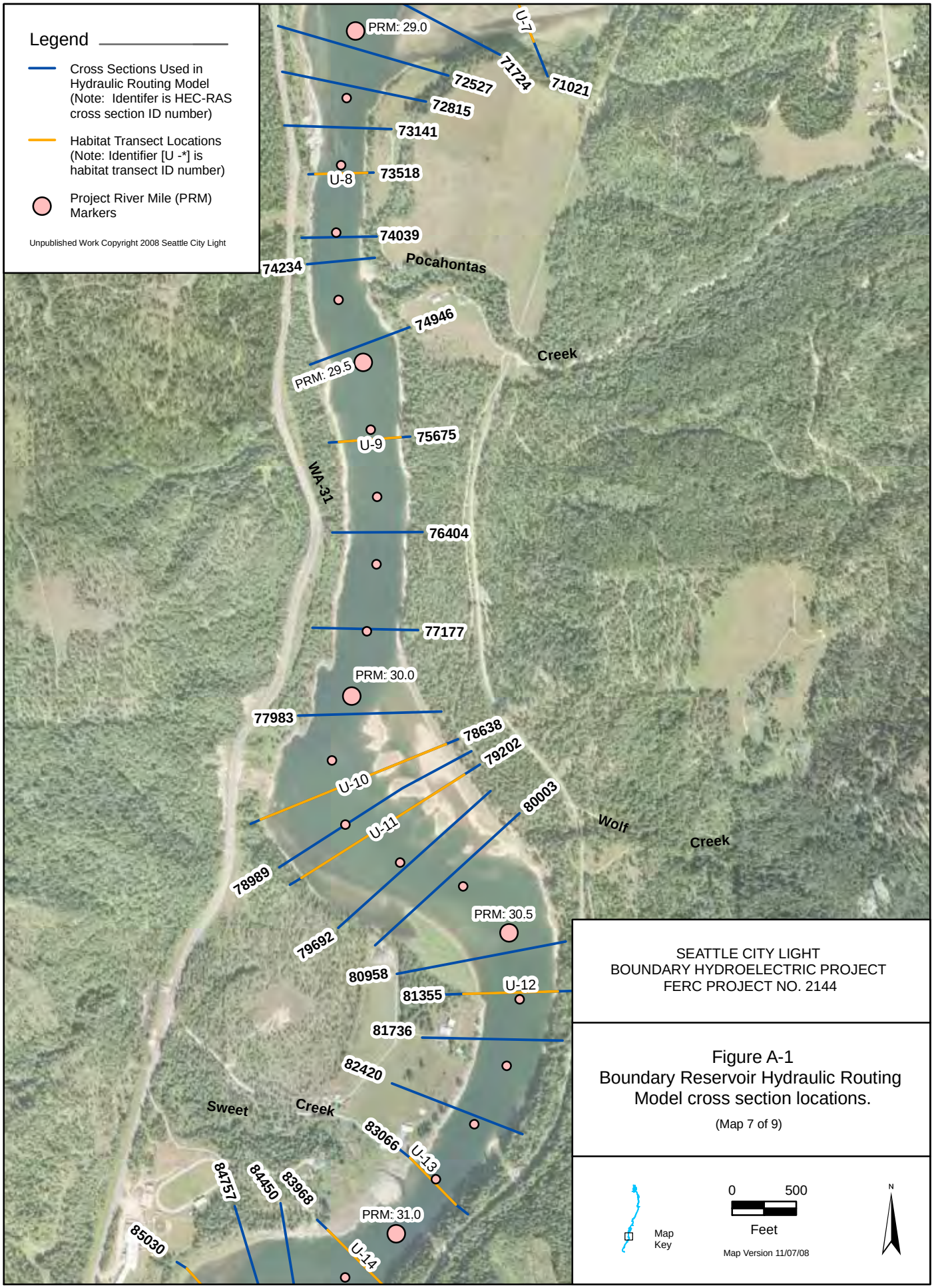
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Habitat Transect Locations (Note: Identifier [U -*] is habitat transect ID number)
Project River Mile (PRM) Markers
Unpublished Work Copyright 2008 Seattle City Light
PRM: 29.0
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71724
71021
72527
72815
73141
U-8
73518
74039
74234
Pocahontas
Creek
74946
PRM: 29.5
U-9
75675
WA-31
76404
77177
PRM: 30.0
77983
78638
79202
U-10
U-11
80003
Wolf
Creek
78989
PRM: 30.5
79692
80958
81355
U-12
81736
82420
Sweet
Creek
83066
U-13
84757
84450
83968
PRM: 31.0
85030
U-14
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 7 of 9)
Map Key
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Map Version 11/07/08
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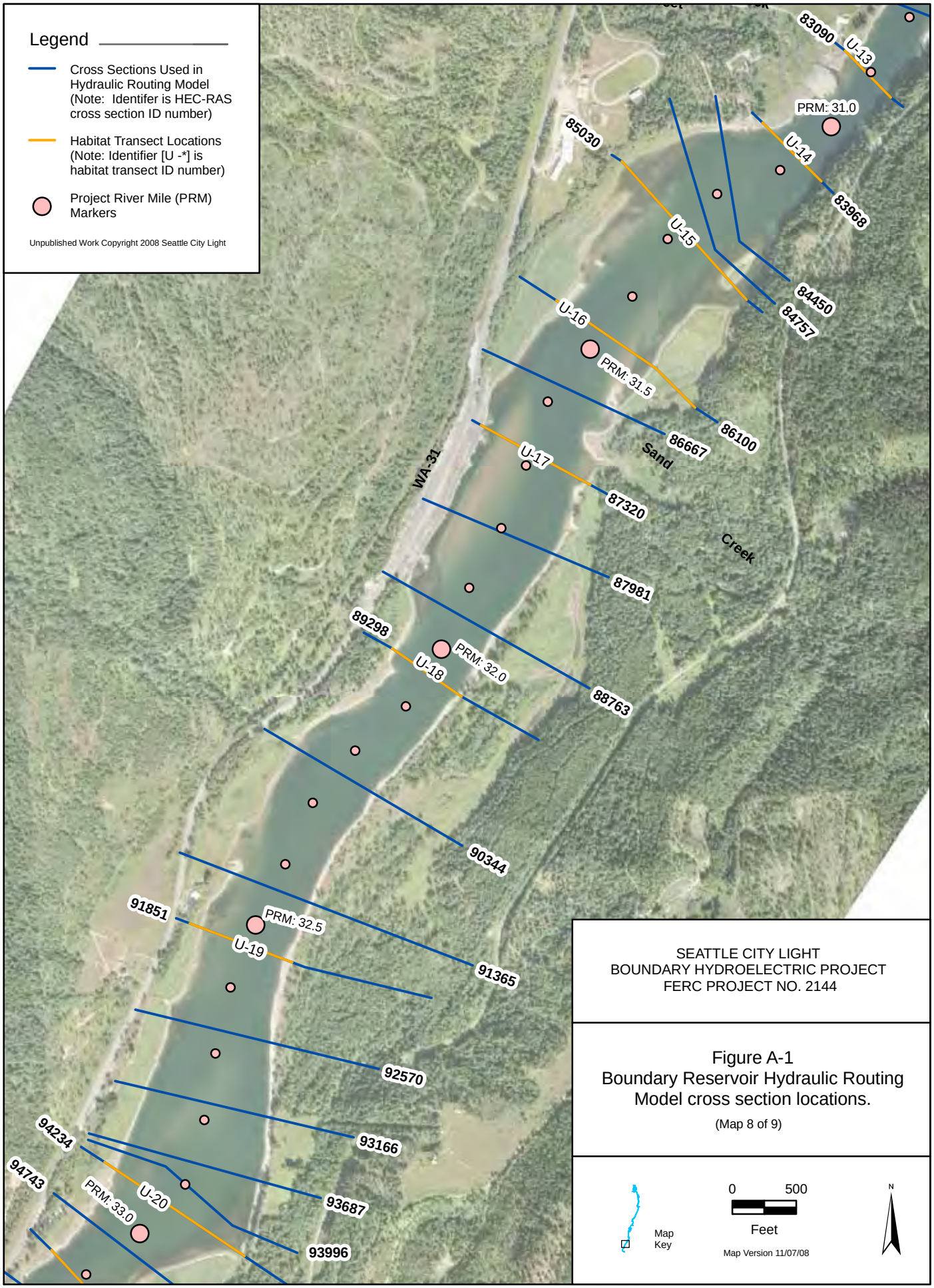
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Cross Sections Used in Hydraulic Routing Model (Note: Identifer is HEC-RAS cross section ID number)
Habitat Transect Locations (Note: Identifier [U -*] is habitat transect ID number)
Project River Mile (PRM) Markers
Unpublished Work Copyright 2008 Seattle City Light
83090
U-13
PRM: 31.0
U-14
83968
85030
U-15
84450
84757
U-16
PRM: 31.5
86667
86100
Sand
Creek
WA-31
U-17
87320
87981
89298
PRM: 32.0
U-18
88763
90344
91851
PRM: 32.5
U-19
91365
92570
94234
93166
94743
PRM: 33.0
U-20
93687
93996
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 8 of 9)
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Feet
Map Version 11/07/08
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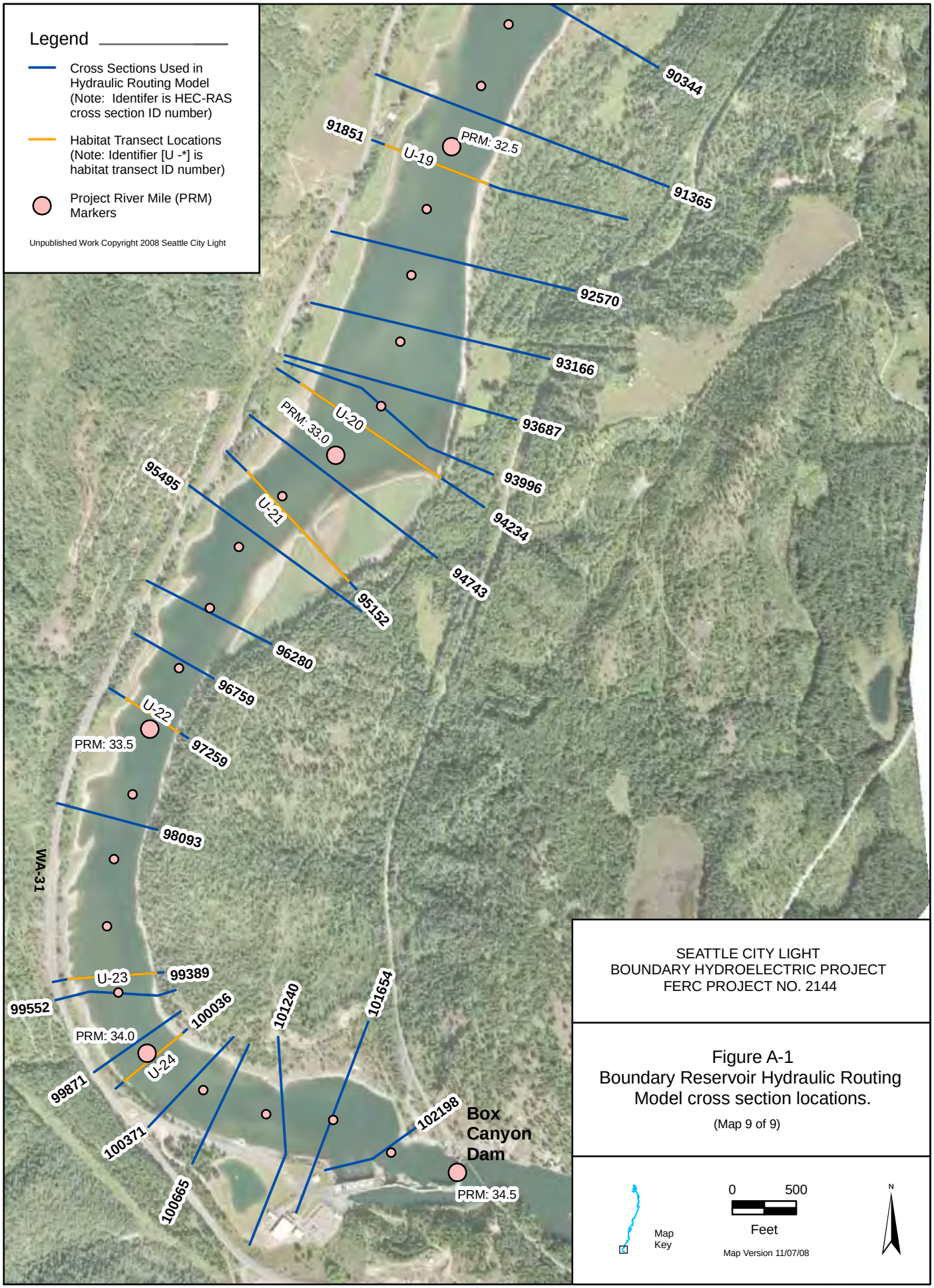
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Cross Sections Used in Hydraulic Routing Model (Note: Identifer is HEC-RAS cross section ID number)
Habitat Transect Locations (Note: Identifier [U -*] is habitat transect ID number)
Project River Mile (PRM) Markers
Unpublished Work Copyright 2008 Seattle City Light
90344
91851
U-19
PRM: 32.5
91365
92570
93166
93687
U-20
PRM: 33.0
93996
94234
95495
U-21
94743
95152
96280
96759
U-22
PRM: 33.5
97259
98093
WA-31
U-23
99389
99552
100036
101240
101654
PRM: 34.0
U-24
99871
100371
102198
Box Canyon Dam
PRM: 34.5
100665
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-1
Boundary Reservoir Hydraulic Routing Model cross section locations.
(Map 9 of 9)
Map Key
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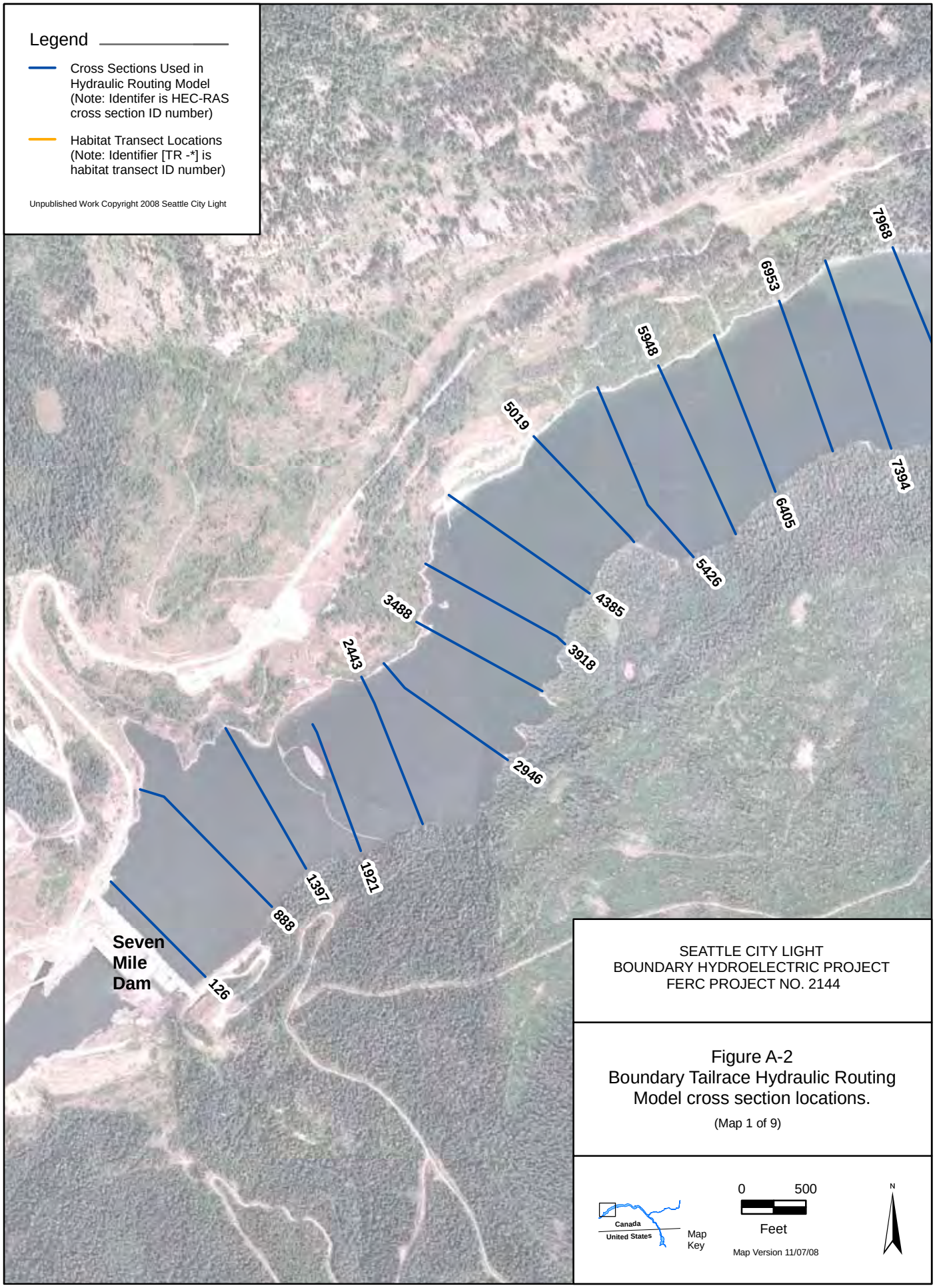
500
Feet
Map Version 11/07/08
N

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BOUNDARY HYDROELECTRIC PROJECT
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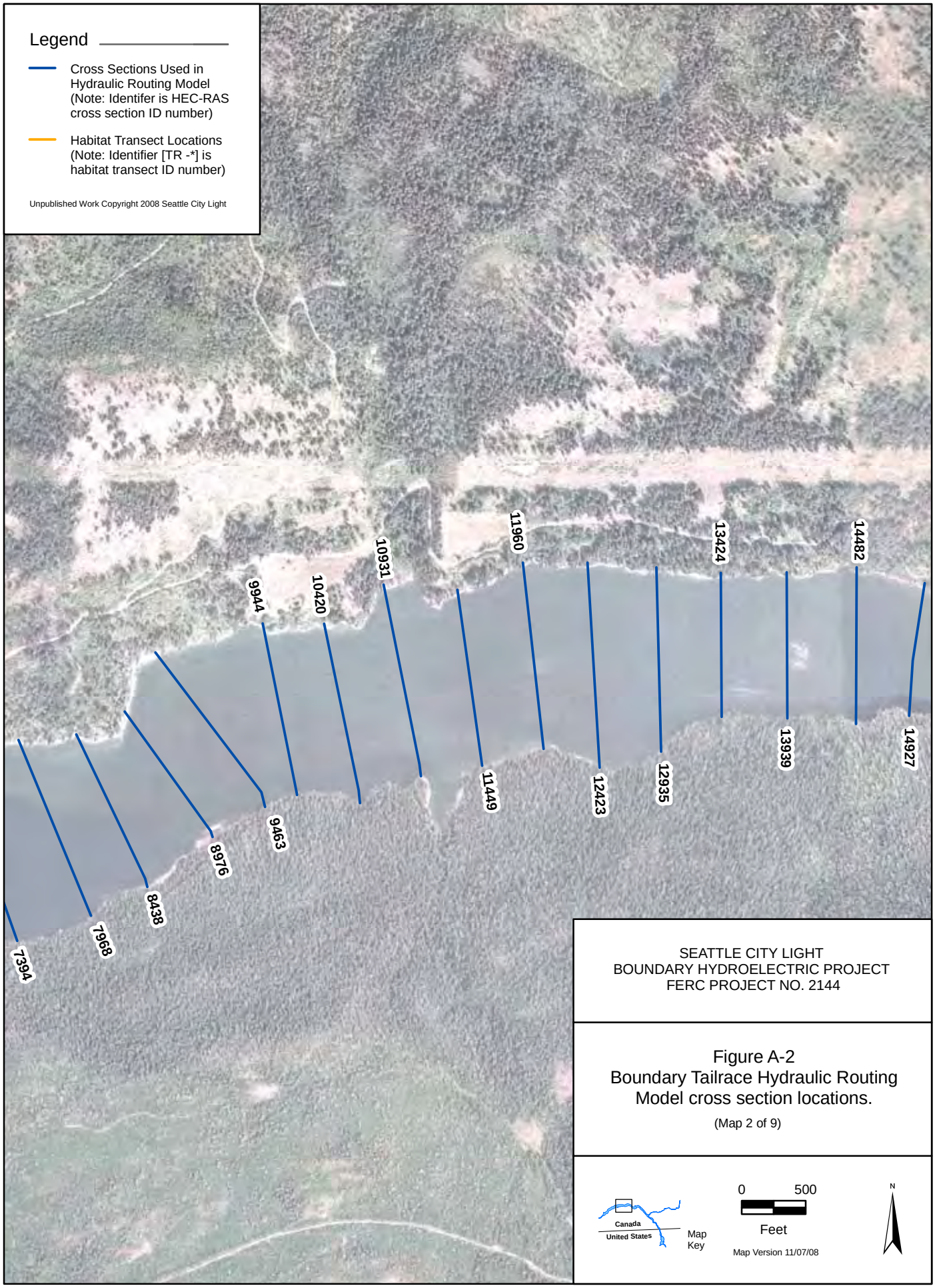
Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 1 of 9)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Cross Sections Used in Hydraulic Routing Model (Note: Identifer is HEC-RAS cross section ID number)
Habitat Transect Locations (Note: Identifier [TR -*] is habitat transect ID number)
Unpublished Work Copyright 2008 Seattle City Light
7394
7968
8438
8976
9463
9944
10420
10931
11449
11960
12423
12935
13424
13939
14482
14927
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.
(Map 2 of 9)
Canada
United States
Map Key
0
500
Feet
Map Version 11/07/08
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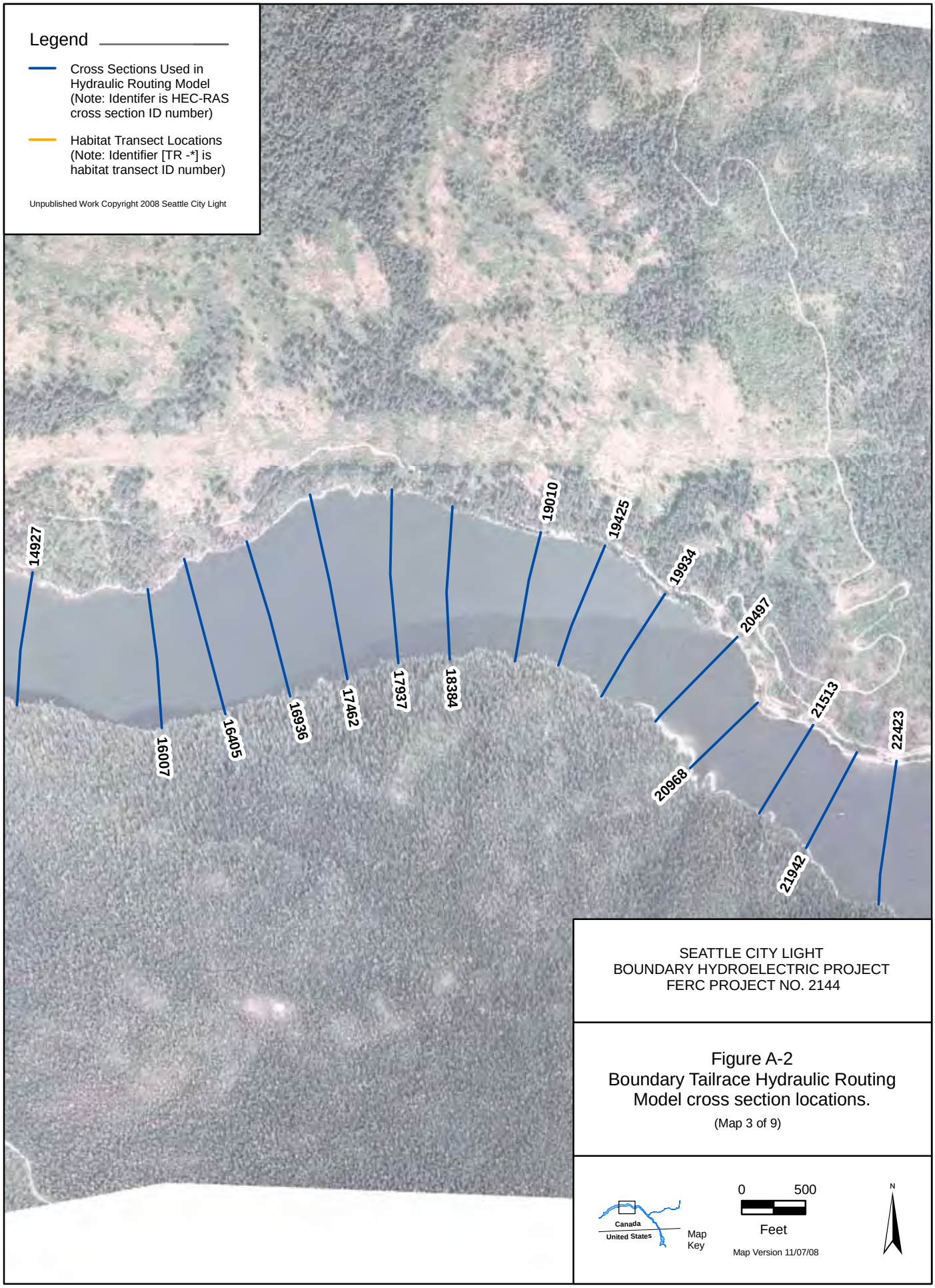


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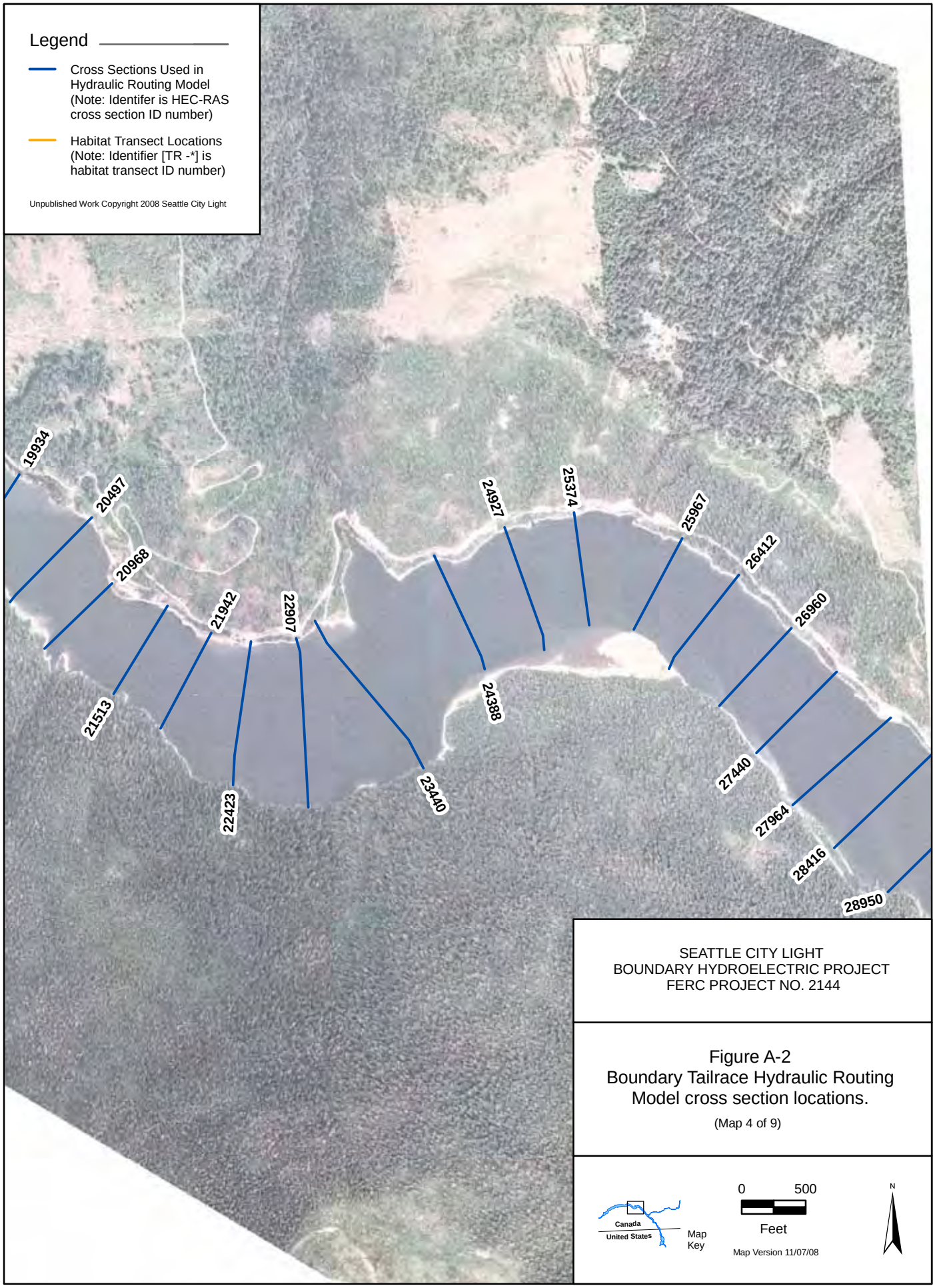
FERC PROJECT NO. 2144

Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 3 of 9)

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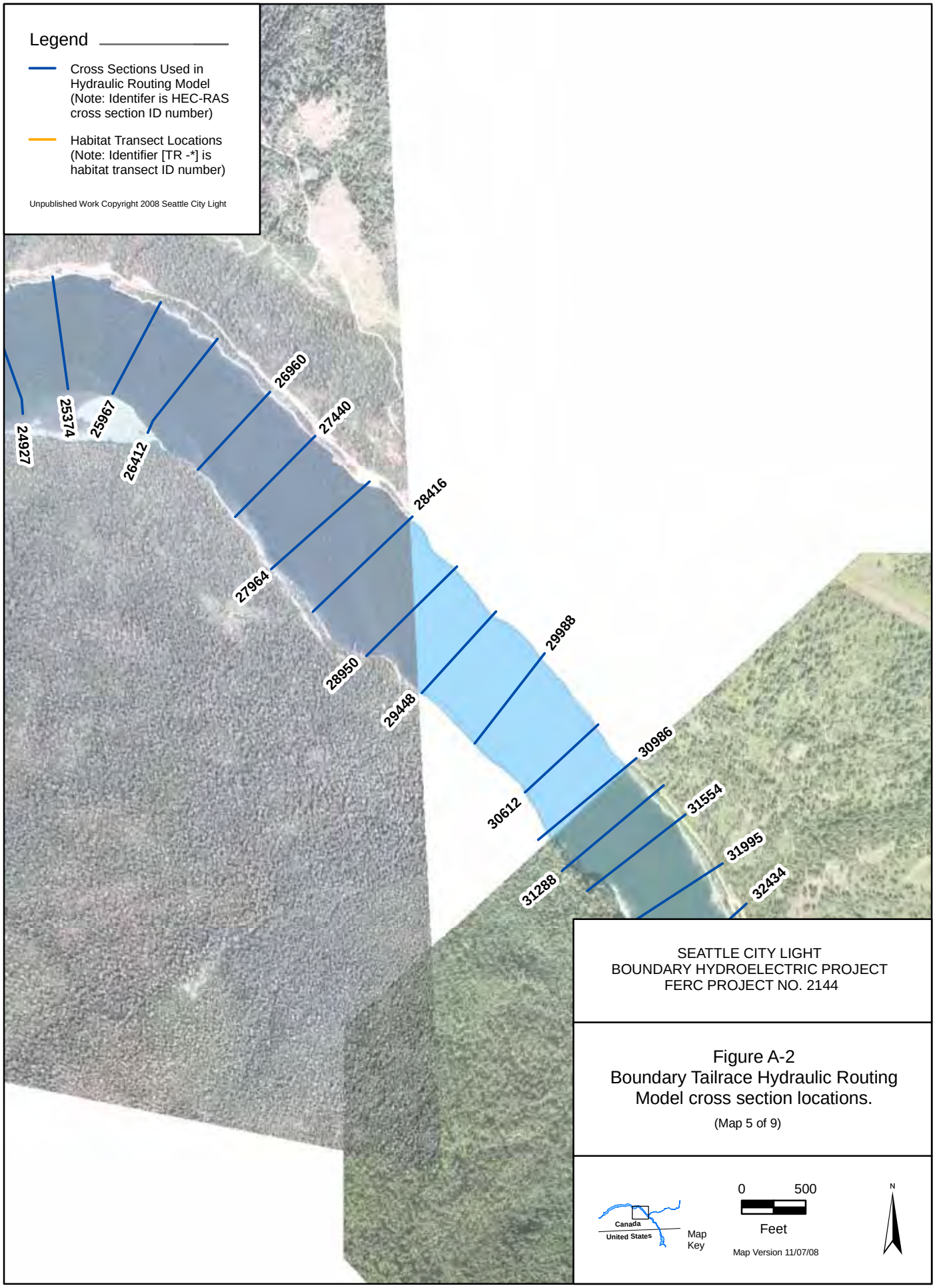
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 4 of 9)

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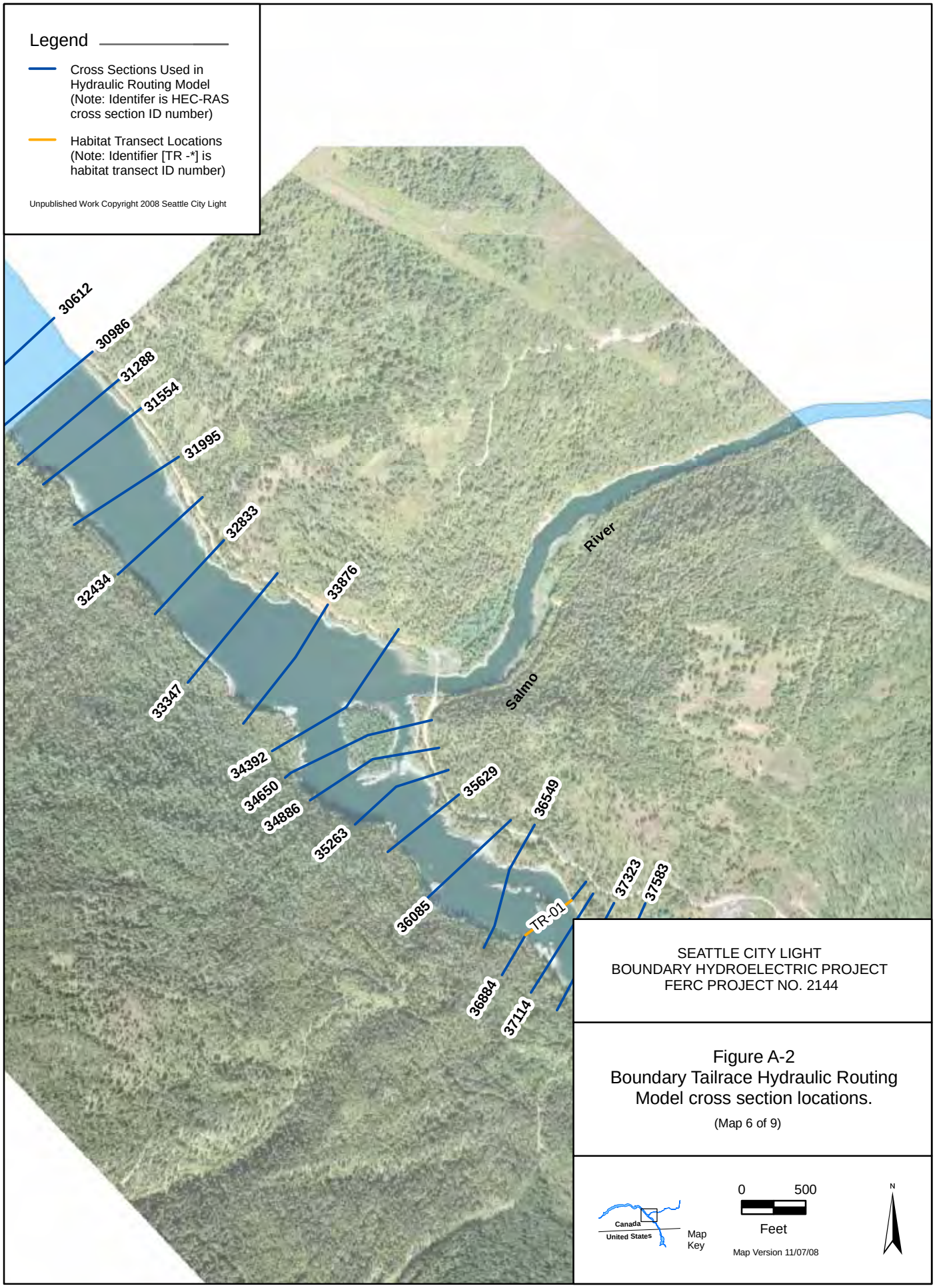
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 5 of 9)


Legend
Cross Sections Used in Hydraulic Routing Model (Note: Identifer is HEC-RAS cross section ID number)
Habitat Transect Locations (Note: Identifier [TR -*] is habitat transect ID number)
Unpublished Work Copyright 2008 Seattle City Light
30612
30986
31288
31554
31995
32833
32434
33876
33347
34392
34650
34886
35629
35263
36549
36085
TR-01
37323
37583
36884
37114
Salmo
River
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.
(Map 6 of 9)
Canada
United States
Map Key
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Feet
Map Version 11/07/08
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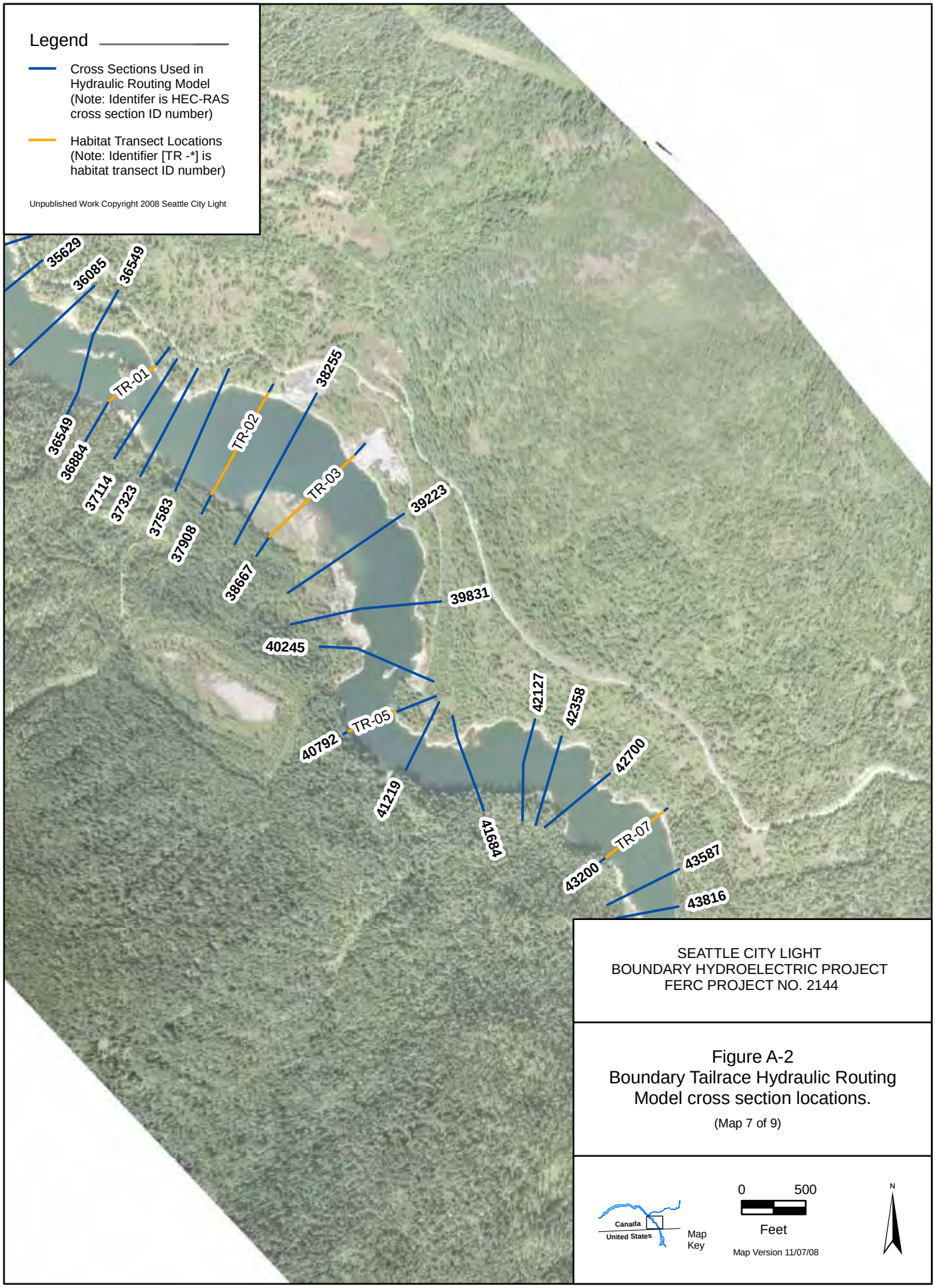
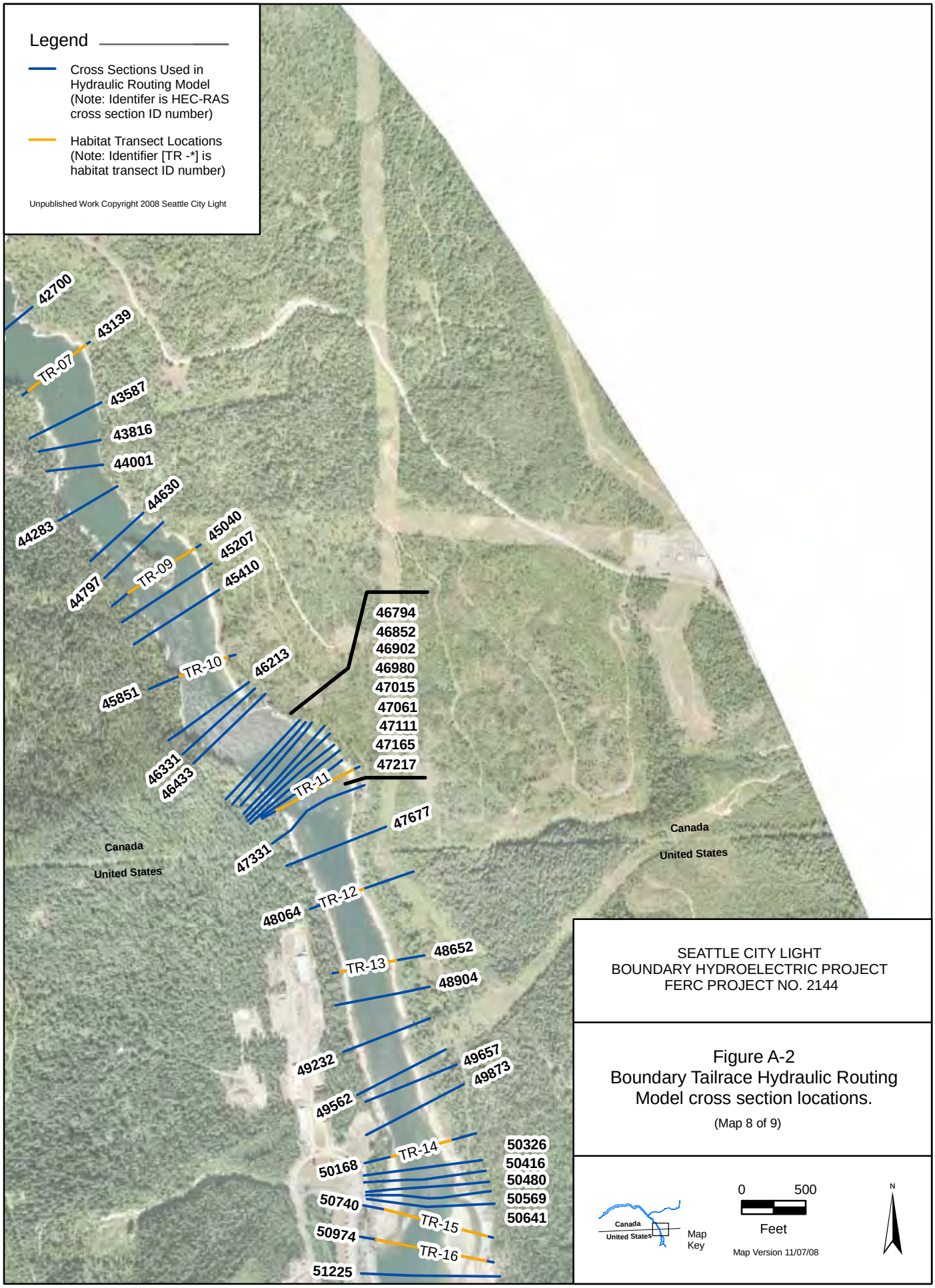



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 7 of 9)


Legend
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Habitat Transect Locations (Note: Identifier [TR -*] is habitat transect ID number)
Unpublished Work Copyright 2008 Seattle City Light
42700
43139
TR-07
43587
43816
44001
44630
44283
45040
45207
TR-09
44797
45410
46794
46852
46902
46980
47015
47061
47111
47165
47217
TR-10
46213
45851
46331
46433
TR-11
47677
Canada
United States
47331
TR-12
48064
TR-13
48652
48904
49232
49657
49873
49562
TR-14
50326
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50569
50740
50641
TR-15
50974
TR-16
51225
Canada
United States
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.
(Map 8 of 9)
Canada
United States
Map Key
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Feet
Map Version 11/07/08
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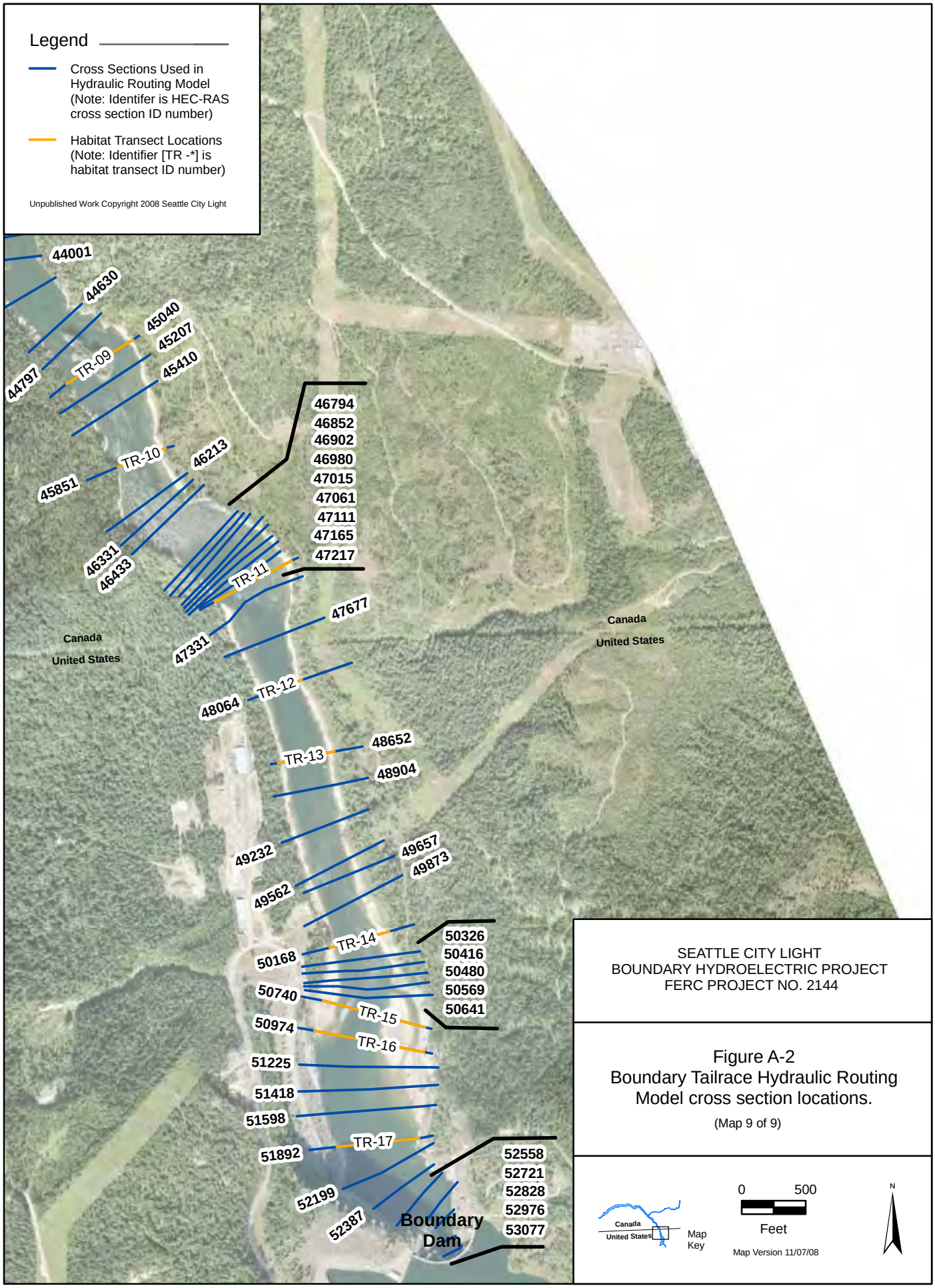


SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A-2
Boundary Tailrace Hydraulic Routing Model cross section locations.

(Map 9 of 9)

# Attachment B: Boundary Condition Hydrograph Figures

This attachment includes the following figures and graphics in support of the development and calibration of the Boundary Reservoir Hydraulic Routing Model (HRM) and the Boundary Tailrace HRM. This attachment contains the following:

- Complete set of boundary condition hydrograph figures for Boundary Reservoir HRM calibration and verification periods (Figures B-1 through B-11). Boundary condition hydrograph figures are included for the six calibration periods and the five verification periods.
- Complete set of boundary condition hydrograph figures for Boundary Tailrace HRM calibration and verification periods (Figures B-12 through B-26). Boundary condition hydrograph figures are included for the nine calibration periods and the six verification periods.

## List of Figures

Figure B-1. Boundary condition hydrographs for Hi_Lo calibration period - Boundary Reservoir HRM.
Figure B-2. Boundary condition hydrographs for Hi_Mod calibration period - Boundary Reservoir HRM.
Figure B-3. Boundary condition hydrographs for Hi_Hi calibration period - Boundary Reservoir HRM.
Figure B-4. Boundary condition hydrographs for Lo_Lo calibration period - Boundary Reservoir HRM.
Figure B-5. Boundary condition hydrographs for Lo_Mod calibration period - Boundary Reservoir HRM.
Figure B-6. Boundary condition hydrographs for Lo_Hi calibration period - Boundary Reservoir HRM.
Figure B-7. Boundary condition hydrographs for Hi_Hi verification period - Boundary Reservoir HRM.
Figure B-8. Boundary condition hydrographs for Var_Var verification period - Boundary Reservoir HRM.
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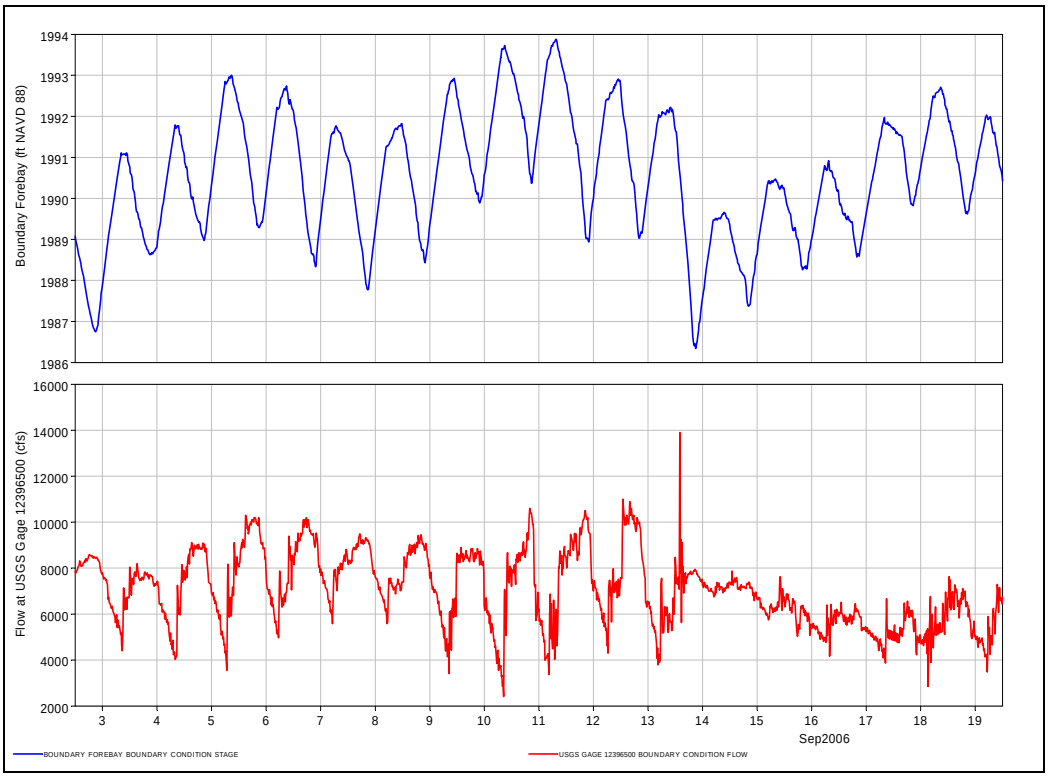



**Figure B-1.** Boundary condition hydrographs for Hi_Lo calibration period - Boundary Reservoir HRM.

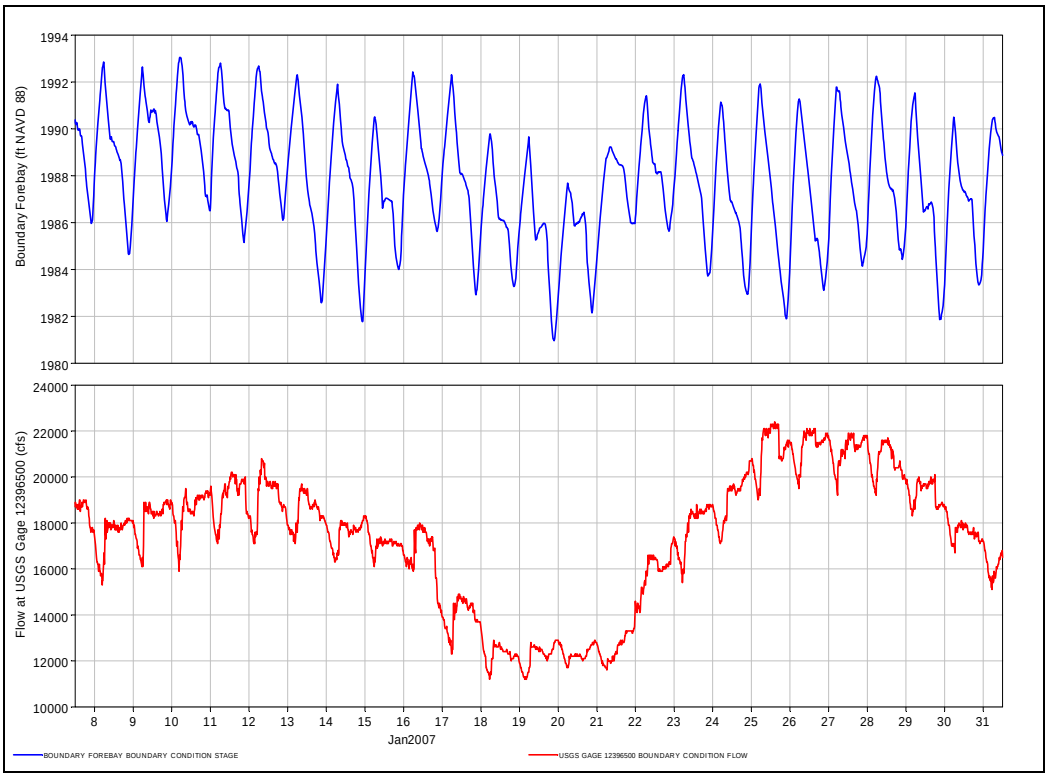
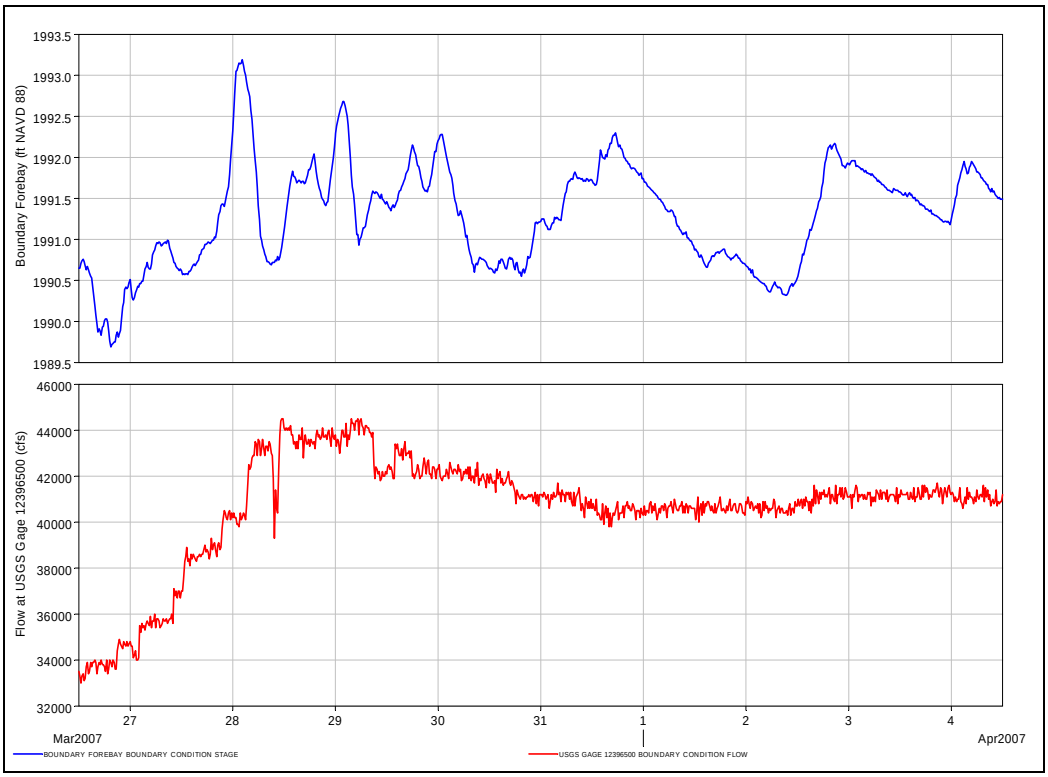



**Figure B-2.** Boundary condition hydrographs for Hi_Mod calibration period - Boundary Reservoir HRM.

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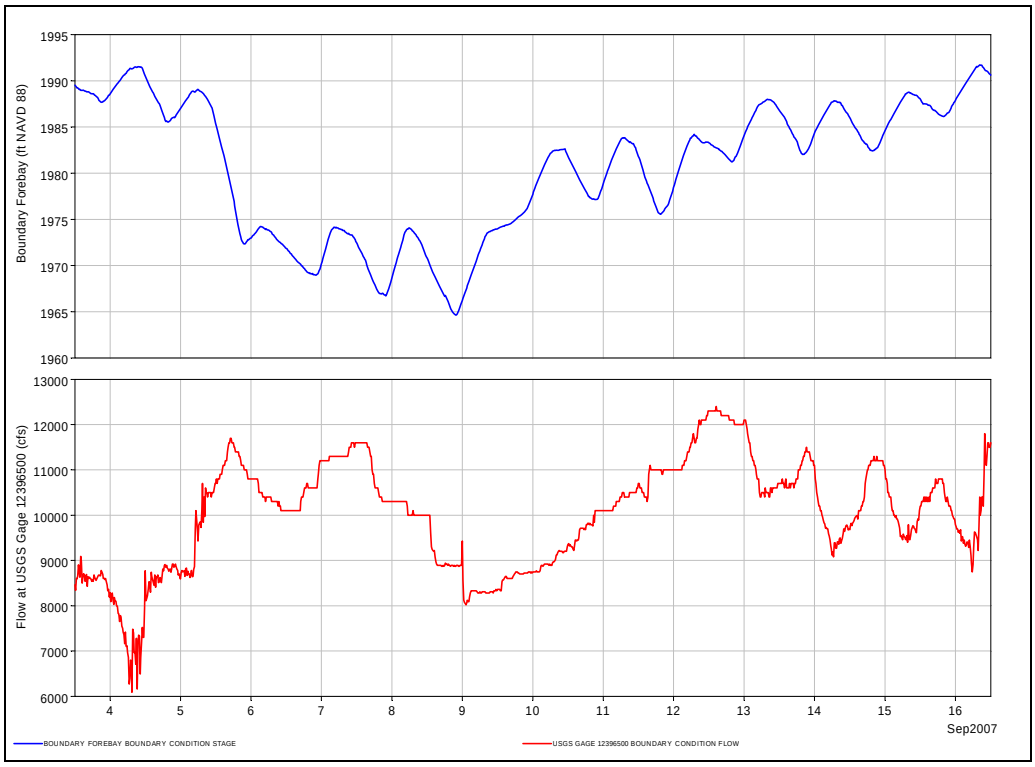



**Figure B-4.** Boundary condition hydrographs for Lo_Lo calibration period - Boundary Reservoir HRM.

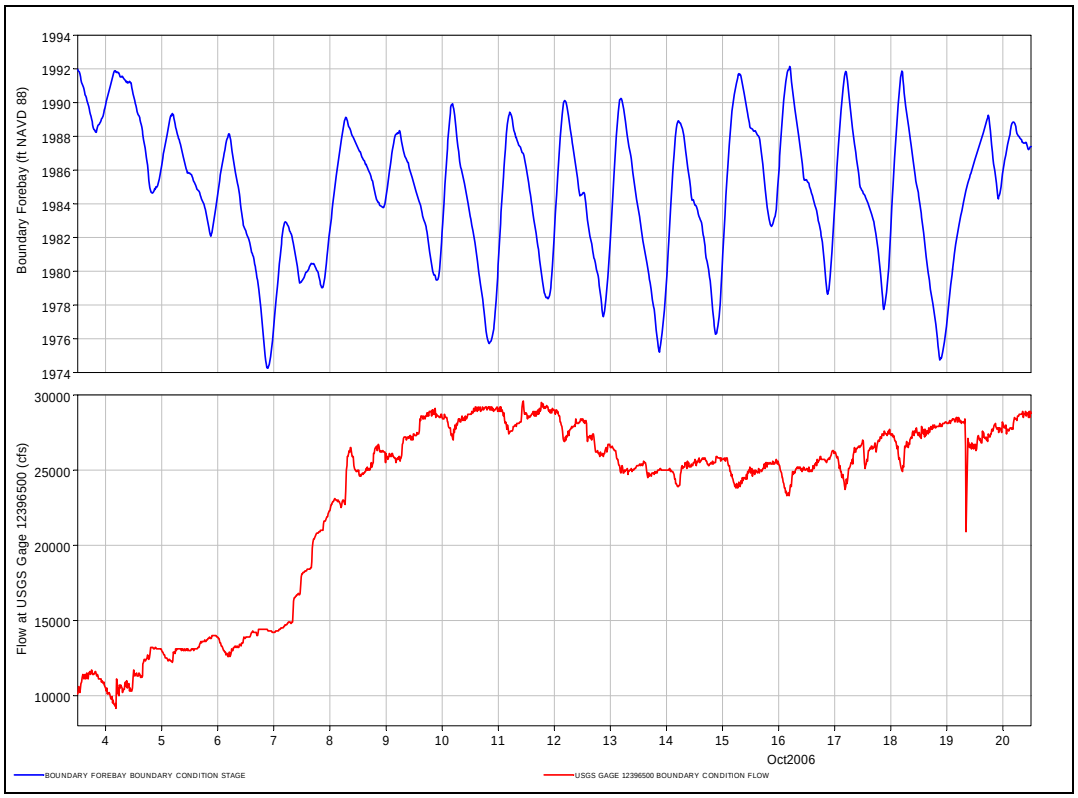



**Figure B-5.** Boundary condition hydrographs for Lo_Mod calibration period - Boundary Reservoir HRM.

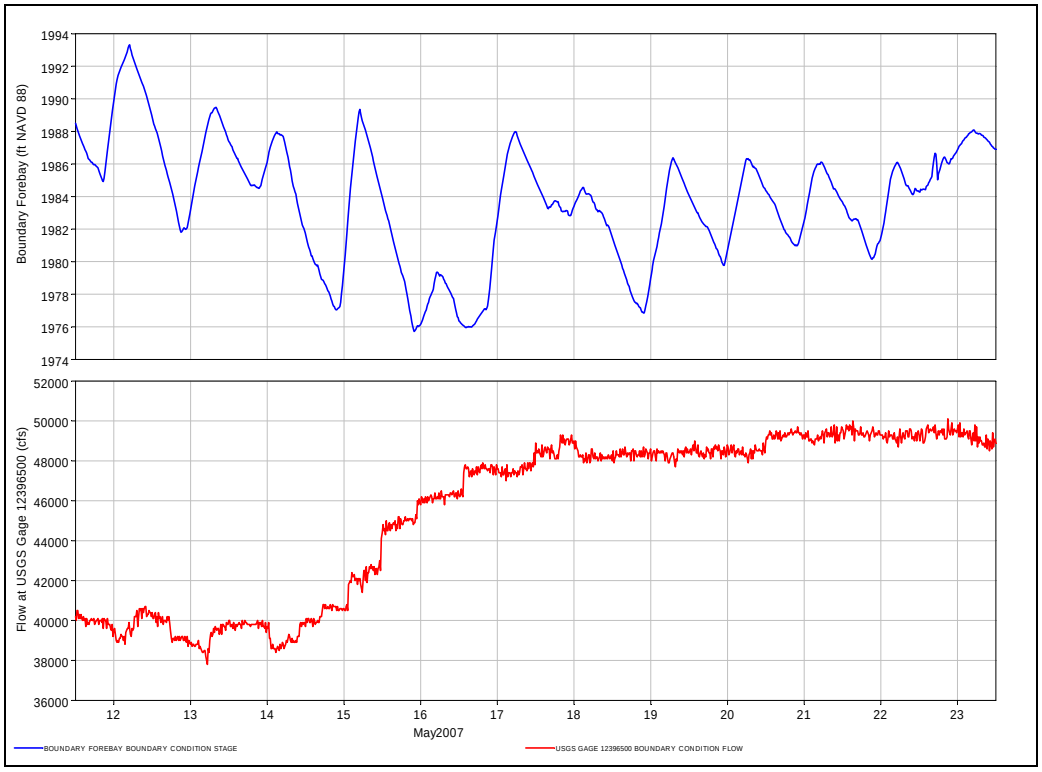



**Figure B-6.** Boundary condition hydrographs for Lo_Hi calibration period - Boundary Reservoir HRM.

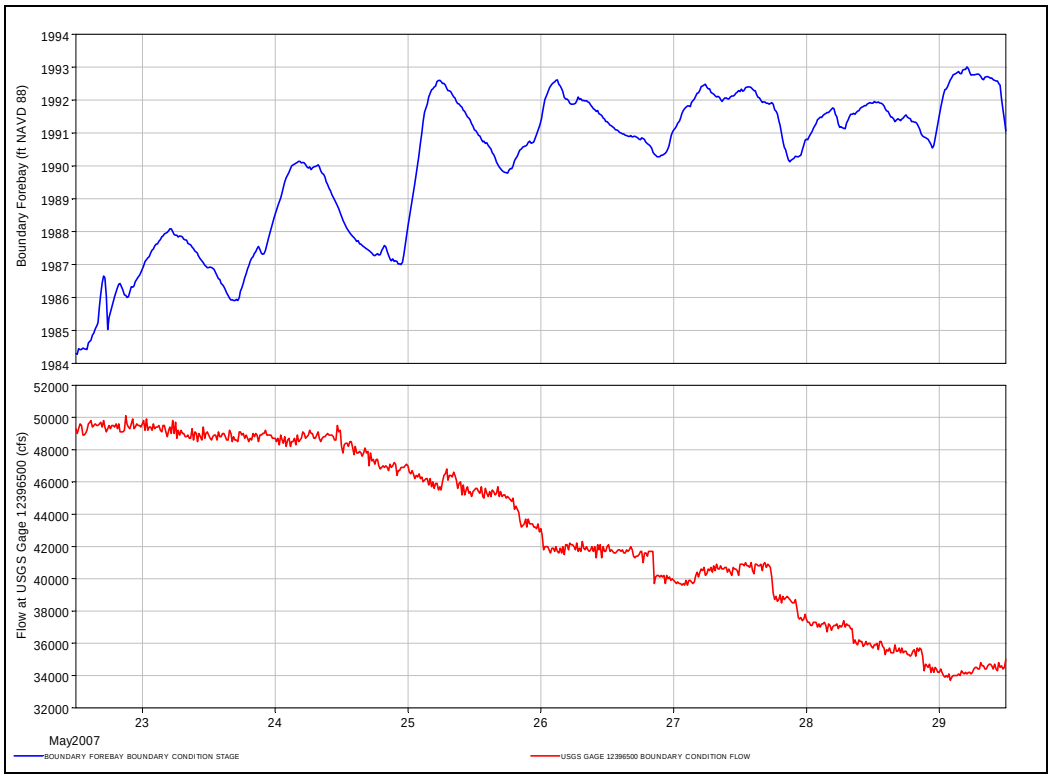



**Figure B-7.** Boundary condition hydrographs for Hi_Hi verification period - Boundary Reservoir HRM.

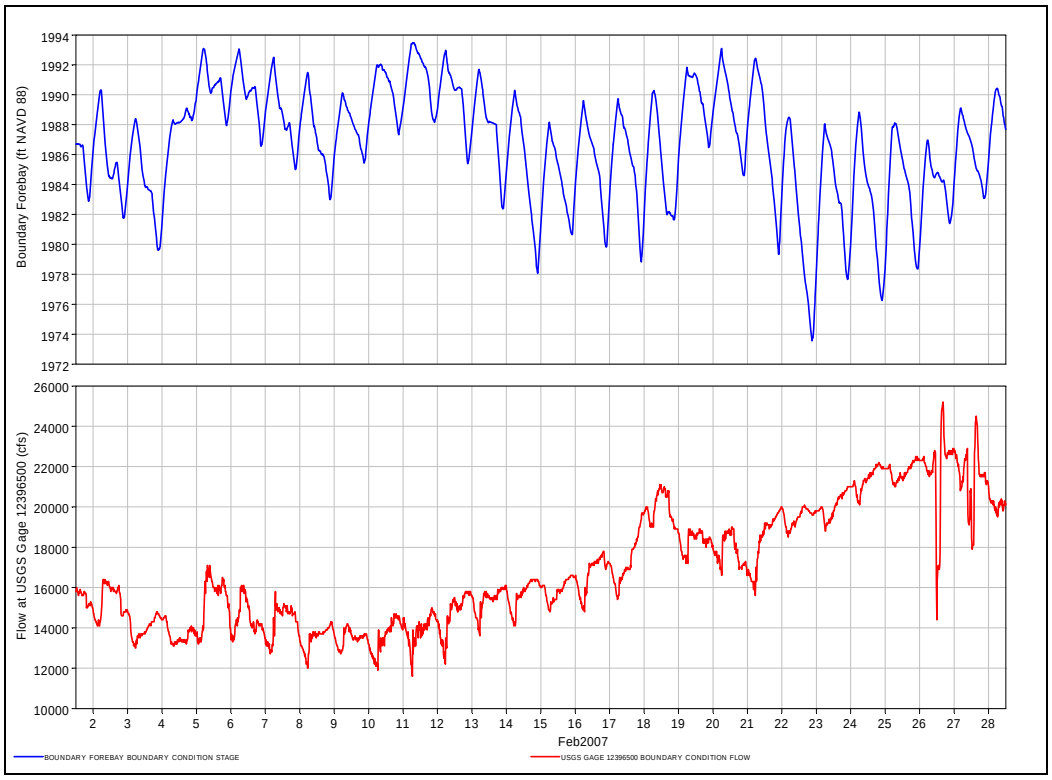



**Figure B-8.** Boundary condition hydrographs for Var_Var verification period - Boundary Reservoir HRM.

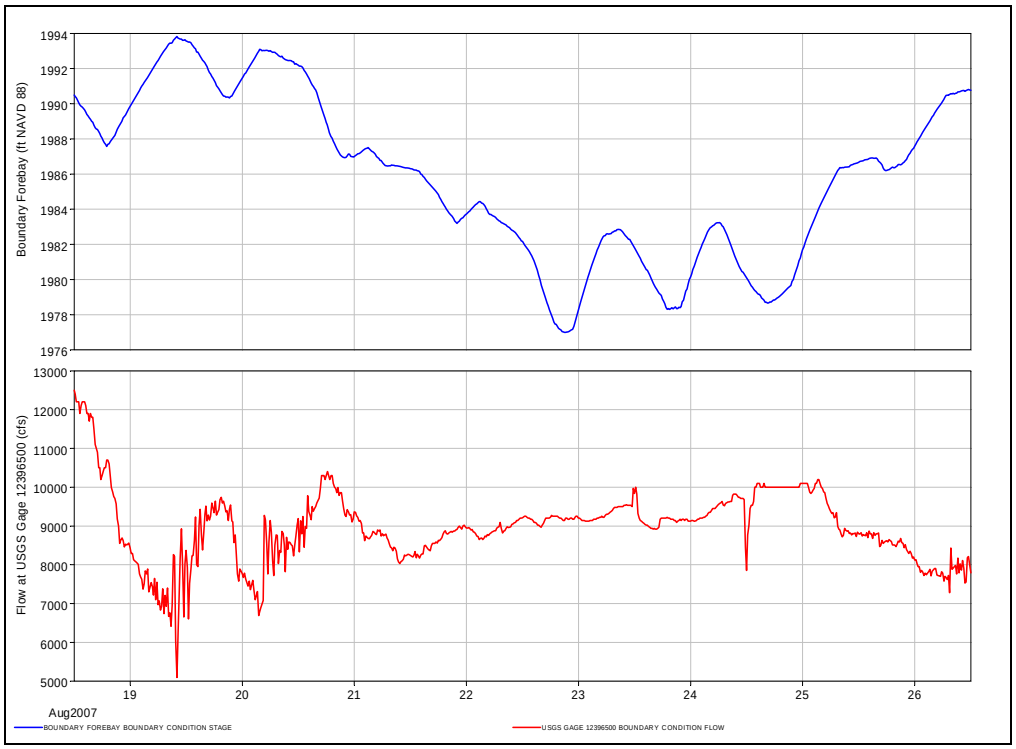



**Figure B-9.** Boundary condition hydrographs for Lo_Lo verification period - Boundary Reservoir HRM.

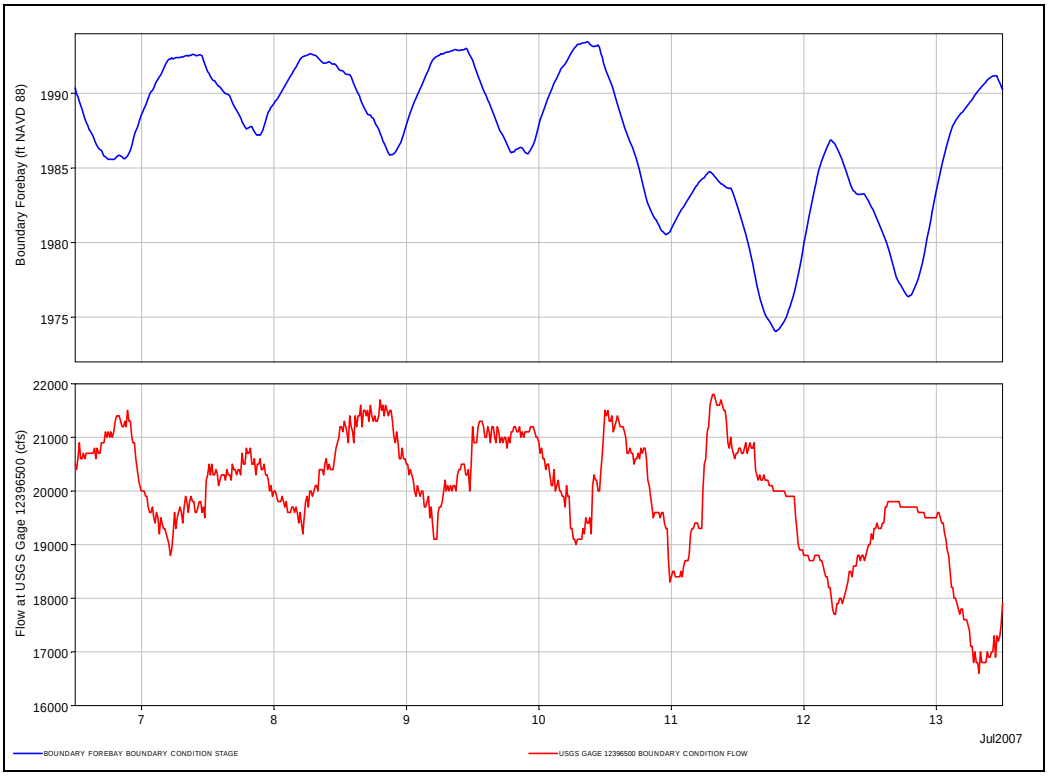



**Figure B-10.** Boundary condition hydrographs for Lo_Mod verification period - Boundary Reservoir HRM.

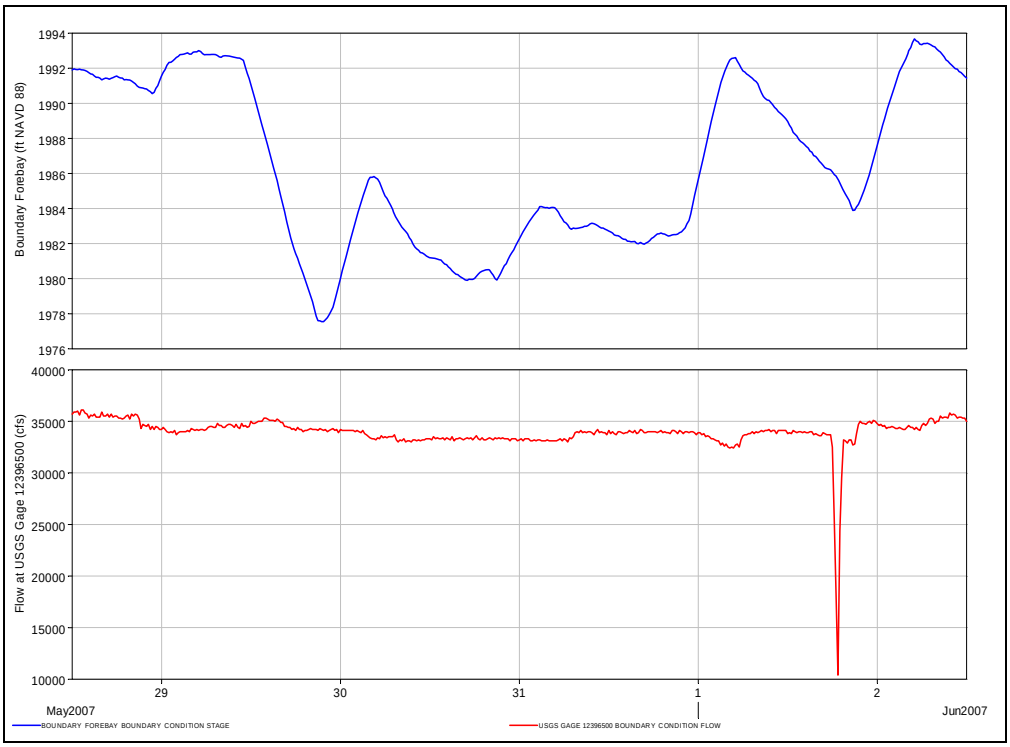



**Figure B-11.** Boundary condition hydrographs for Lo_Hi verification period - Boundary Reservoir HRM.

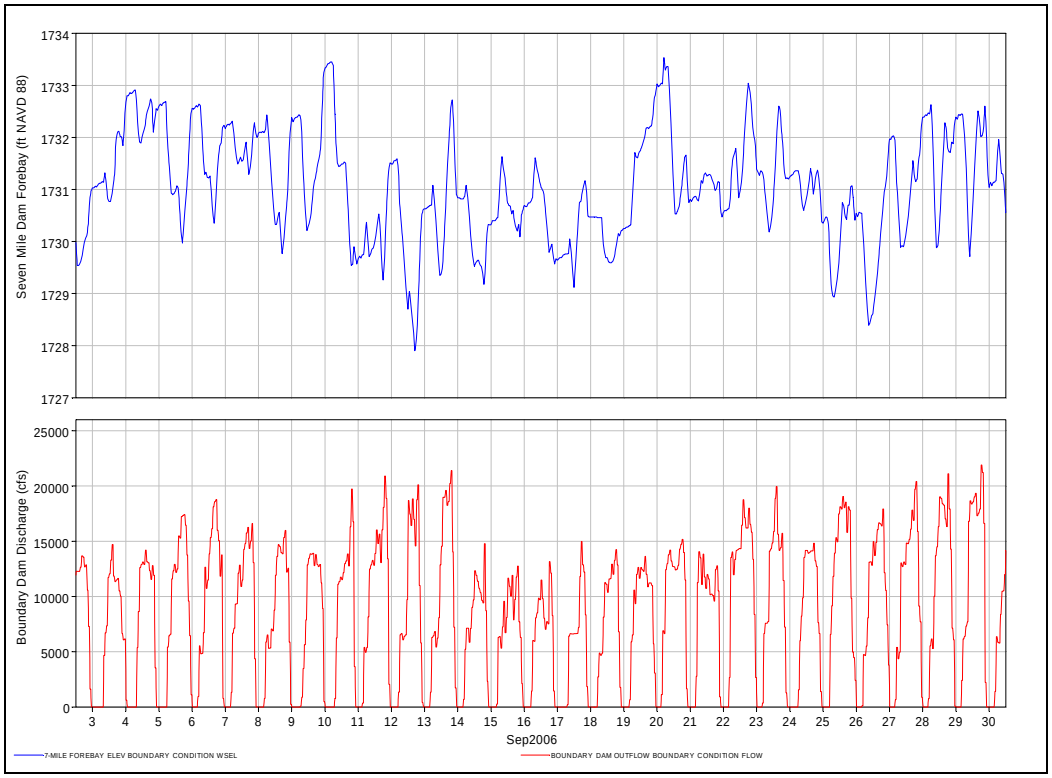



**Figure B-12.** Boundary condition hydrographs for Hi_Lo calibration period - Boundary Tailrace HRM.

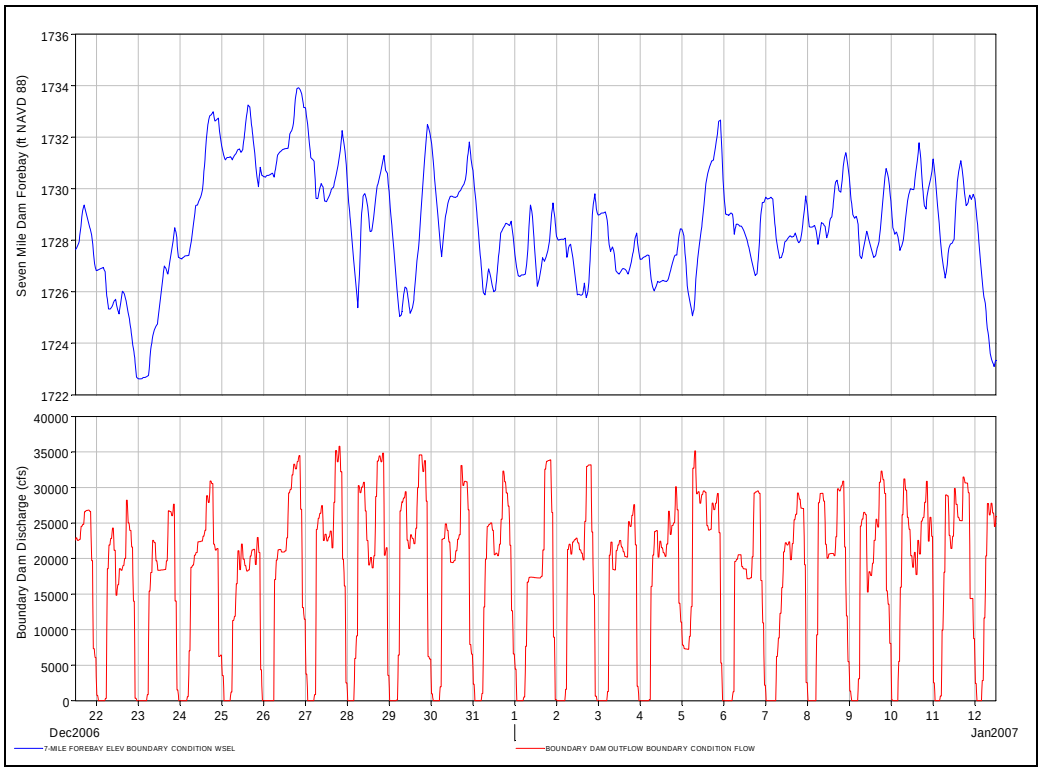



**Figure B-13.** Boundary condition hydrographs for Hi_Mod calibration period - Boundary Tailrace HRM.

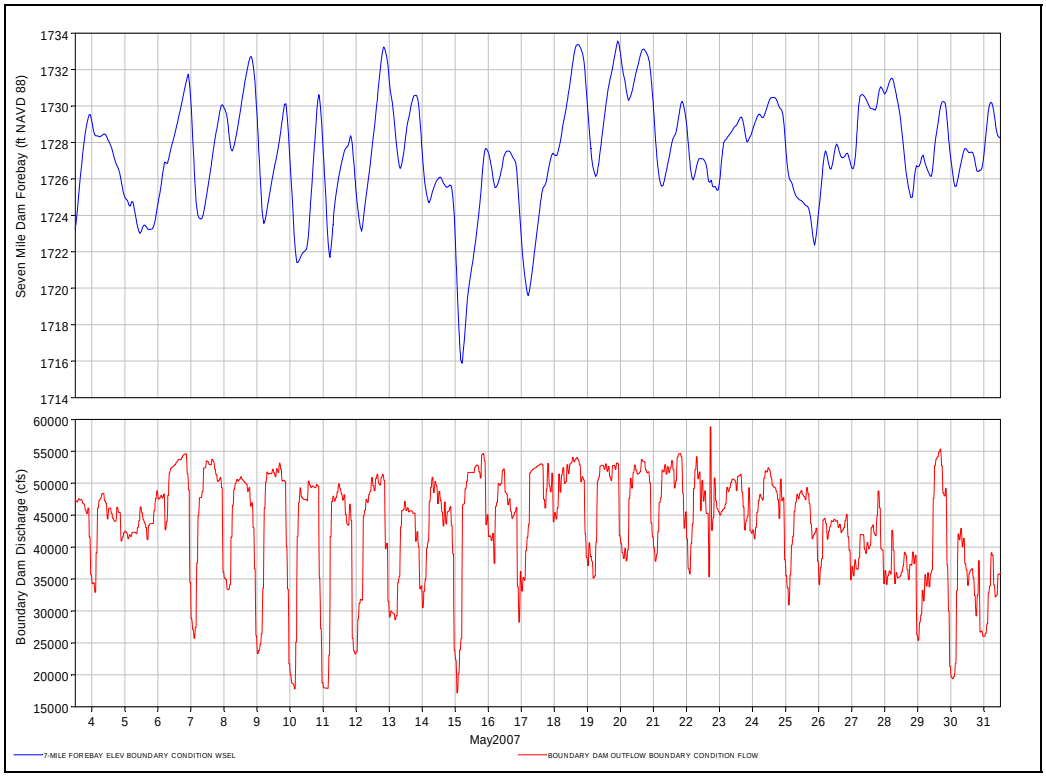



**Figure B-14.** Boundary condition hydrographs for Hi_Hi calibration period - Boundary Tailrace HRM.

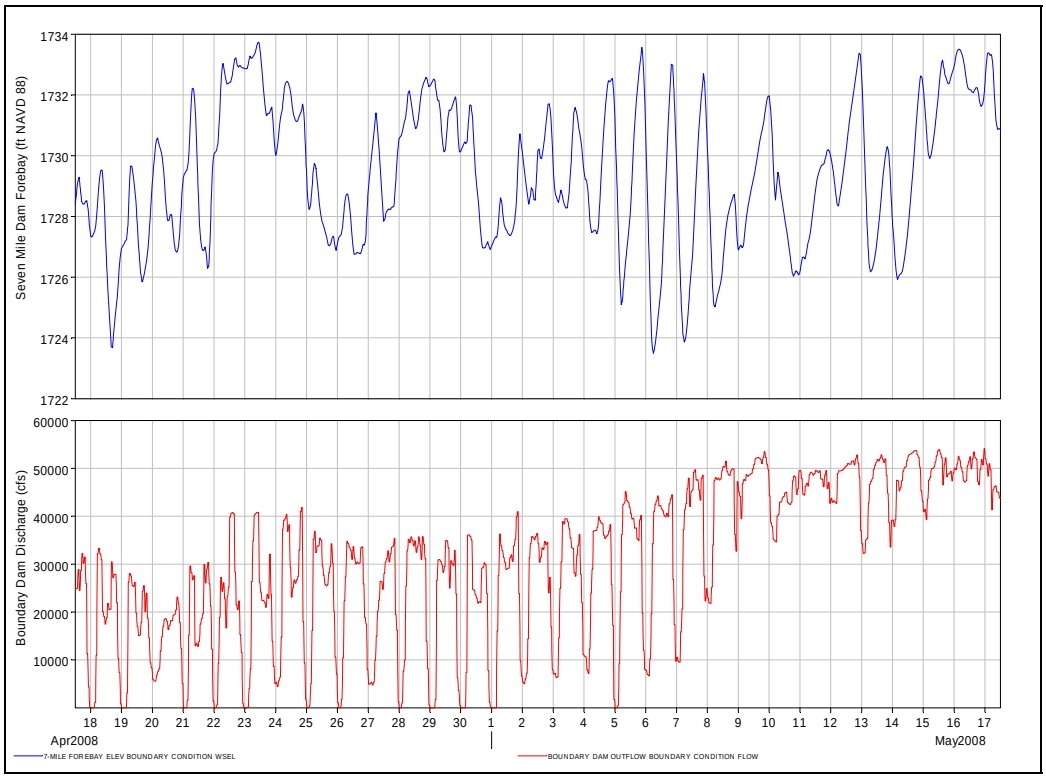



**Figure B-15.** Boundary condition hydrographs for Hi_Hi2 calibration period - Boundary Tailrace HRM.

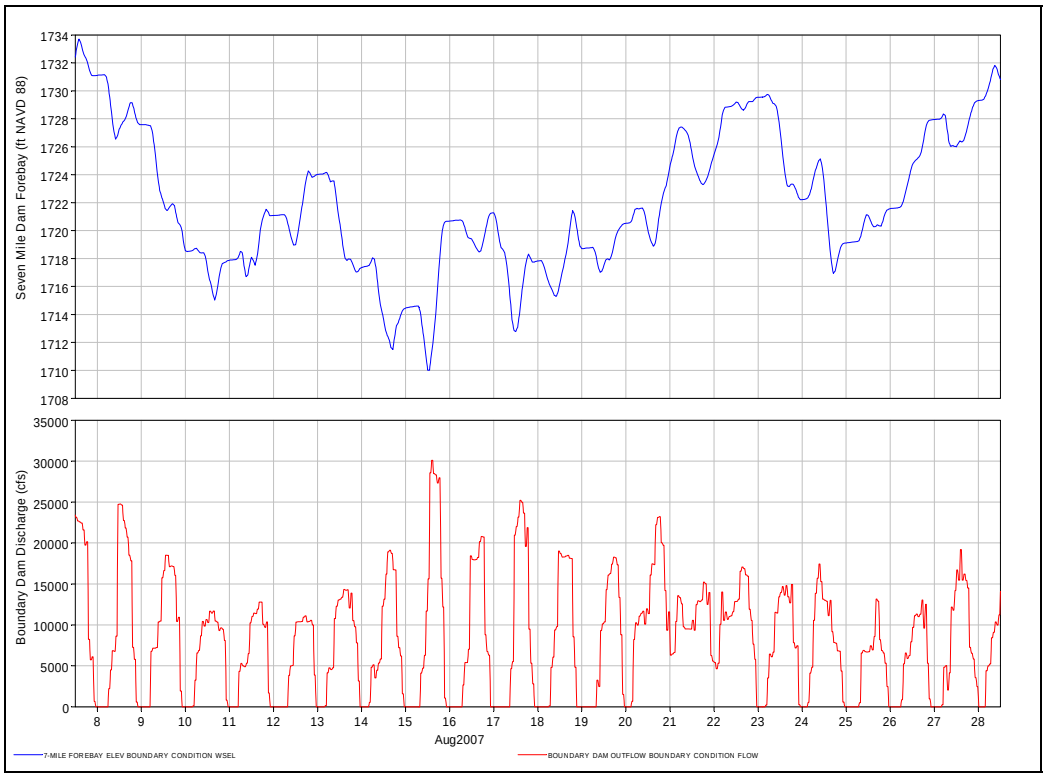



**Figure B-16.** Boundary condition hydrographs for Lo_Lo calibration period - Boundary Tailrace HRM.

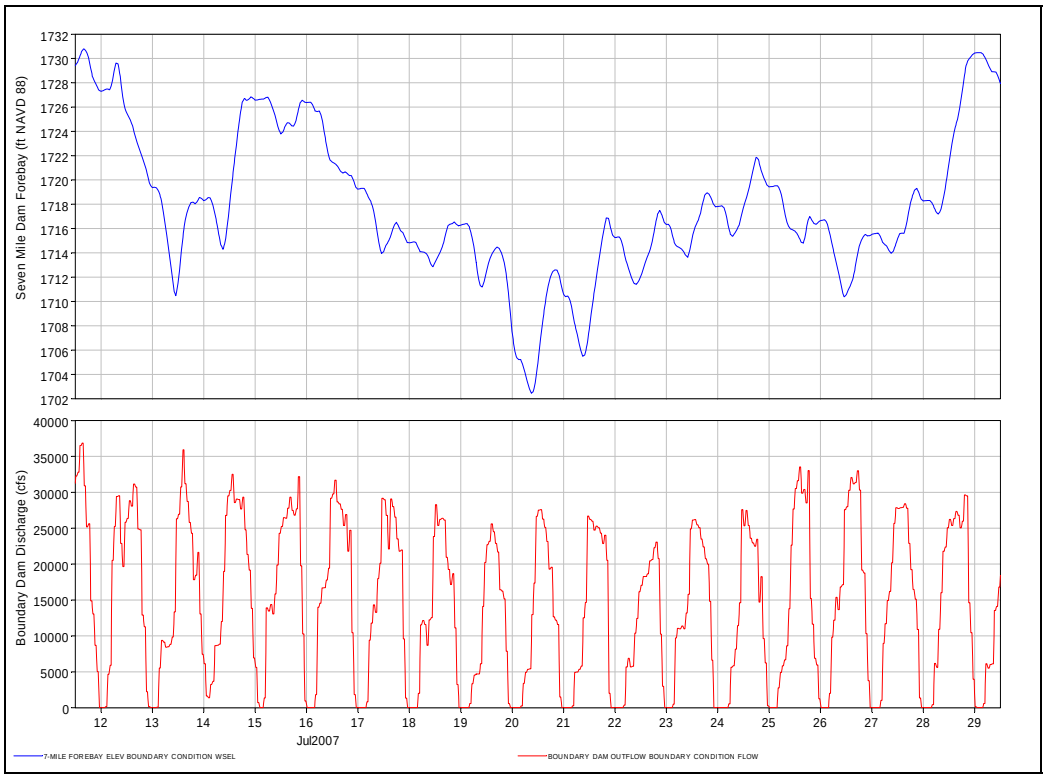



**Figure B-17.** Boundary condition hydrographs for Lo_Mod calibration period - Boundary Tailrace HRM.

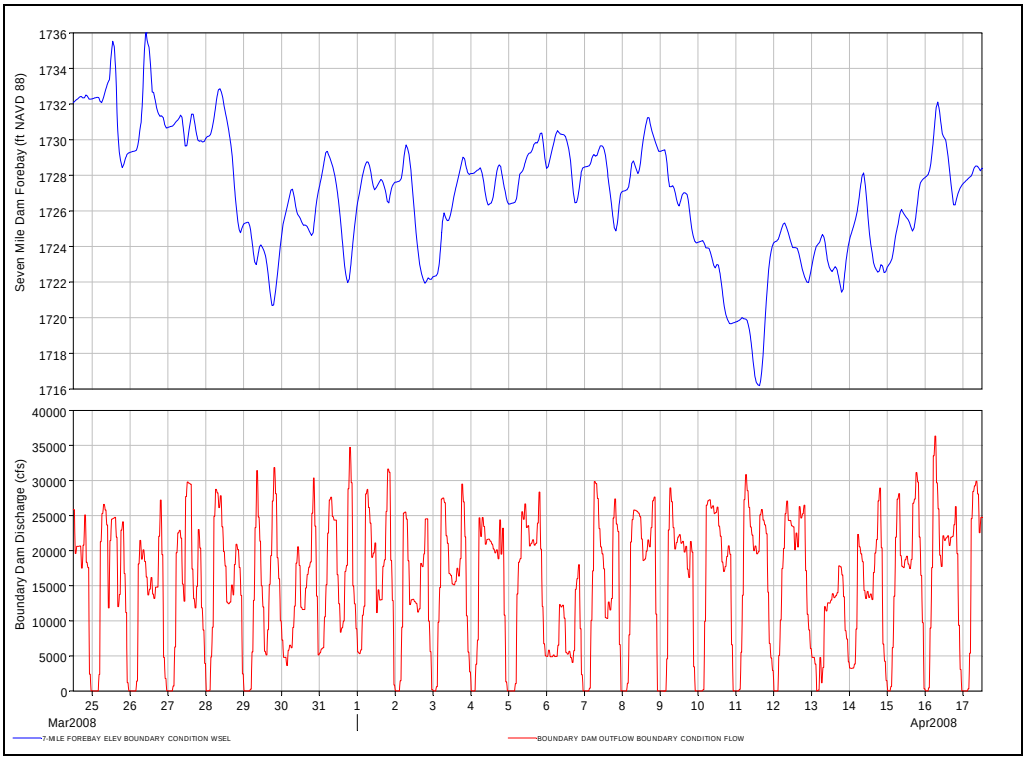
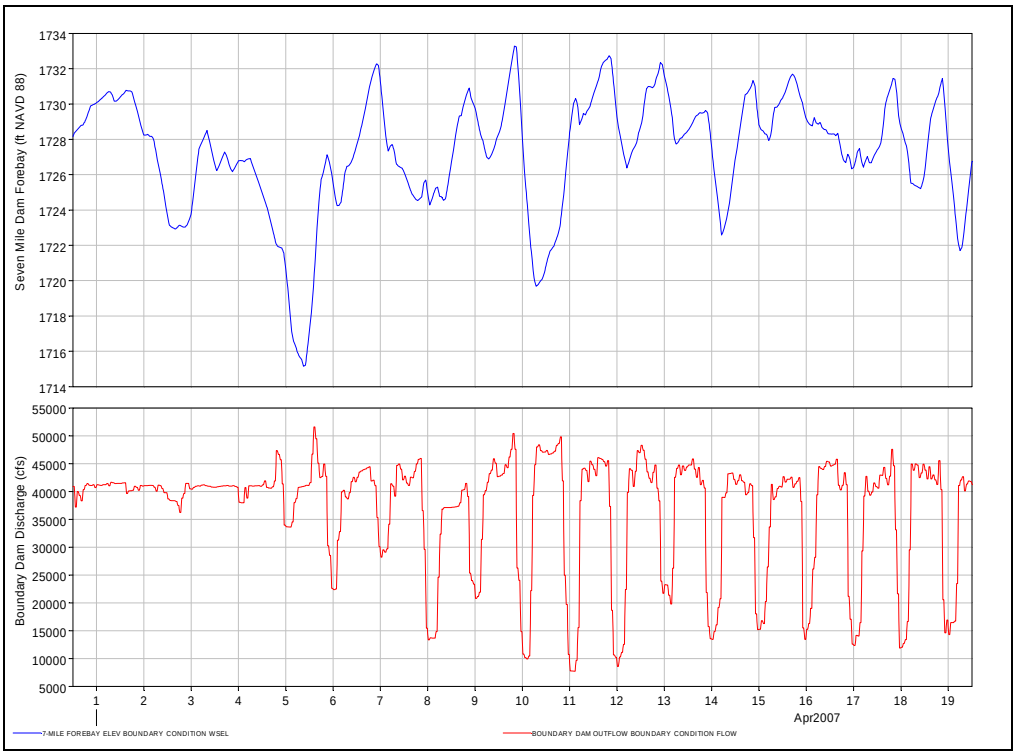



**Figure B-18.** Boundary condition hydrographs for Lo_Mod2 calibration period - Boundary Tailrace HRM.

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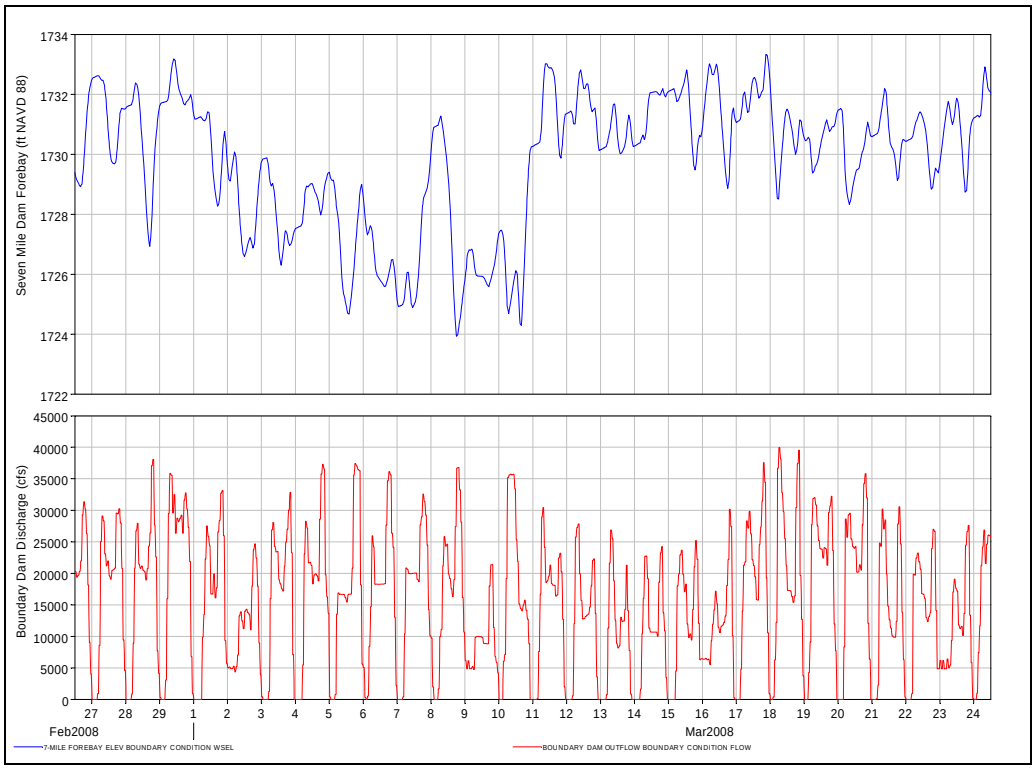



**Figure B-20.** Boundary condition hydrographs for Var_Var calibration period - Boundary Tailrace HRM.

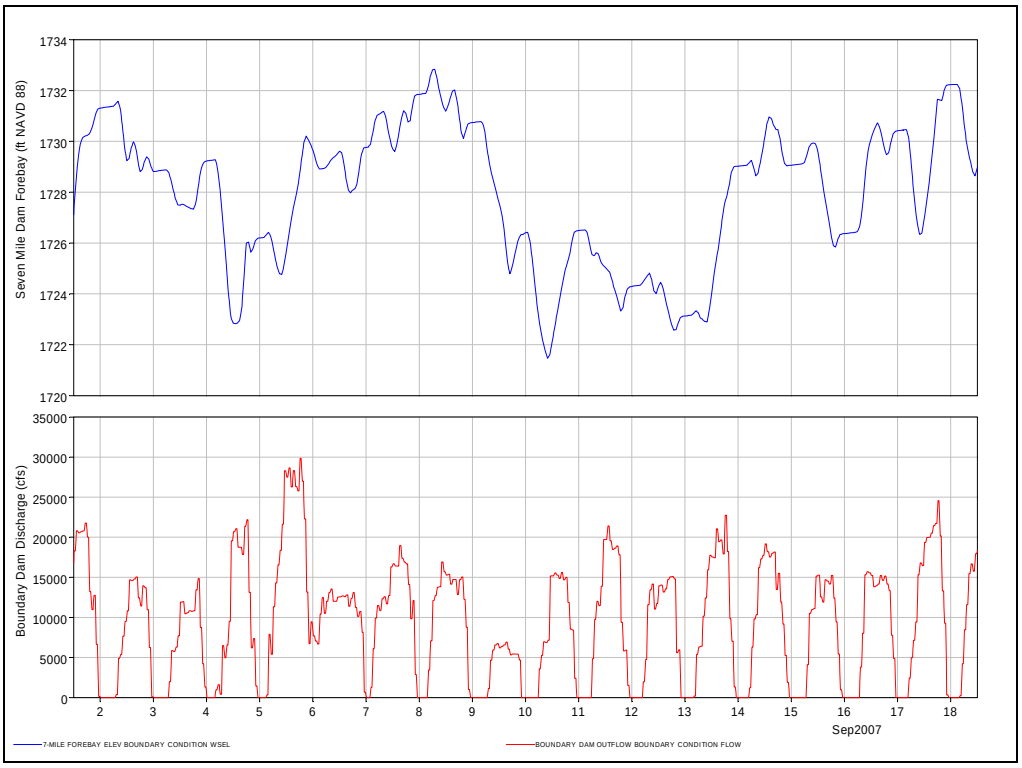



**Figure B-21.** Boundary condition hydrographs for Hi_Lo verification period - Boundary Tailrace HRM.

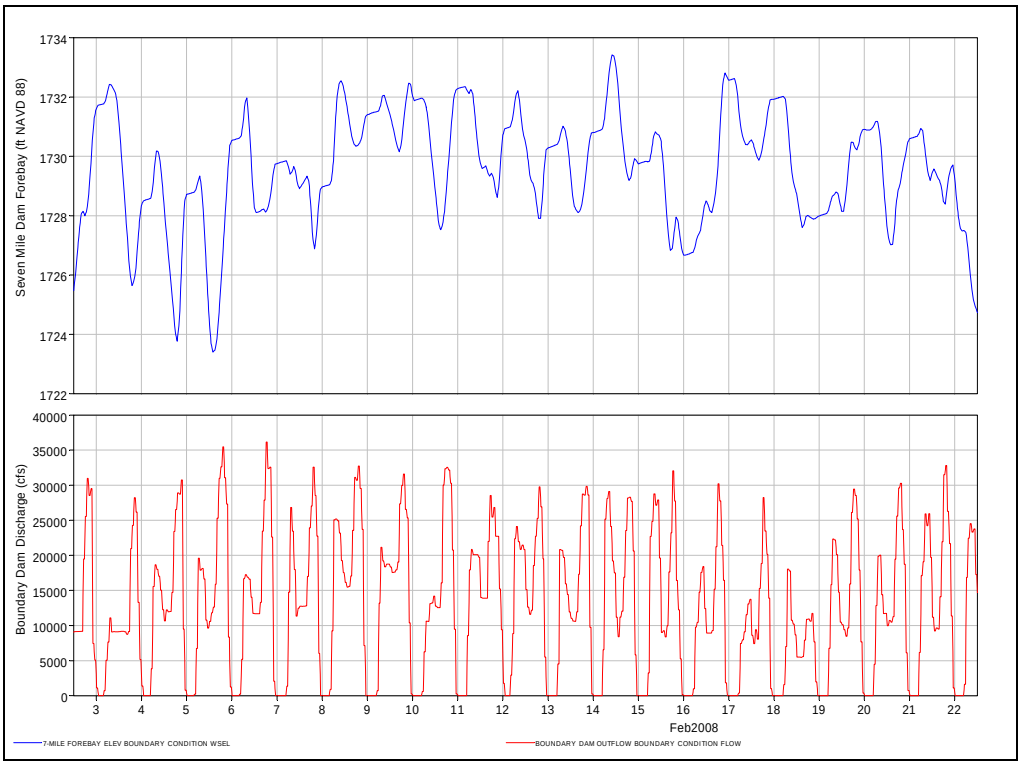
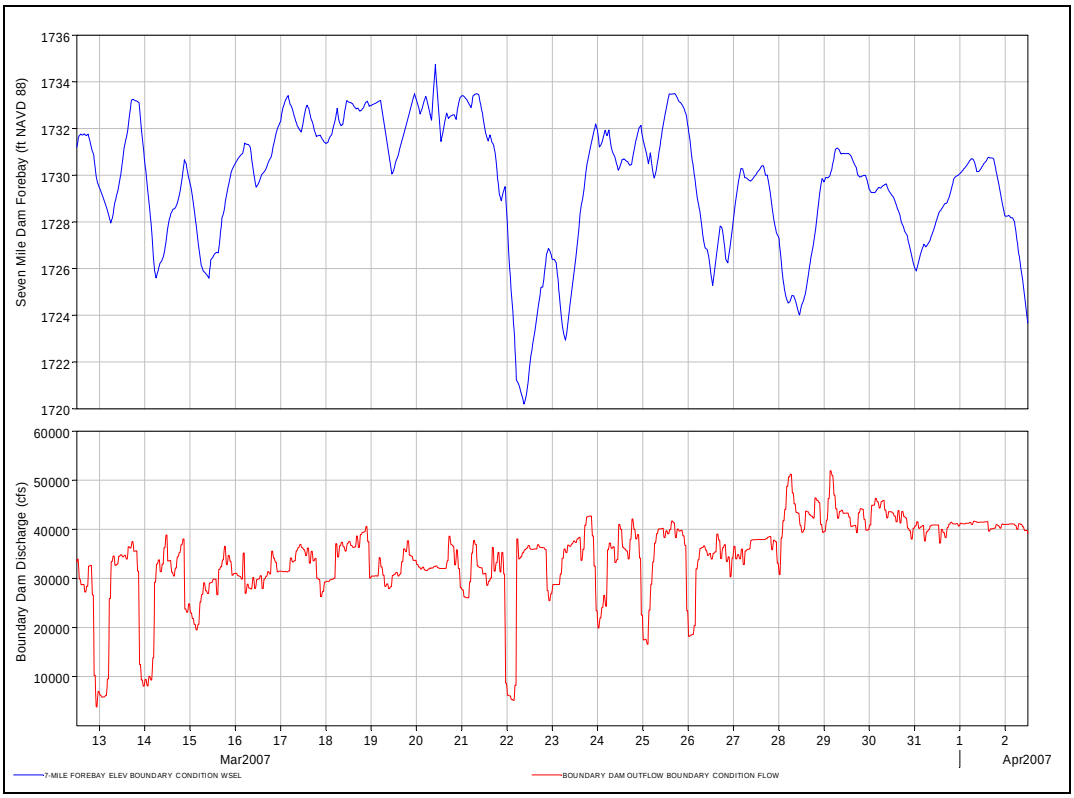



**Figure B-22.** Boundary condition hydrographs for Hi_Mod verification period - Boundary Tailrace HRM.

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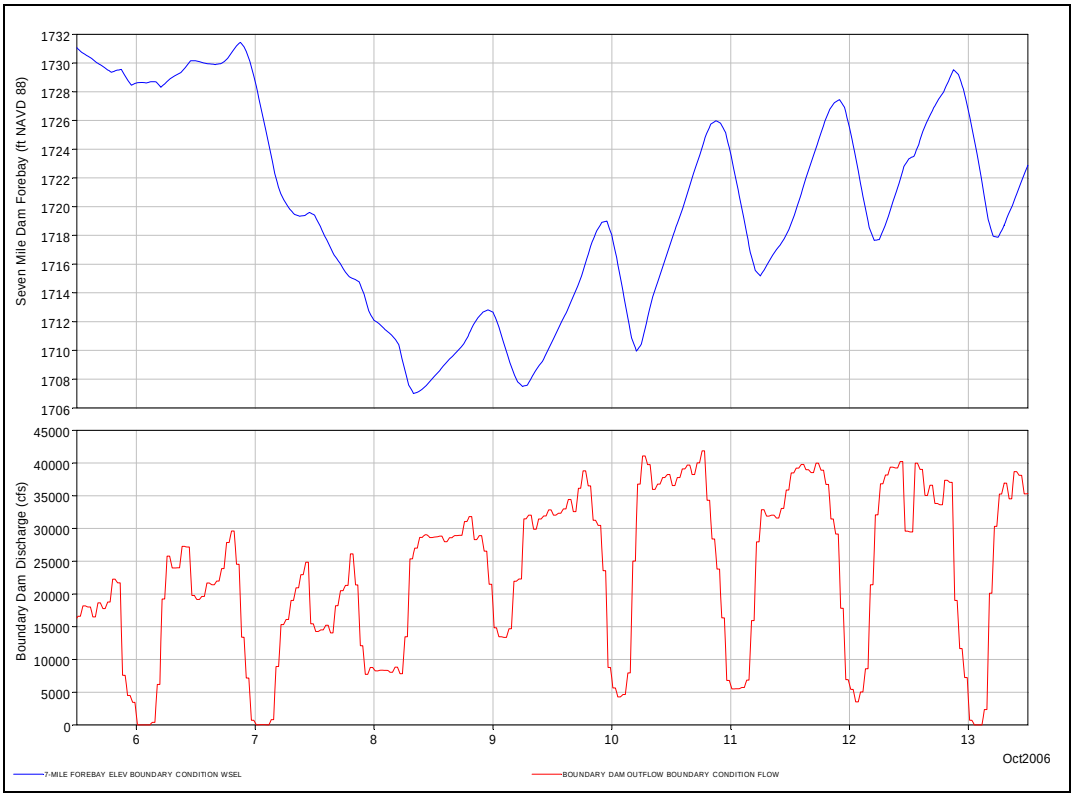
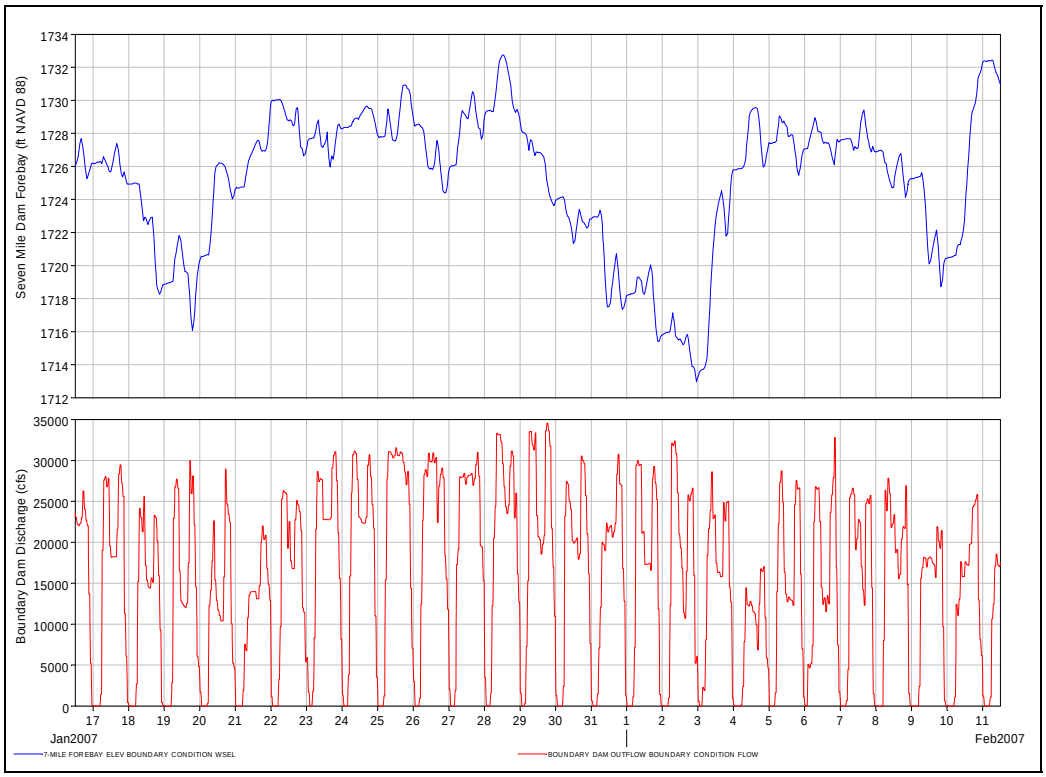



**Figure B-24.** Boundary condition hydrographs for Lo_Lo verification period - Boundary Tailrace HRM.

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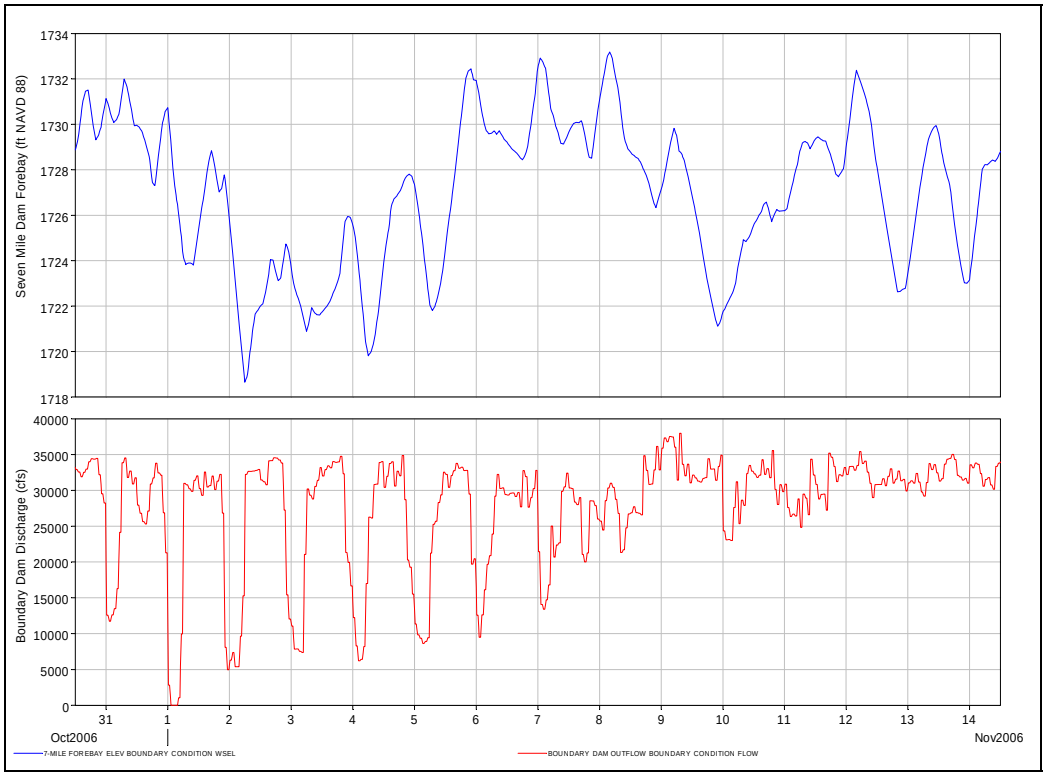


**Figure B-26.** Boundary condition hydrographs for Lo_Hi verification period - Boundary Tailrace HRM.

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# Attachment C: Calibration and Verification Results

This attachment includes the following figures and graphics in support of the development and calibration of the Boundary Reservoir Hydraulic Routing Model (HRM) and the Boundary Tailrace HRM. This attachment contains the following:

- Graphical presentation of Boundary Reservoir HRM calibration and verification results (Figures C-1 through C-66).
- Graphical presentation of Boundary Tailrace HRM calibration and verification results (Figures C-67 through C-99)

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Figure C-99. Model calibration results for Lo_Hi verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

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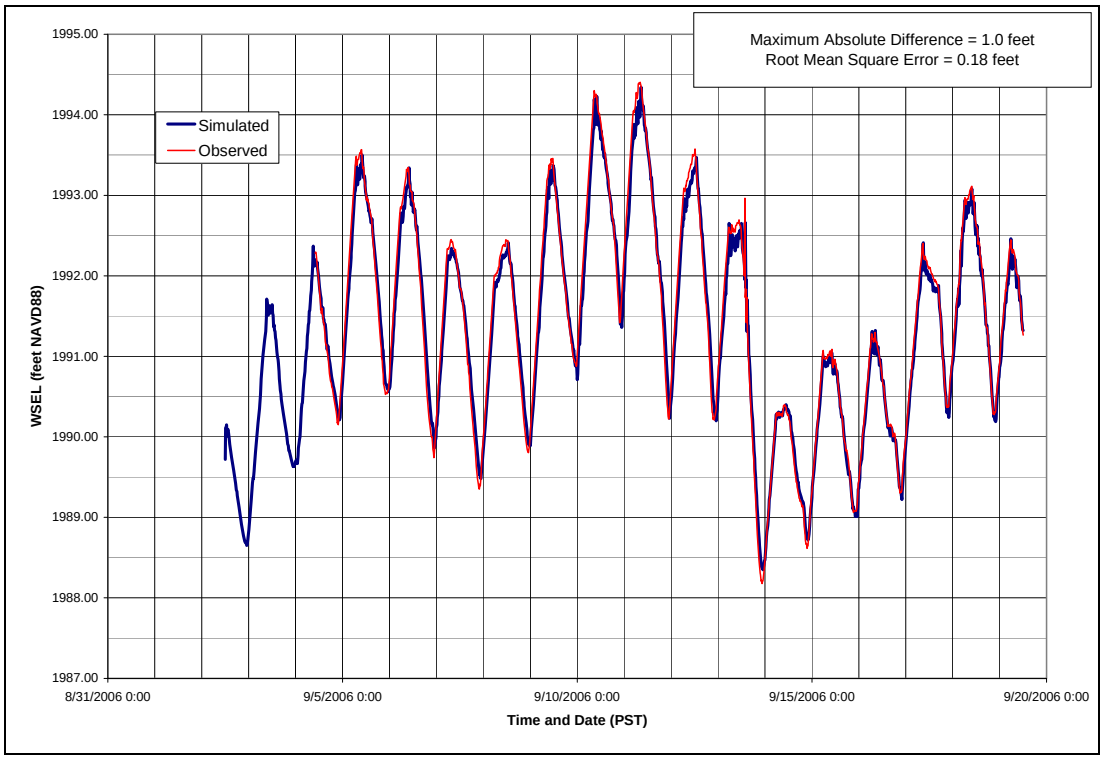


**Figure C-1.** Model calibration results for Hi_Lo calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

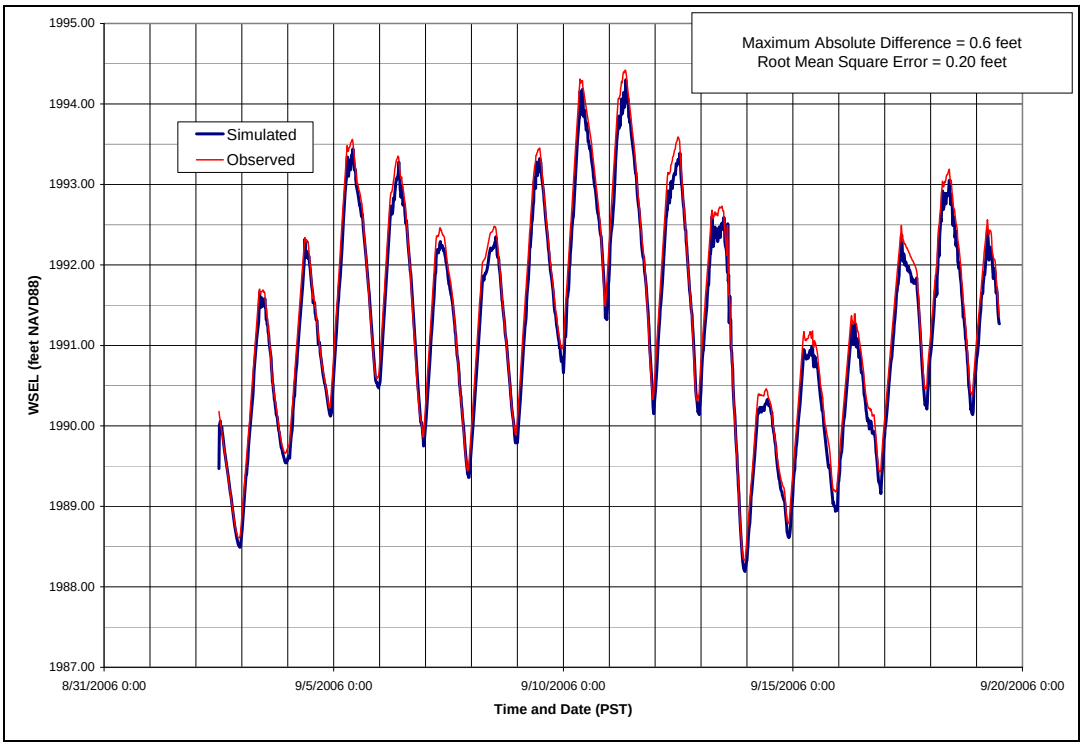


**Figure C-2.** Model calibration results for Hi_Lo calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

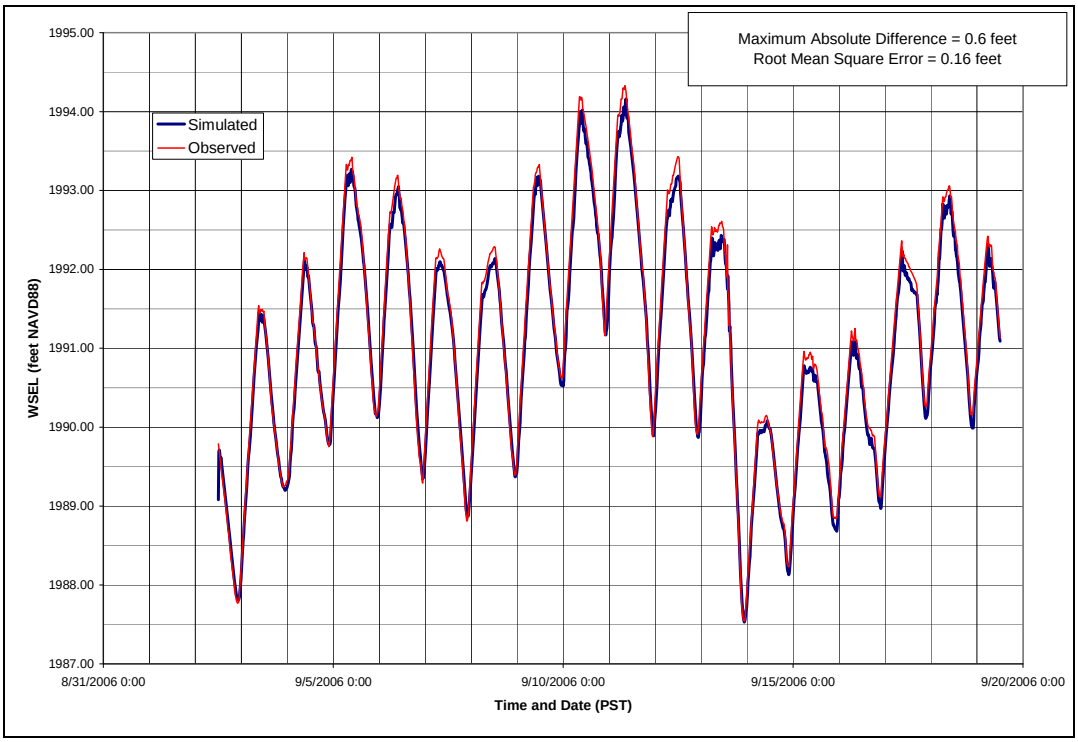


**Figure C-3.** Model calibration results for Hi_Lo calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

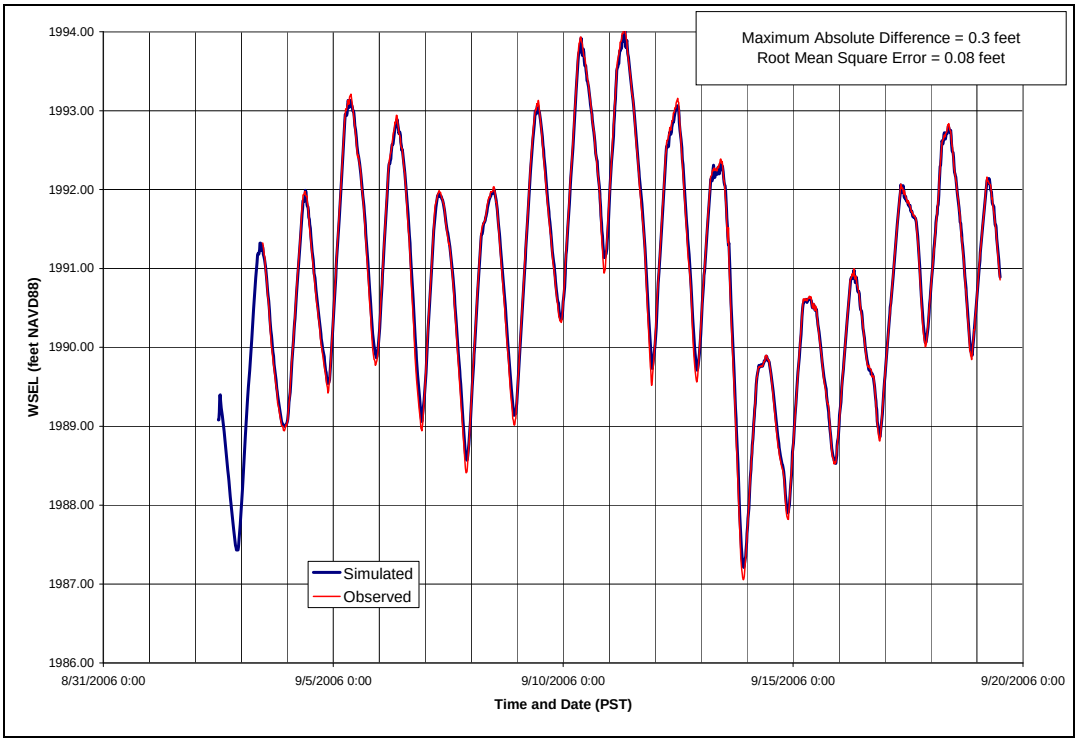


**Figure C-4.** Model calibration results for Hi_Lo calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

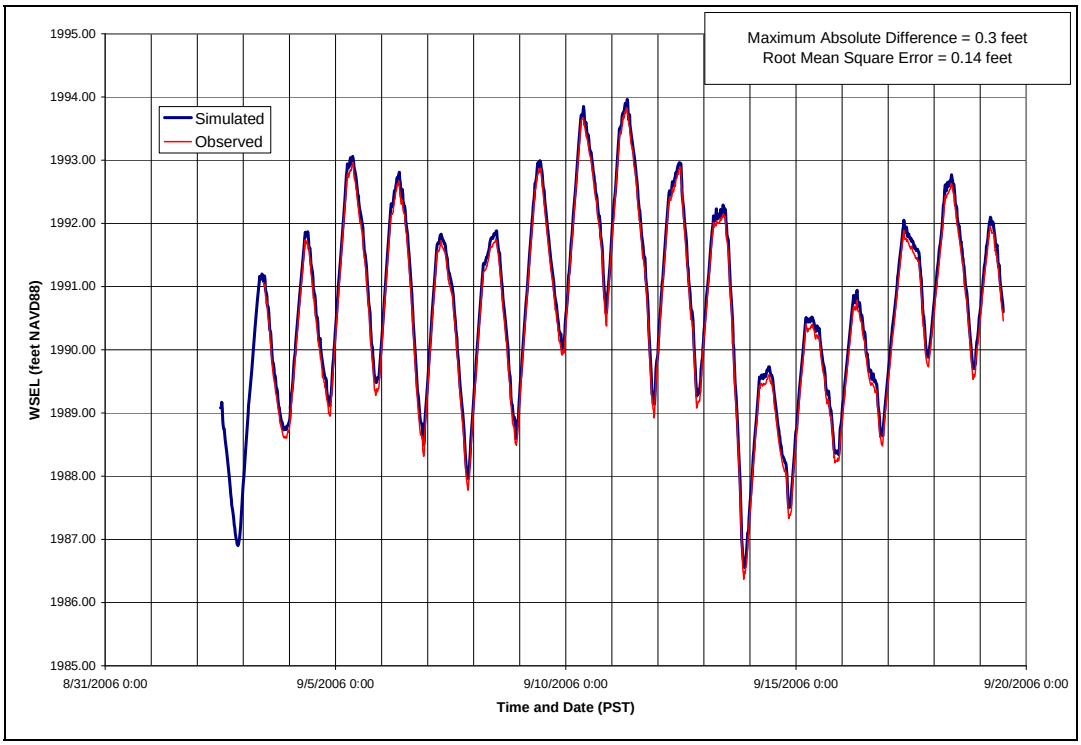


**Figure C-5.** Model calibration results for Hi_Lo calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

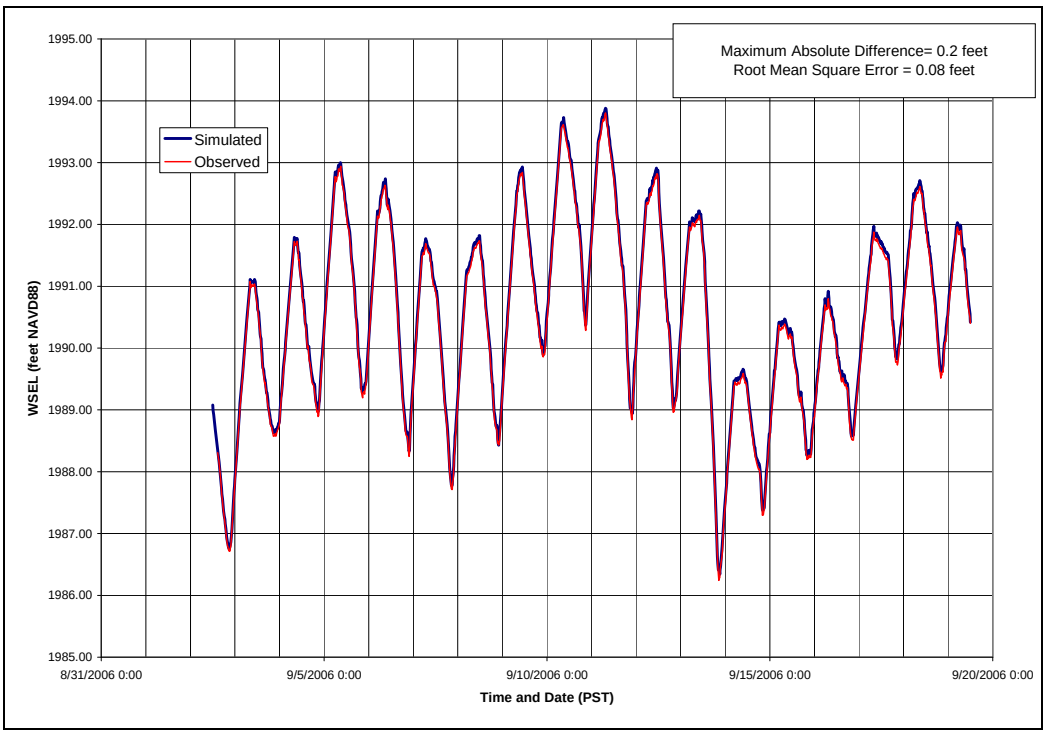


**Figure C-6.** Model calibration results for Hi_Lo calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

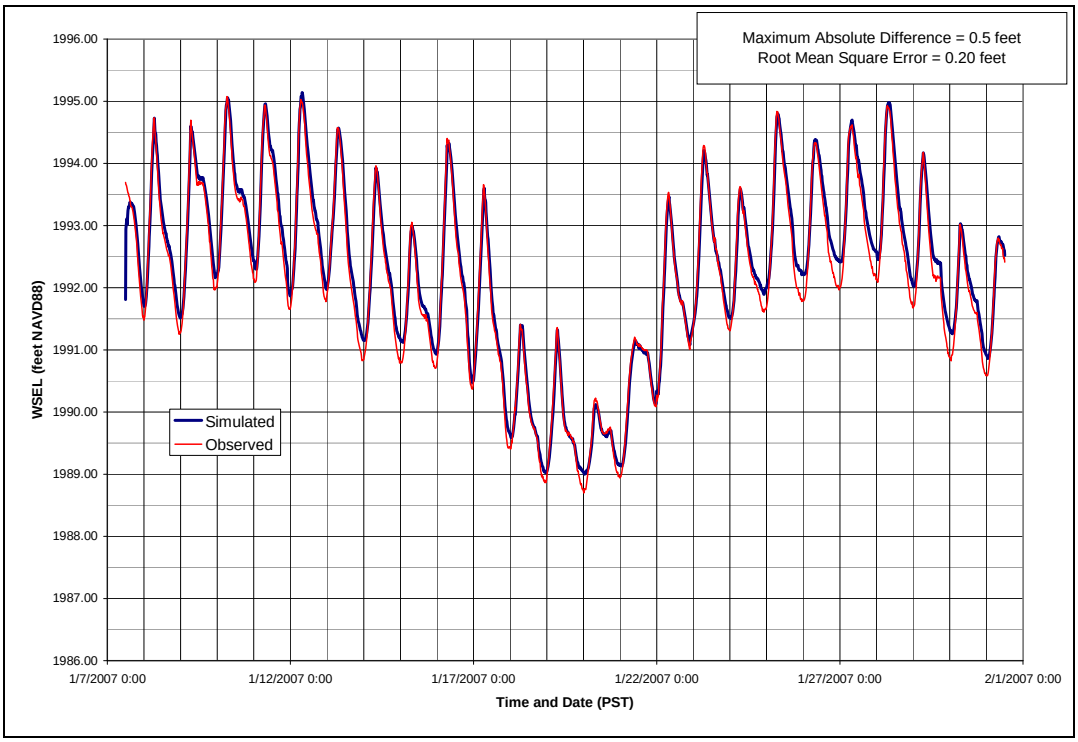


**Figure C-7.** Model calibration results for Hi_Mod calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

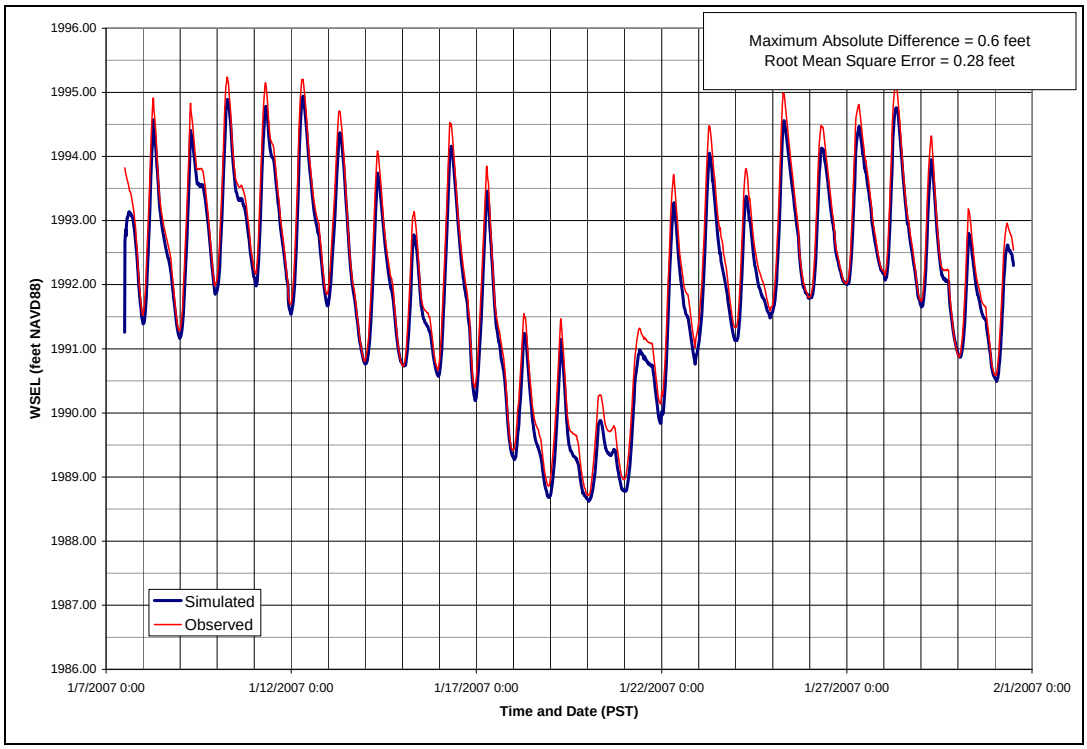


**Figure C-8.** Model calibration results for Hi_Mod calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

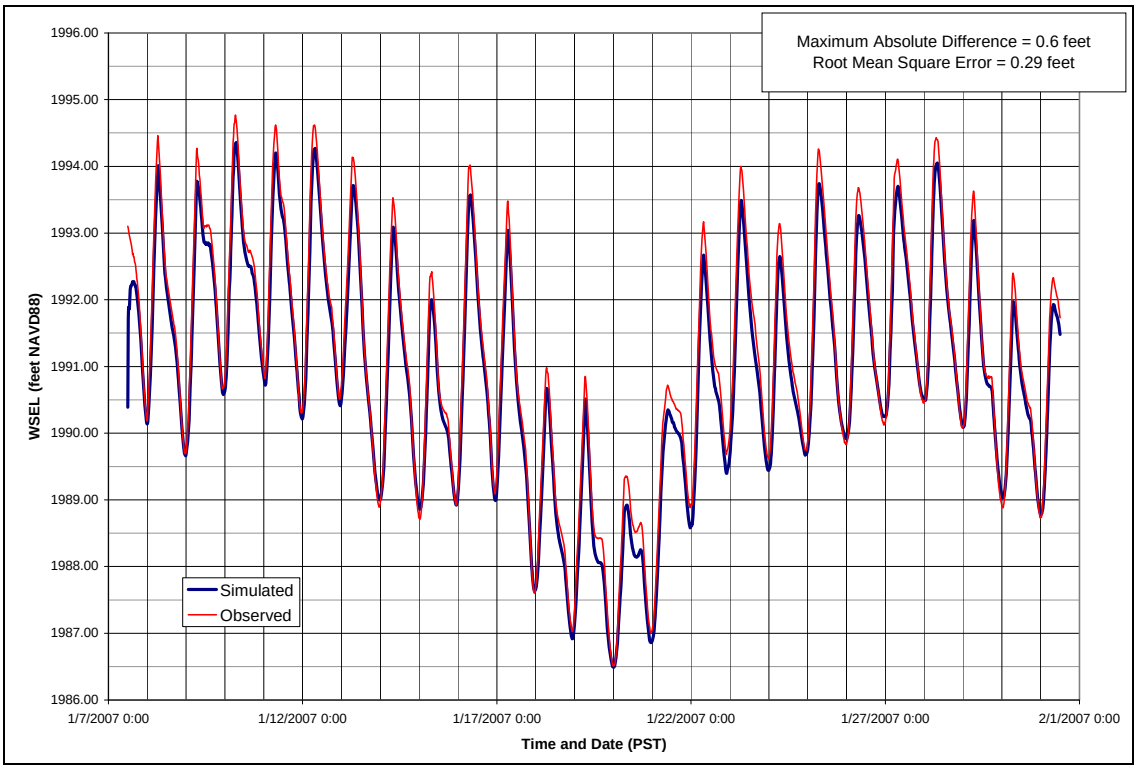


**Figure C-9.** Model calibration results for Hi_Mod calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

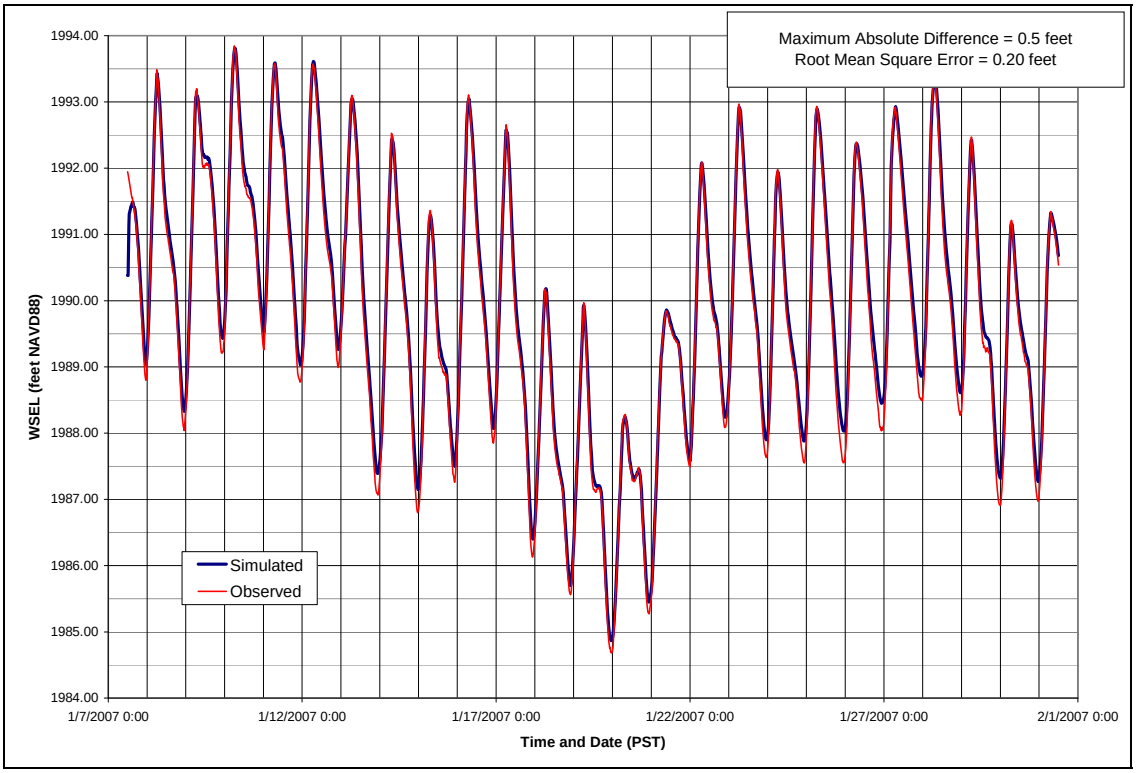


**Figure C-10.** Model calibration results for Hi_Mod calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

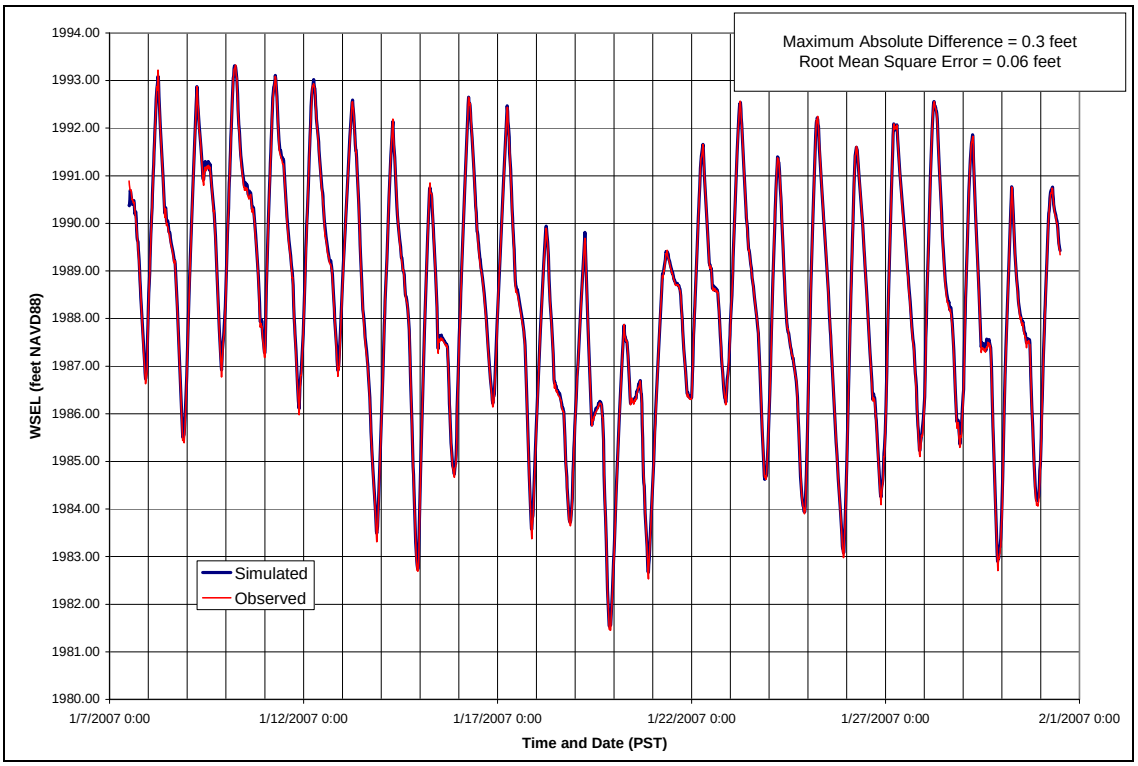


**Figure C-11.** Model calibration results for Hi_Mod calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

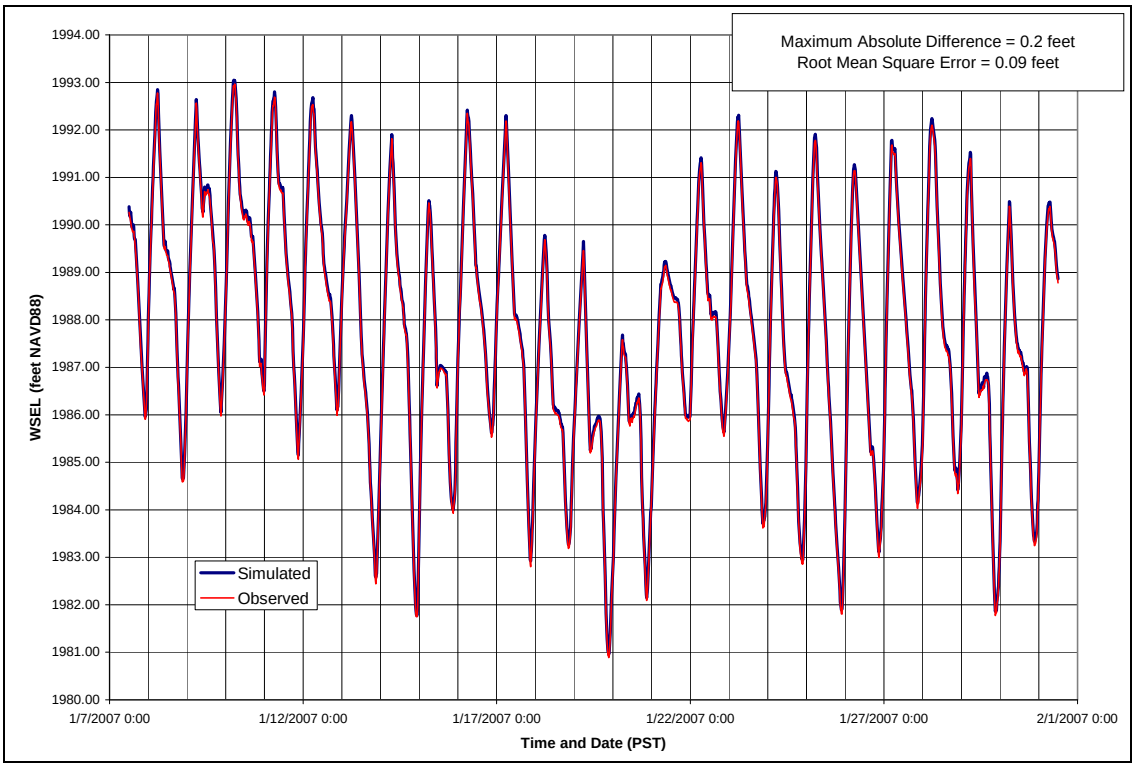


**Figure C-12.** Model calibration results for Hi_Mod calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

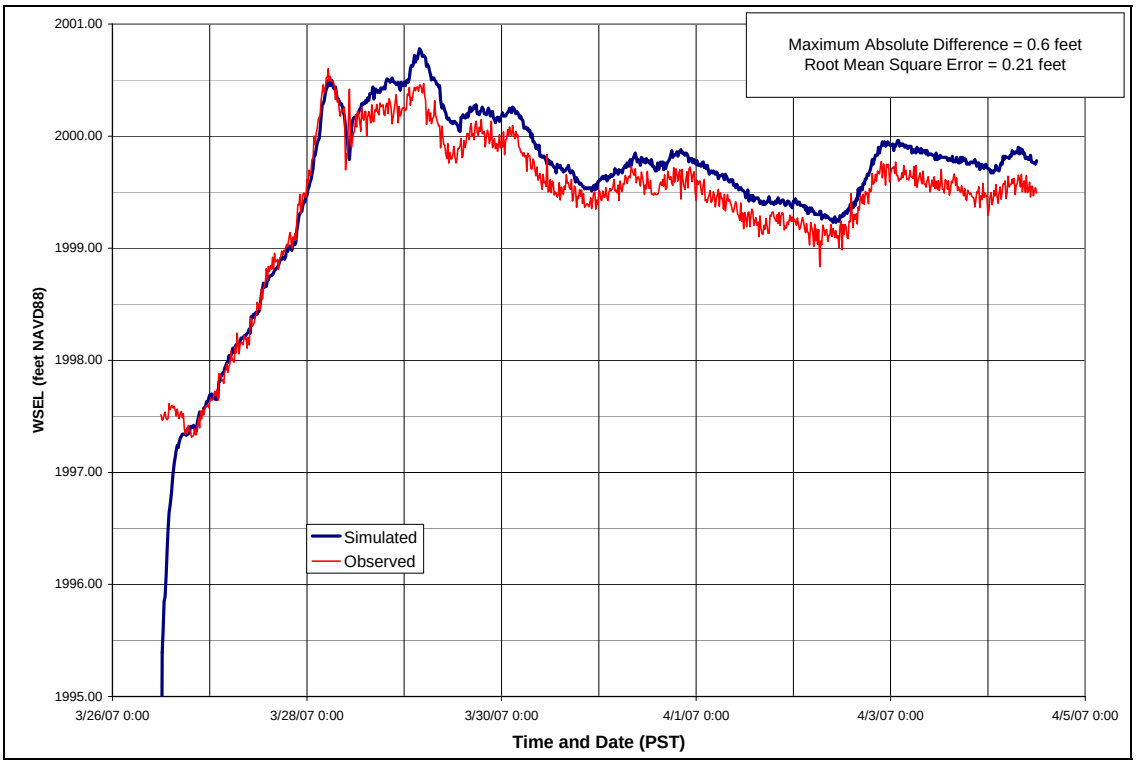


**Figure C-13.** Model calibration results for Hi_Hi calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

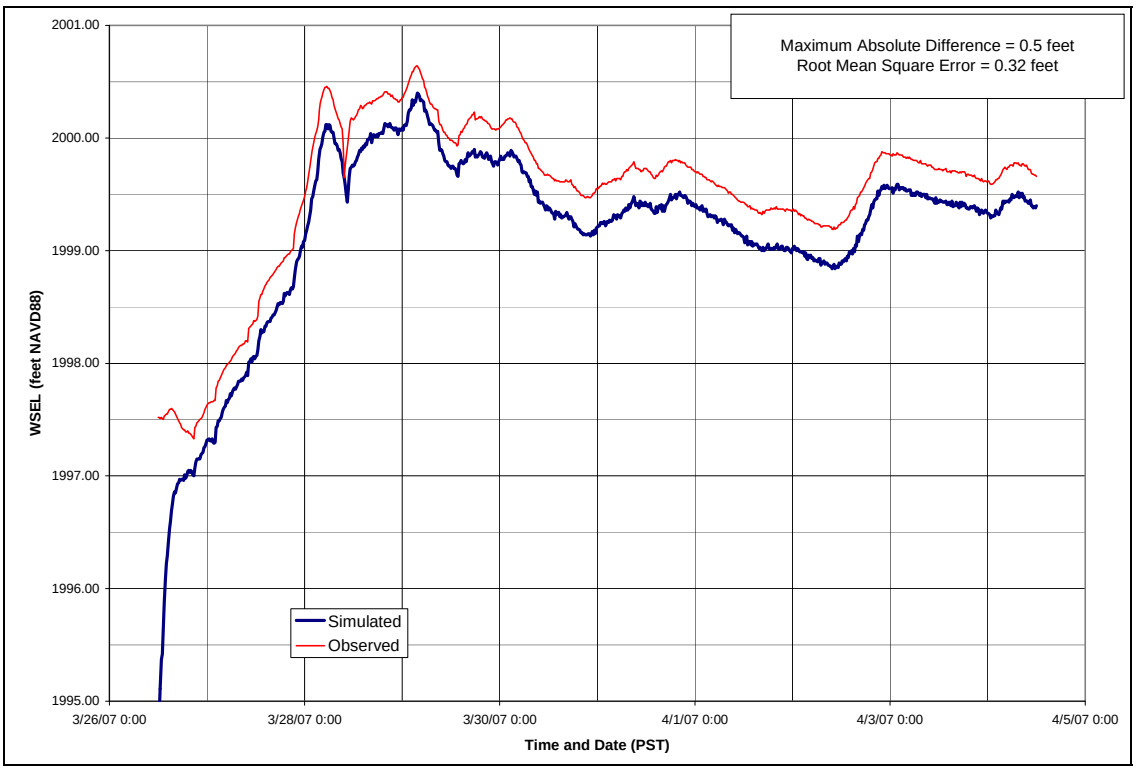


**Figure C-14.** Model calibration results for Hi_Hi calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

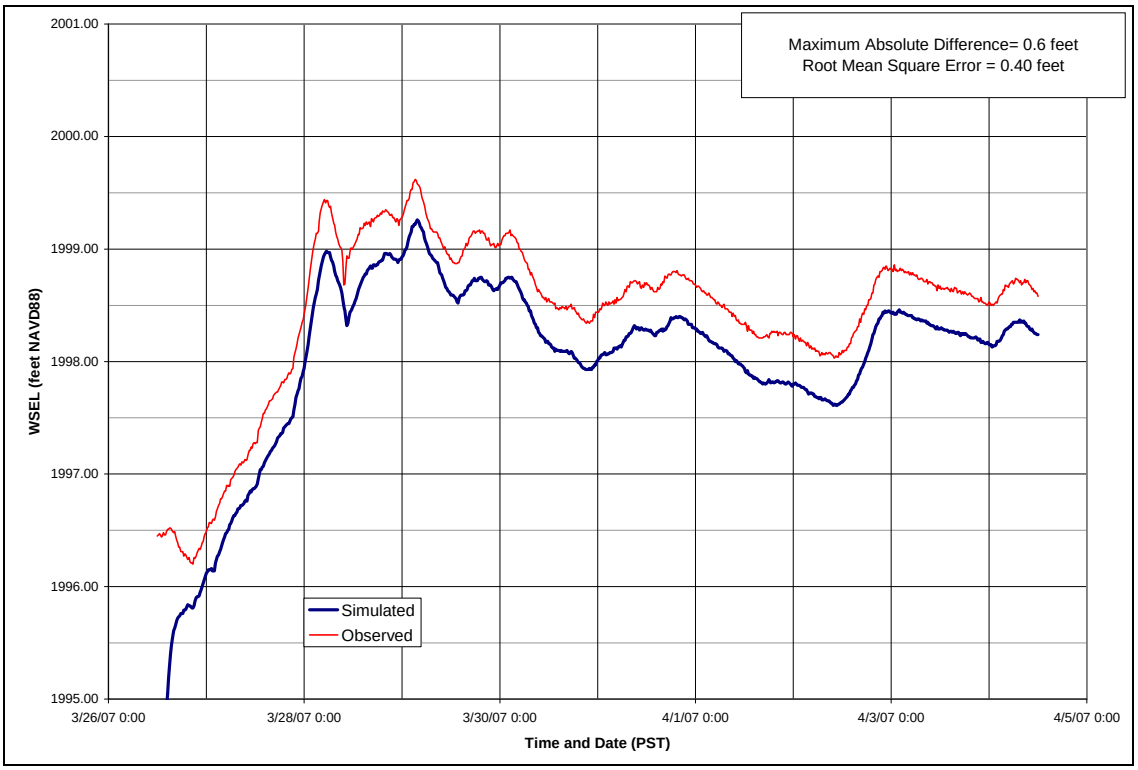


**Figure C-15.** Model calibration results for Hi_Hi calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

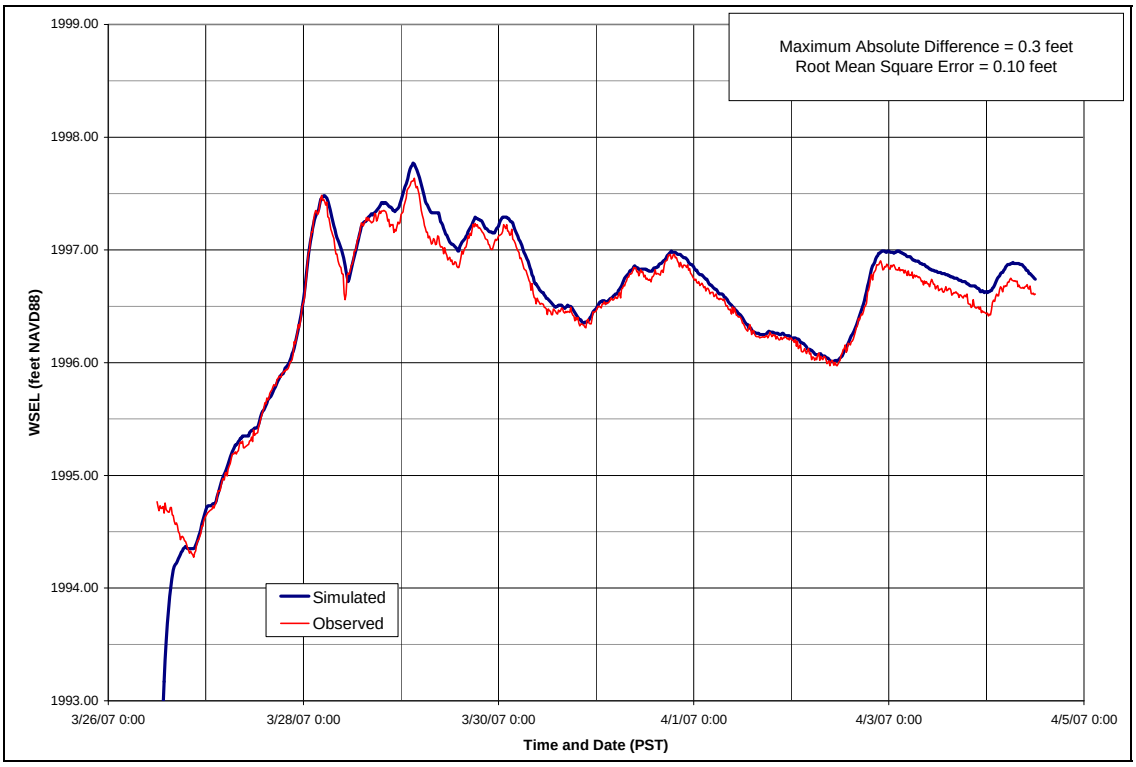


**Figure C-16.** Model calibration results for Hi_Hi calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

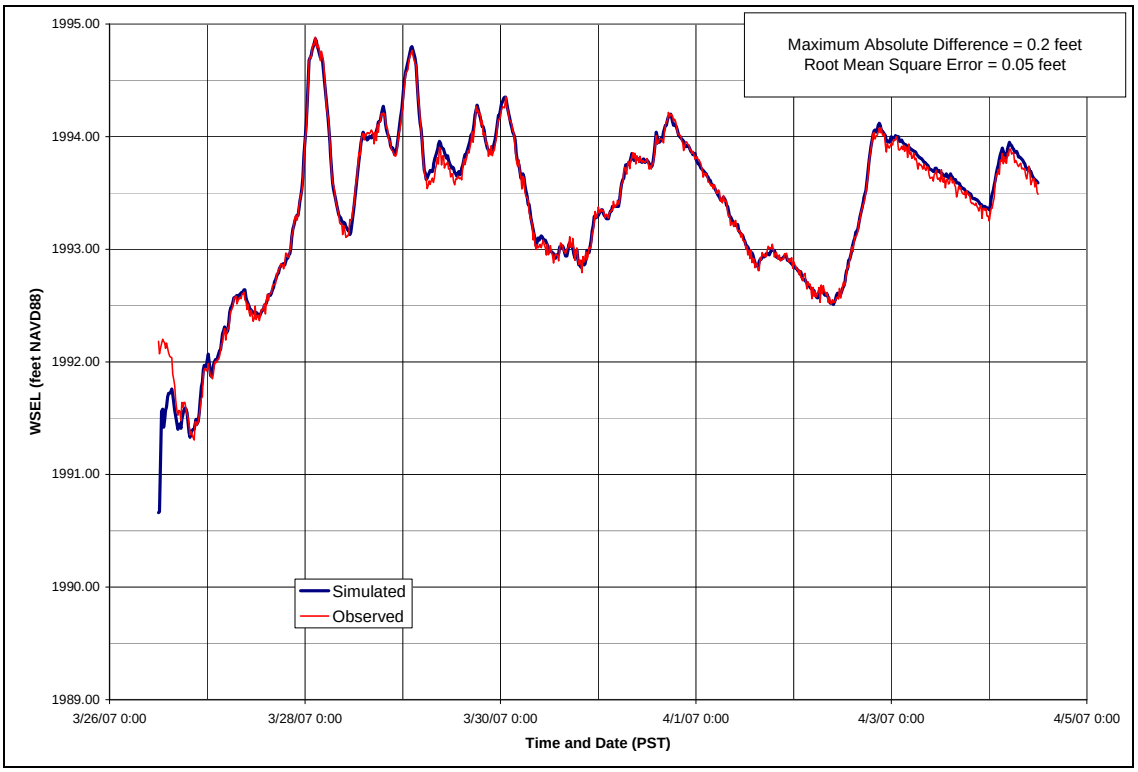


**Figure C-17.** Model calibration results for Hi_Hi calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

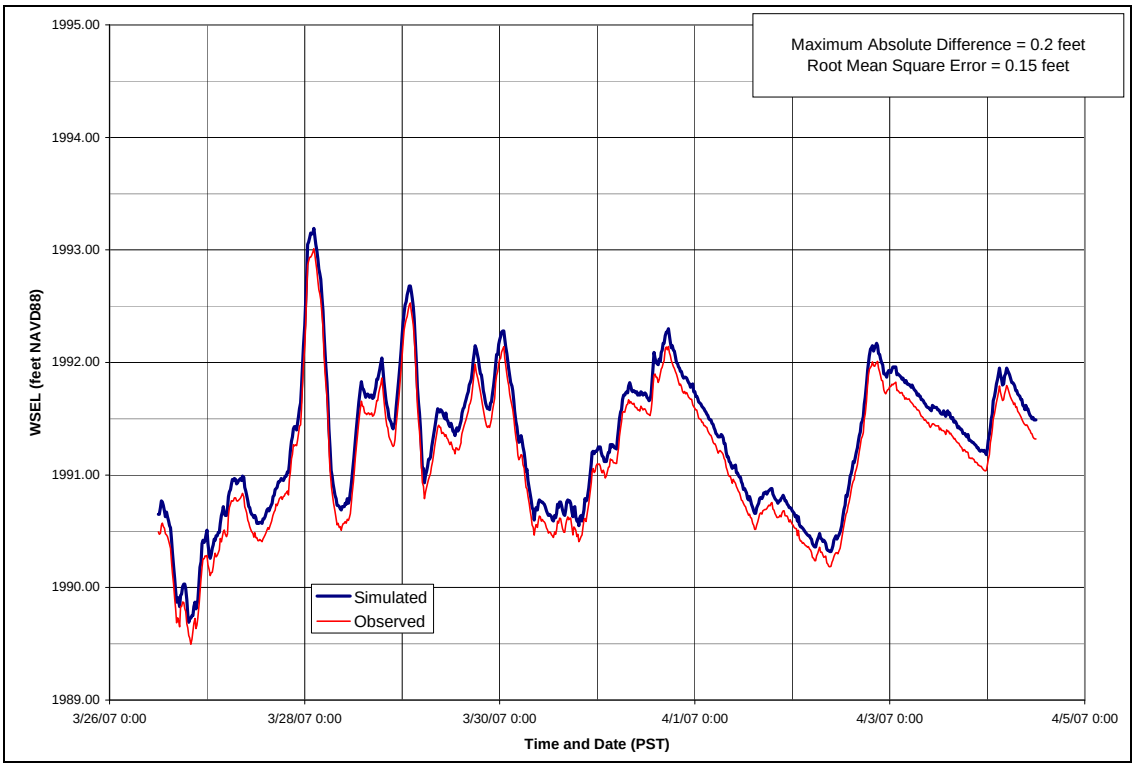


**Figure C-18.** Model calibration results for Hi_Hi calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

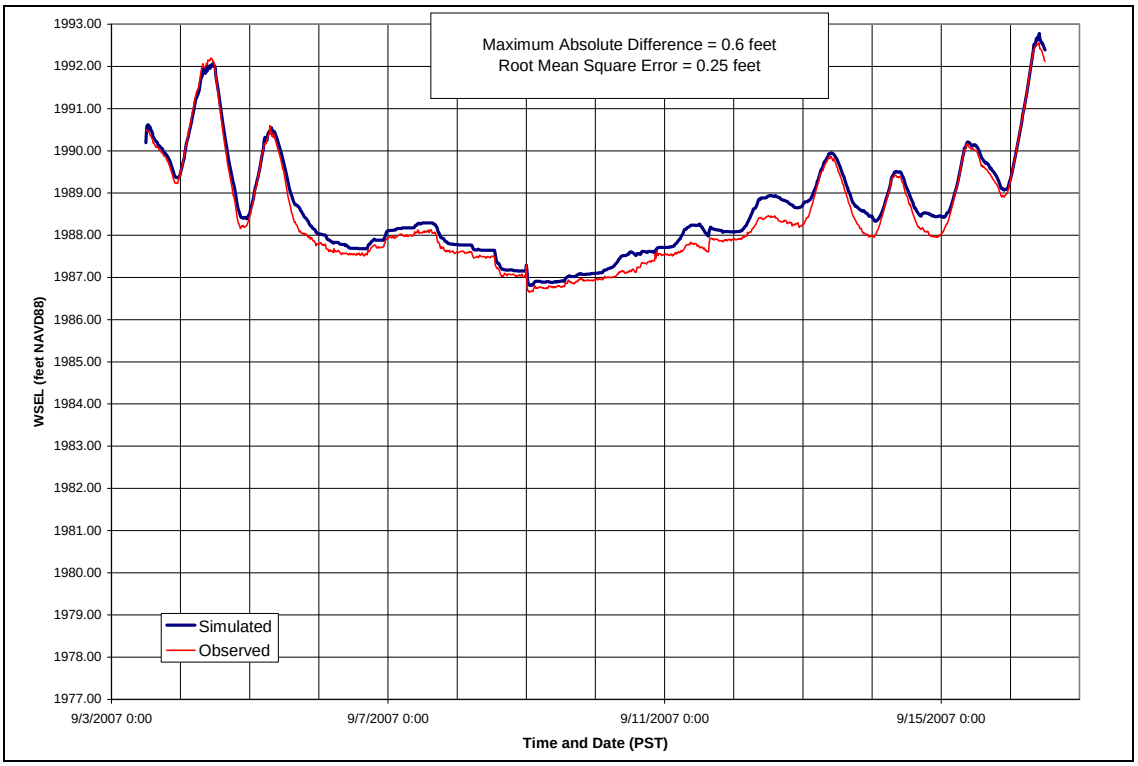


**Figure C-19.** Model calibration results for Lo_Lo calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

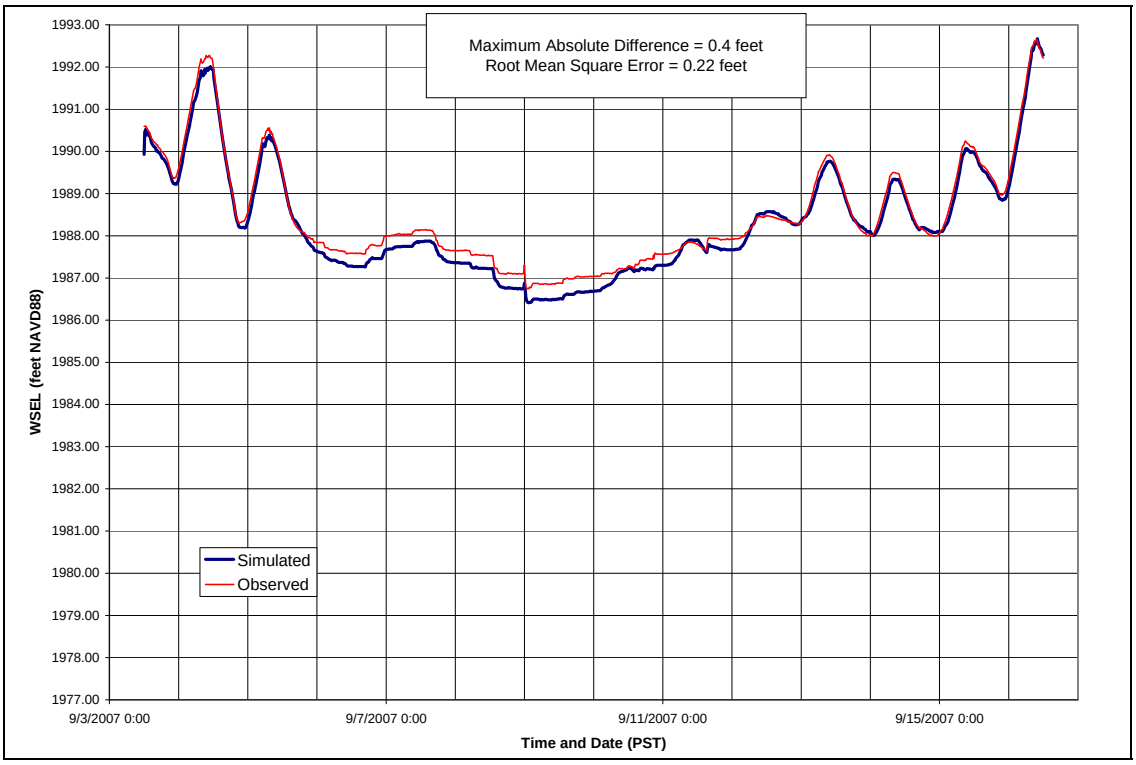


**Figure C-20.** Model calibration results for Lo_Lo calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

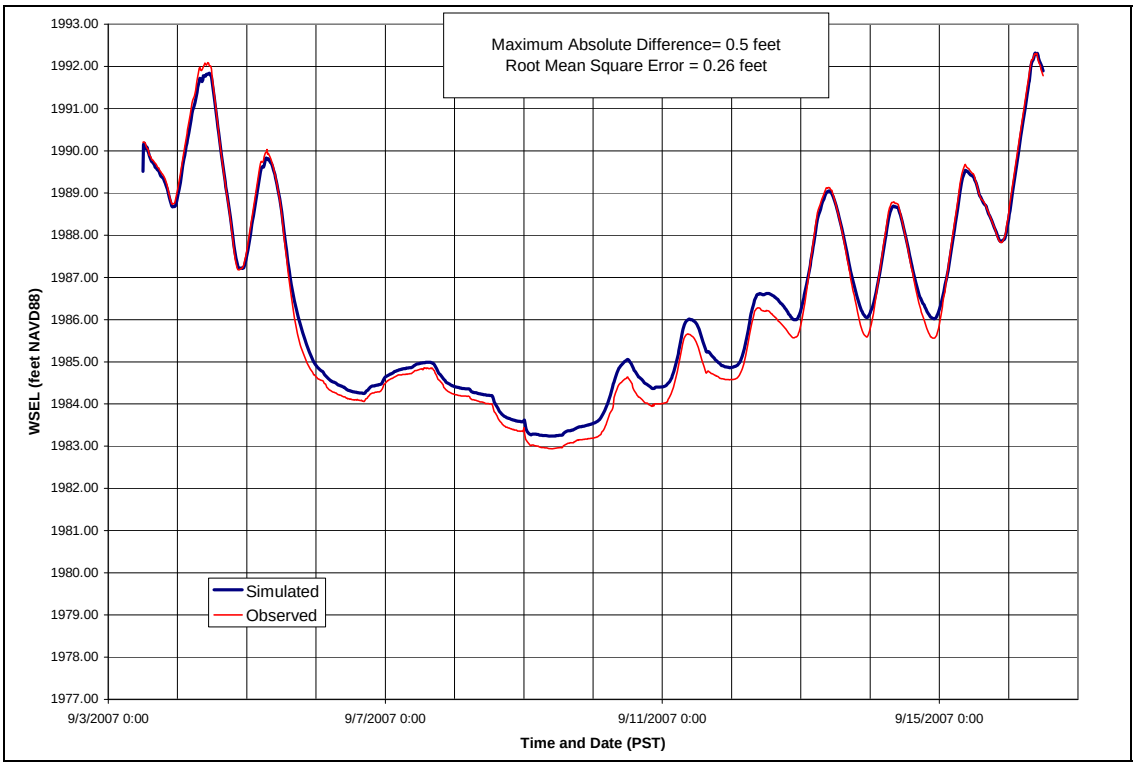


**Figure C-21.** Model calibration results for Lo_Lo calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

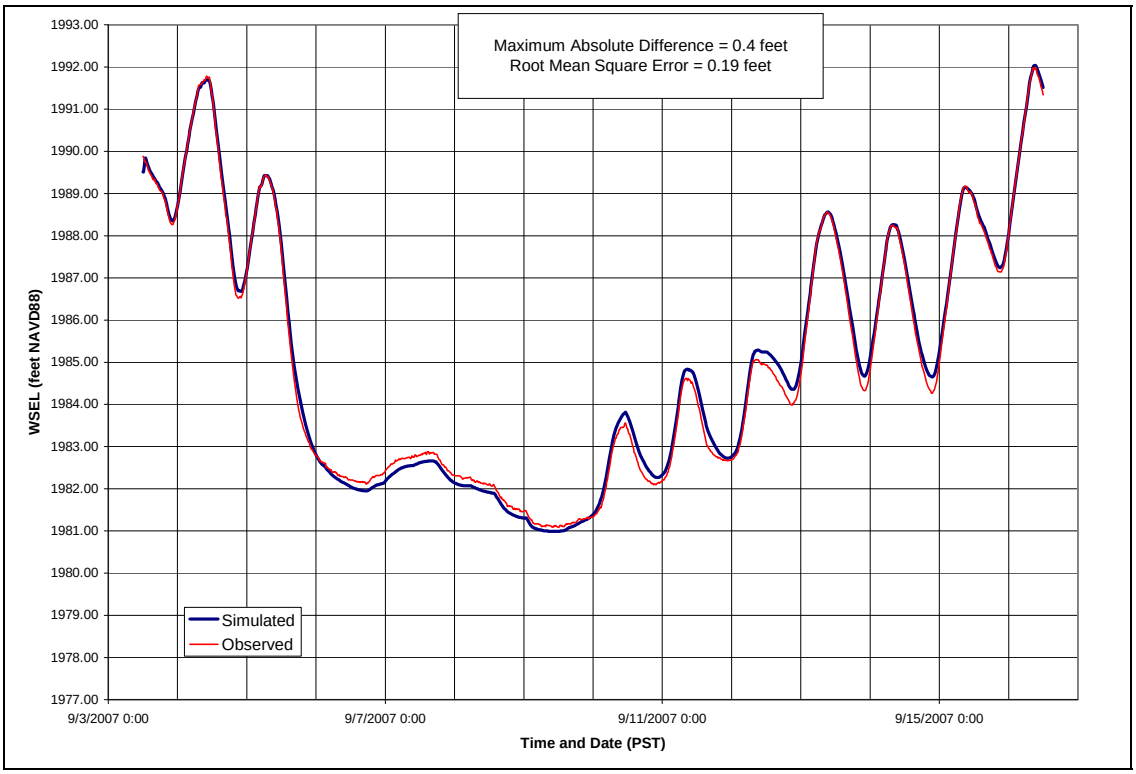


**Figure C-22.** Model calibration results for Lo_Lo calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

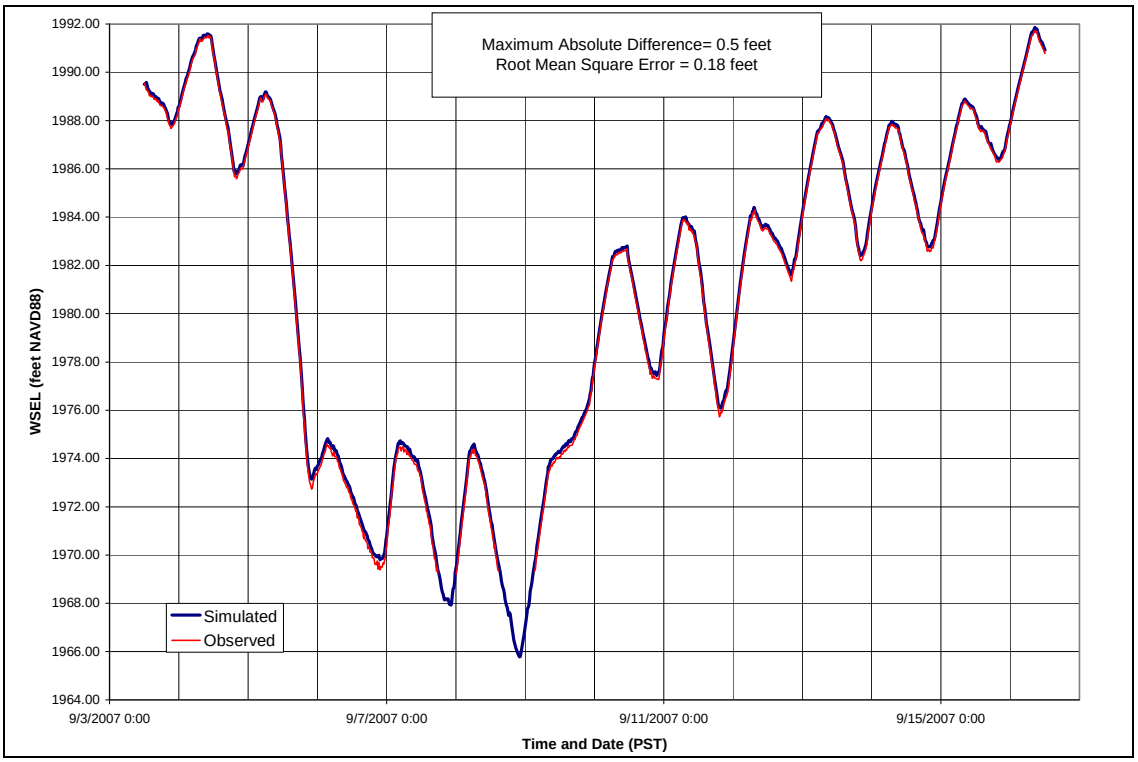


**Figure C-23.** Model calibration results for Lo_Lo calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

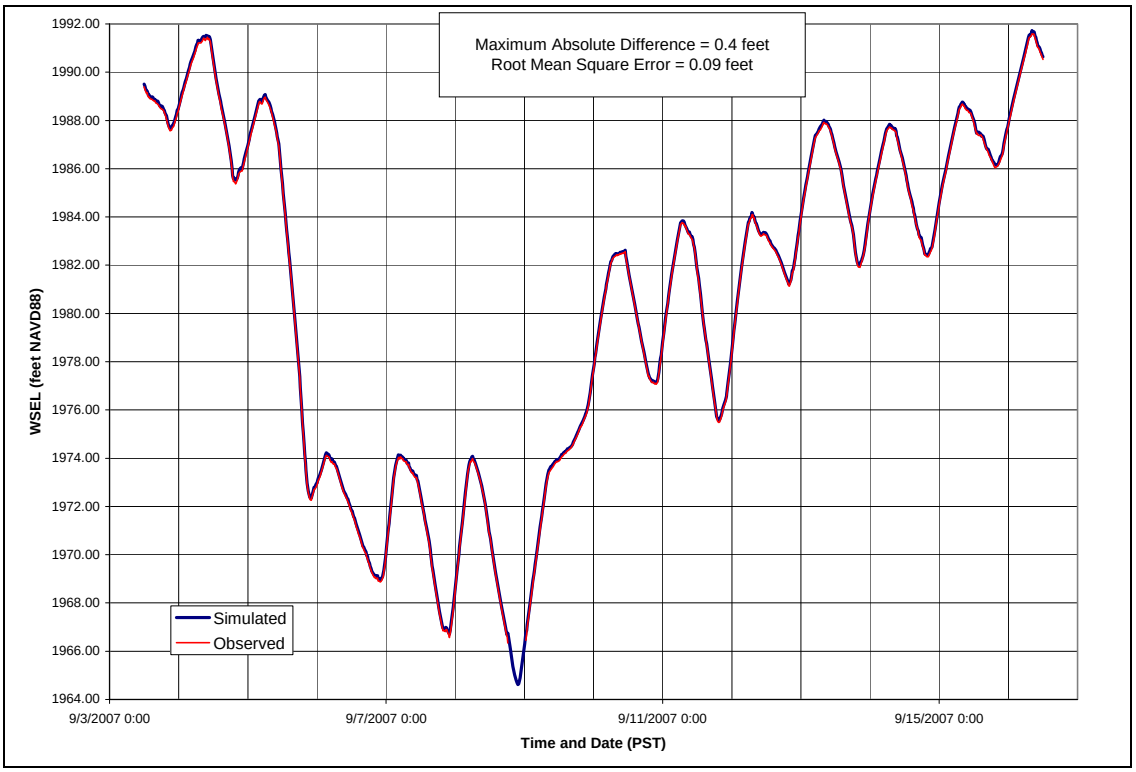


**Figure C-24.** Model calibration results for Lo_Lo calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

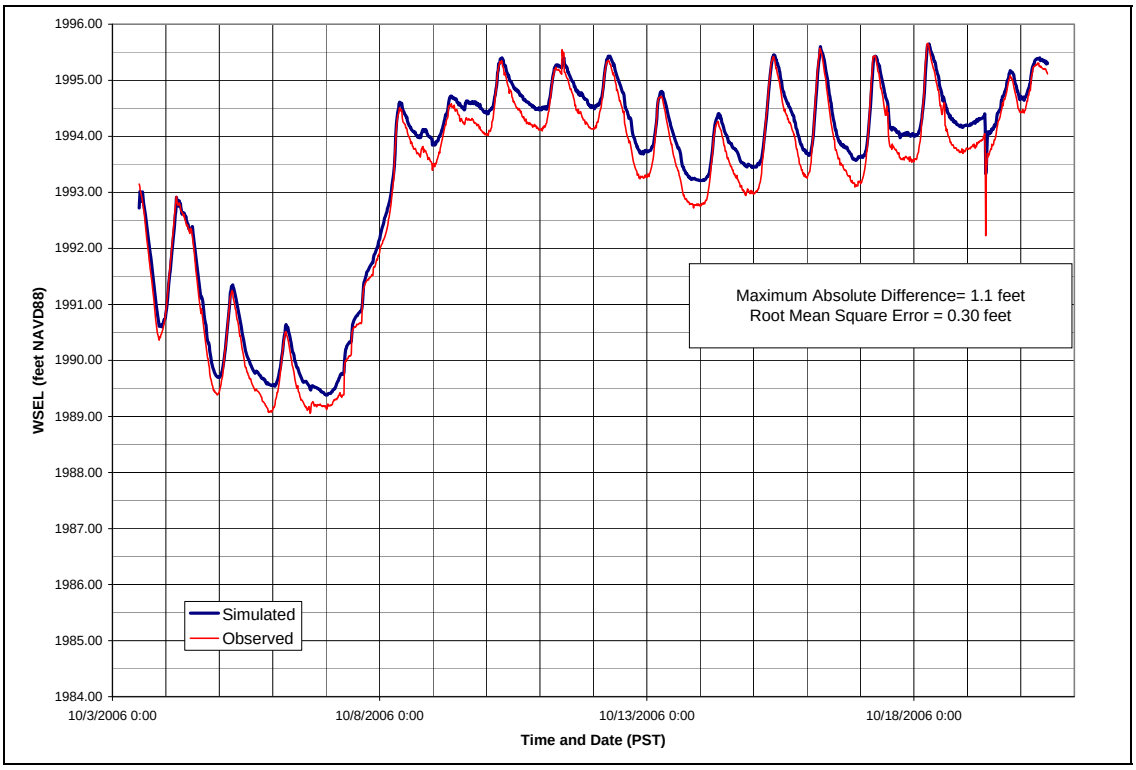


**Figure C-25.** Model calibration results for Lo_Mod calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

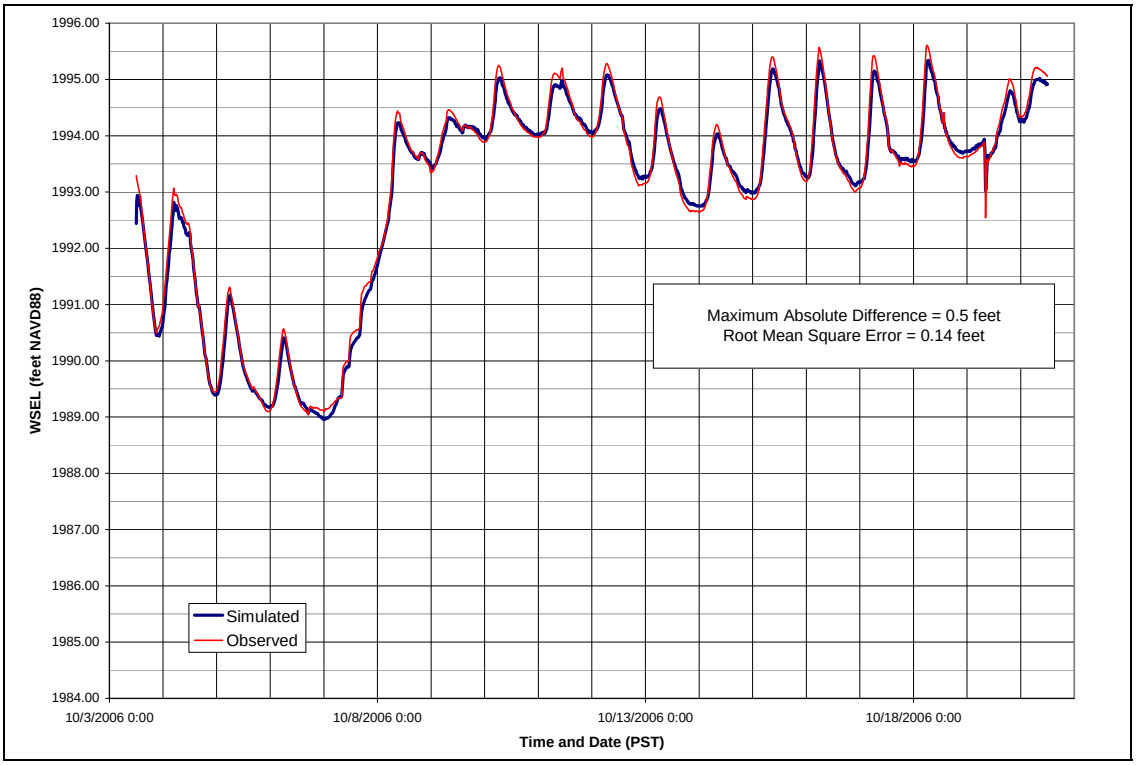


**Figure C-26.** Model calibration results for Lo_Mod calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

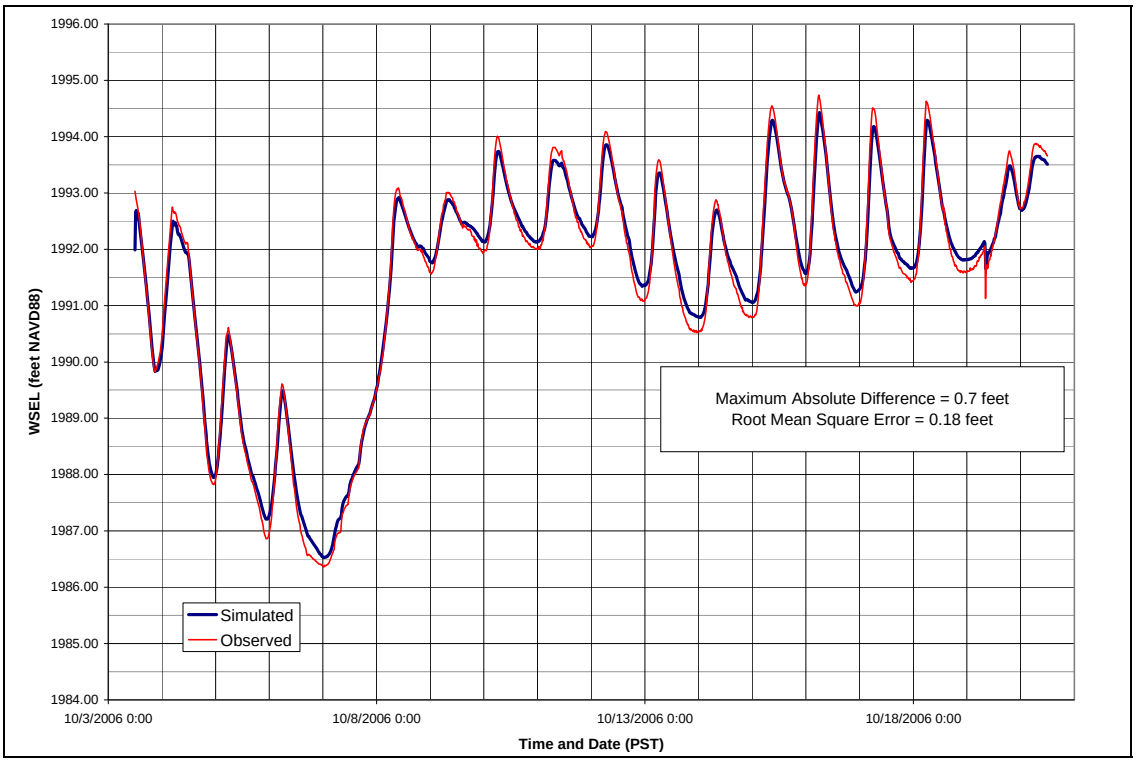


**Figure C-27.** Model calibration results for Lo_Mod calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

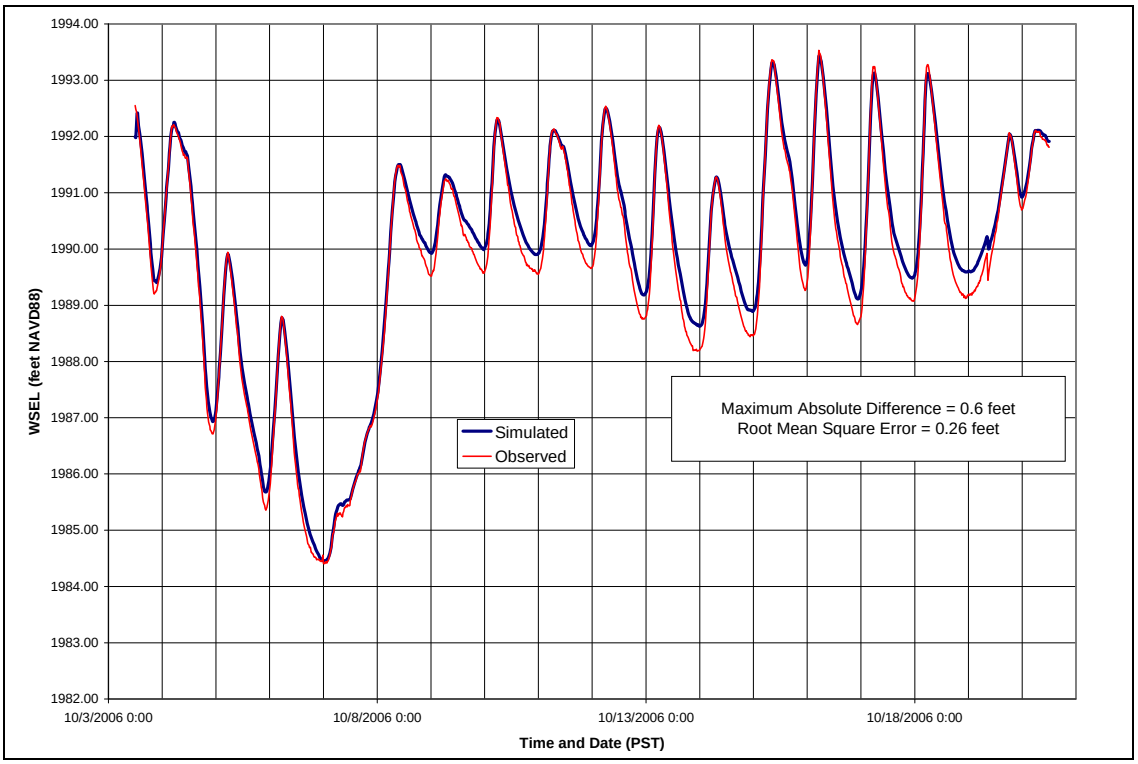


**Figure C-28.** Model calibration results for Lo_Mod calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

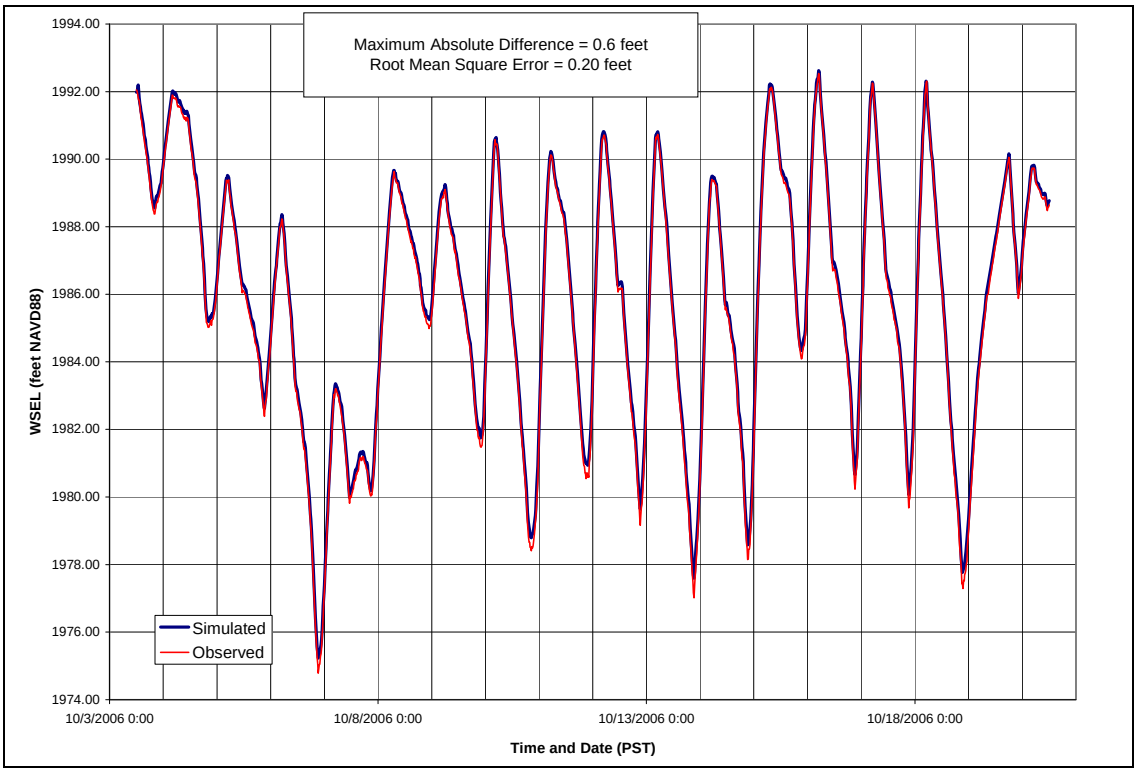


**Figure C-29.** Model calibration results for Lo_Mod calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

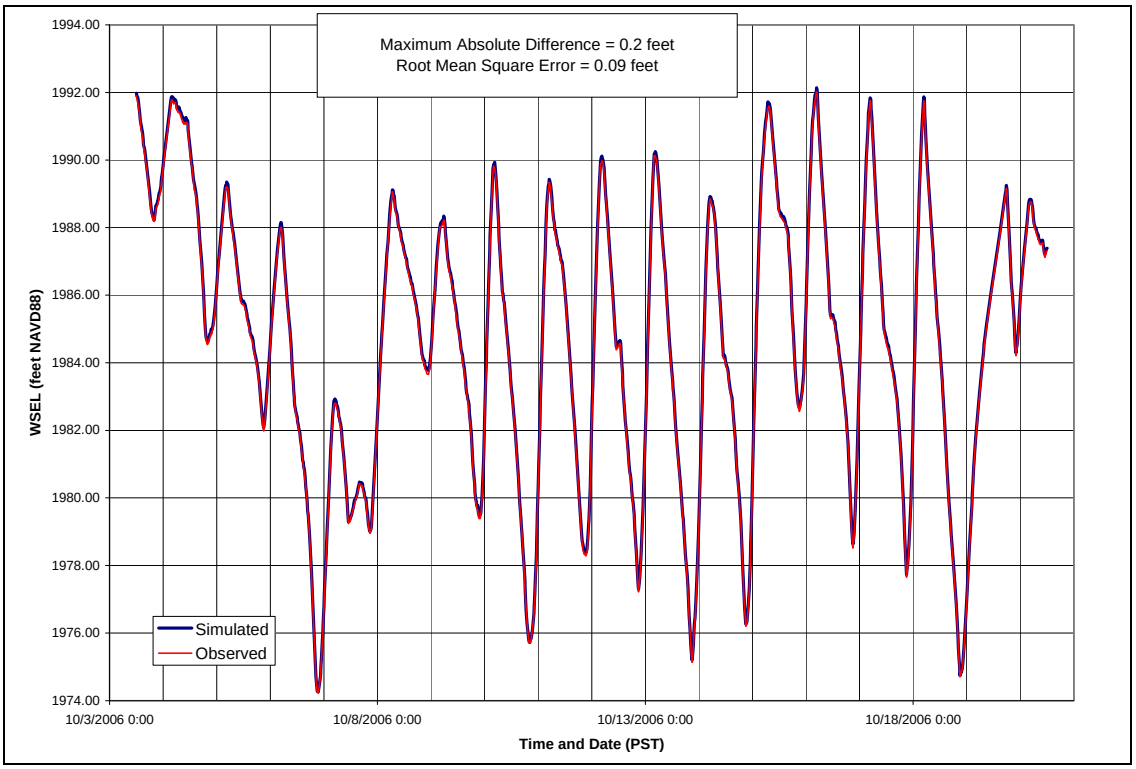


**Figure C-30.** Model calibration results for Lo_Mod calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

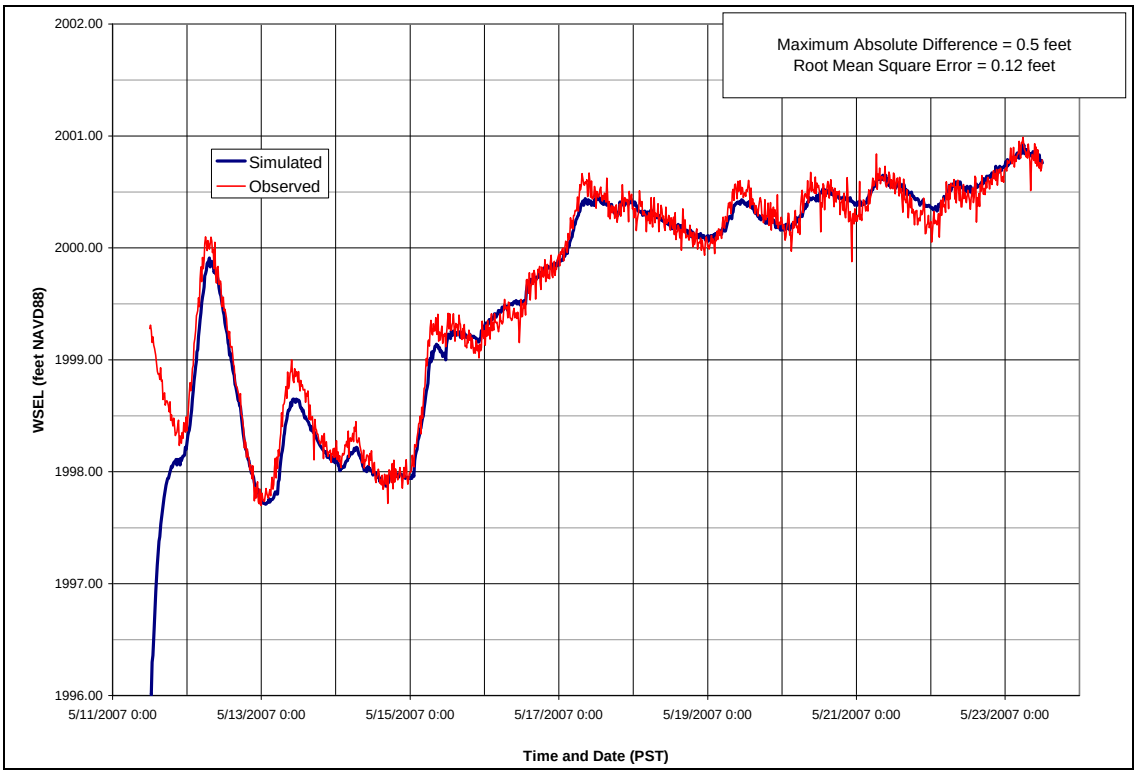


**Figure C-31.** Model calibration results for Lo_Hi calibration period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

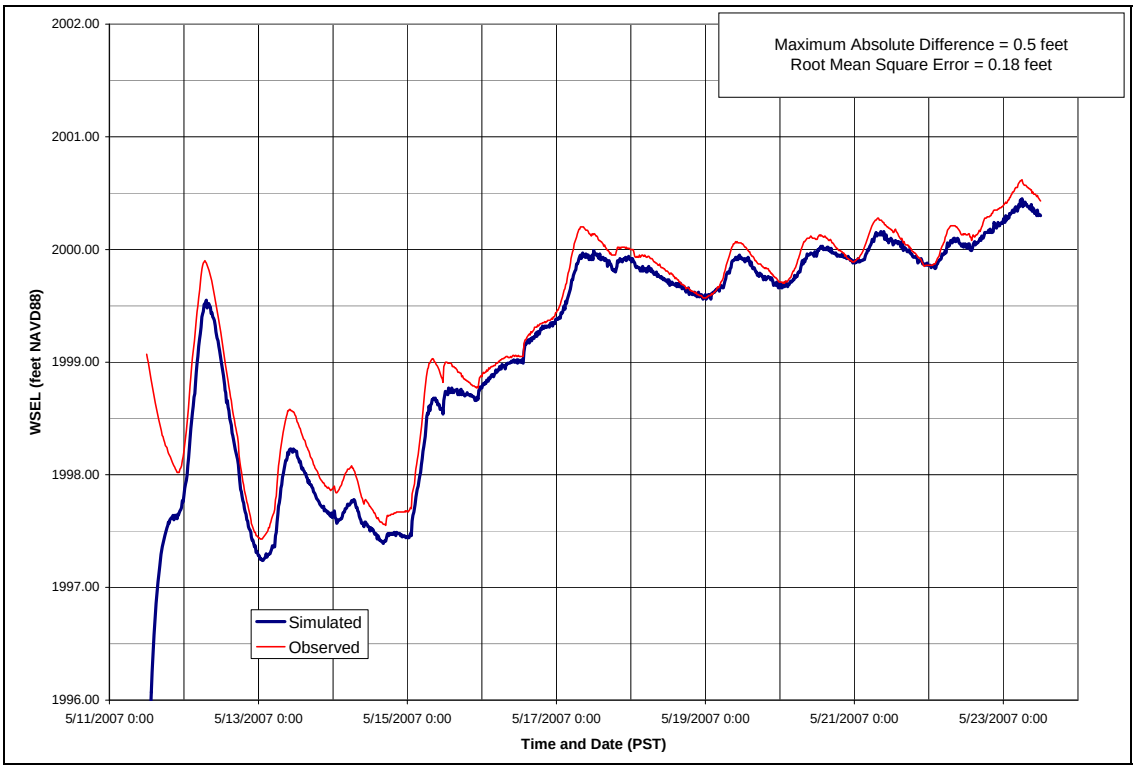


**Figure C-32.** Model calibration results for Lo_Hi calibration period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

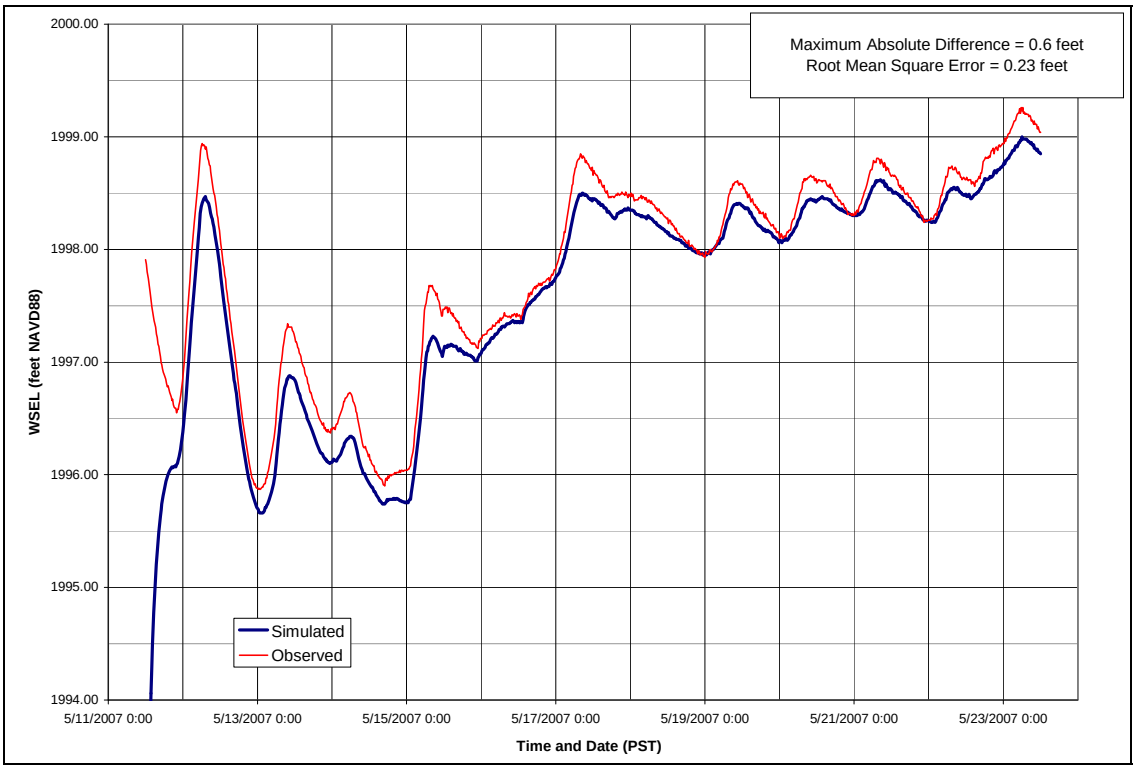


**Figure C-33.** Model calibration results for Lo_Hi calibration period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

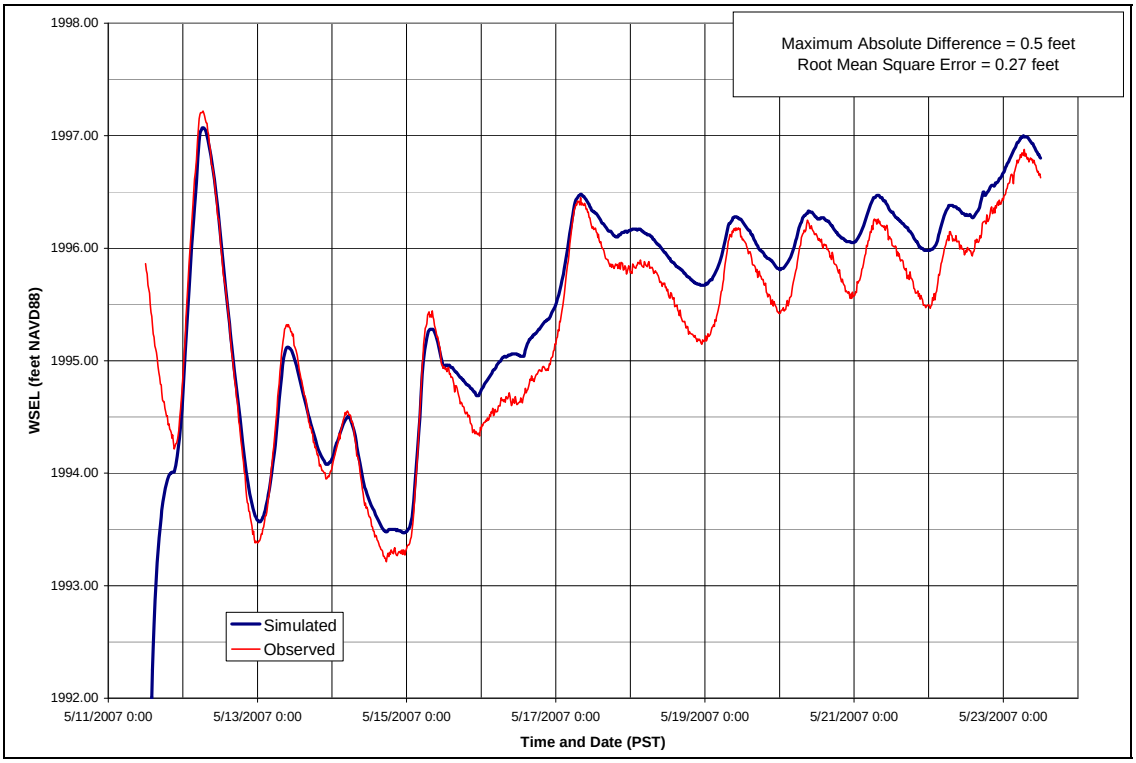


**Figure C-34.** Model calibration results for Lo_Hi calibration period at US_MET pressure transducer location – Boundary Reservoir HRM.

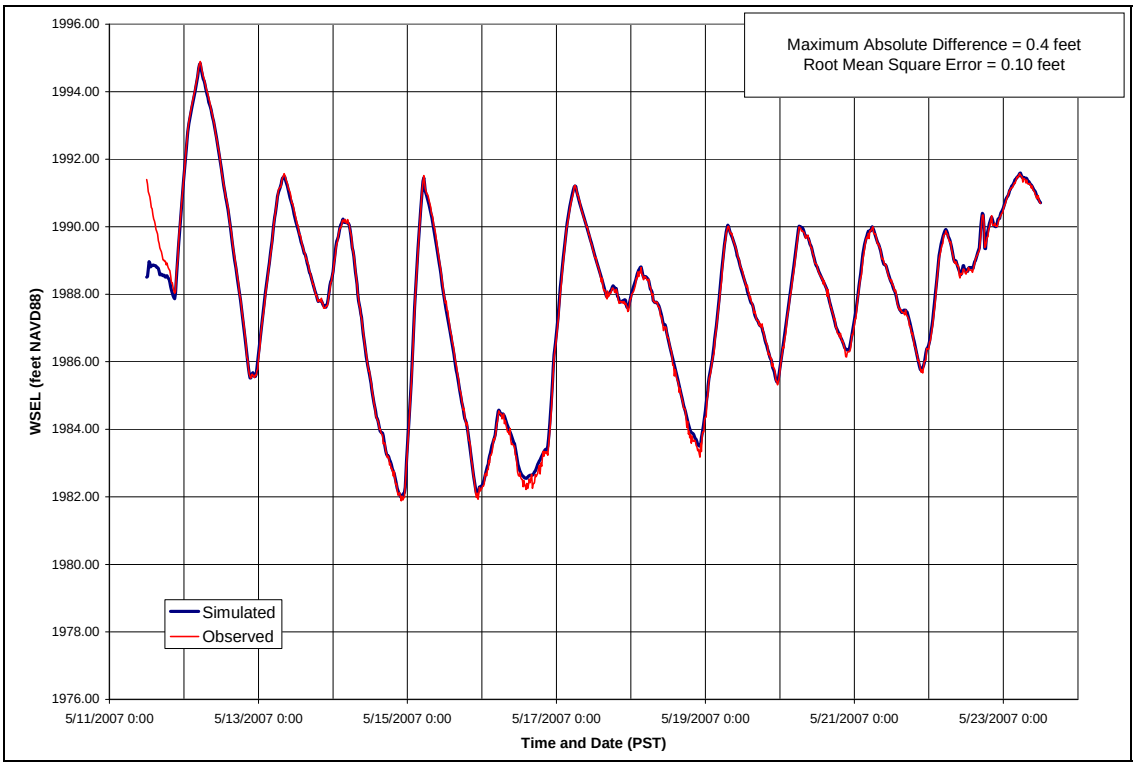


**Figure C-35.** Model calibration results for Lo_Hi calibration period at DS_MET pressure transducer location – Boundary Reservoir HRM.

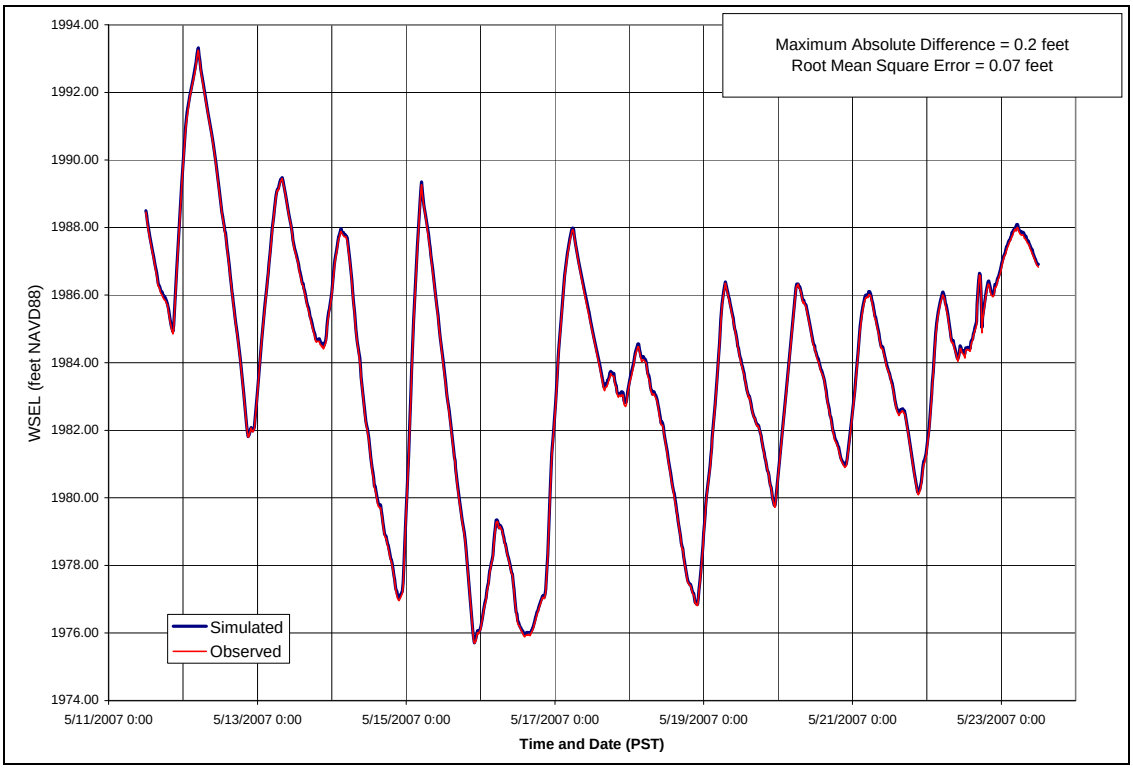


**Figure C-36.** Model calibration results for Lo_Hi calibration period at CANYON pressure transducer location – Boundary Reservoir HRM.

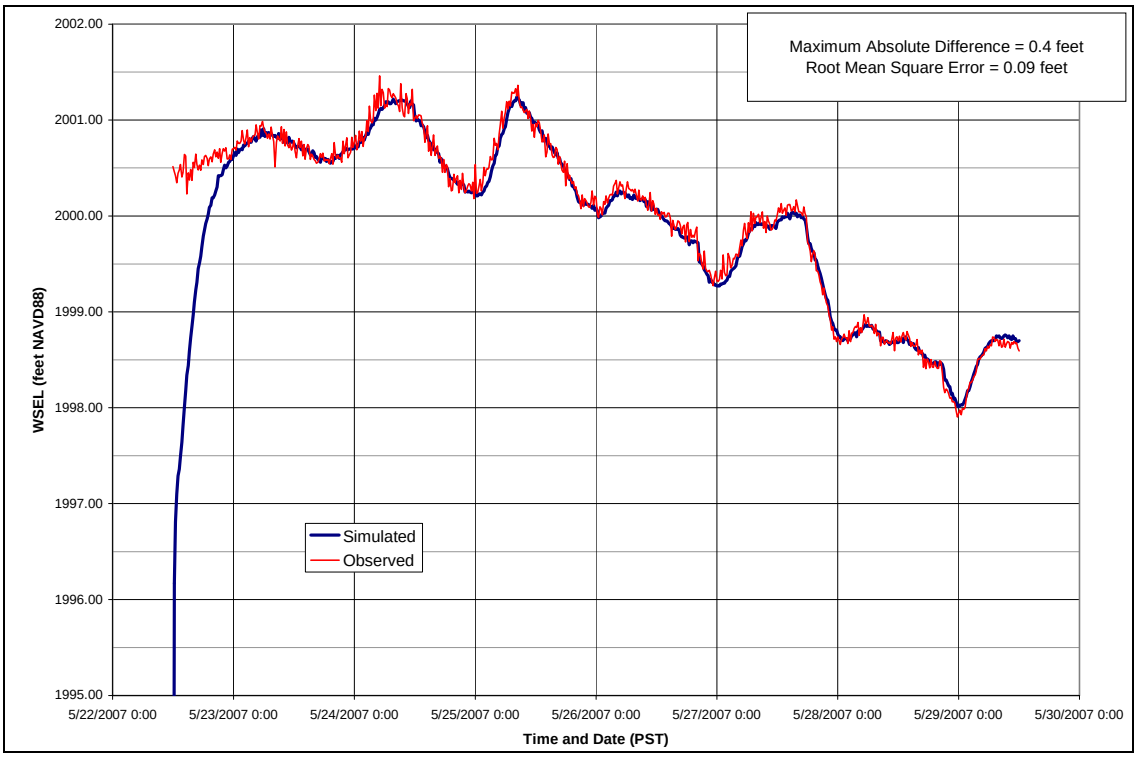


**Figure C-37.** Model calibration results for Hi_Hi verification period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

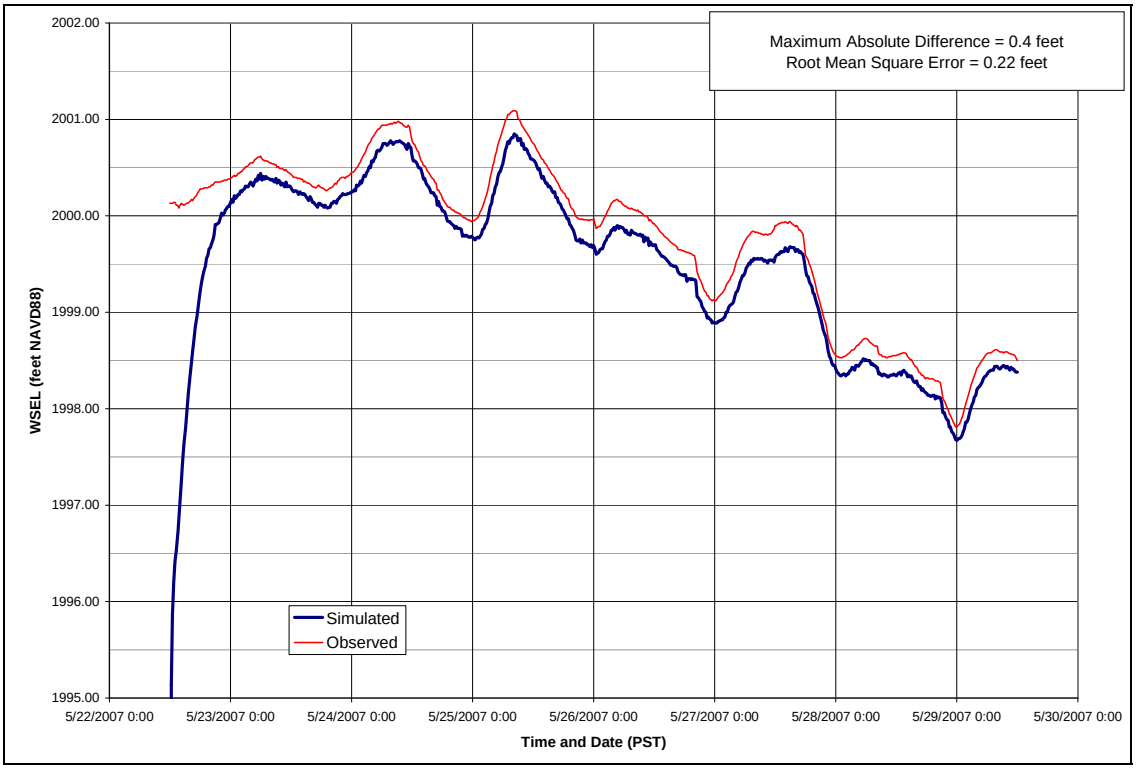


**Figure C-38.** Model calibration results for Hi_Hi verification period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

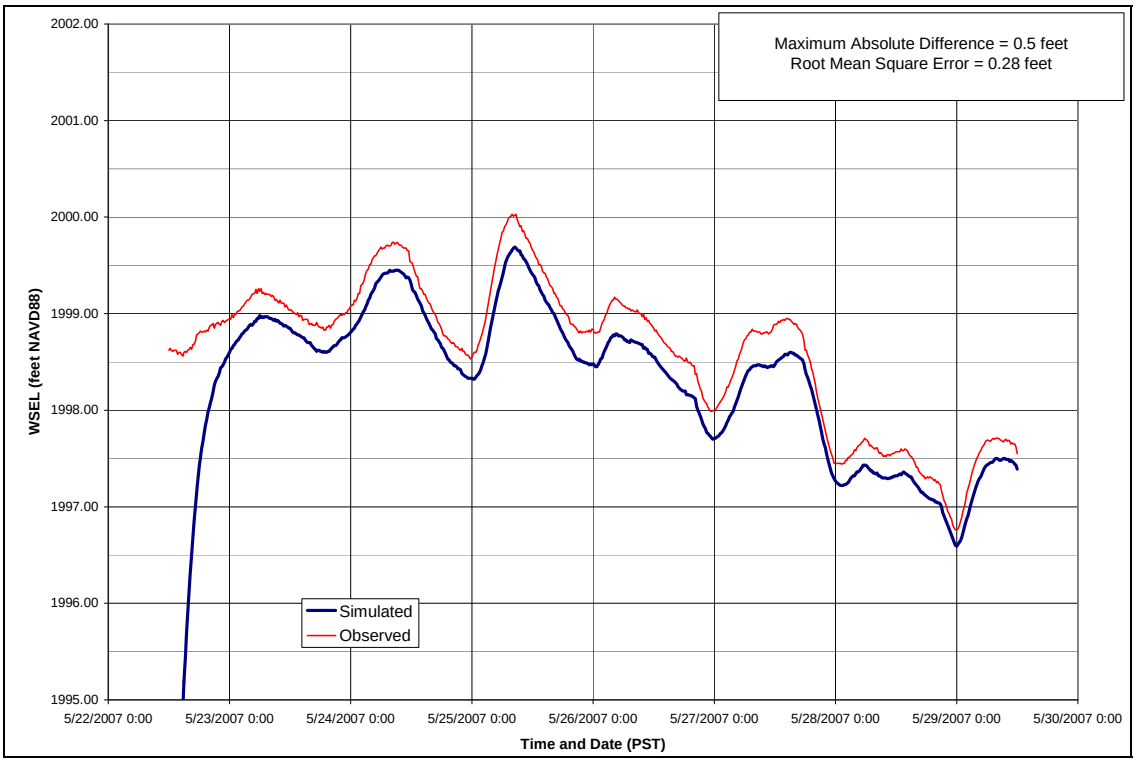


**Figure C-39.** Model calibration results for Hi_Hi verification period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

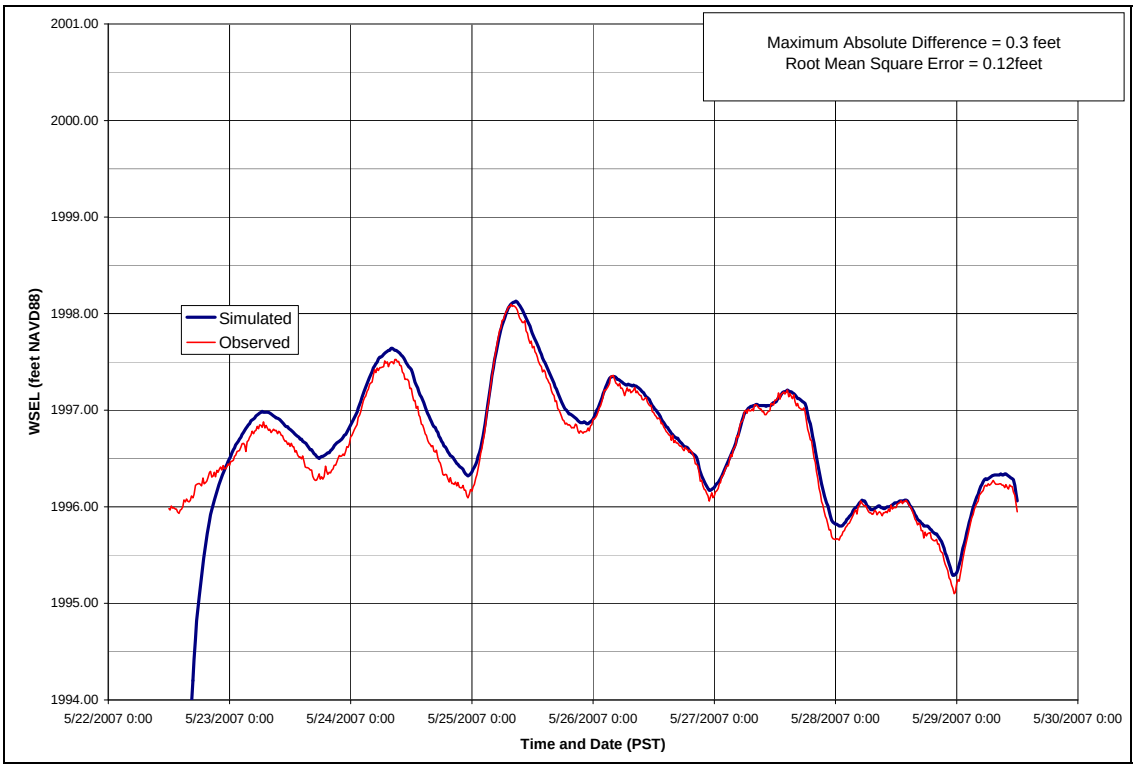


**Figure C-40.** Model calibration results for Hi_Hi verification period at US_MET pressure transducer location – Boundary Reservoir HRM.

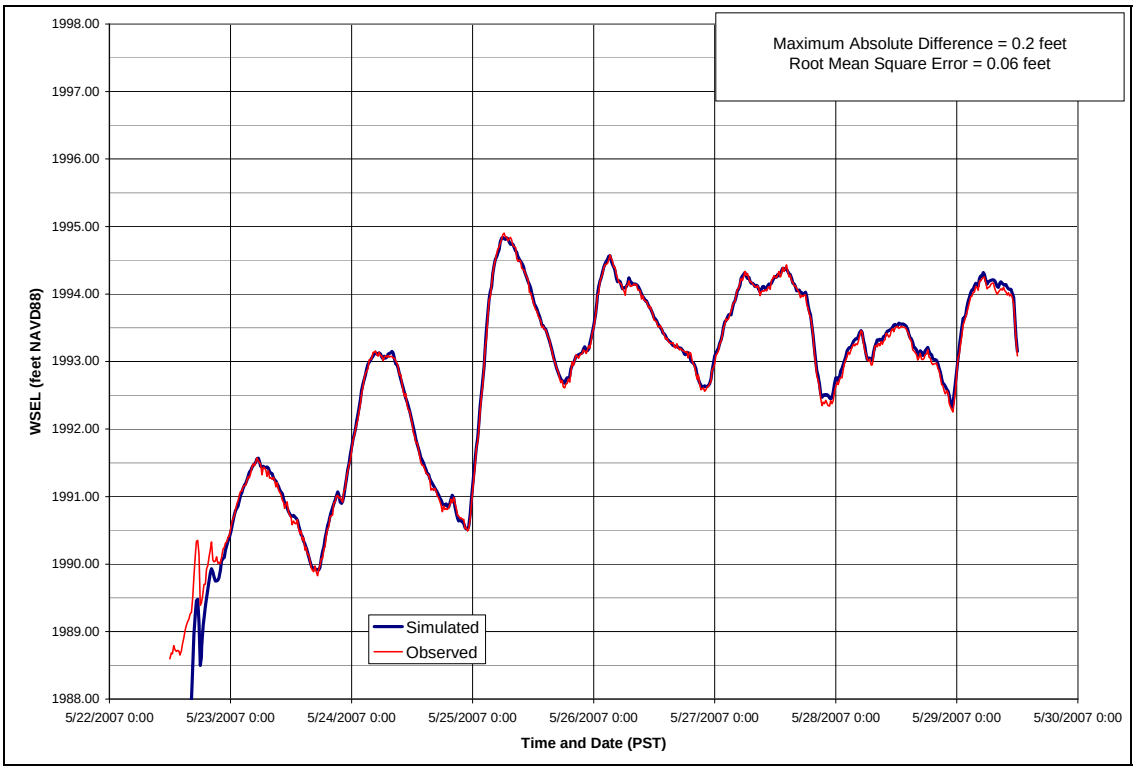


**Figure C-41.** Model calibration results for Hi_Hi verification period at DS_MET pressure transducer location – Boundary Reservoir HRM.

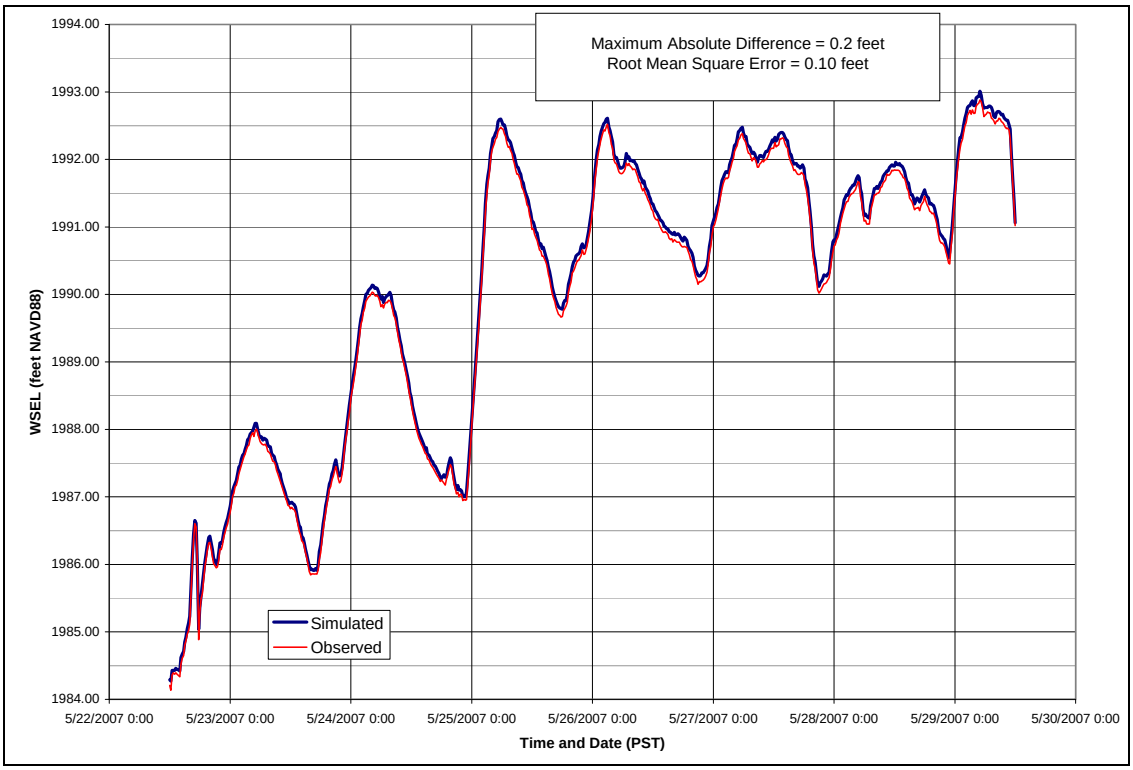


**Figure C-42.** Model calibration results for Hi_Hi verification period at CANYON pressure transducer location – Boundary Reservoir HRM.

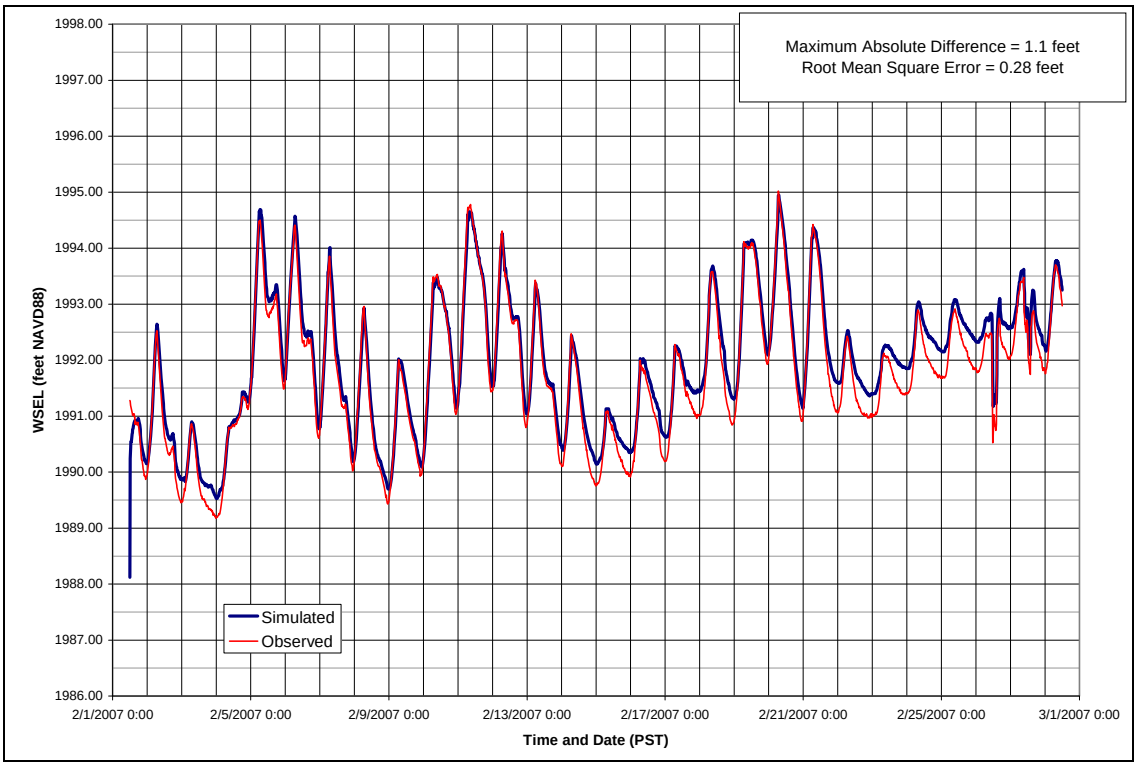


**Figure C-43.** Model calibration results for Var_Var verification period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

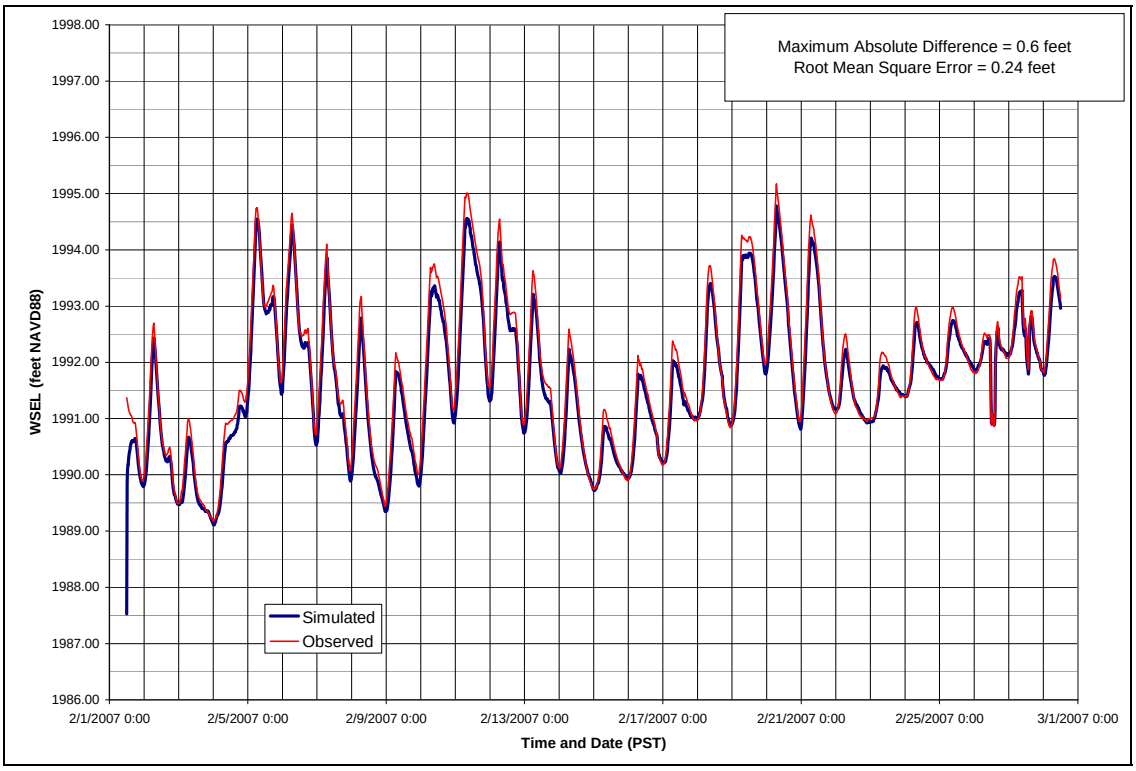


**Figure C-44.** Model calibration results for Var_Var verification period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

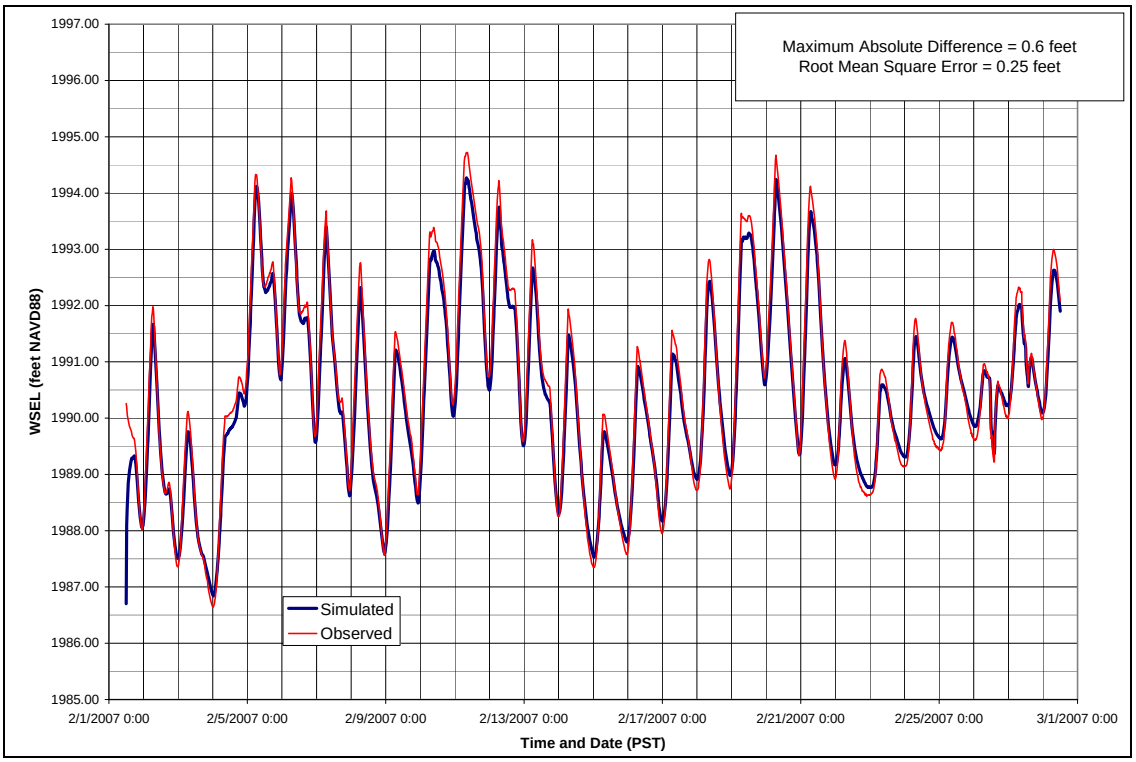


**Figure C-45.** Model calibration results for Var_Var verification period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

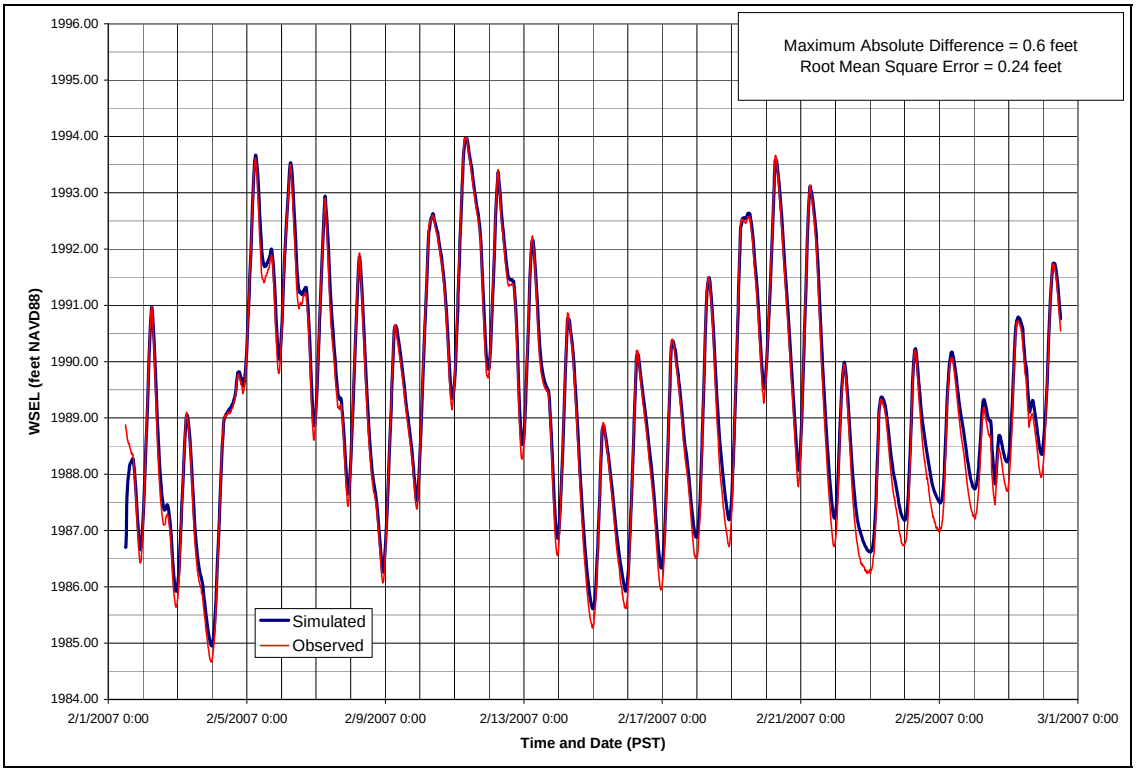


**Figure C-46.** Model calibration results for Var_Var verification period at US_MET pressure transducer location – Boundary Reservoir HRM.

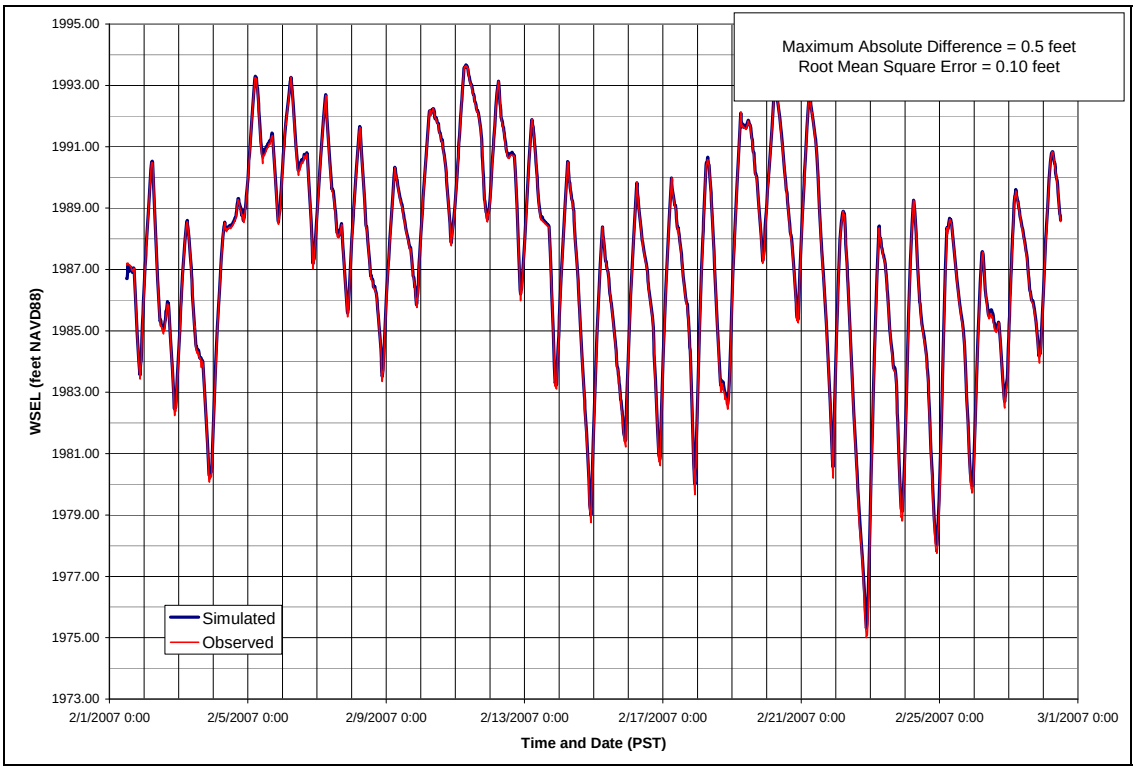


**Figure C-47.** Model calibration results for Var_Var verification period at DS_MET pressure transducer location – Boundary Reservoir HRM.

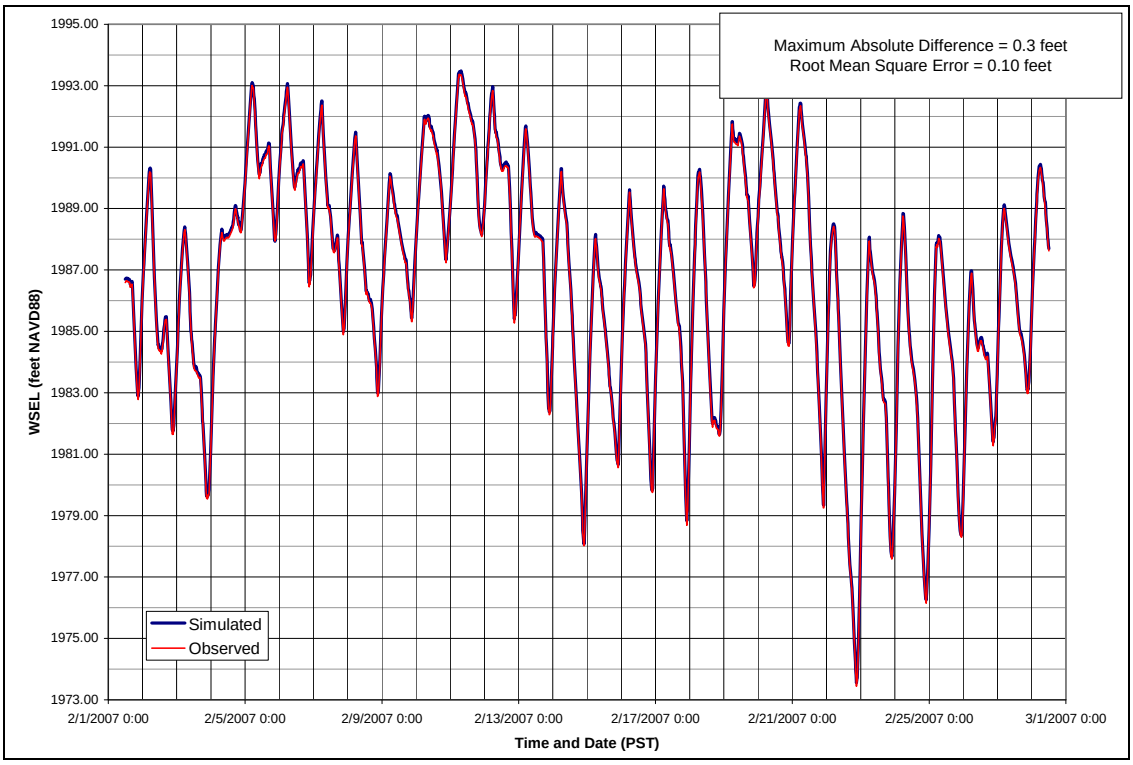


**Figure C-48.** Model calibration results for Var_Var verification period at CANYON pressure transducer location – Boundary Reservoir HRM.

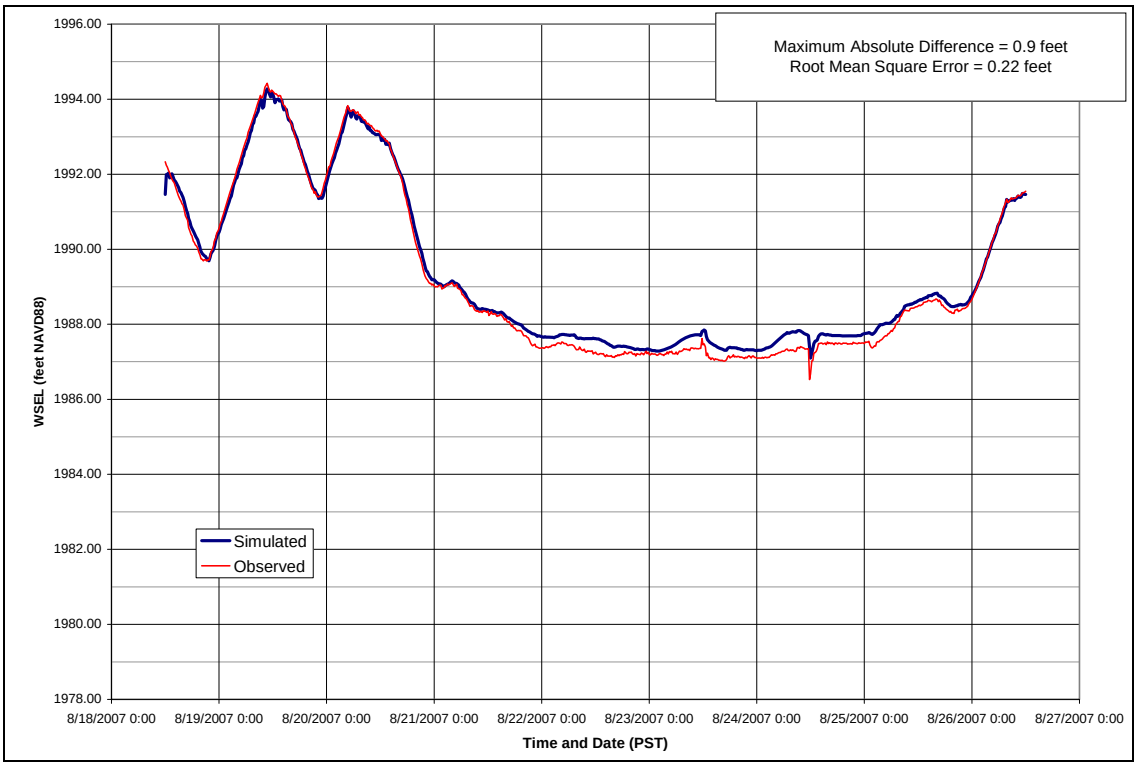


**Figure C-49.** Model calibration results for Lo_Lo verification period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

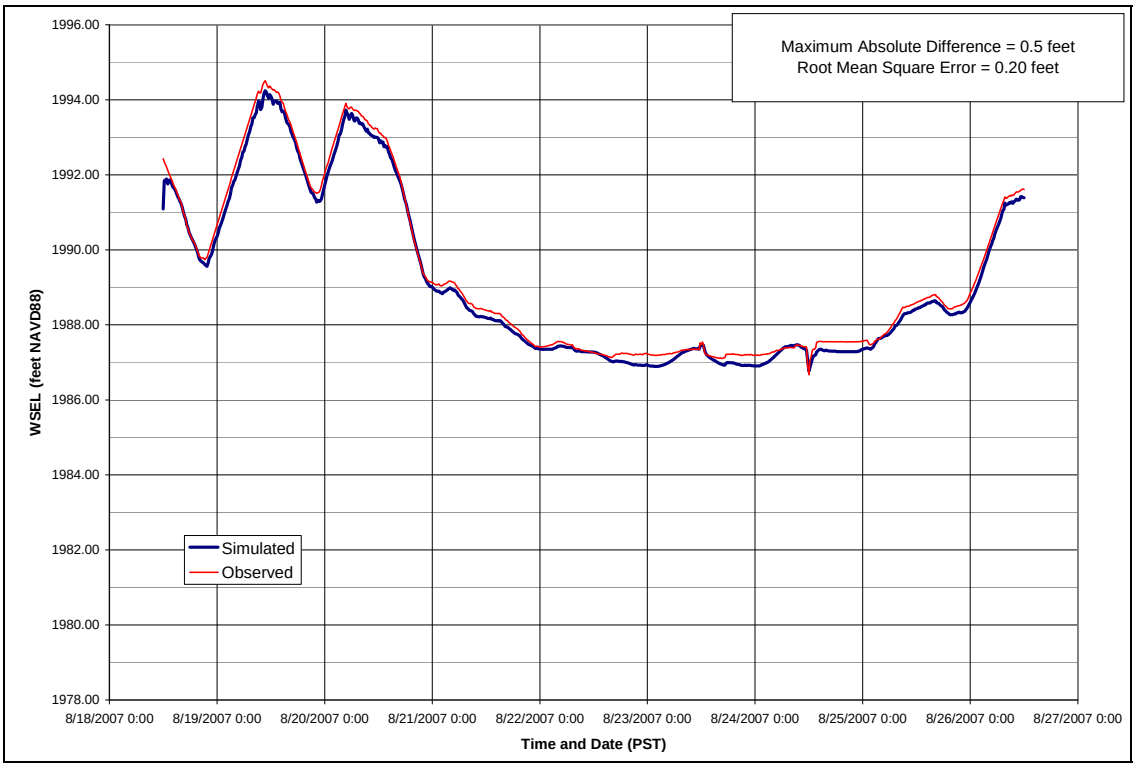


**Figure C-50.** Model calibration results for Lo_Lo verification period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

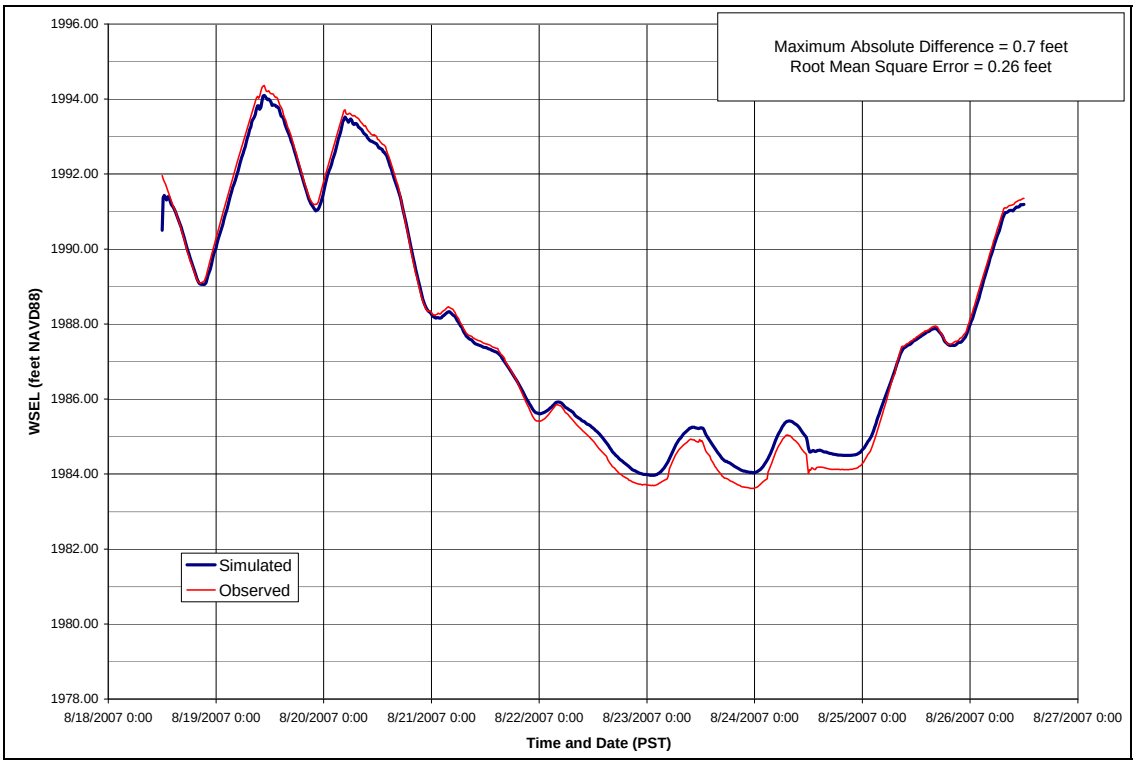


**Figure C-51.** Model calibration results for Lo_Lo verification period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

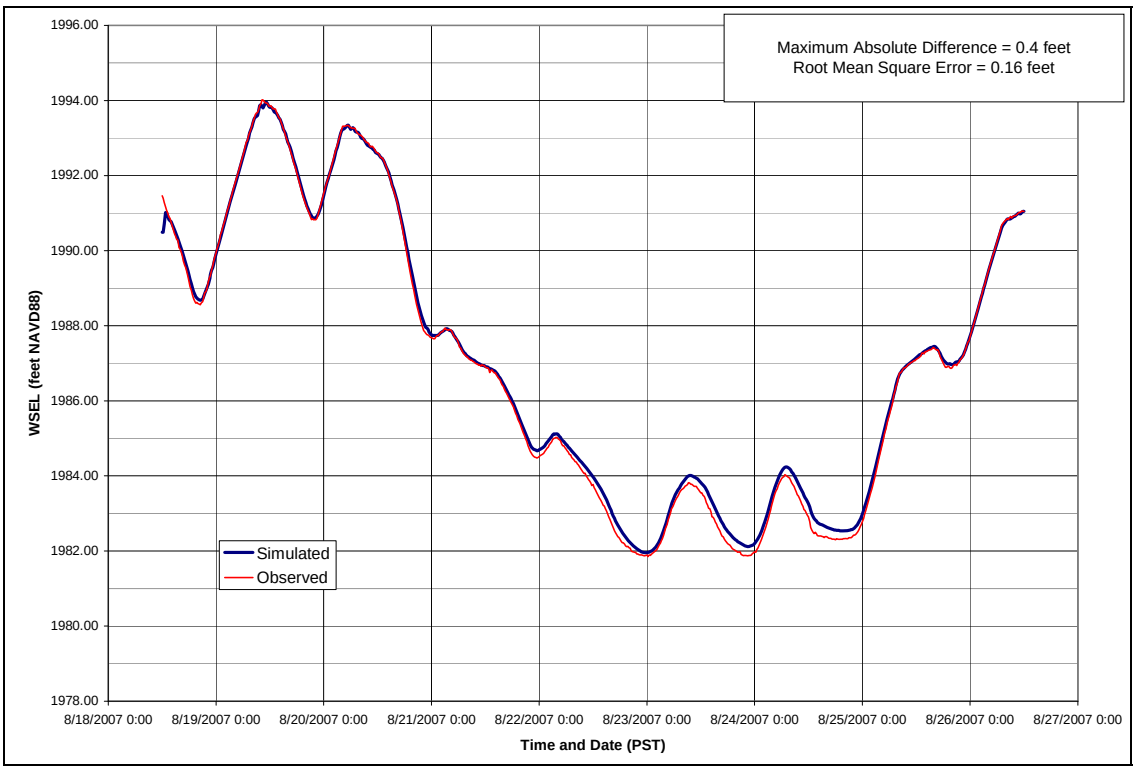


**Figure C-52.** Model calibration results for Lo_Lo verification period at US_MET pressure transducer location – Boundary Reservoir HRM.

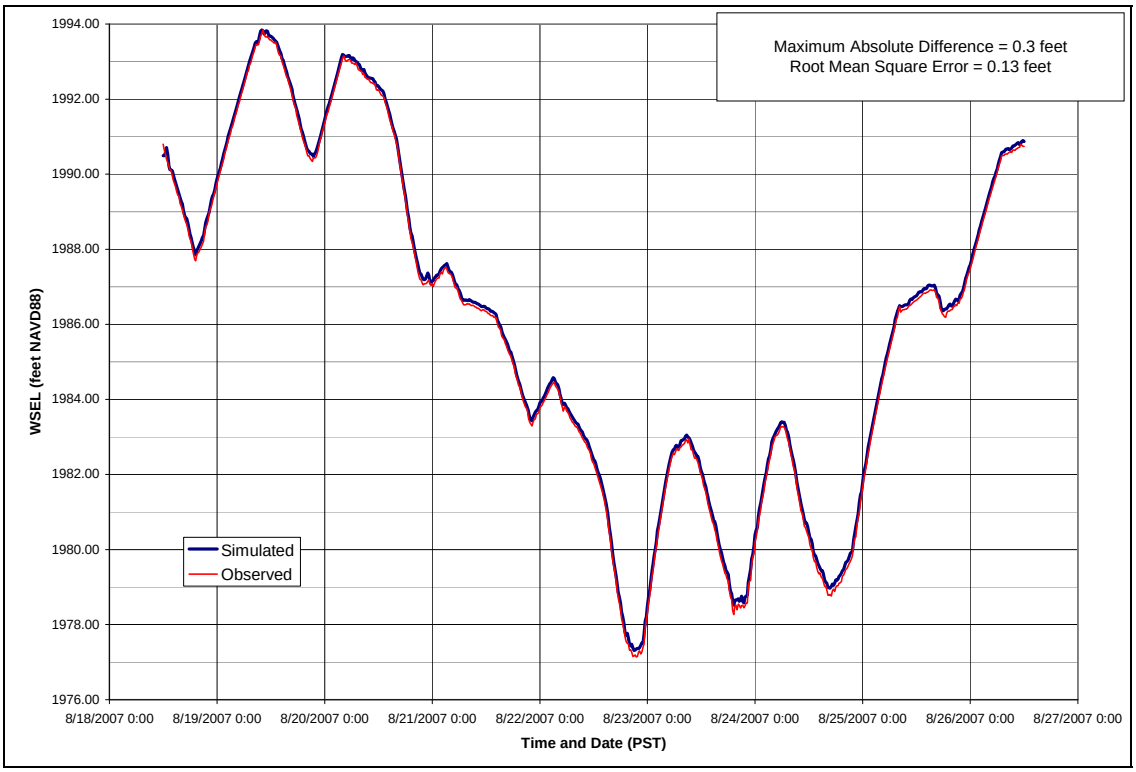


**Figure C-53.** Model calibration results for Lo_Lo verification period at DS_MET pressure transducer location – Boundary Reservoir HRM.

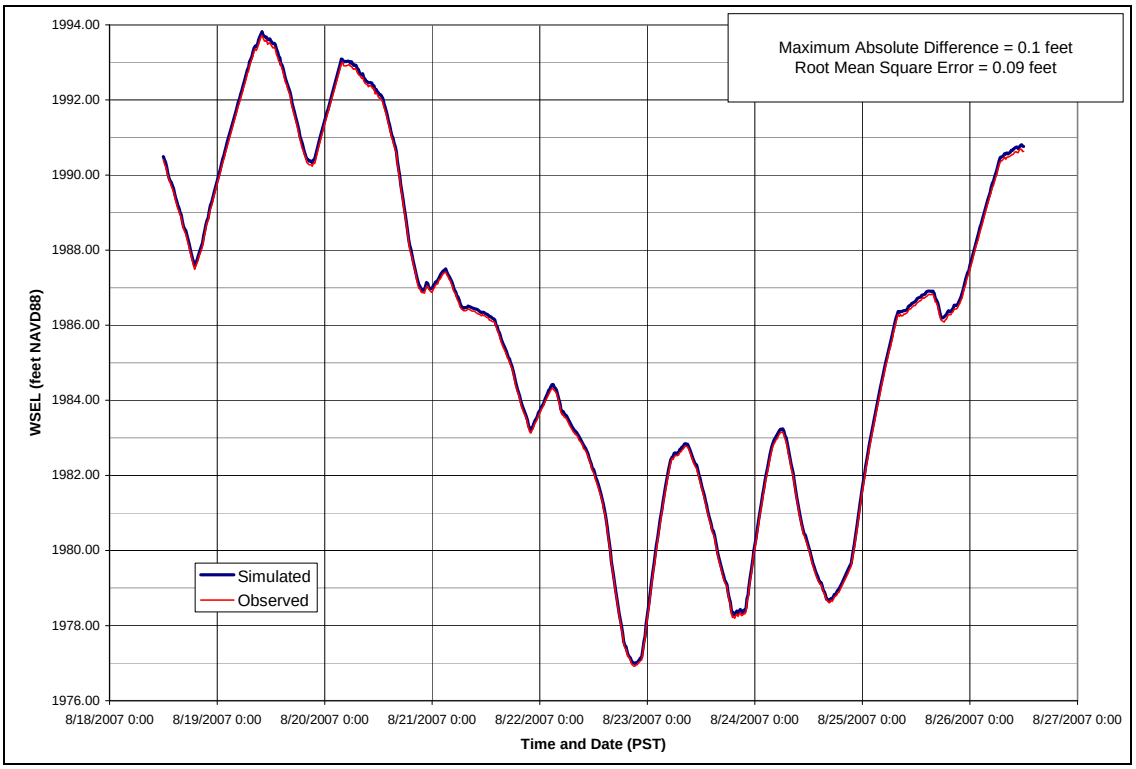


**Figure C-54.** Model calibration results for Lo_Lo verification period at CANYON pressure transducer location – Boundary Reservoir HRM.

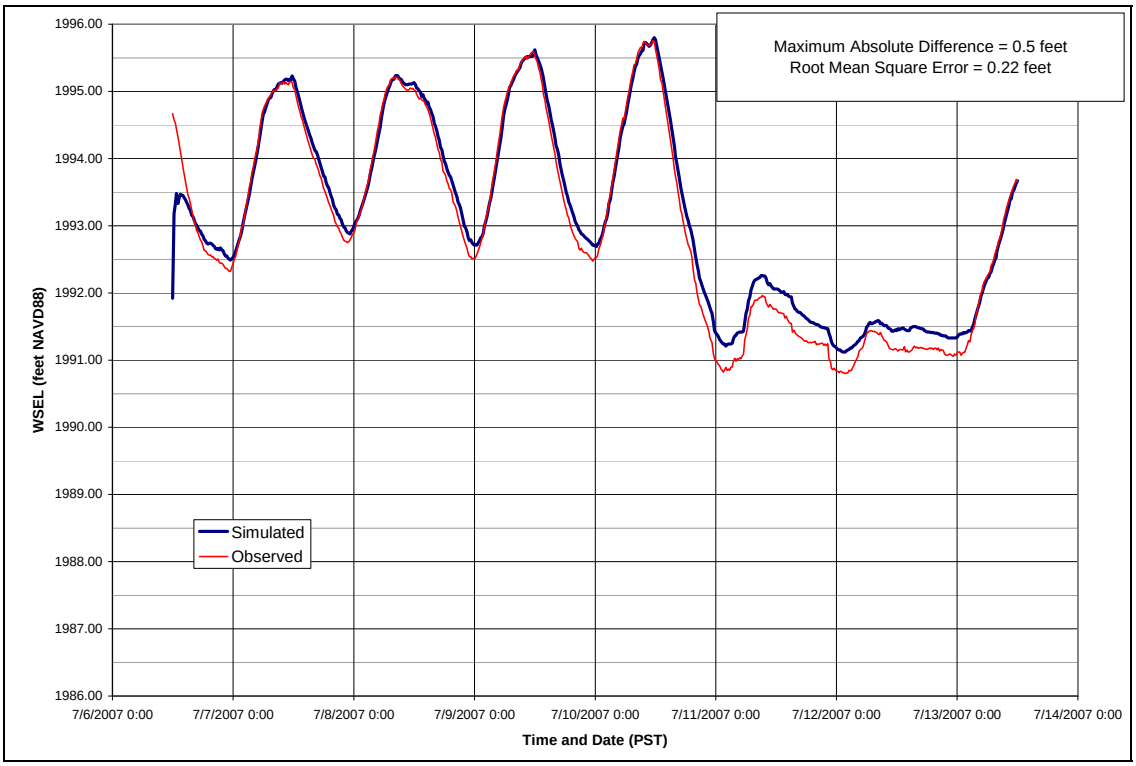


**Figure C-55.** Model calibration results for Lo_Mod verification period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

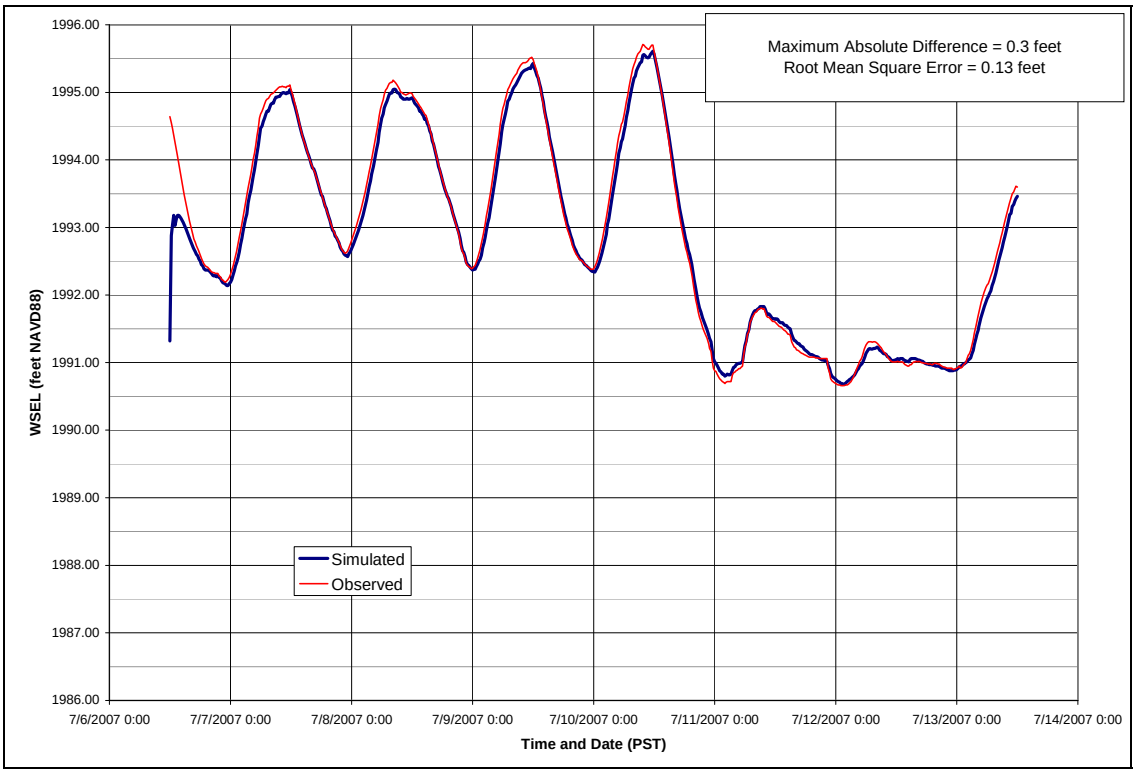


**Figure C-56.** Model calibration results for Lo_Mod verification period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

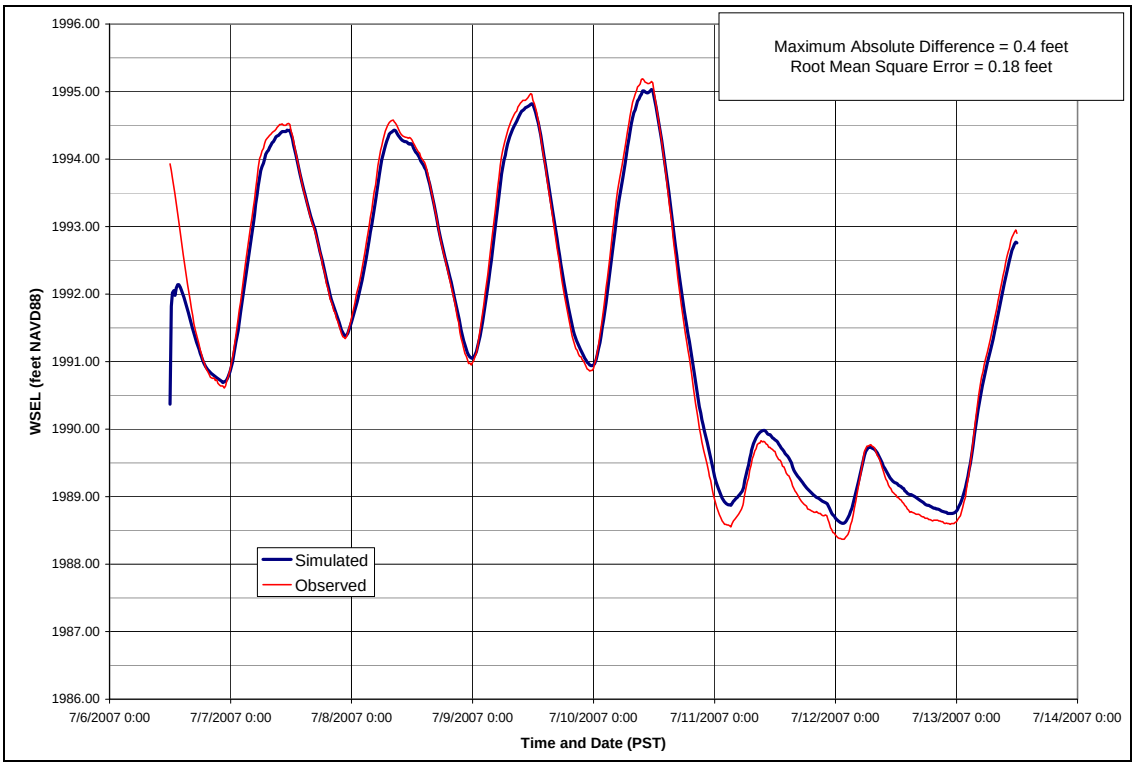


**Figure C-57.** Model calibration results for Lo_Mod verification period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

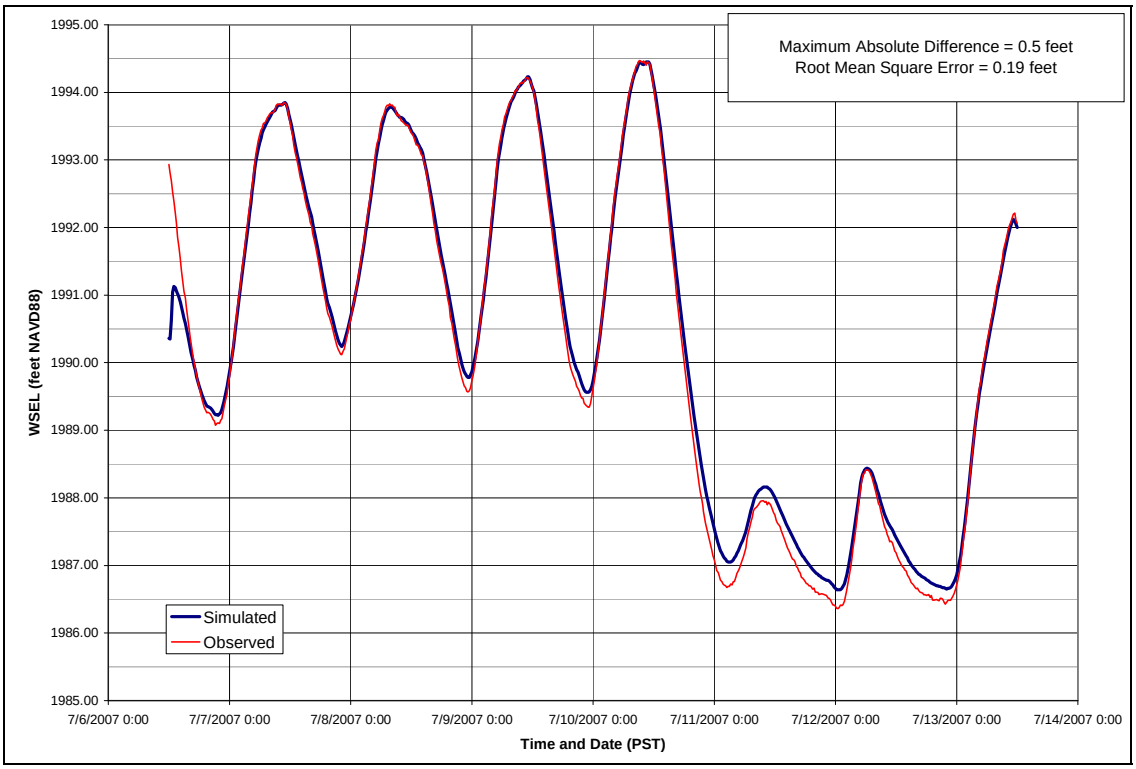


**Figure C-58.** Model calibration results for Lo_Mod verification period at US_MET pressure transducer location – Boundary Reservoir HRM.

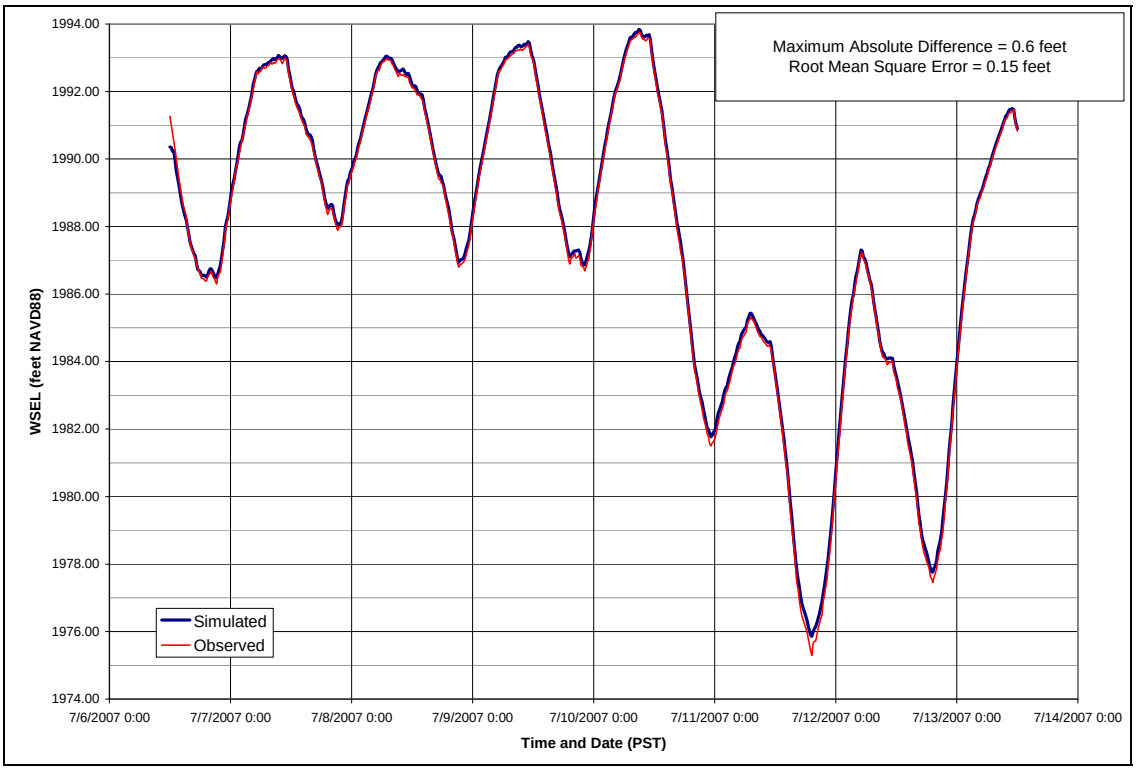


**Figure C-59.** Model calibration results for Lo_Mod verification period at DS_MET pressure transducer location – Boundary Reservoir HRM.

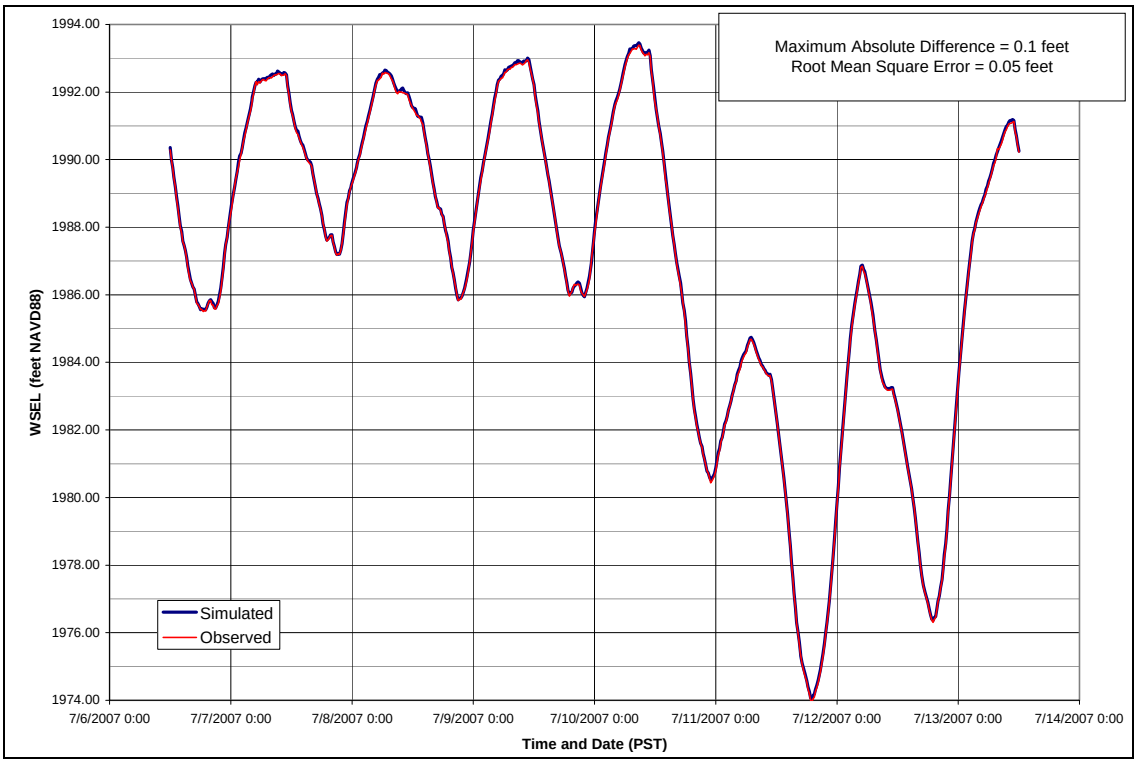


**Figure C-60.** Model calibration results for Lo_Mod verification period at CANYON pressure transducer location – Boundary Reservoir HRM.

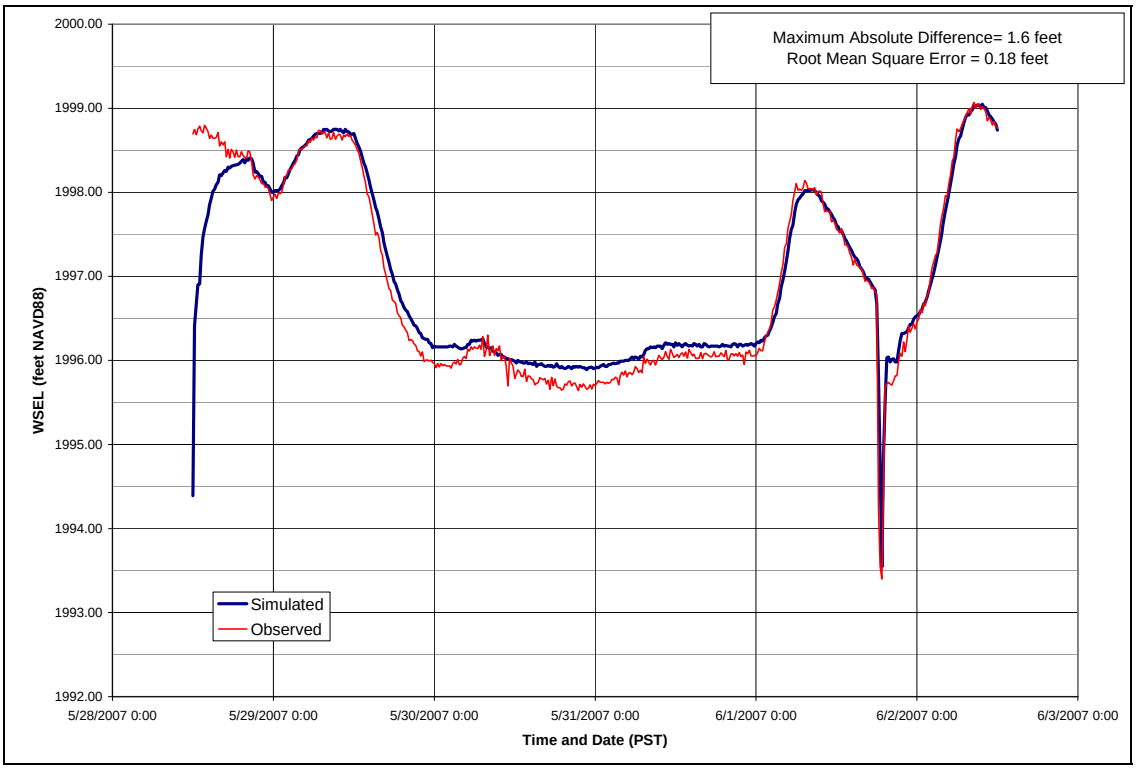


**Figure C-61.** Model calibration results for Lo_Hi verification period at BOX_TR pressure transducer location – Boundary Reservoir HRM.

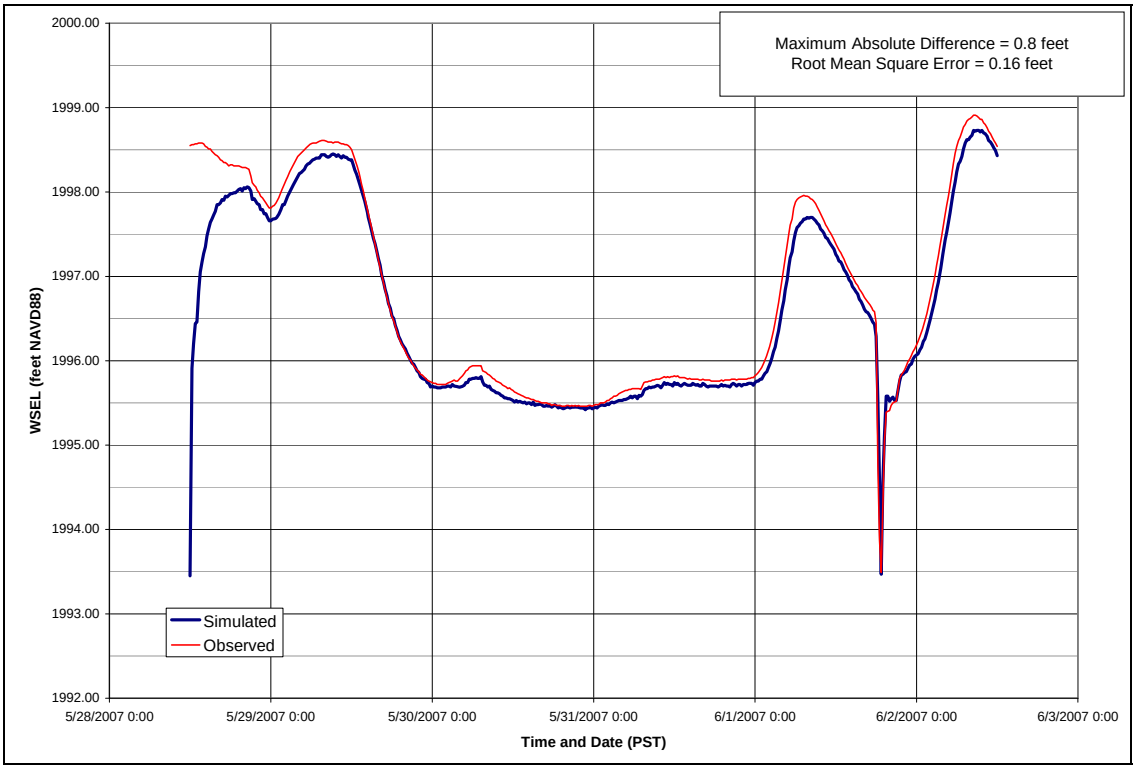


**Figure C-62.** Model calibration results for Lo_Hi verification period at USGS Station 12396500 (Primary) location – Boundary Reservoir HRM.

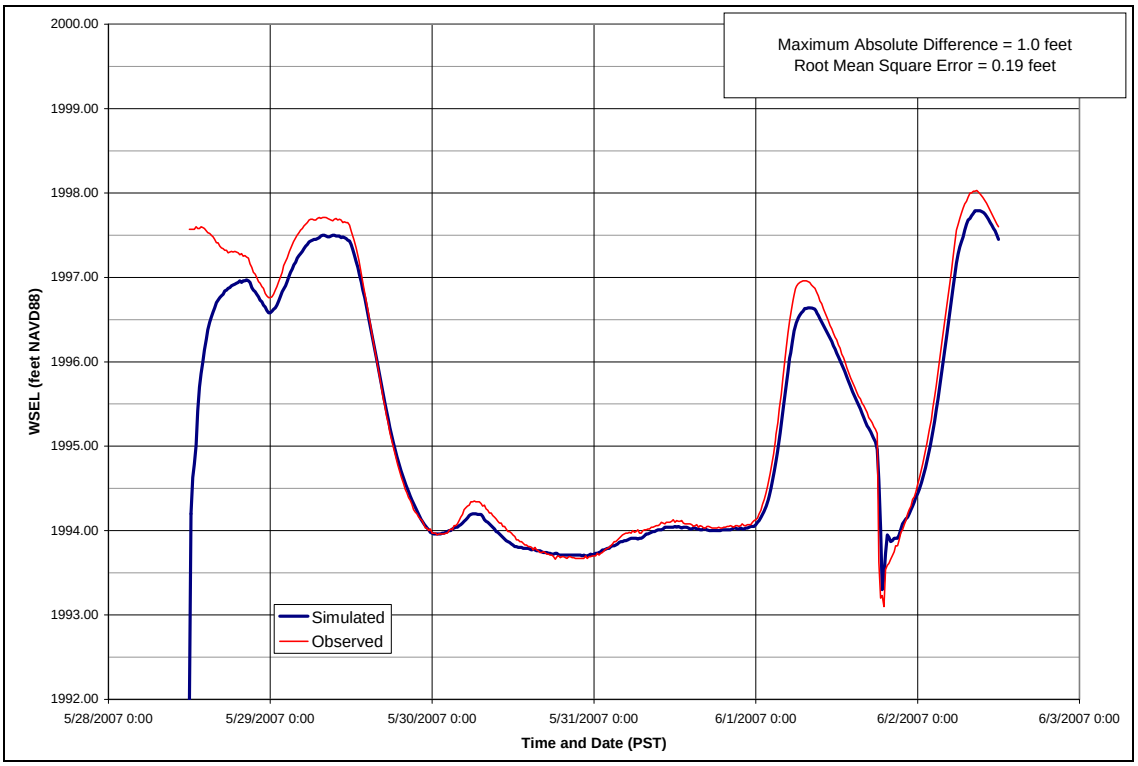


**Figure C-63.** Model calibration results for Lo_Hi verification period at USGS Station 12396500 (Auxiliary) location – Boundary Reservoir HRM.

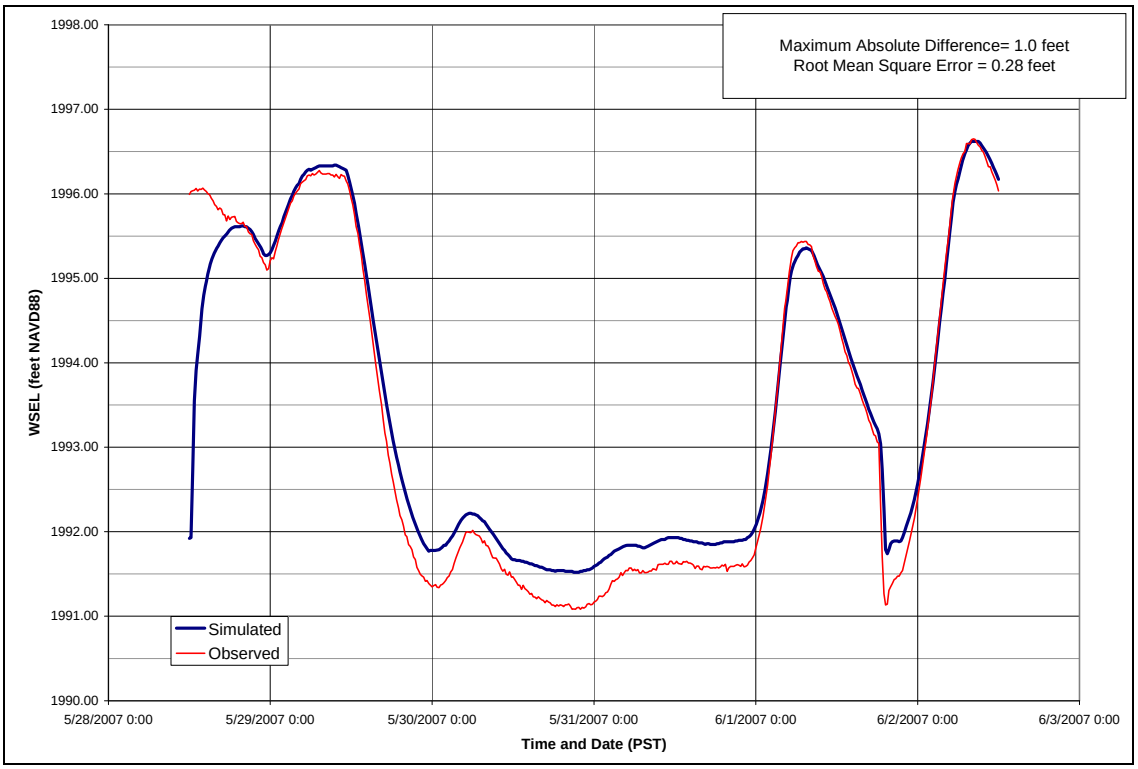


**Figure C-64.** Model calibration results for Lo_Hi verification period at US_MET pressure transducer location – Boundary Reservoir HRM.

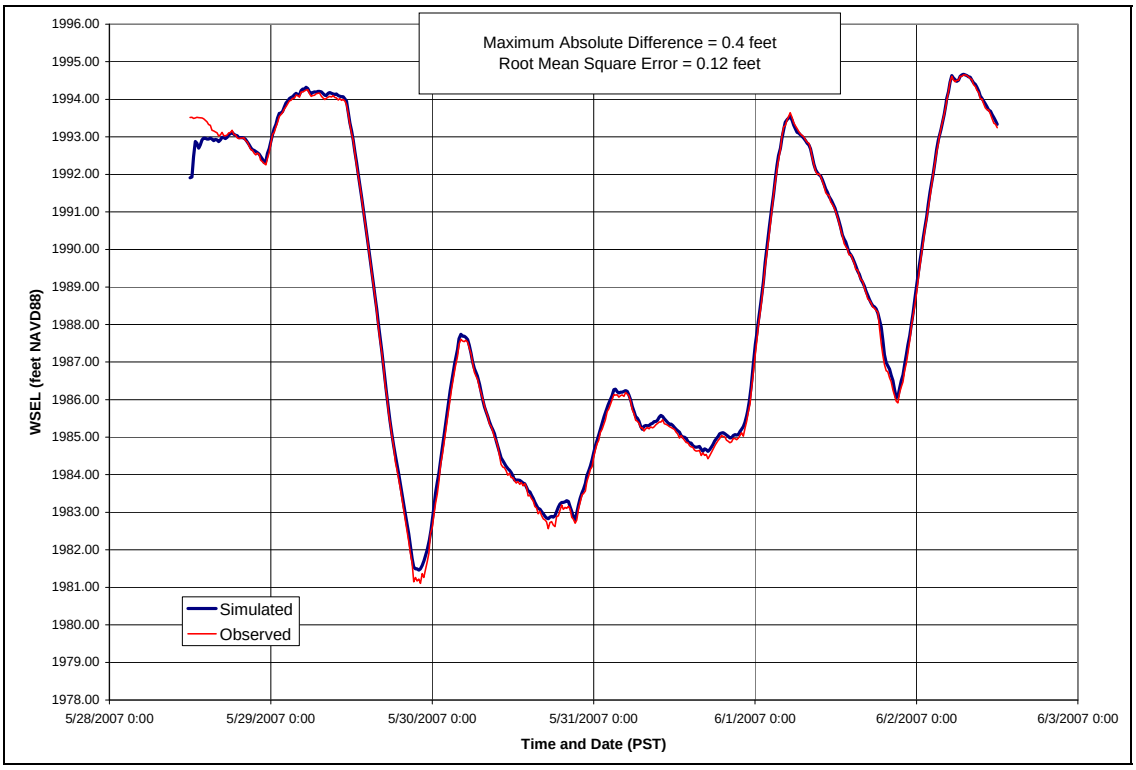


**Figure C-65.** Model calibration results for Lo_Hi verification period at DS_MET pressure transducer location – Boundary Reservoir HRM.

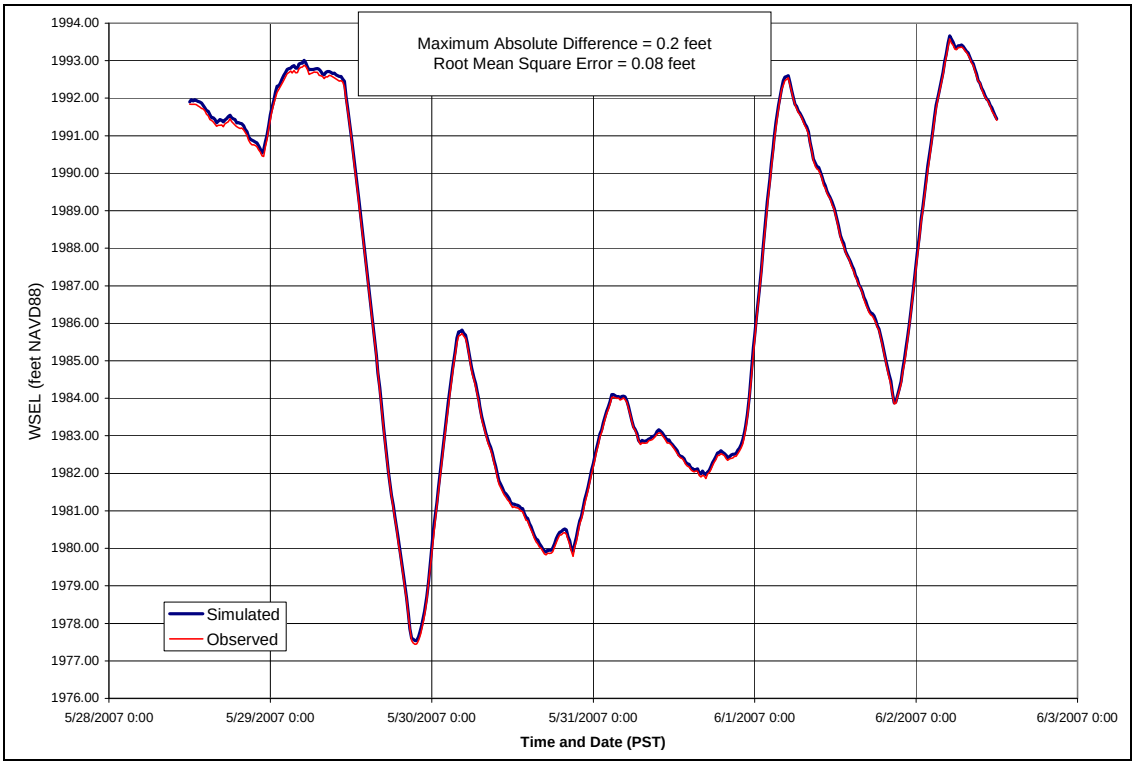


**Figure C-66.** Model calibration results for Lo_Hi verification period at CANYON pressure transducer location – Boundary Reservoir HRM.

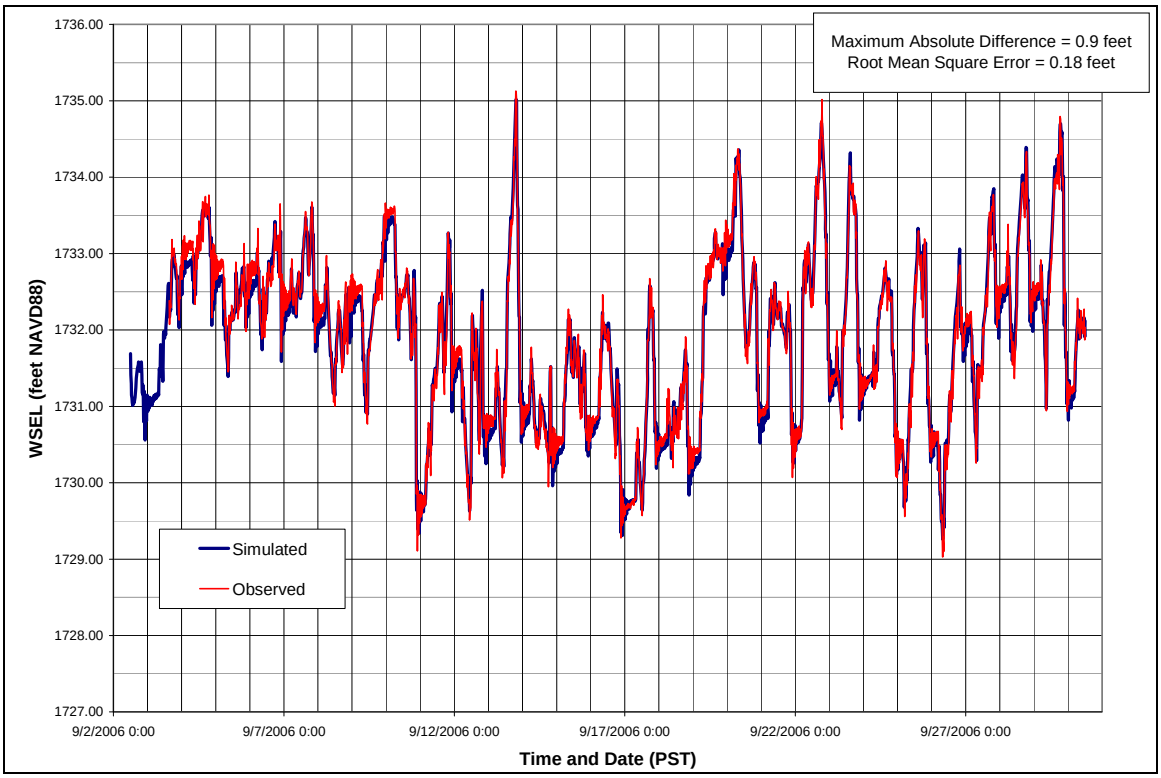


**Figure C-67.** Model calibration results for Hi_Lo calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

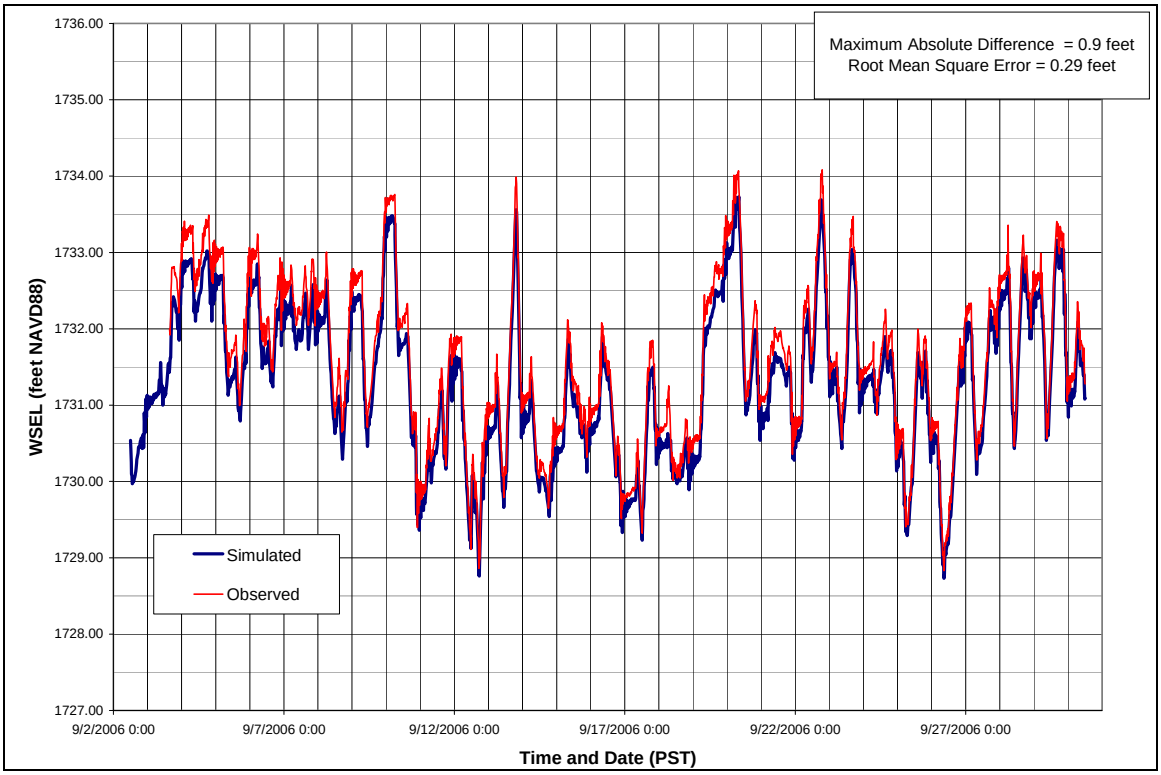


**Figure C-68.** Model calibration results for Hi_Lo calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

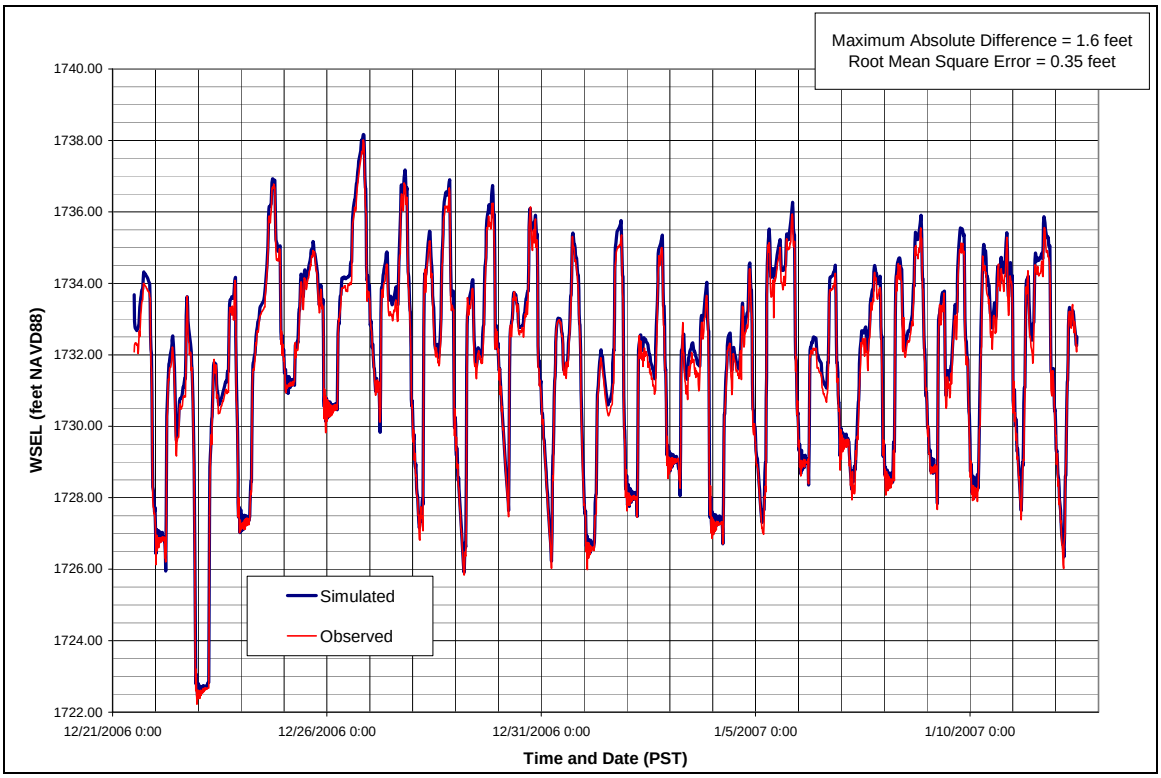


**Figure C-69.** Model calibration results for Hi_Mod calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

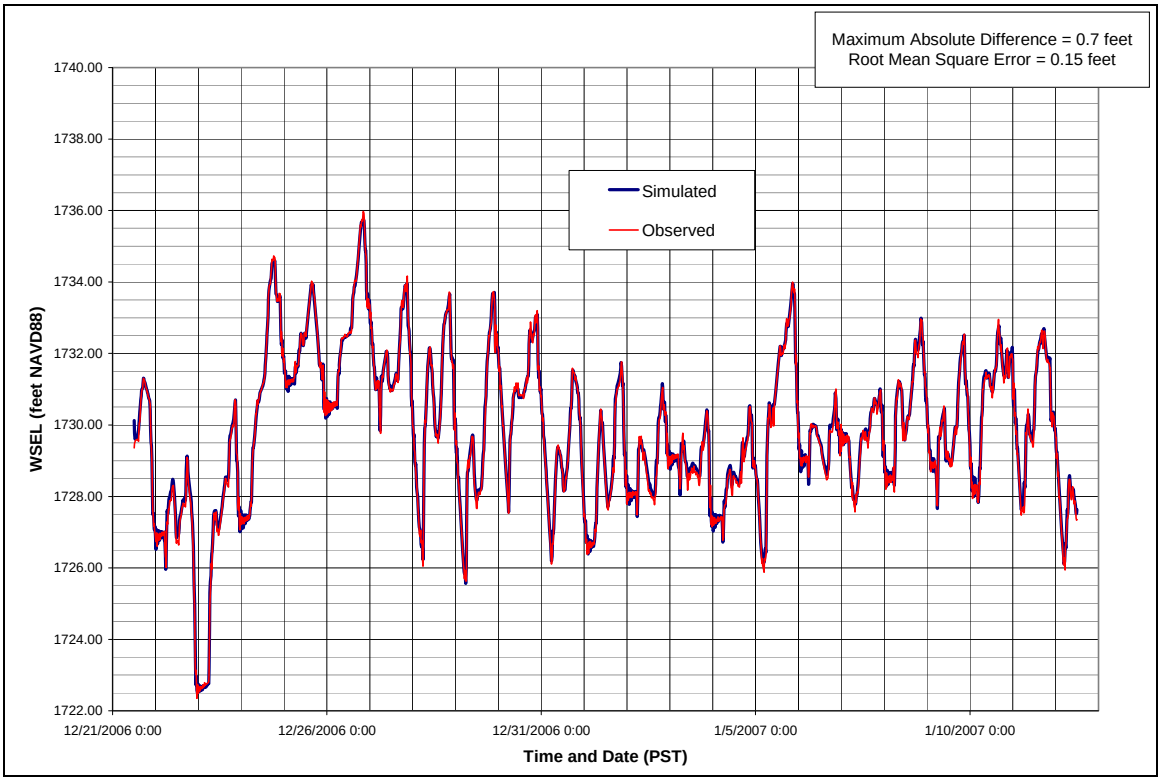


**Figure C-70.** Model calibration results for Hi_Mod calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

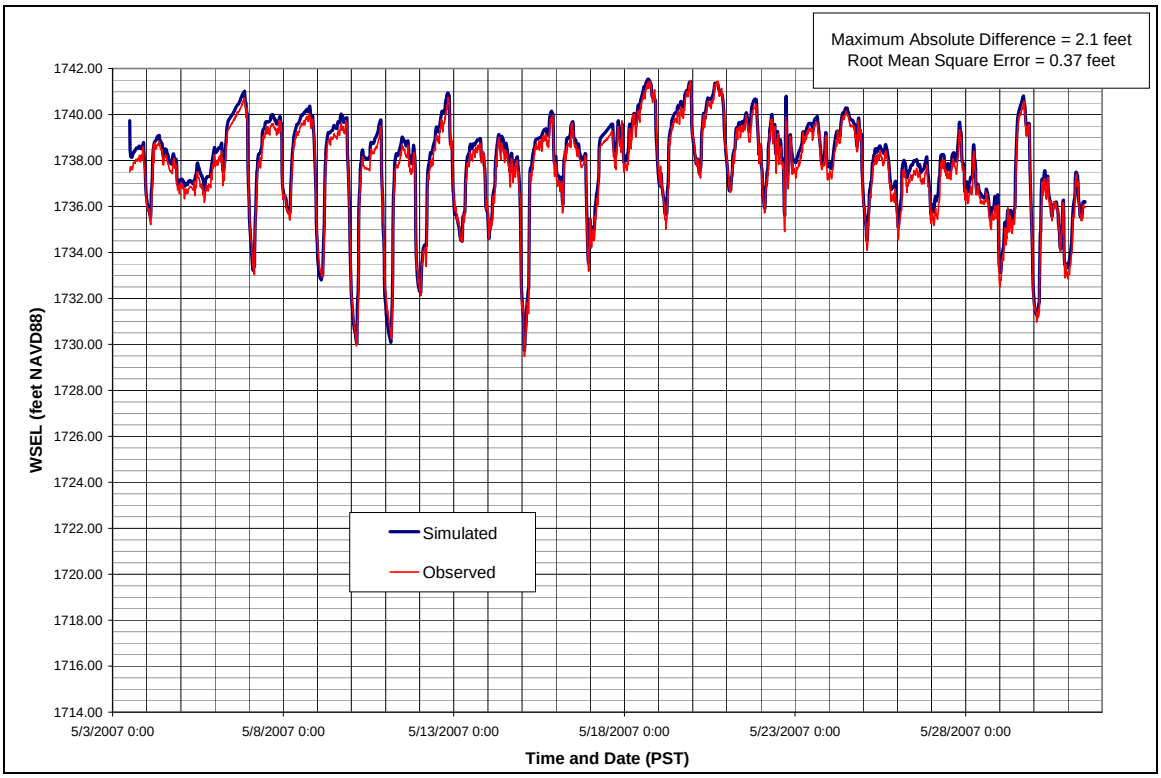


**Figure C-71.** Model calibration results for Hi_Hi calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

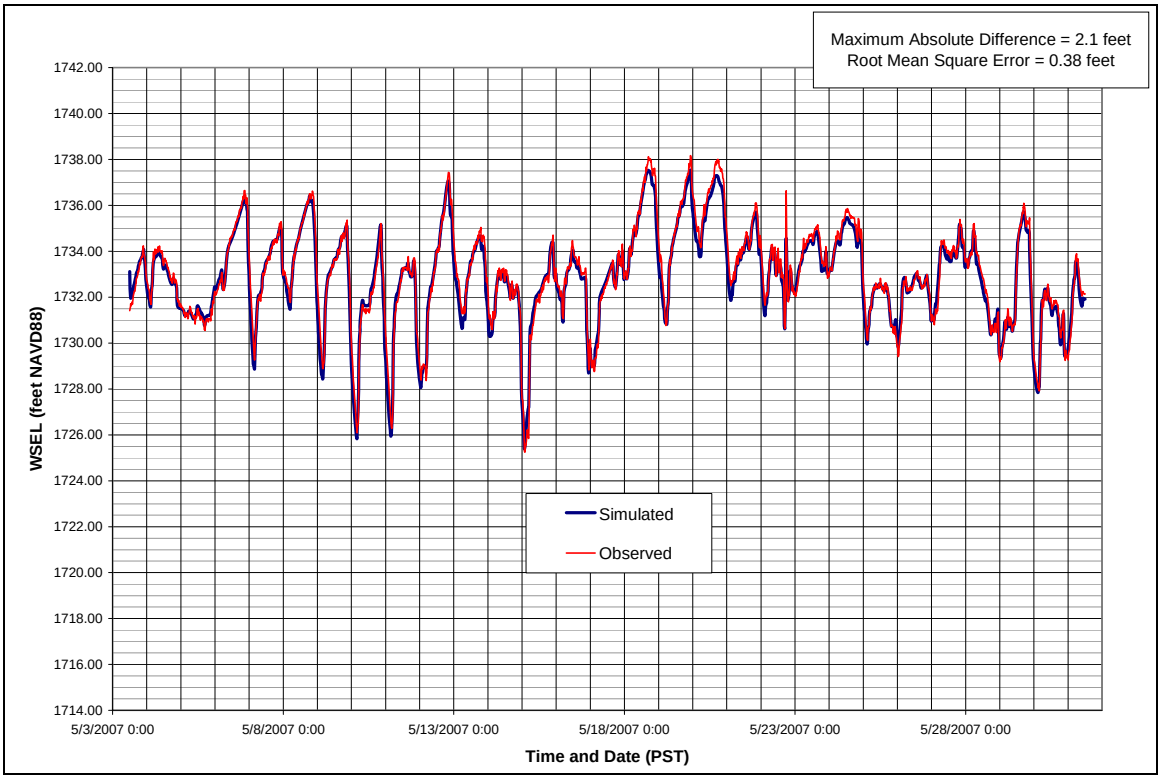


**Figure C-72.** Model calibration results for Hi_Hi calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

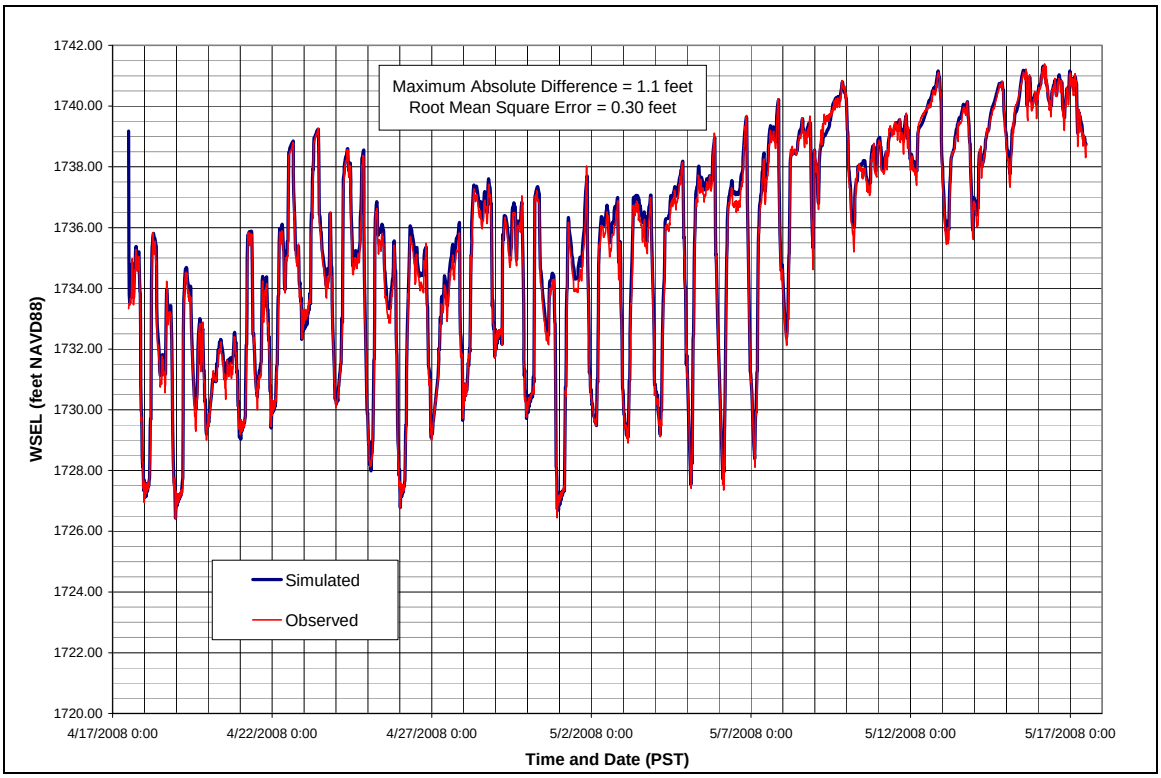


**Figure C-73.** Model calibration results for Hi_Hi2 calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

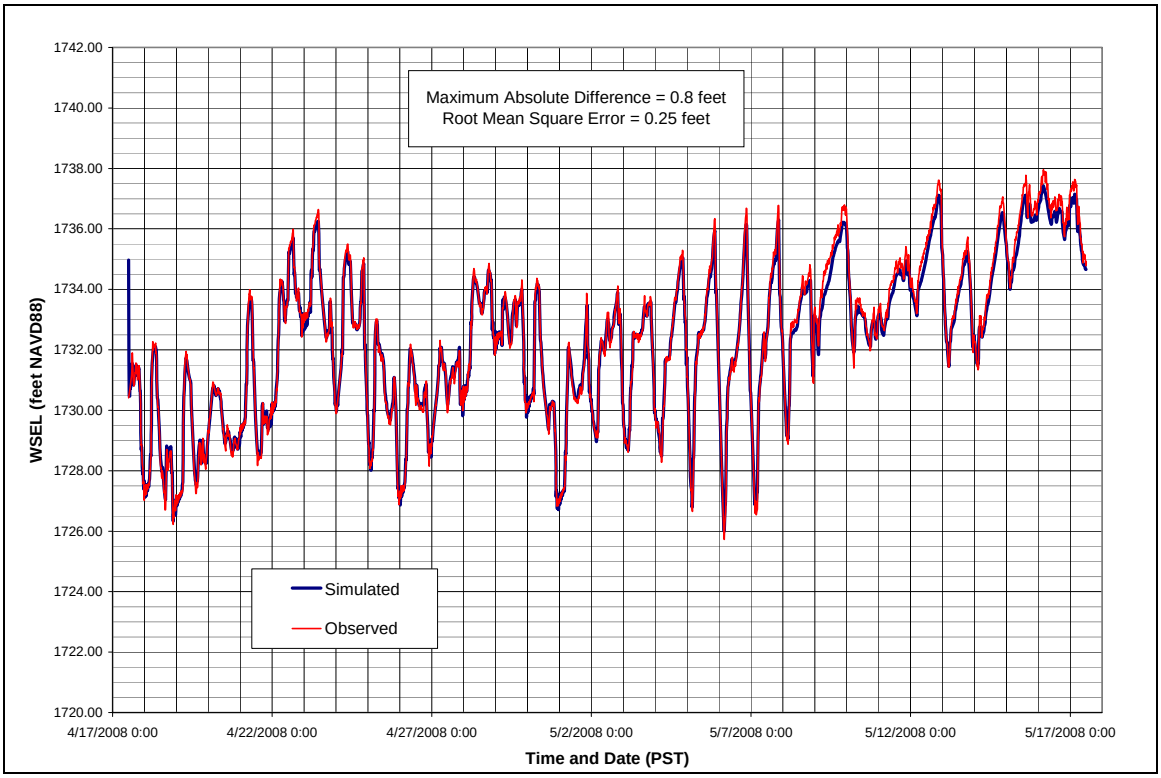


**Figure C-74.** Model calibration results for Hi_Hi2 calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

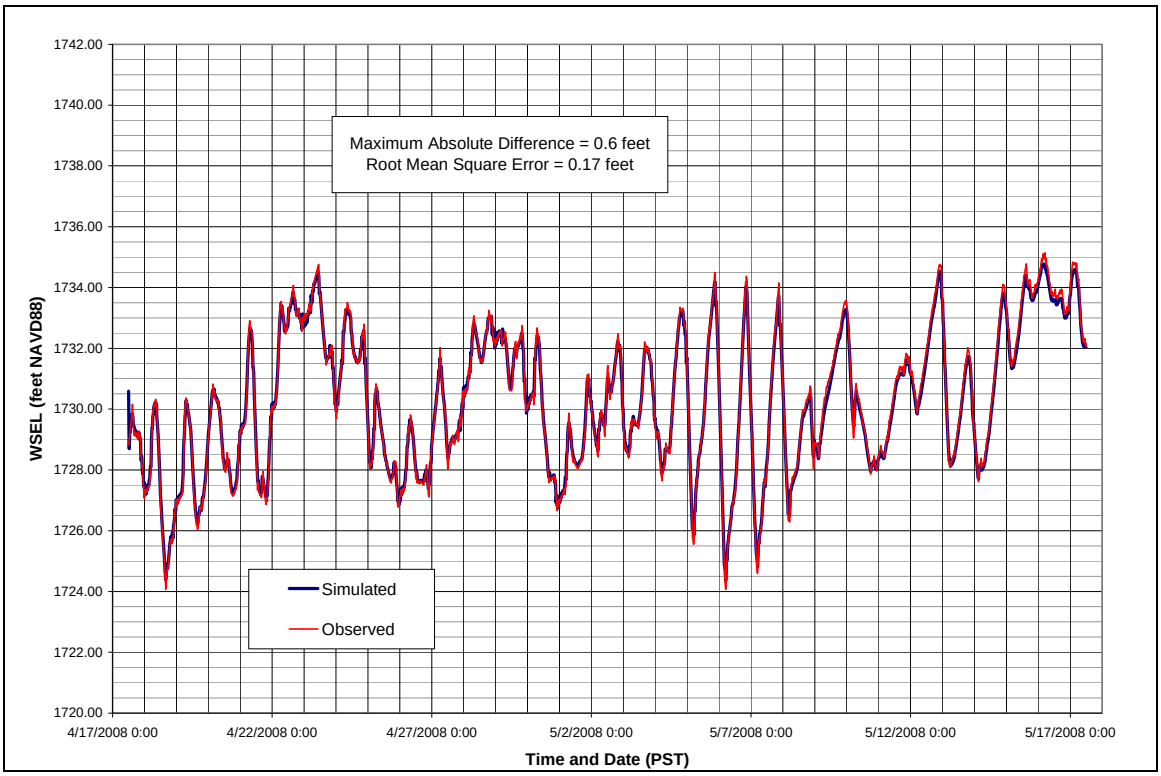


**Figure C-75.** Model calibration results for Hi_Hi2 calibration period at BRIDGE pressure transducer location – Boundary Tailrace HRM.

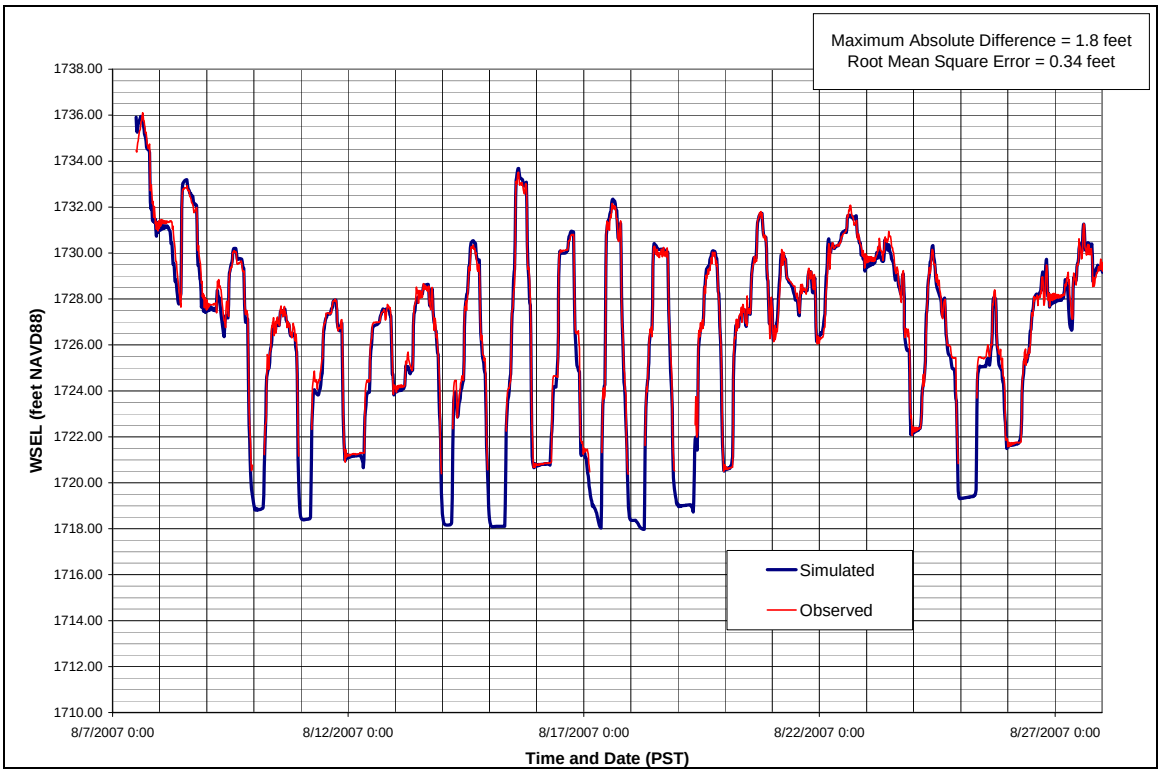


**Figure C-76.** Model calibration results for Lo_Lo calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

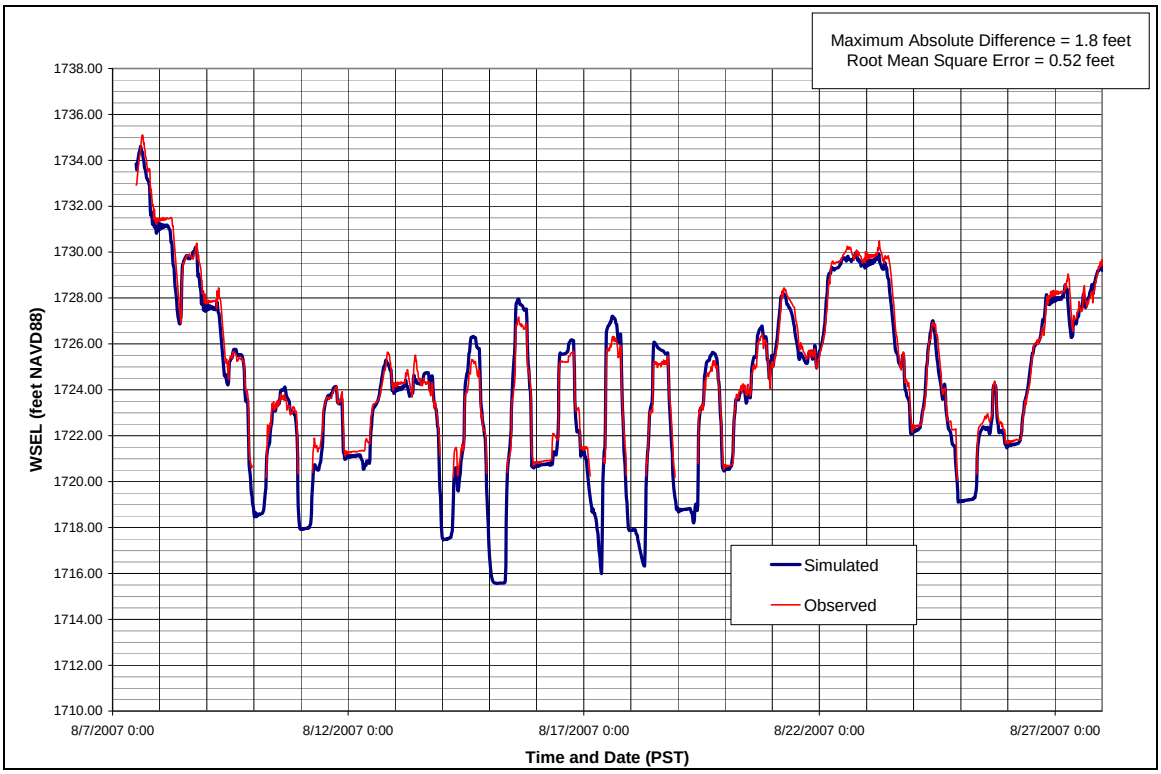


**Figure C-77.** Model calibration results for Lo_Lo calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

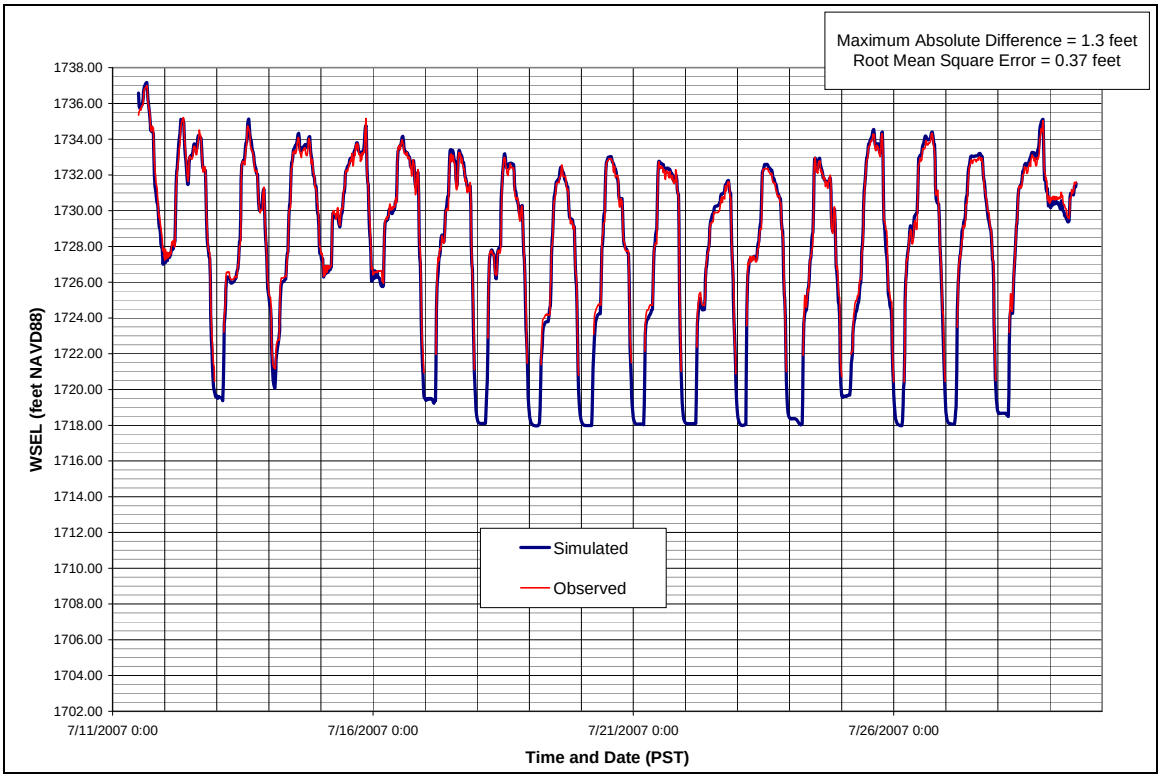


**Figure C-78.** Model calibration results for Lo_Mod calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

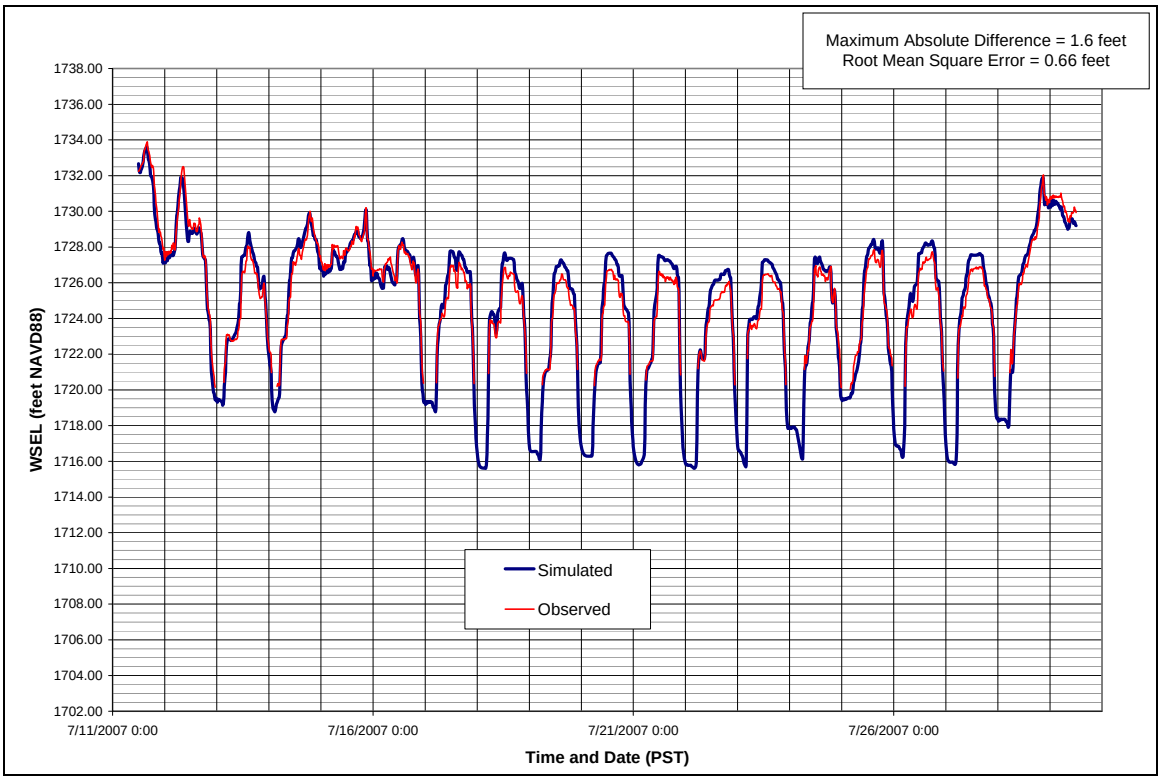


**Figure C-79.** Model calibration results for Lo_Mod calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

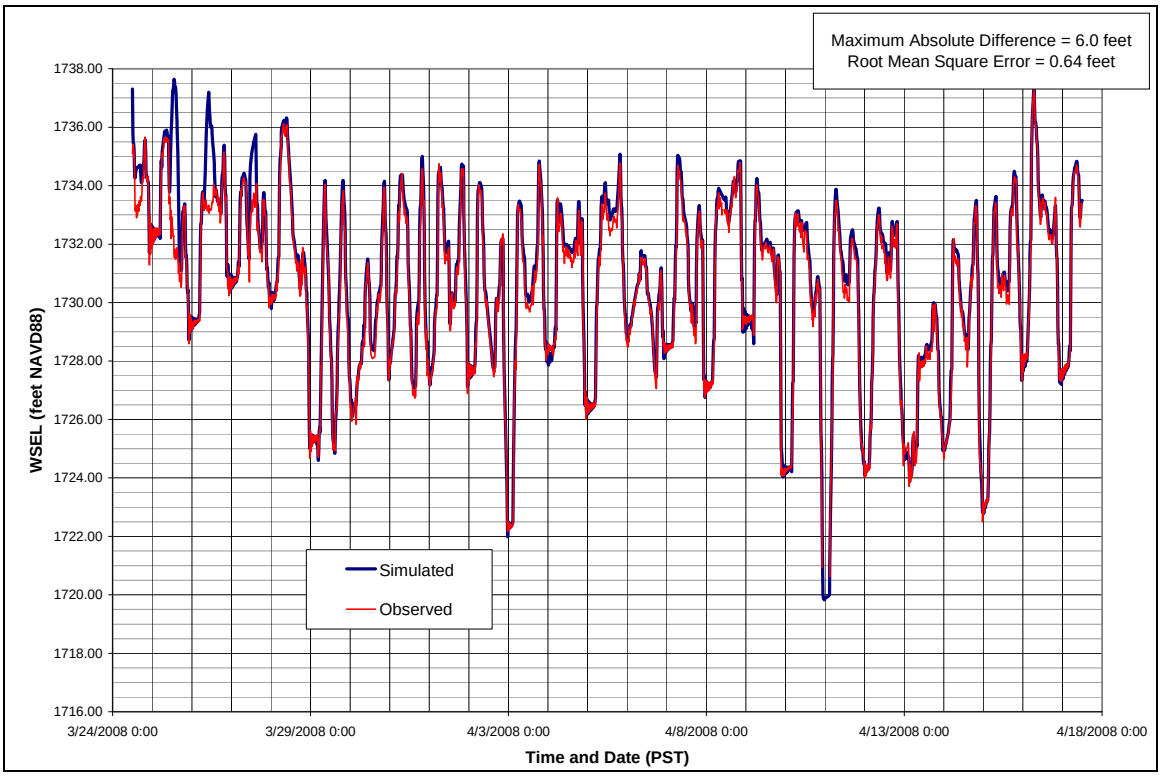


**Figure C-80.** Model calibration results for Lo_Mod2 calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

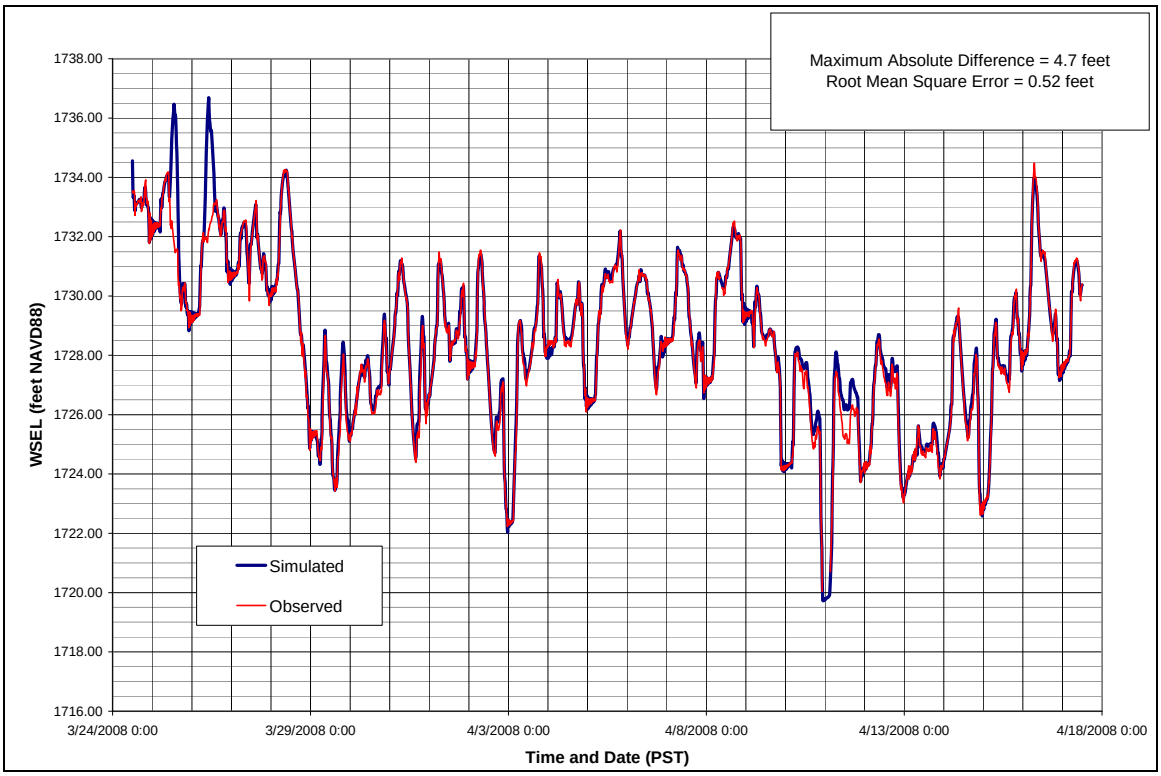


**Figure C-81.** Model calibration results for Lo_Mod2 calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

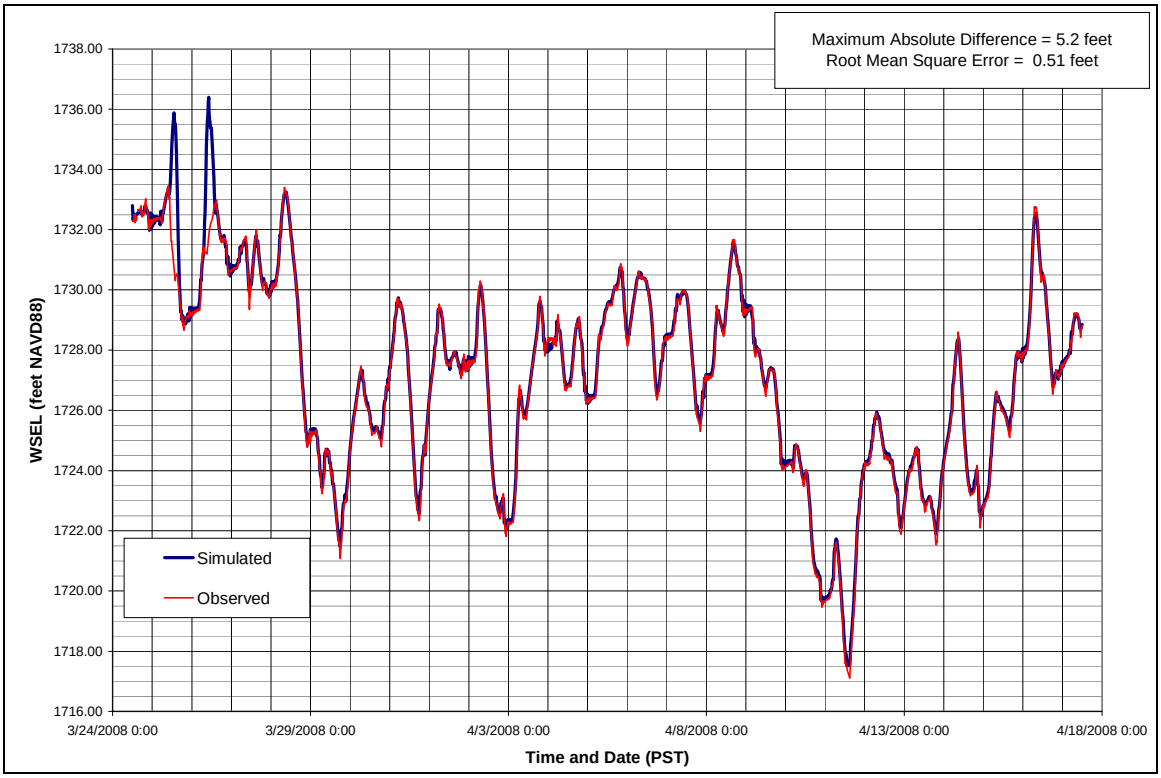


**Figure C-82.** Model calibration results for Lo_Mod2 calibration period at BRIDGE pressure transducer location – Boundary Tailrace HRM.

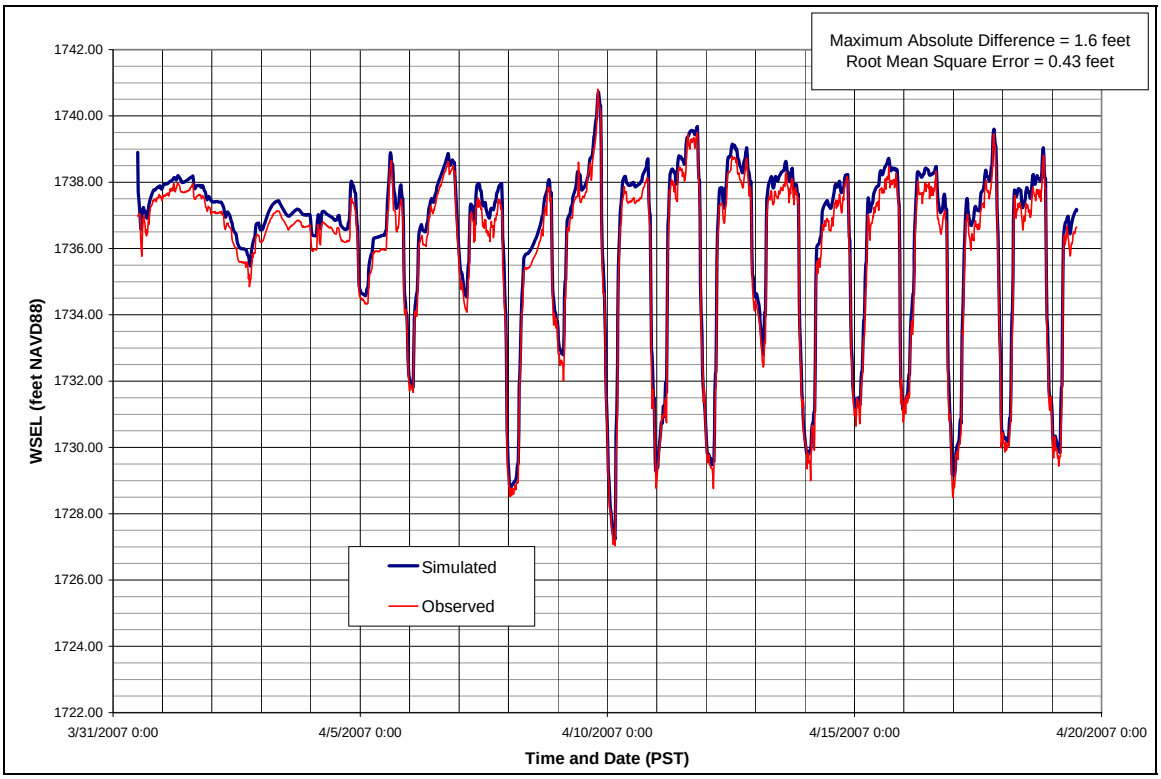


**Figure C-83.** Model calibration results for Lo_Hi calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

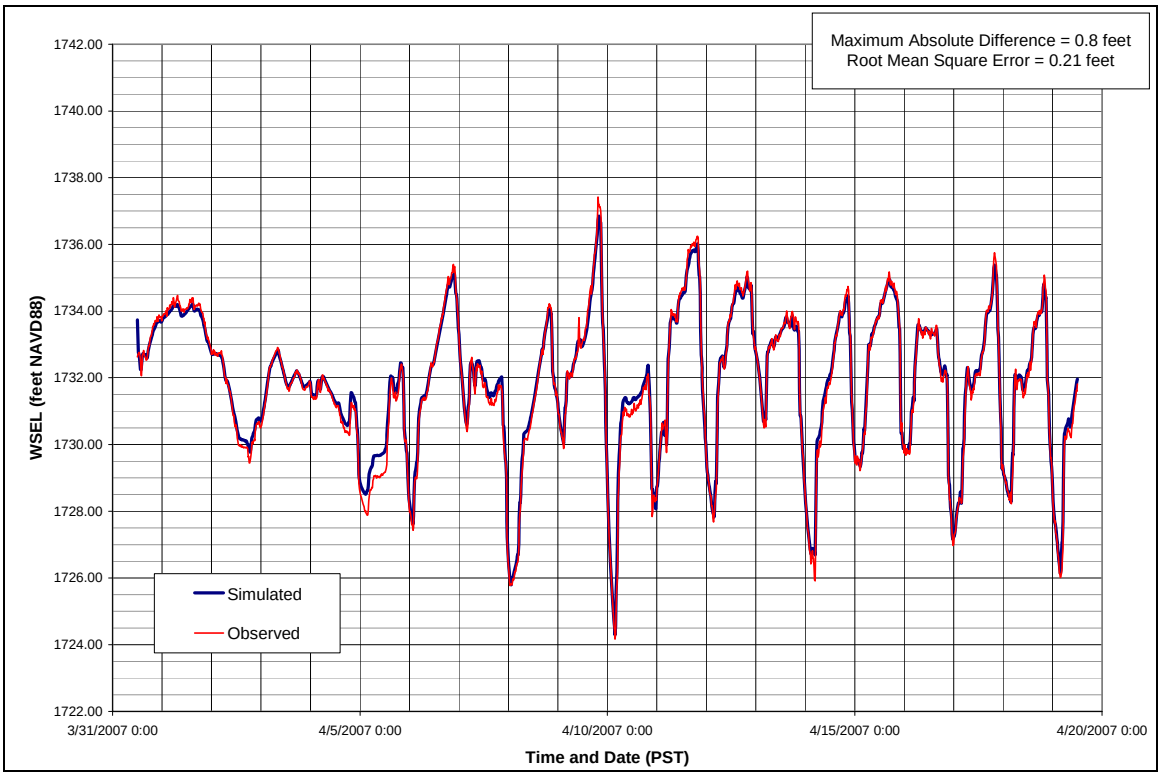


**Figure C-84.** Model calibration results for Lo_Hi calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

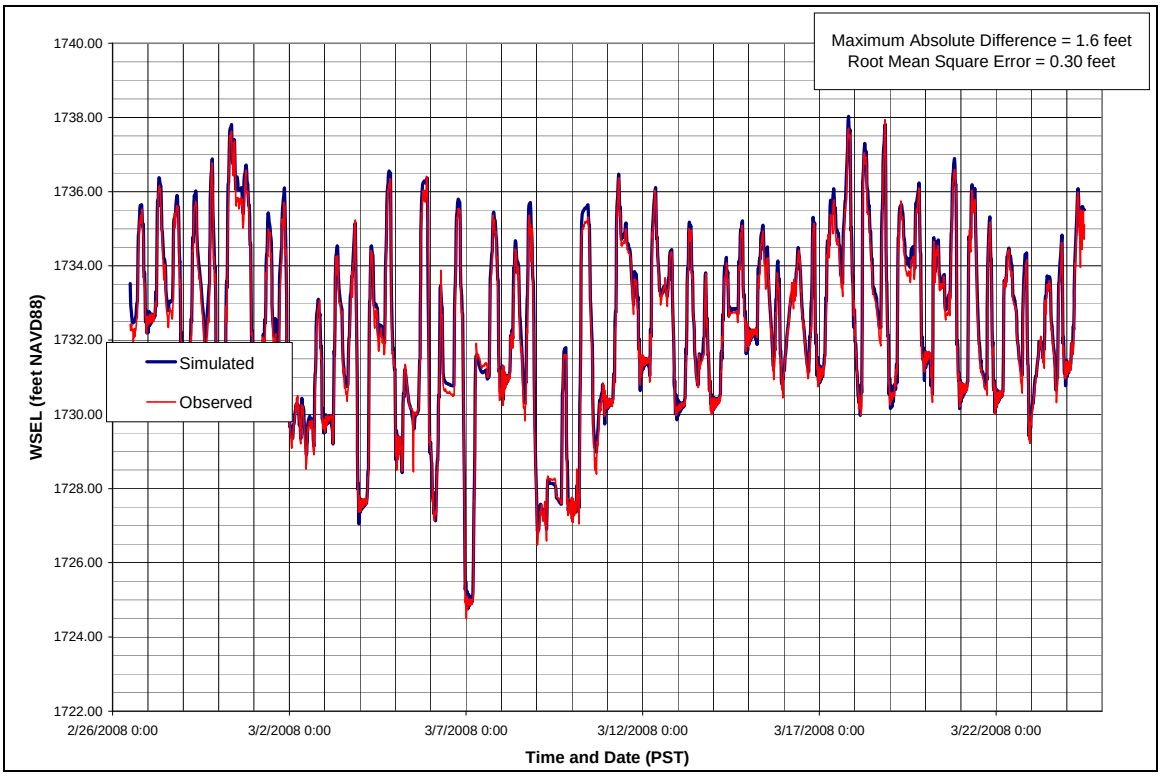


**Figure C-85.** Model calibration results for Var_Var calibration period at BND_TR pressure transducer location – Boundary Tailrace HRM.

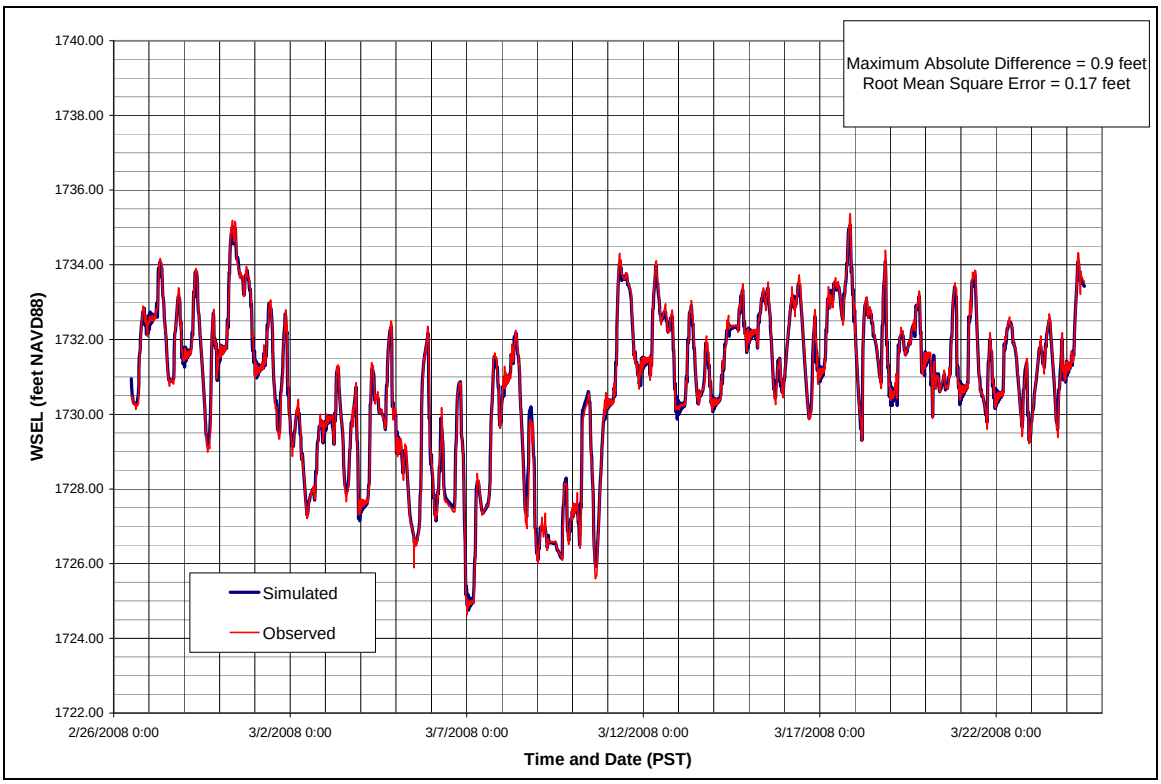


**Figure C-86.** Model calibration results for Var_Var calibration period at BORDER pressure transducer location – Boundary Tailrace HRM.

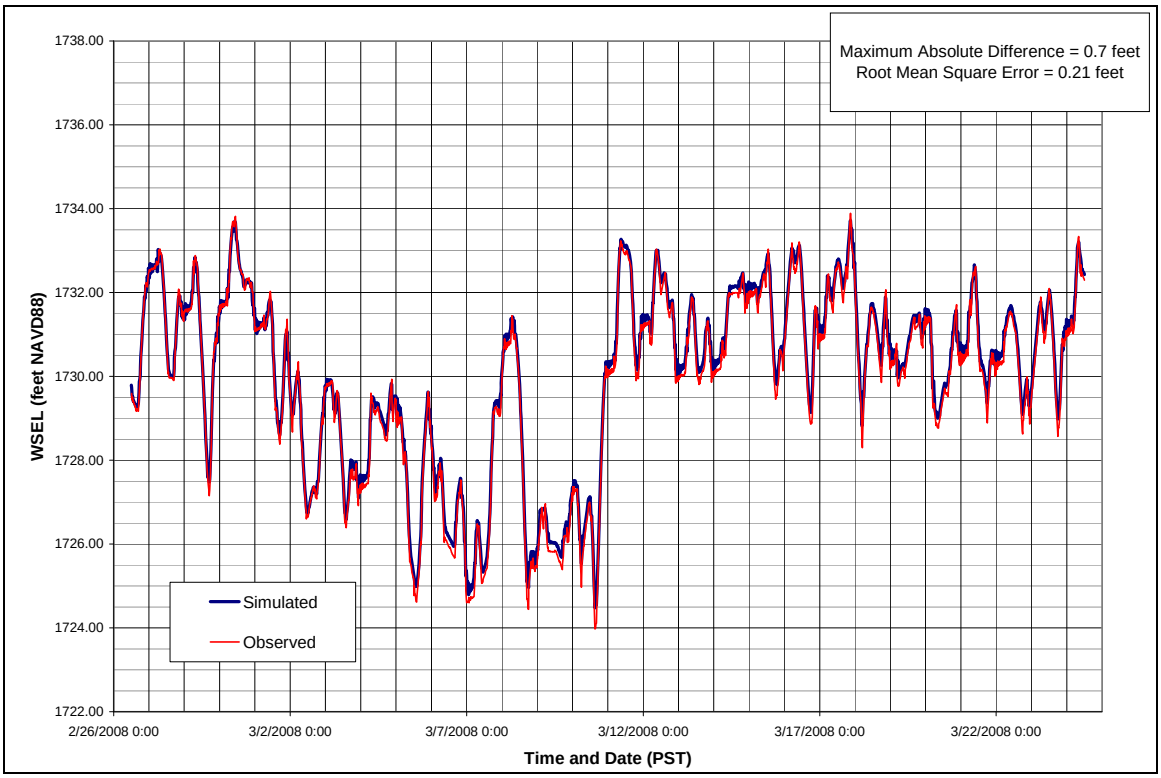


**Figure C-87.** Model calibration results for Var_Var calibration period at BRIDGE pressure transducer location – Boundary Tailrace HRM.

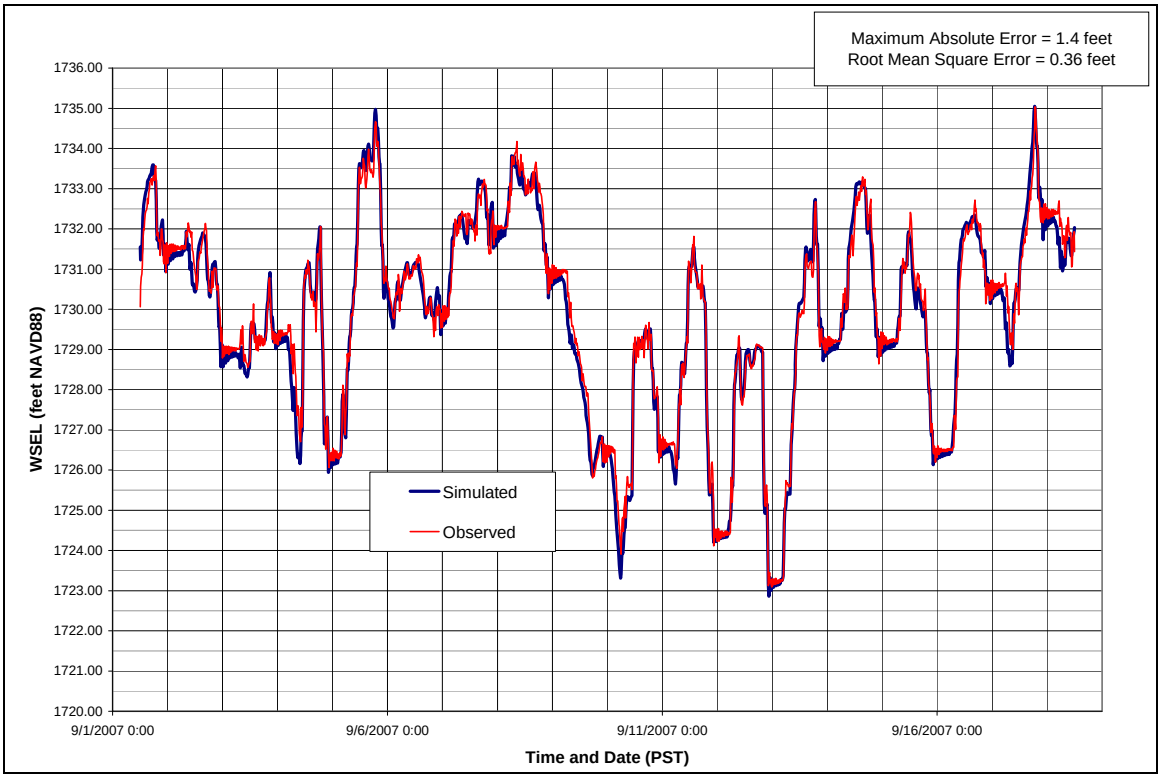


**Figure C-88.** Model calibration results for Hi_Lo verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

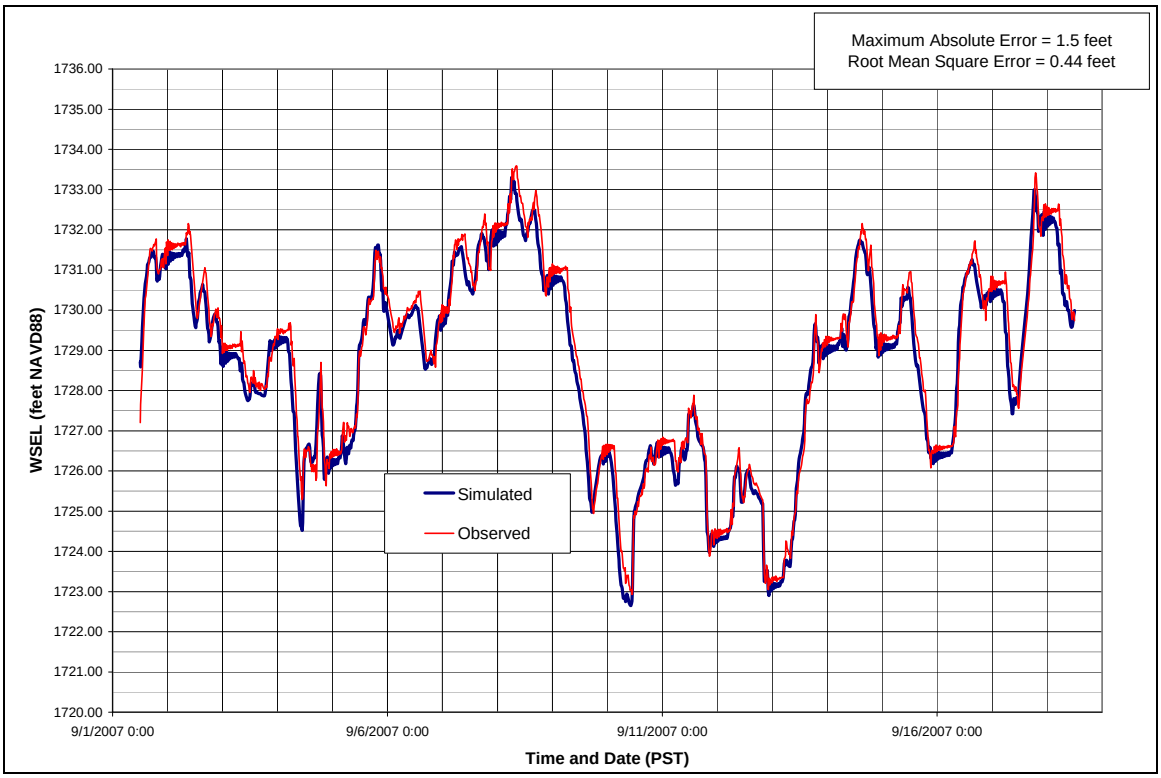


**Figure C-89.** Model calibration results for Hi_Lo verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

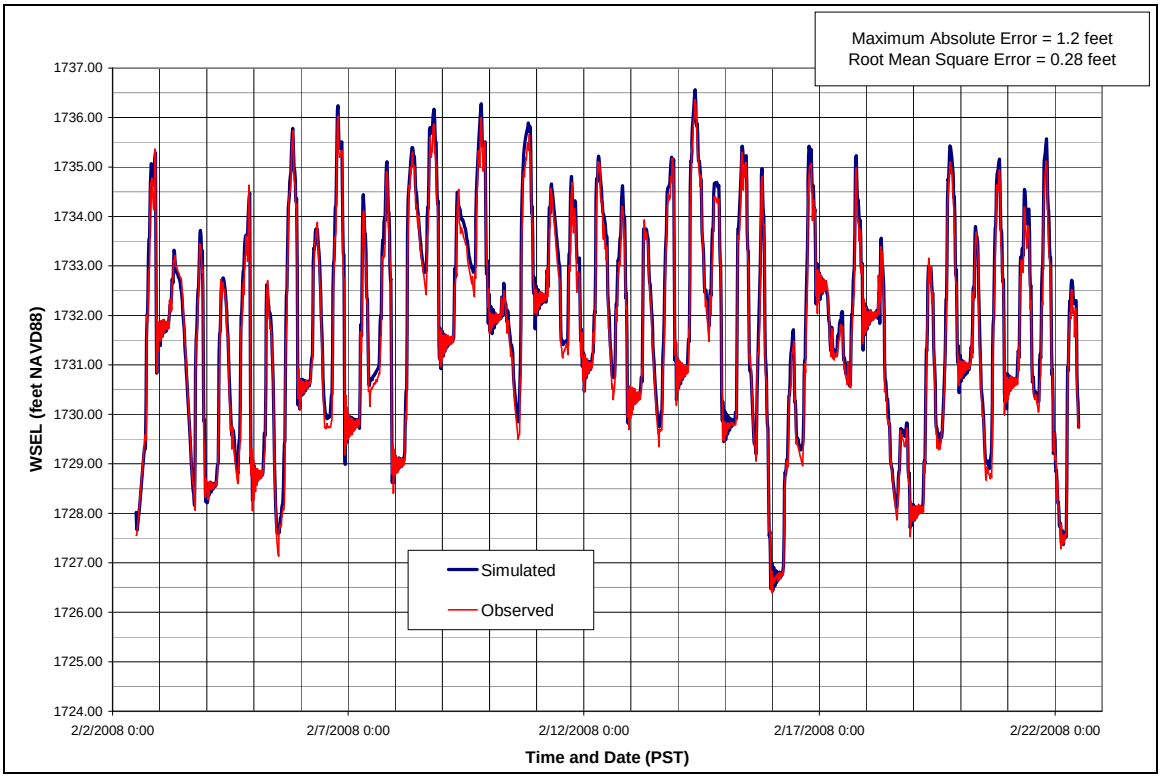


**Figure C-90.** Model calibration results for Hi_Mod verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

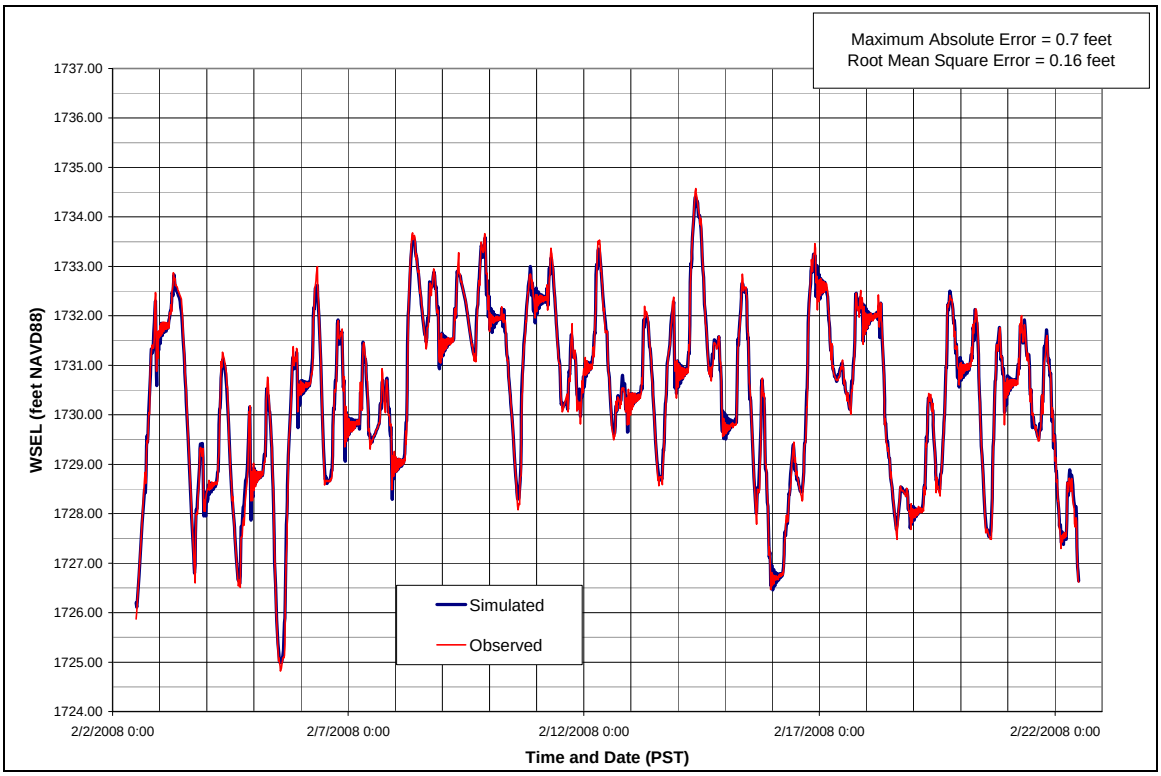


**Figure C-91.** Model calibration results for Hi_Mod verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

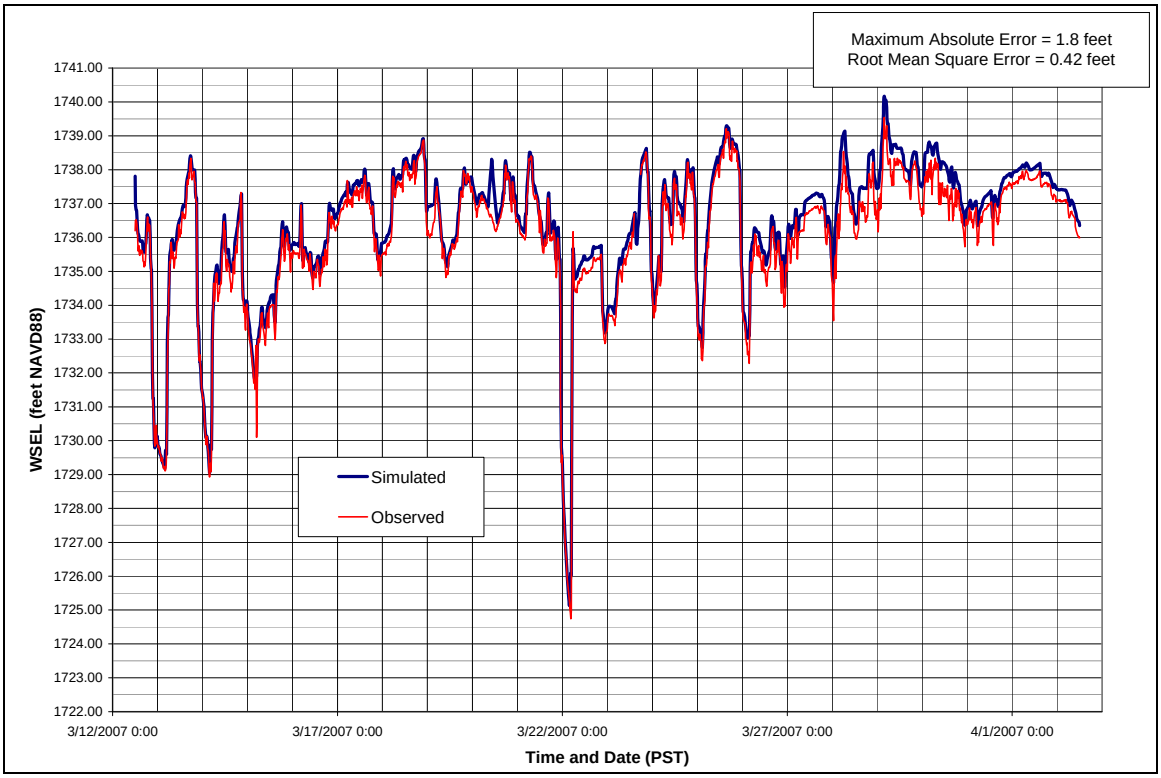


**Figure C-92.** Model calibration results for Hi_Hi verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

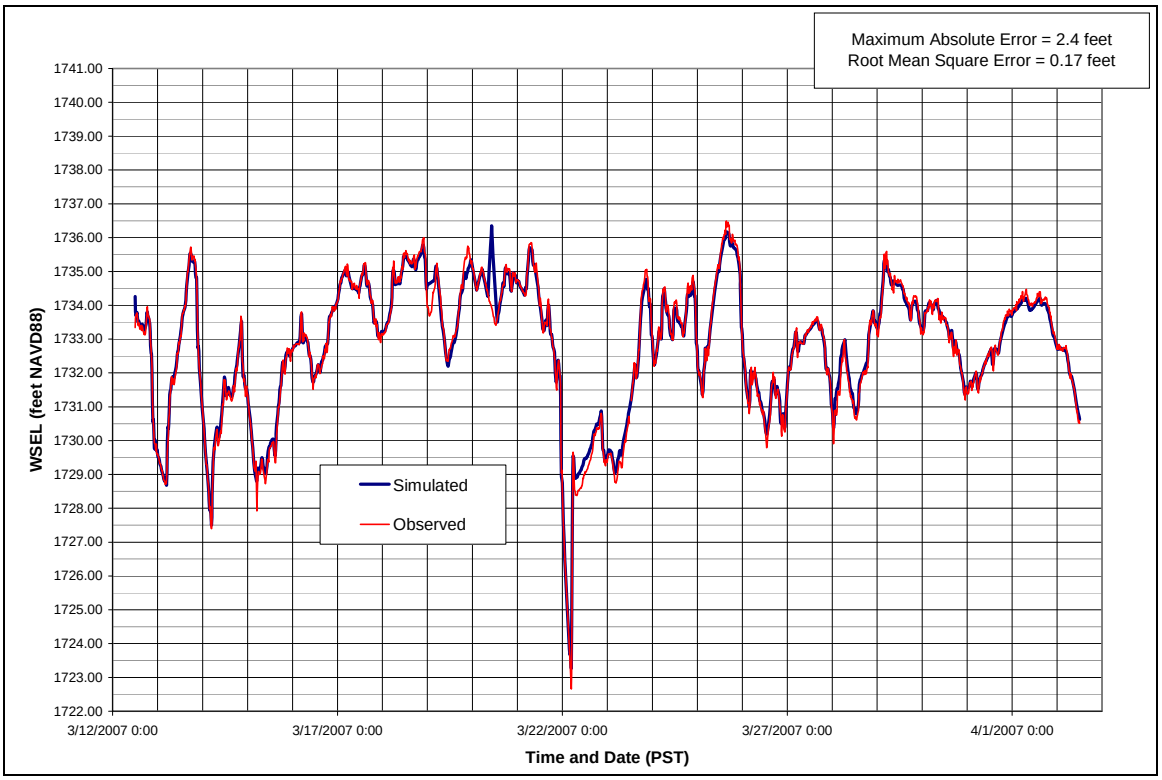


**Figure C-93.** Model calibration results for Hi_Hi verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

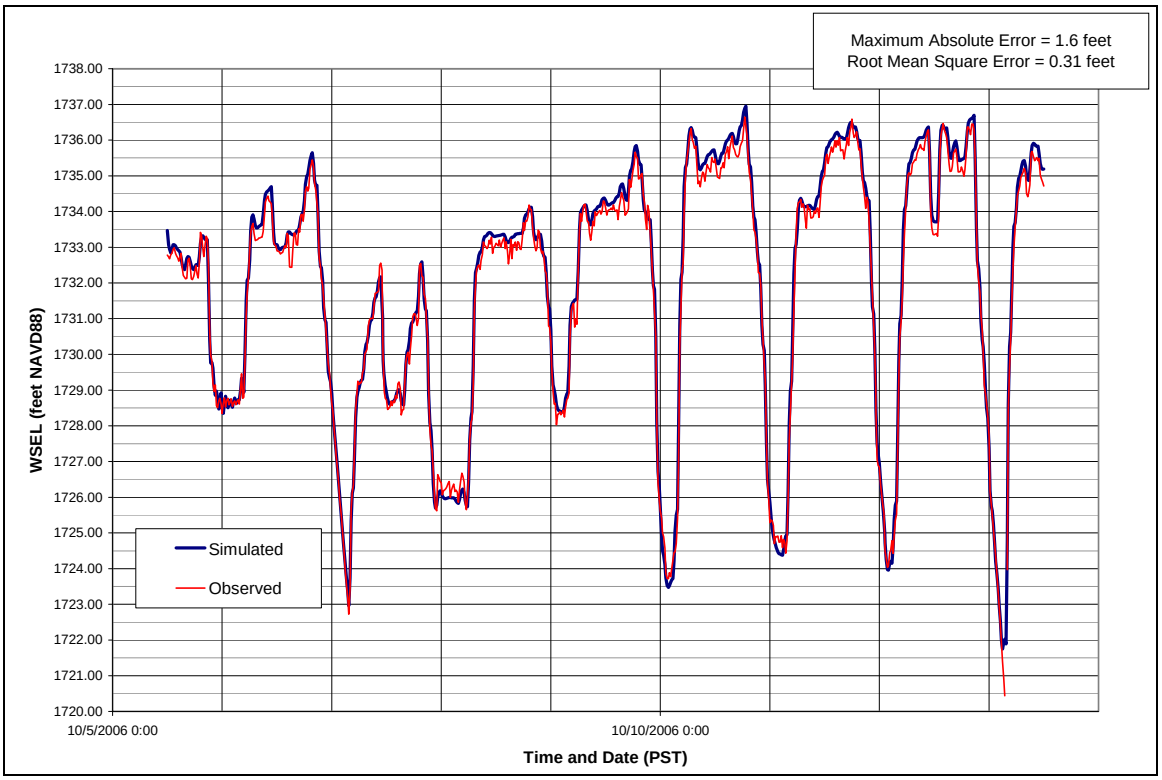


**Figure C-94.** Model calibration results for Lo_Lo verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

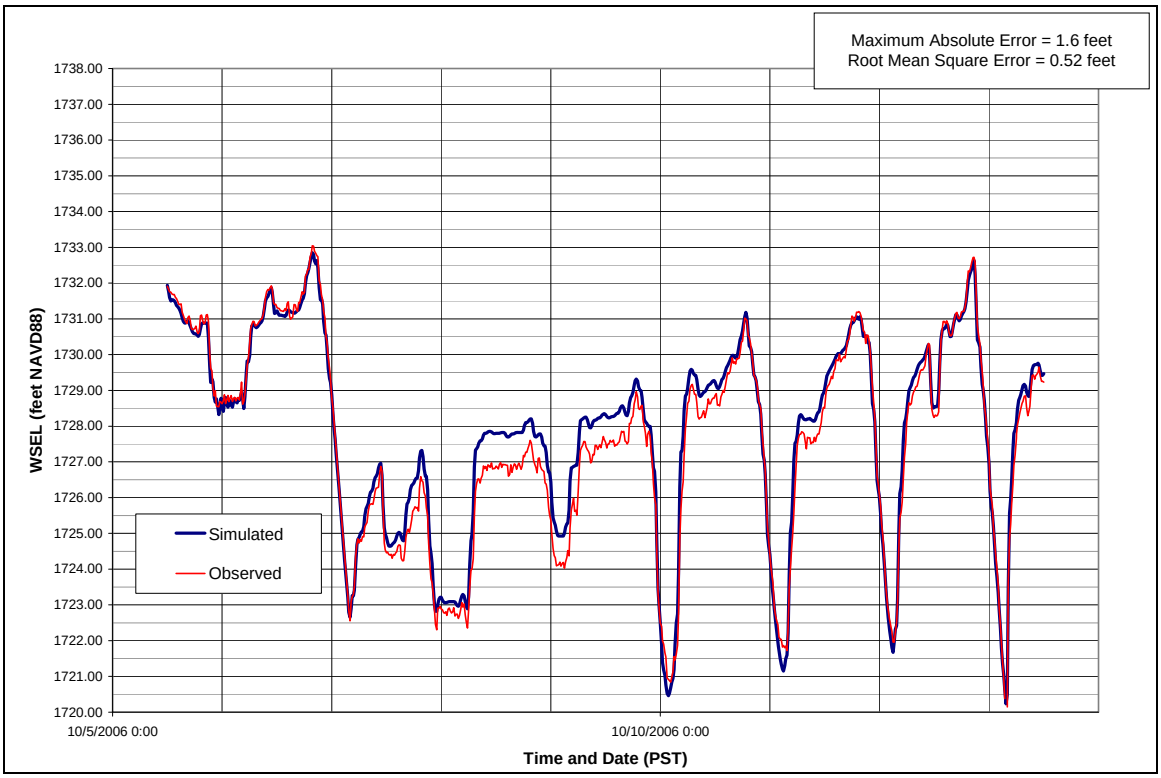


**Figure C-95.** Model calibration results for Lo_Lo verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

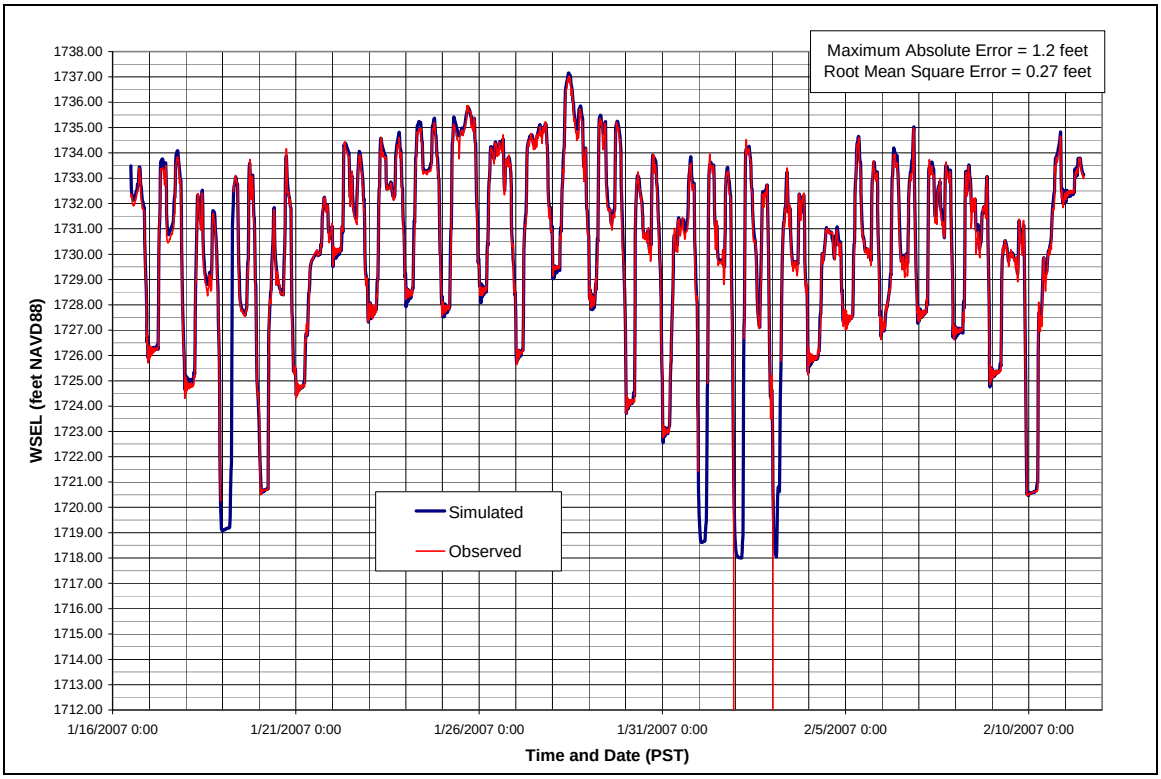


**Figure C-96.** Model calibration results for Lo_Mod verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

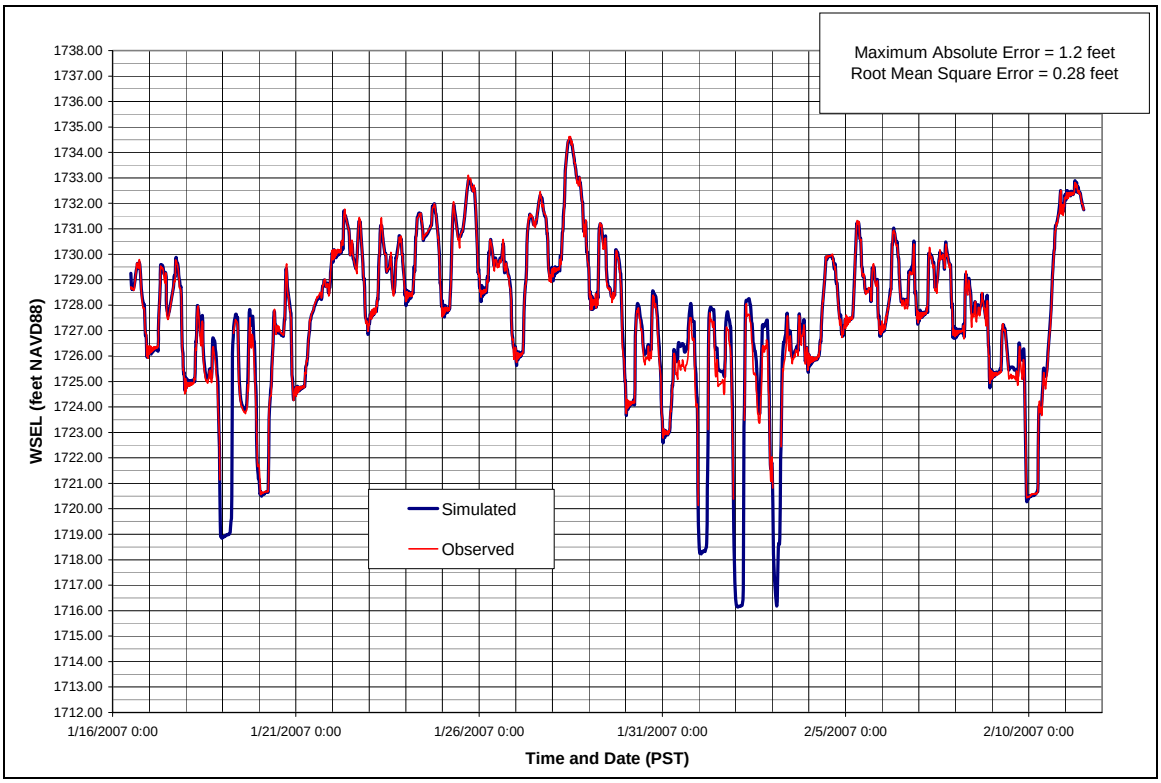


**Figure C-97.** Model calibration results for Lo_Mod verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

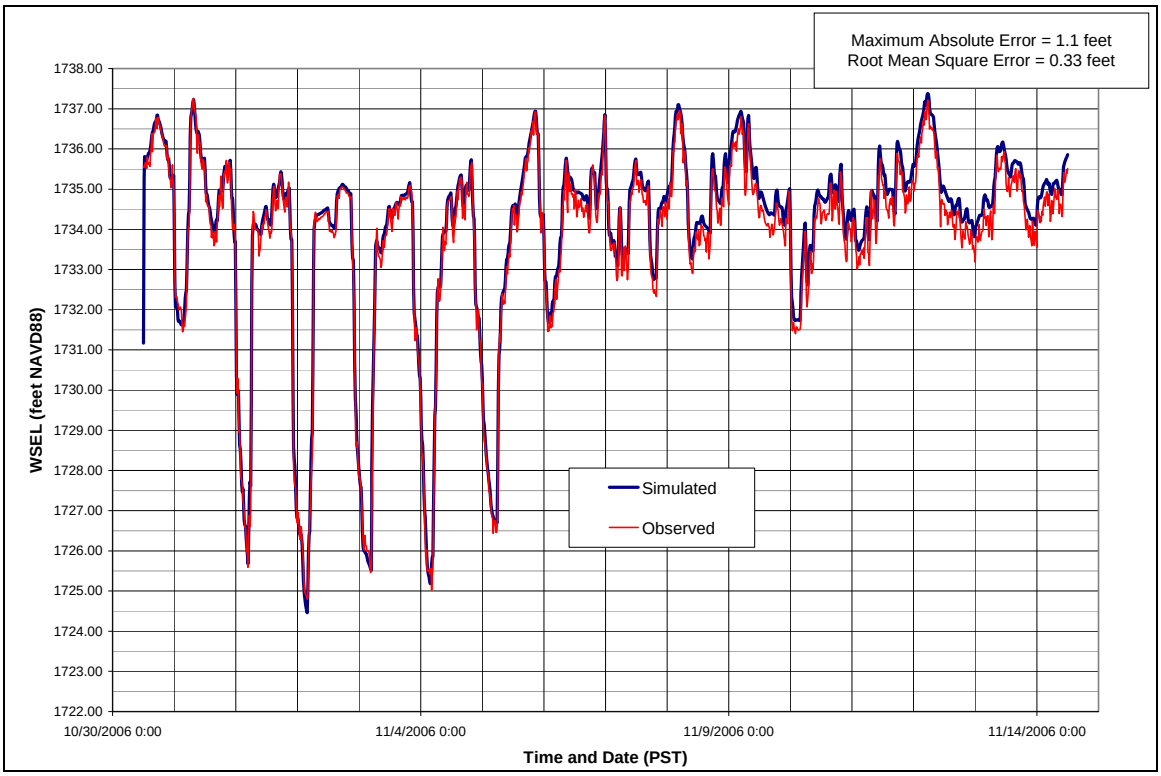


**Figure C-98.** Model calibration results for Lo_Hi verification period at BND_TR pressure transducer location – Boundary Tailrace HRM.

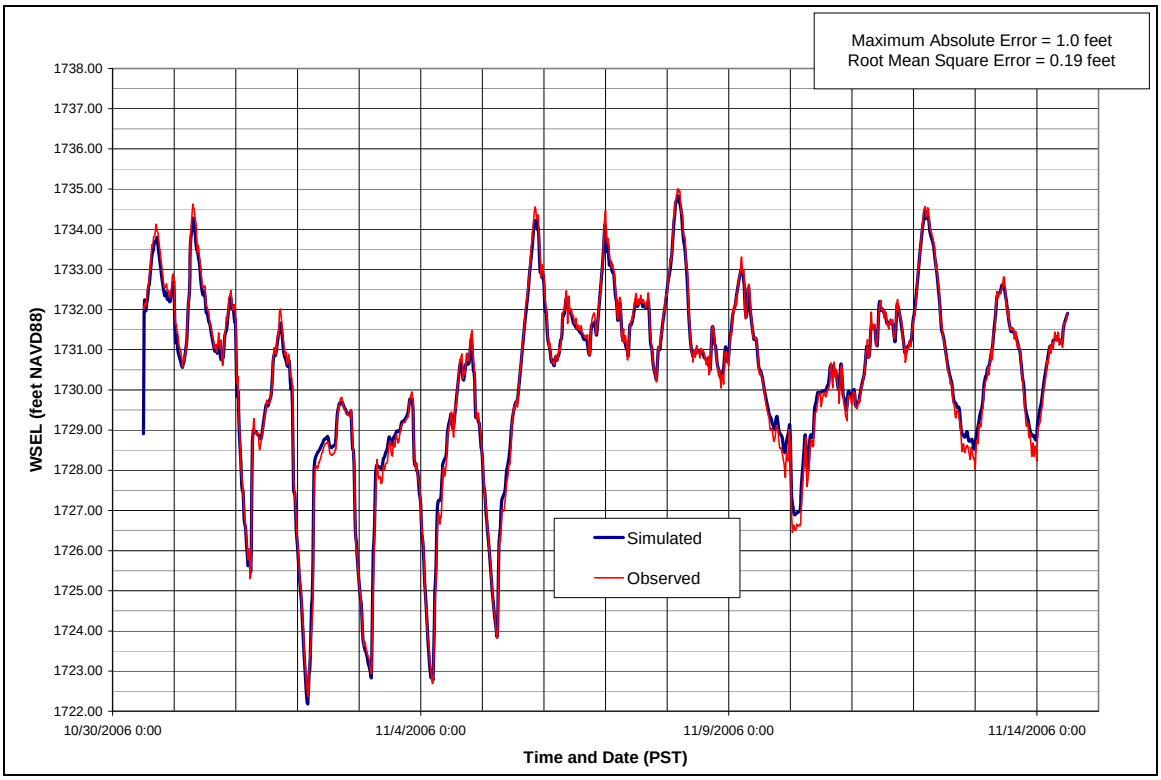


**Figure C-99.** Model calibration results for Lo_Hi verification period at BORDER pressure transducer location – Boundary Tailrace HRM.

# Attachment D: Hydraulic Influence of Project Operations Results

This attachment includes the following figures that present the results of the analysis Project operation influence on hydraulic conditions in the Boundary Reservoir and the Boundary Tailrace. The analysis quantified the influence of Project operations on water surface elevations and average cross section velocity. This attachment contains the following:

- Complete set of figures that illustrate the influence of Project operations on water surface elevations and average cross section velocities throughout the Boundary Reservoir (Figures D-1 through D-14). The analysis of Project operations influence on hydraulic conditions in the Boundary Reservoir was conducted for seven distinct flow rates. Therefore there are separate figures included for each flow rate.
- Complete set of figures that illustrate the influence of Project operations on water surface elevations and average cross section velocities through the Tailrace Reach (Figures D-15 through D-32). The quantification of Project operations influence on hydraulic conditions in the Tailrace Reach was conducted relative to nine distinct hydrologic conditions. Therefore, there are separate figures for each of the nine hydrologic conditions.

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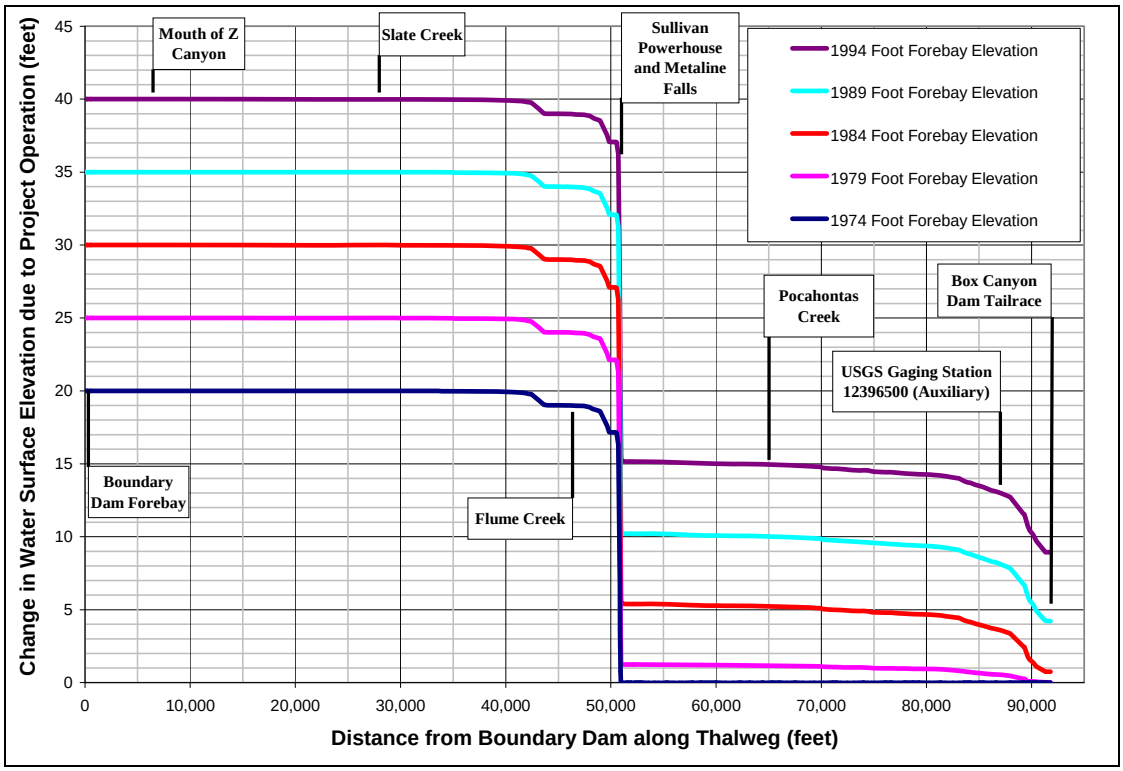


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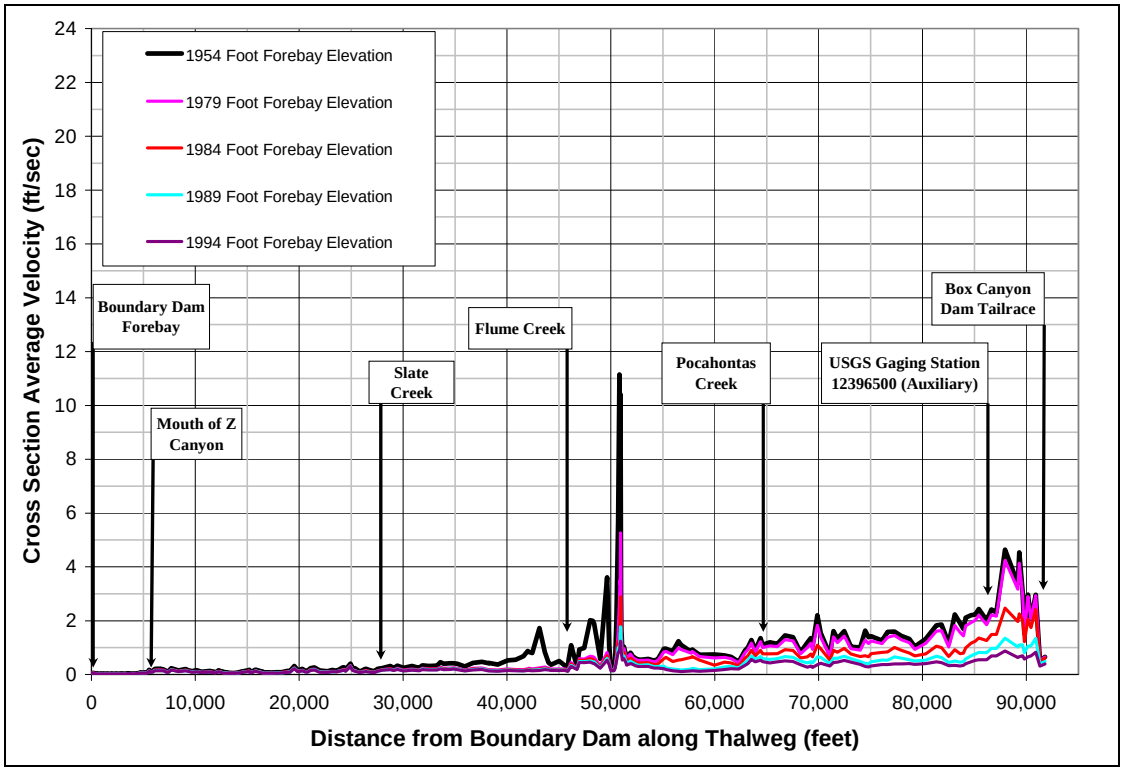


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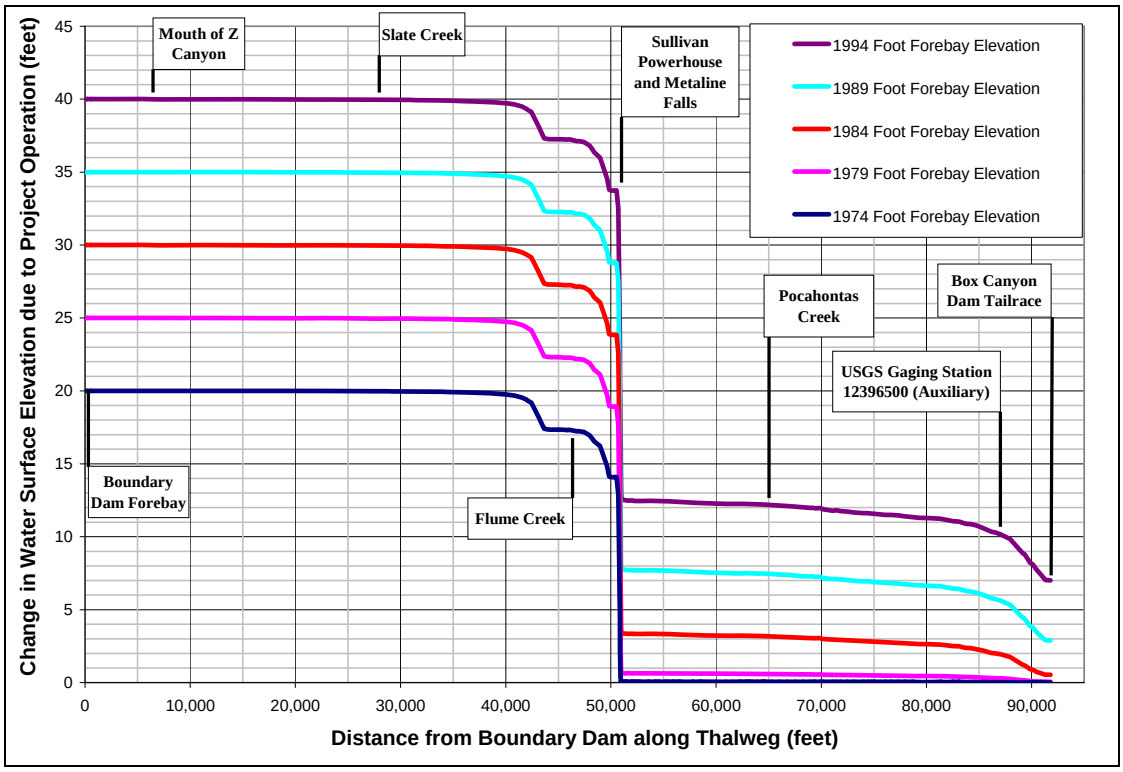


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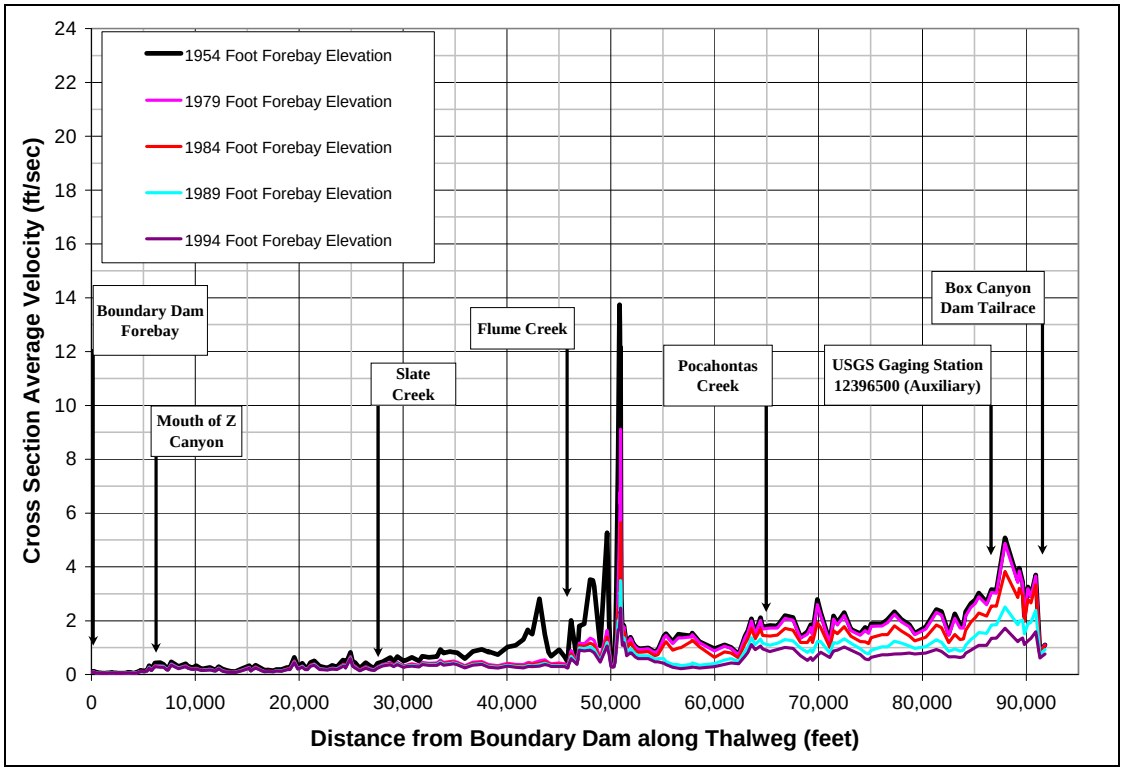


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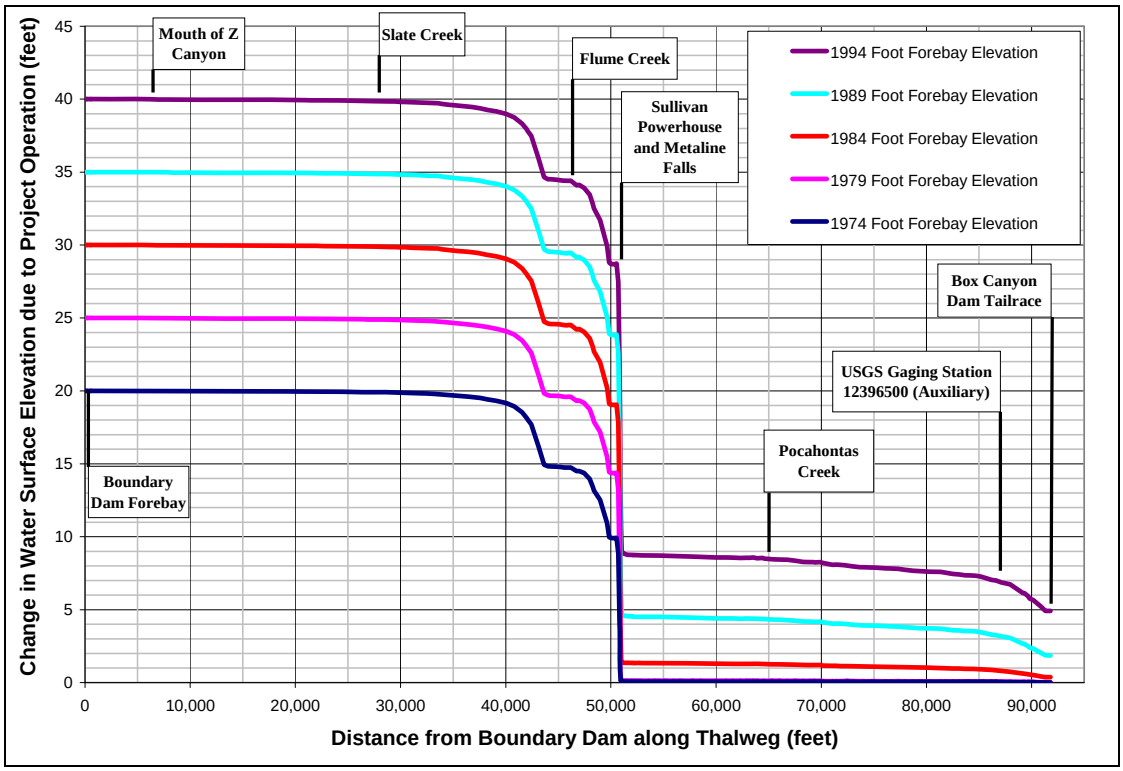


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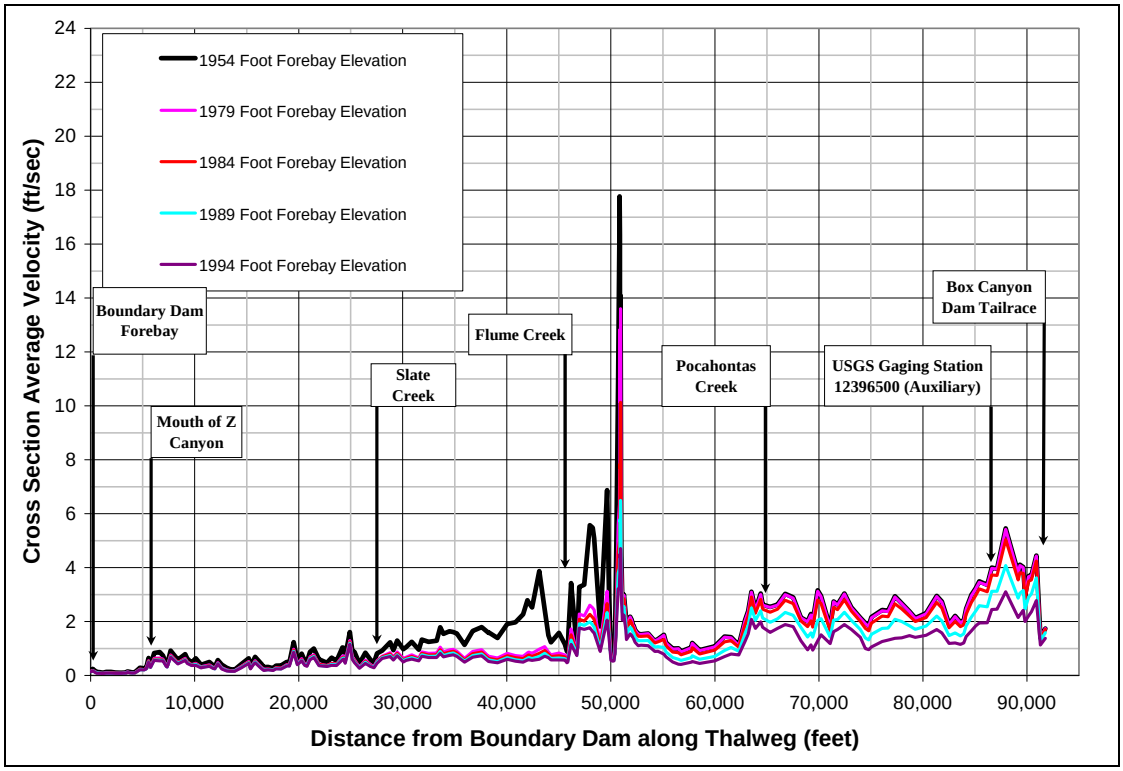


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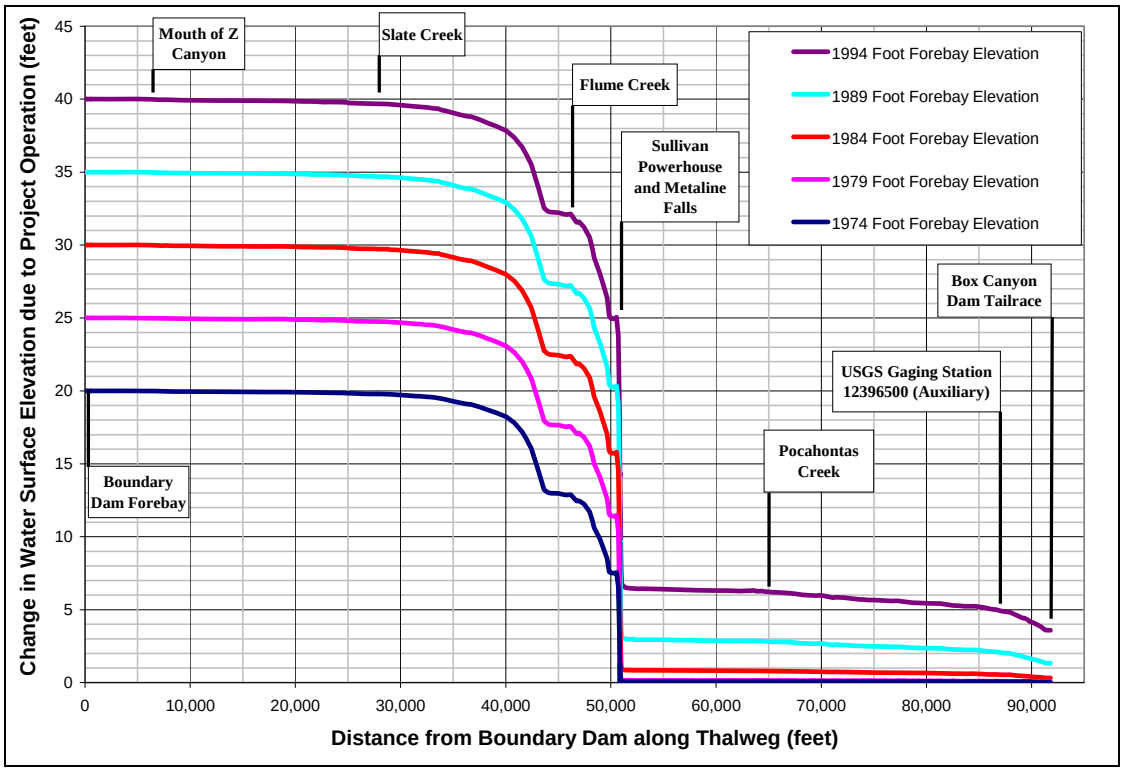


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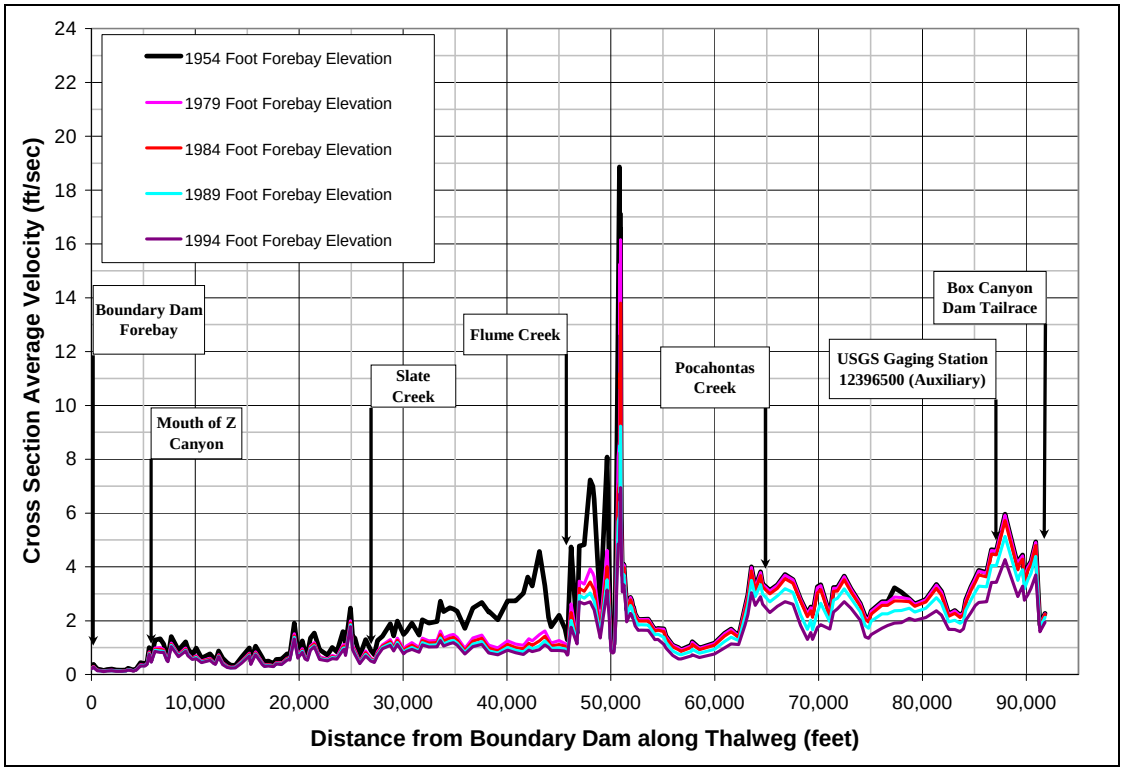


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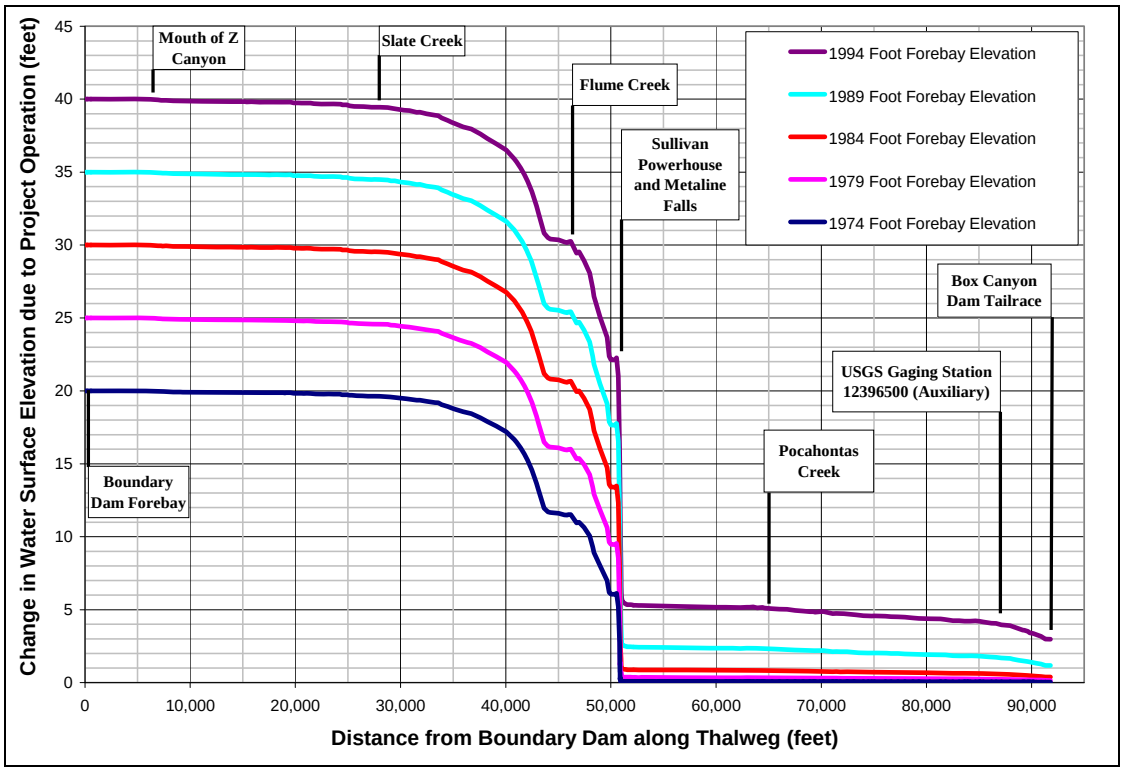


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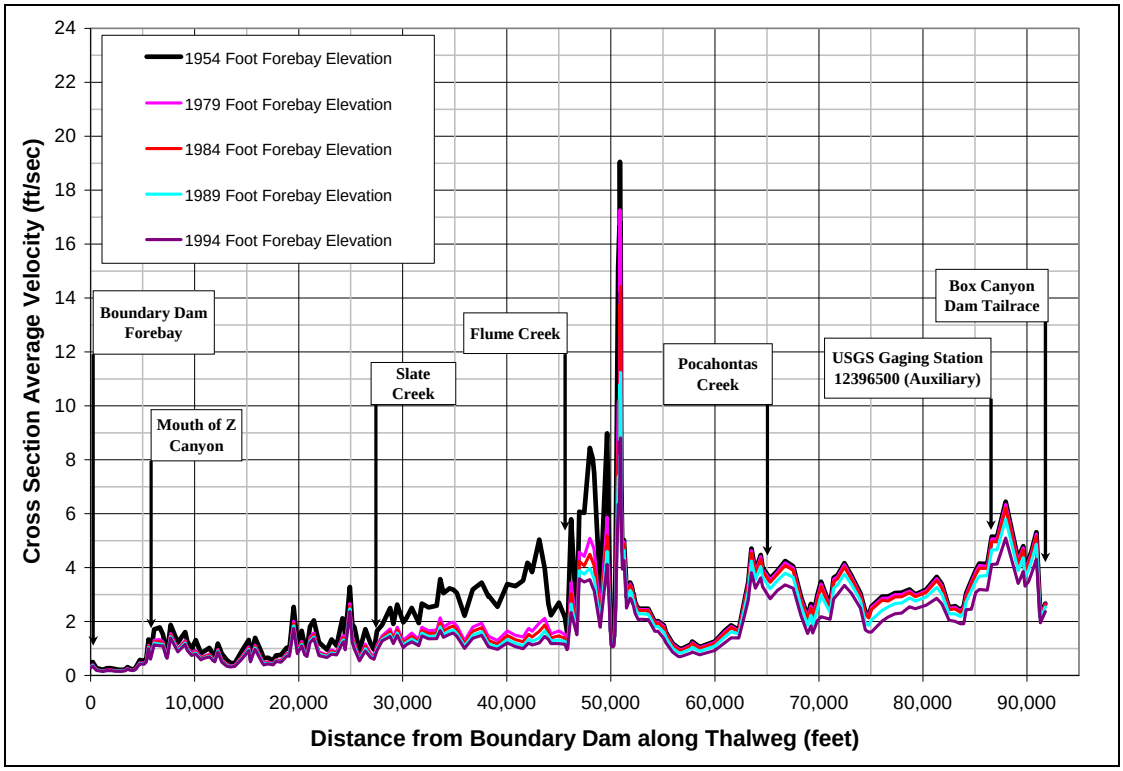


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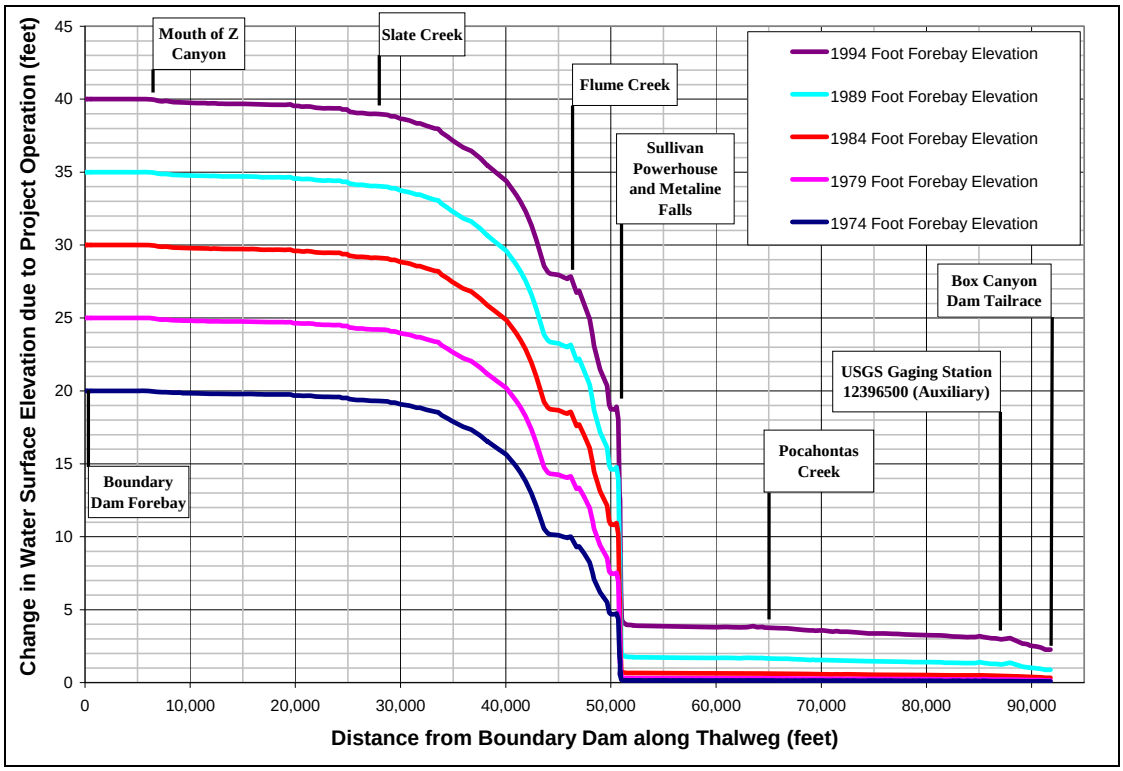


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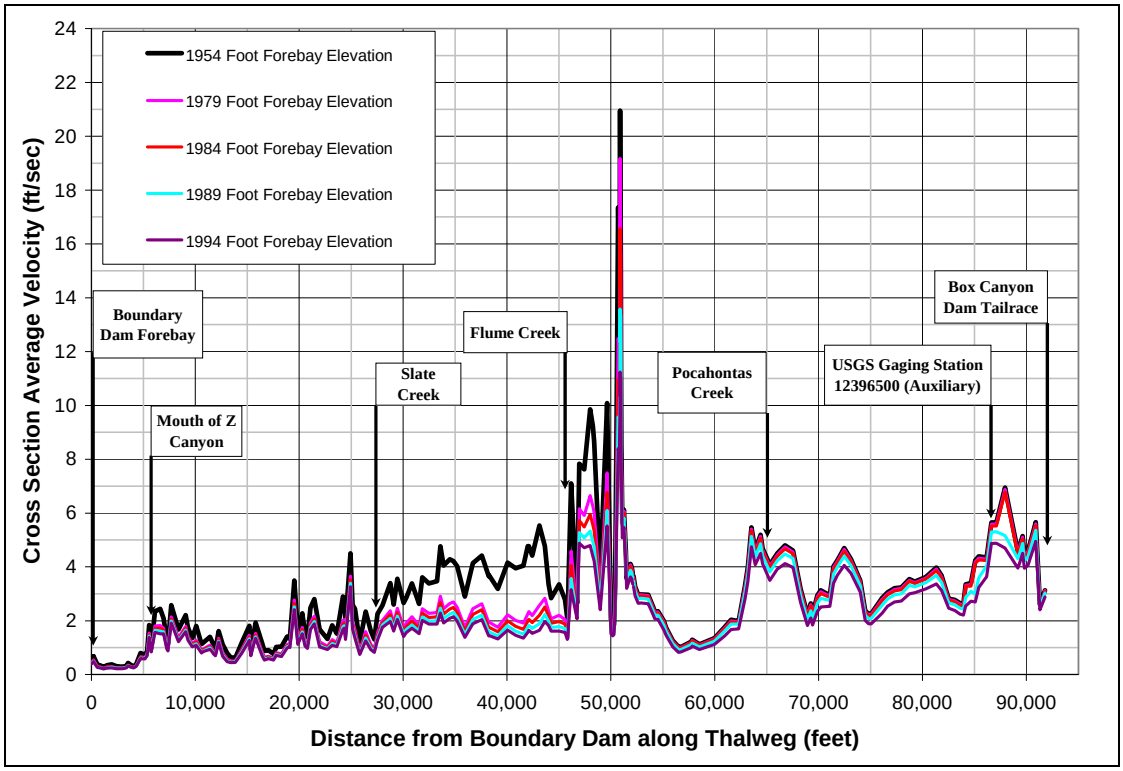


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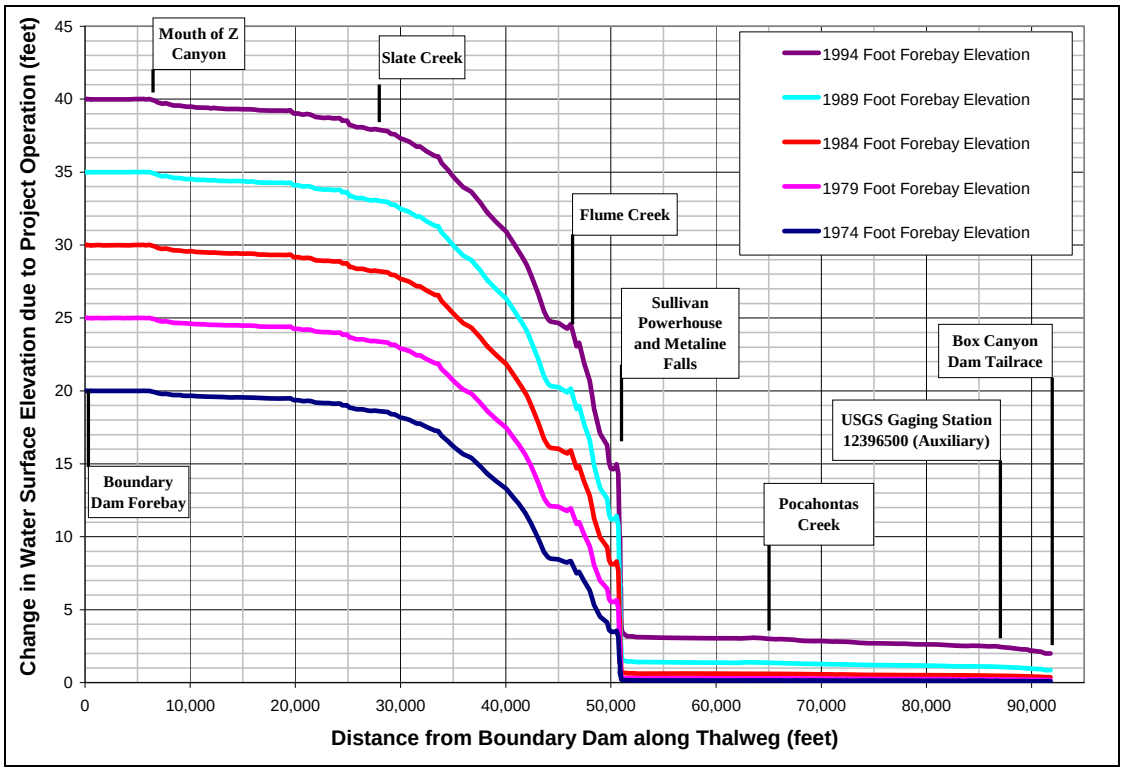


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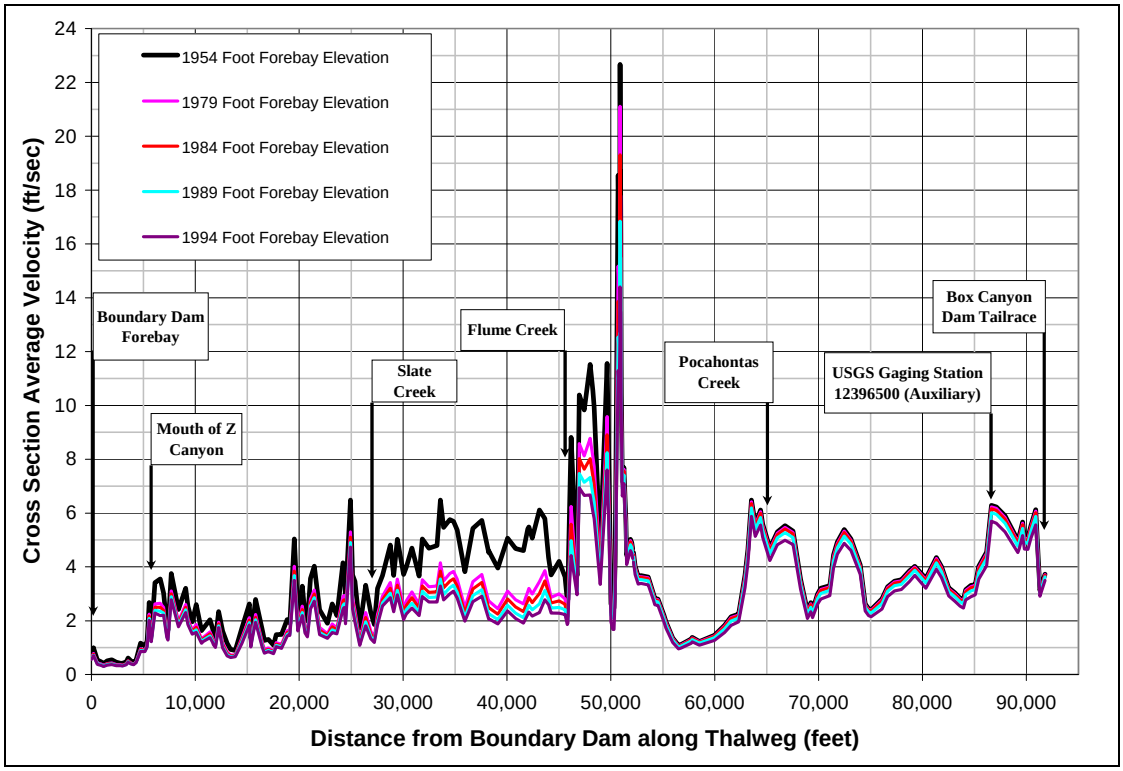


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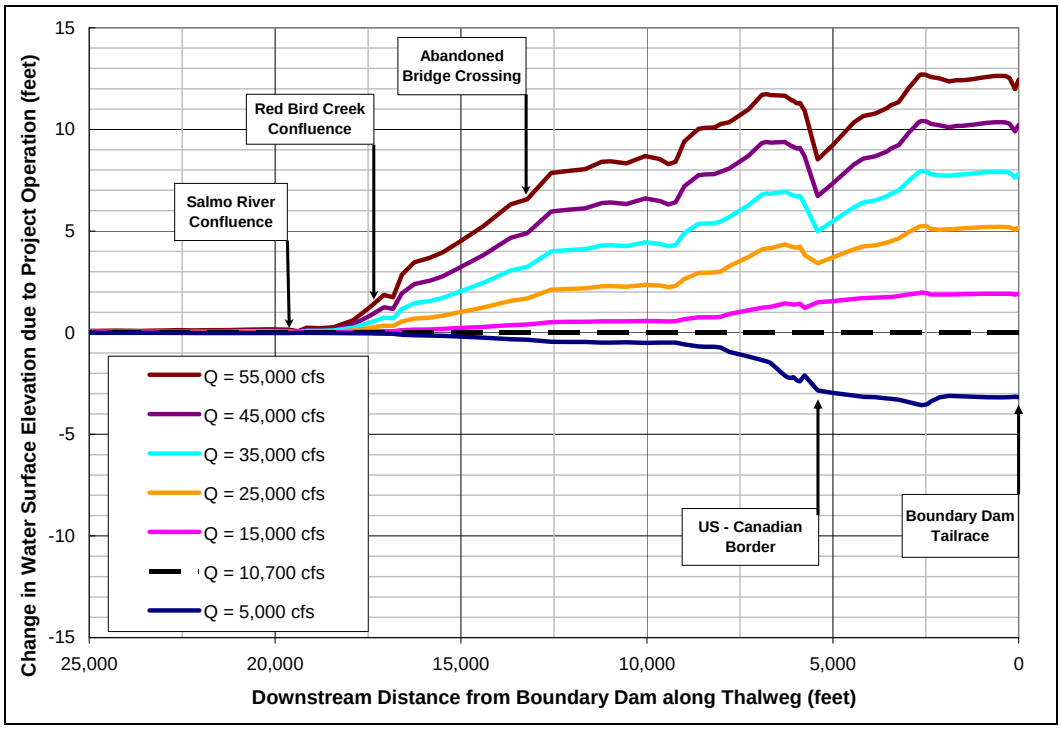


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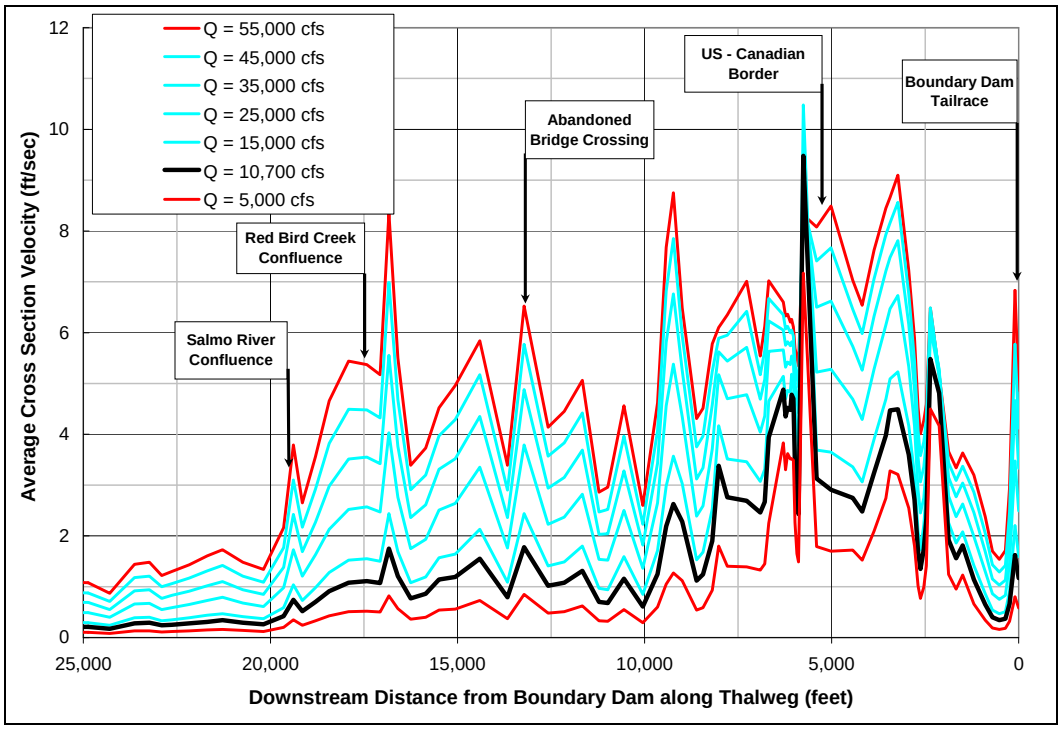


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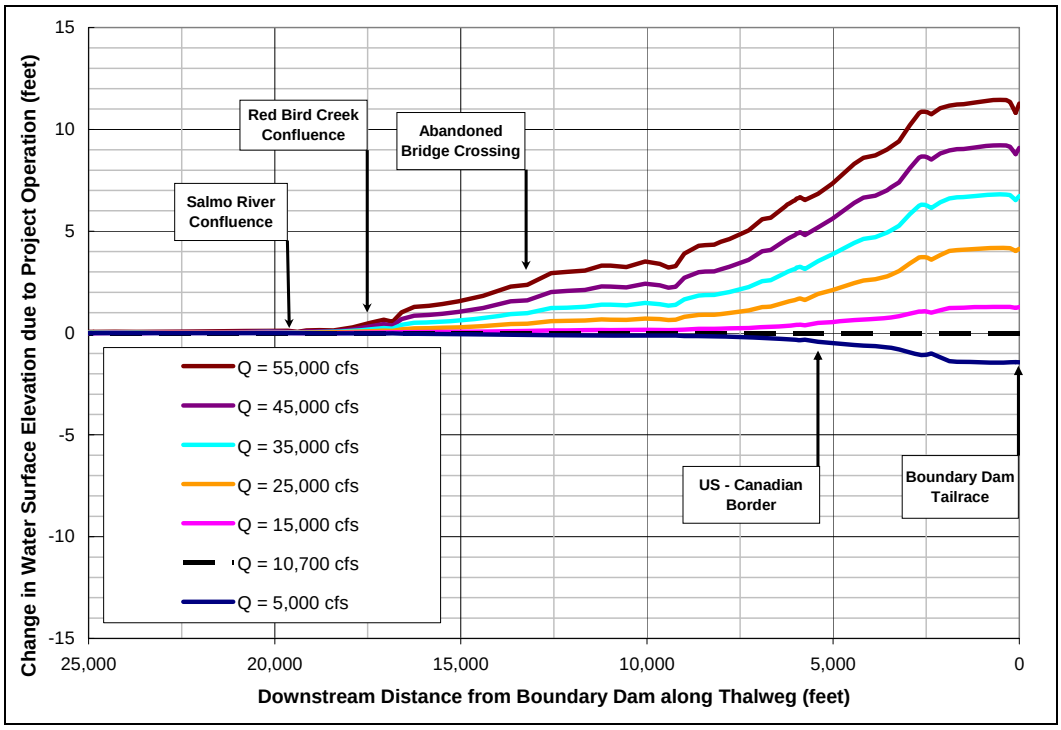


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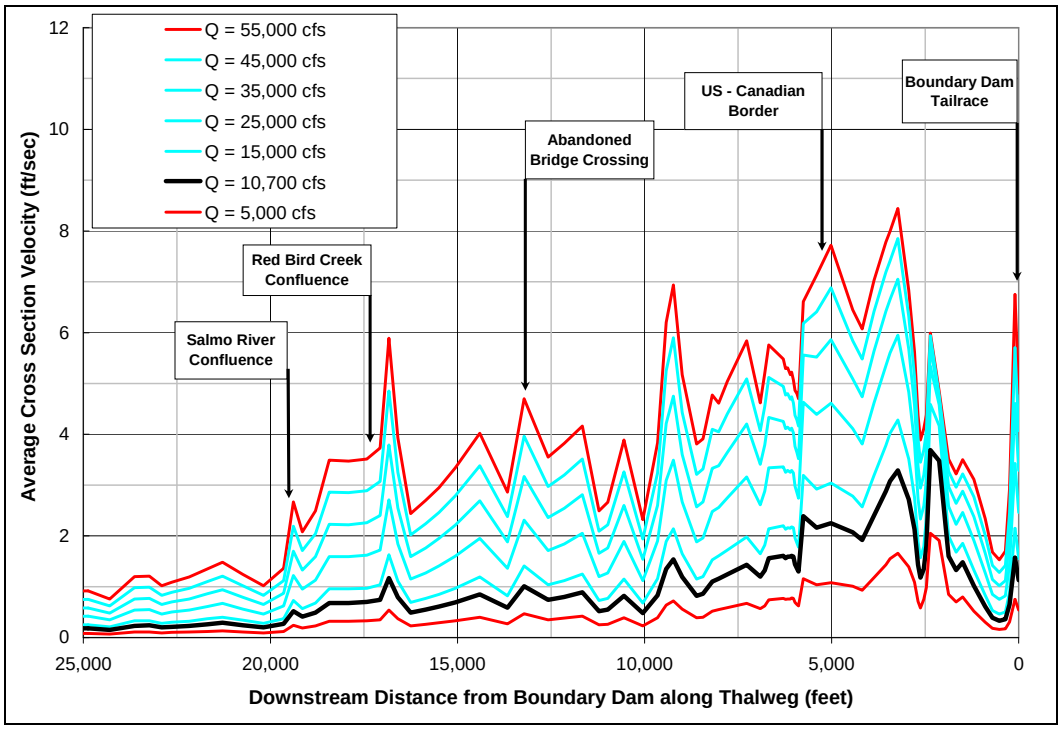


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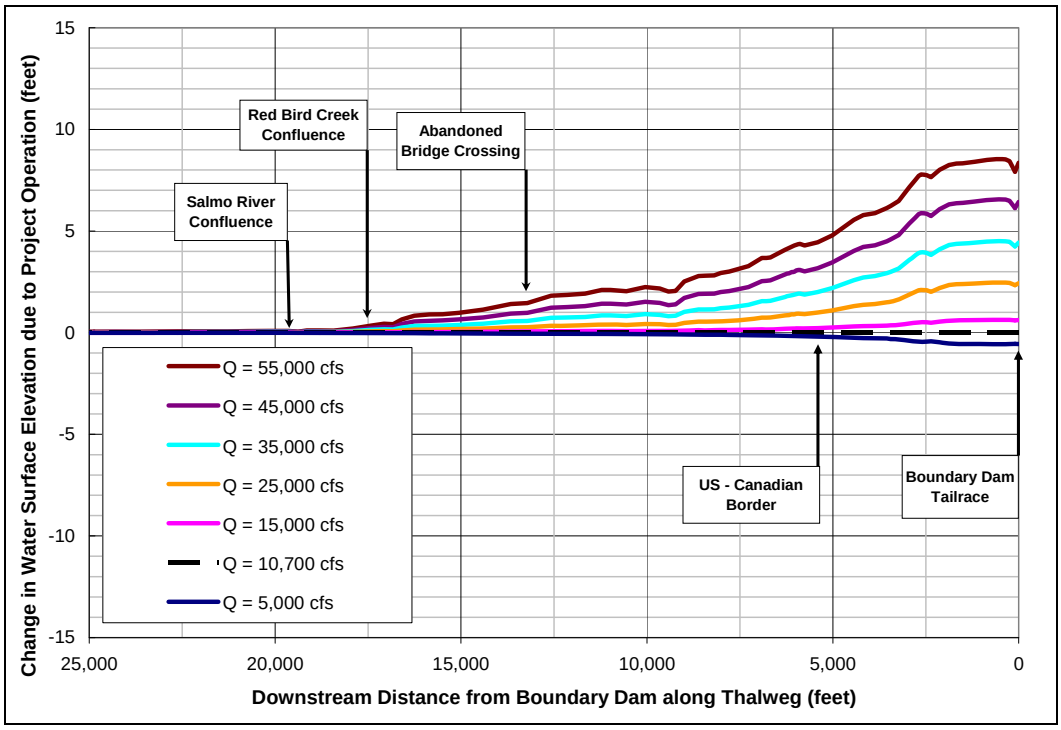


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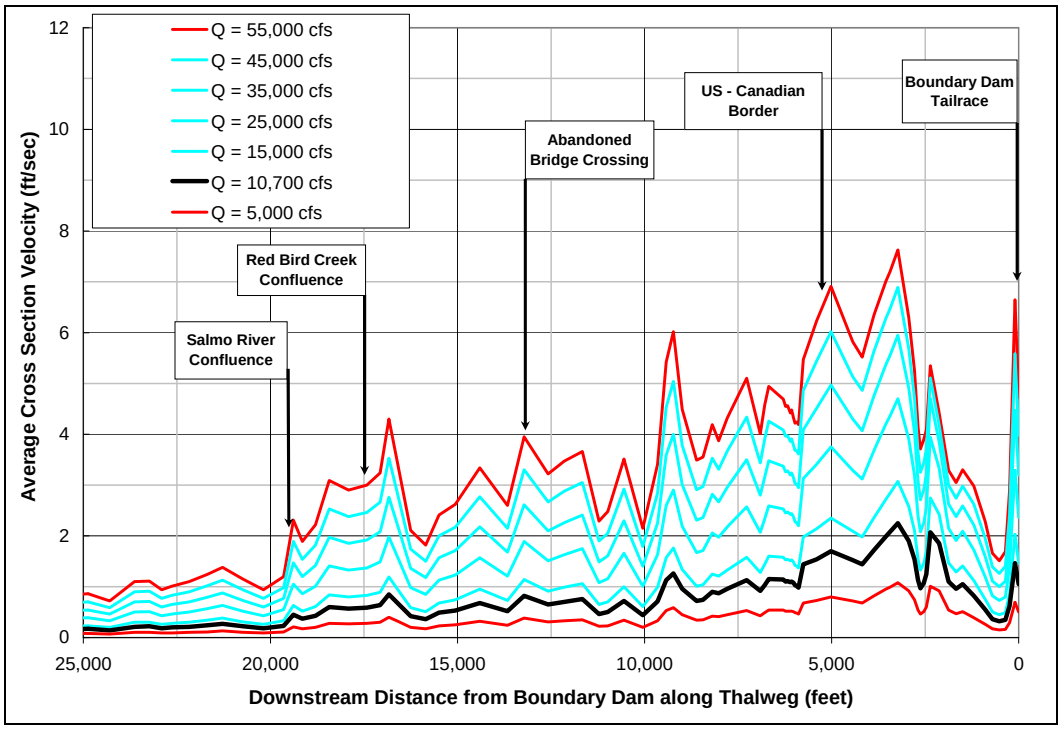


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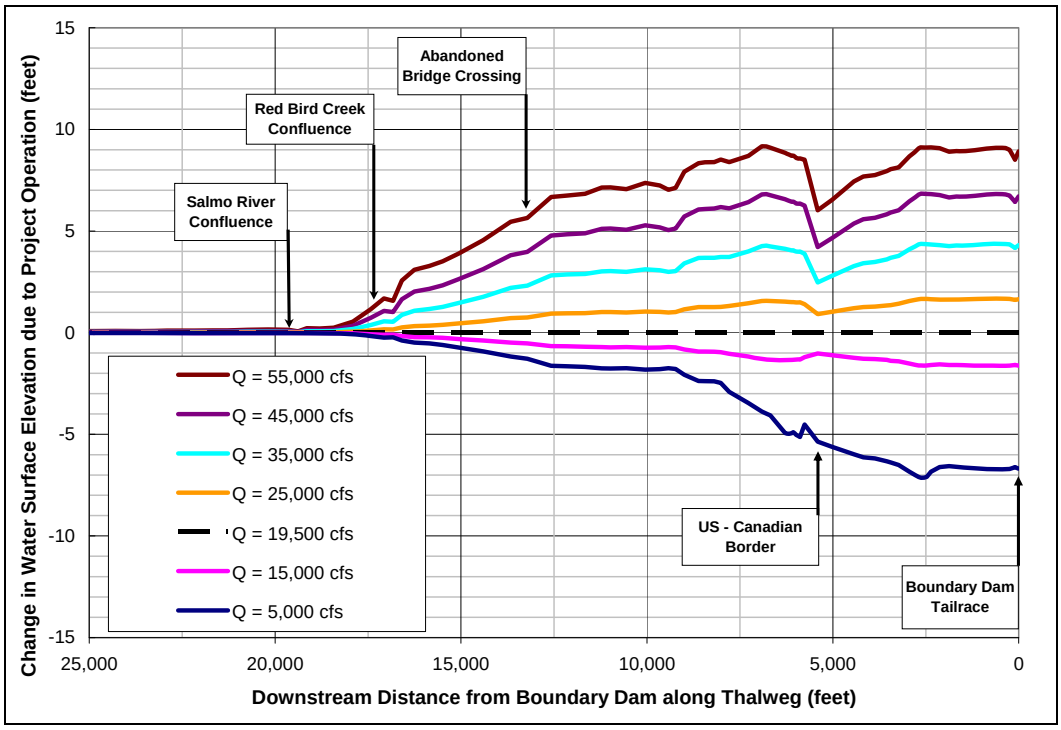


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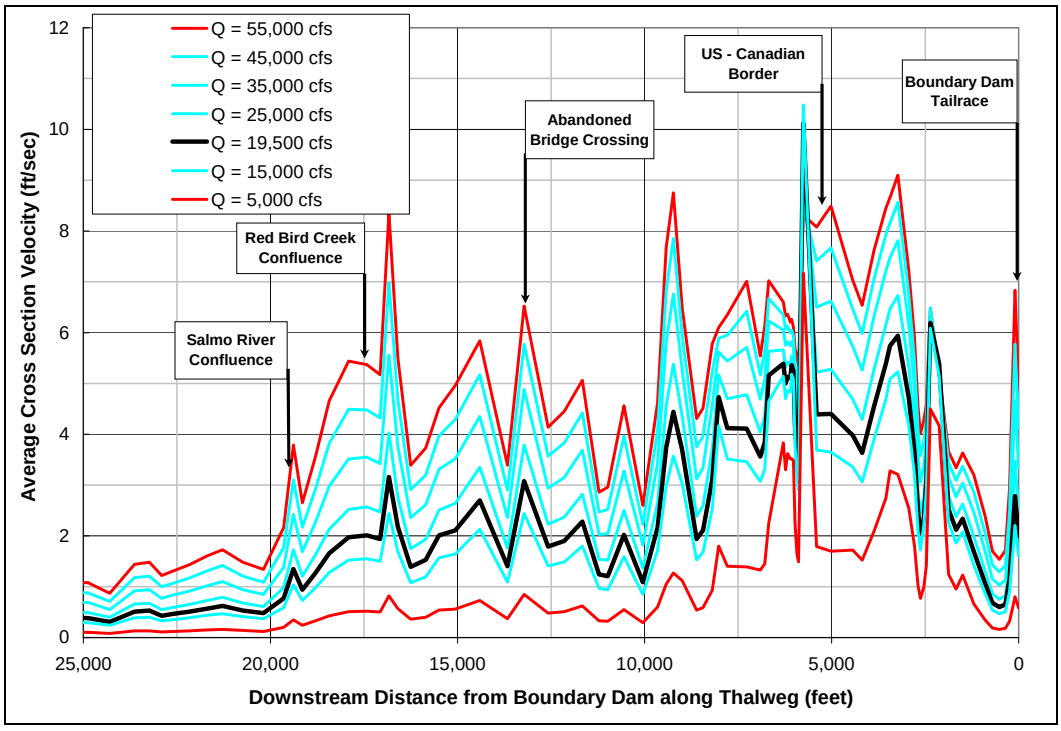


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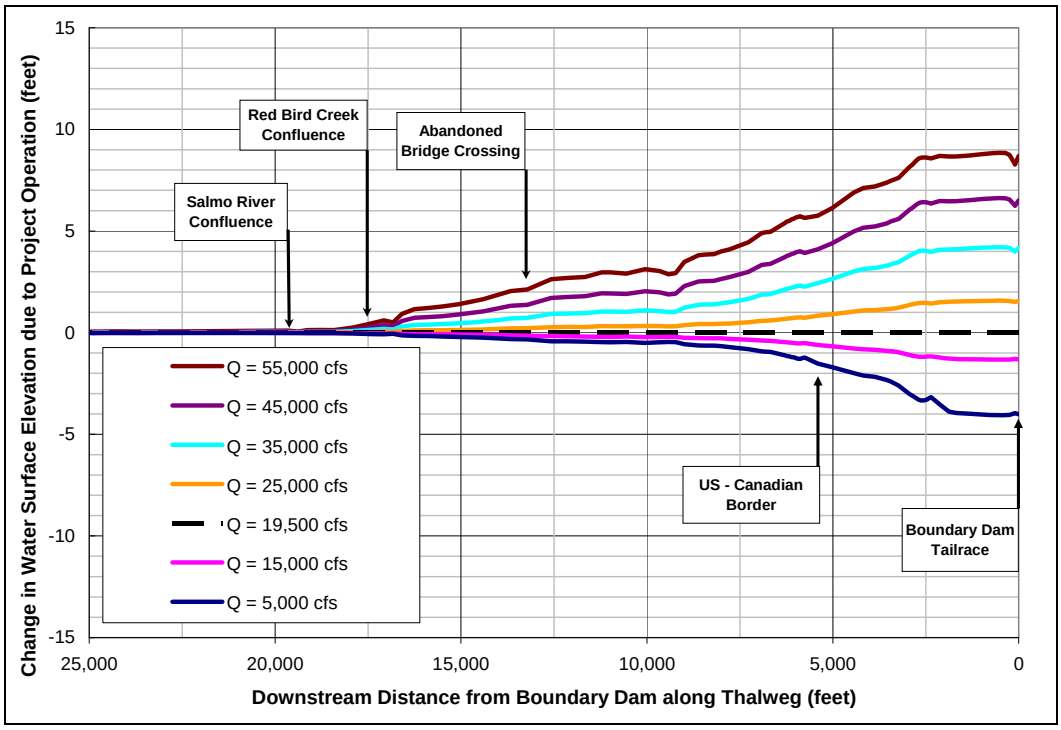


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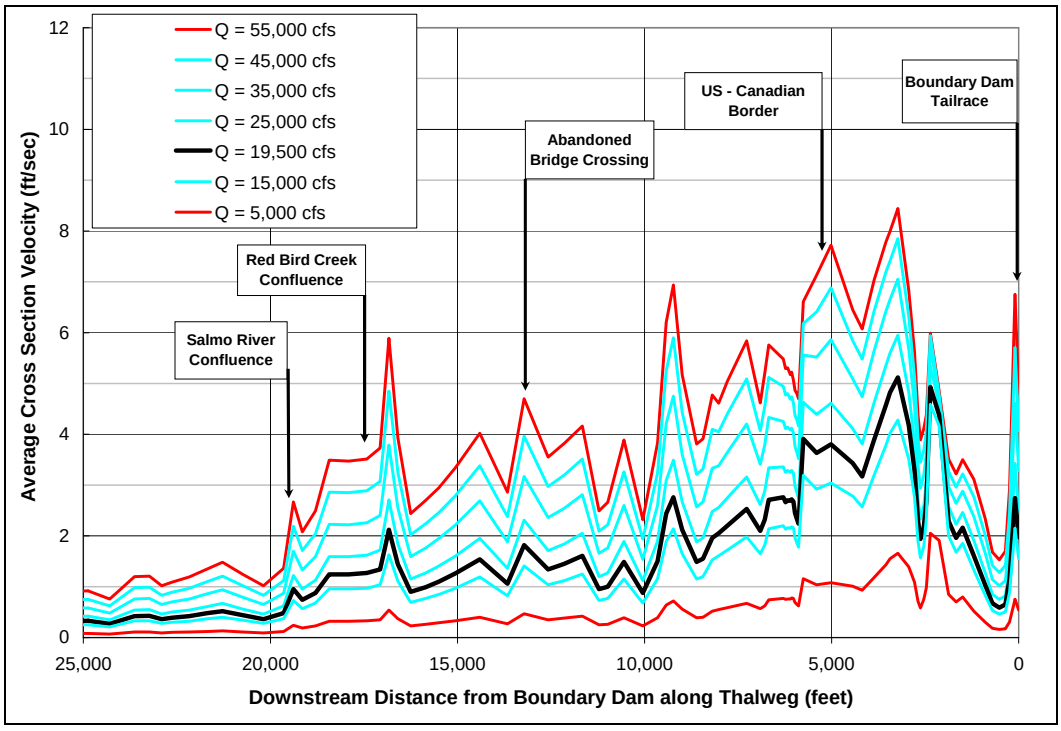


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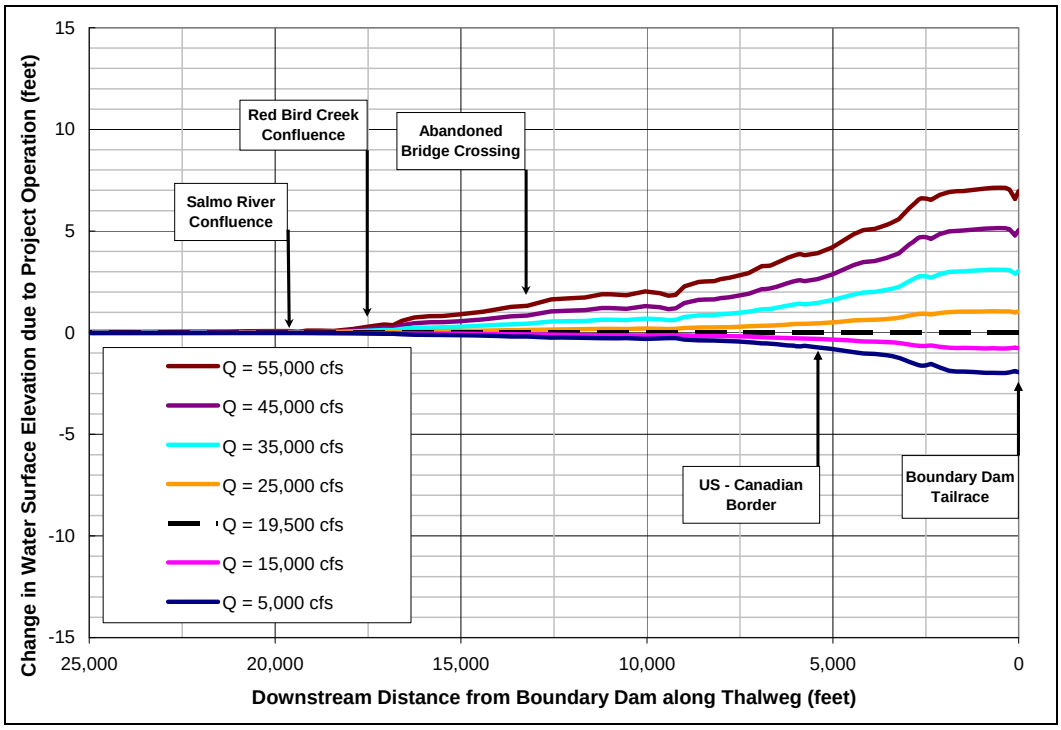


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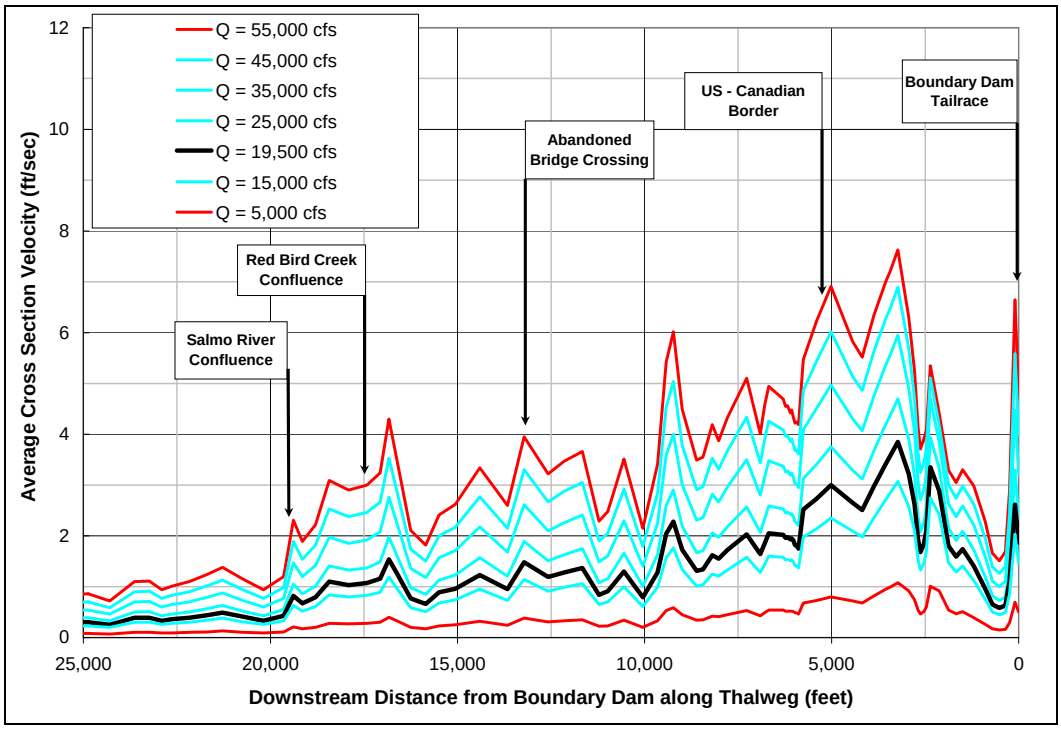


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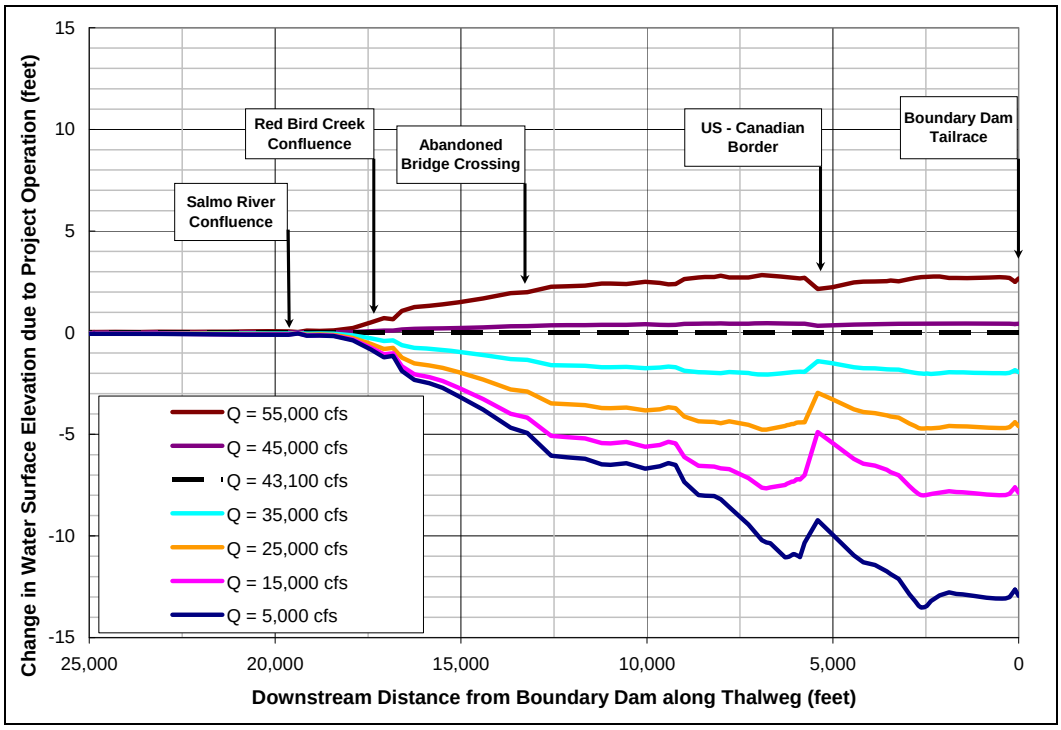


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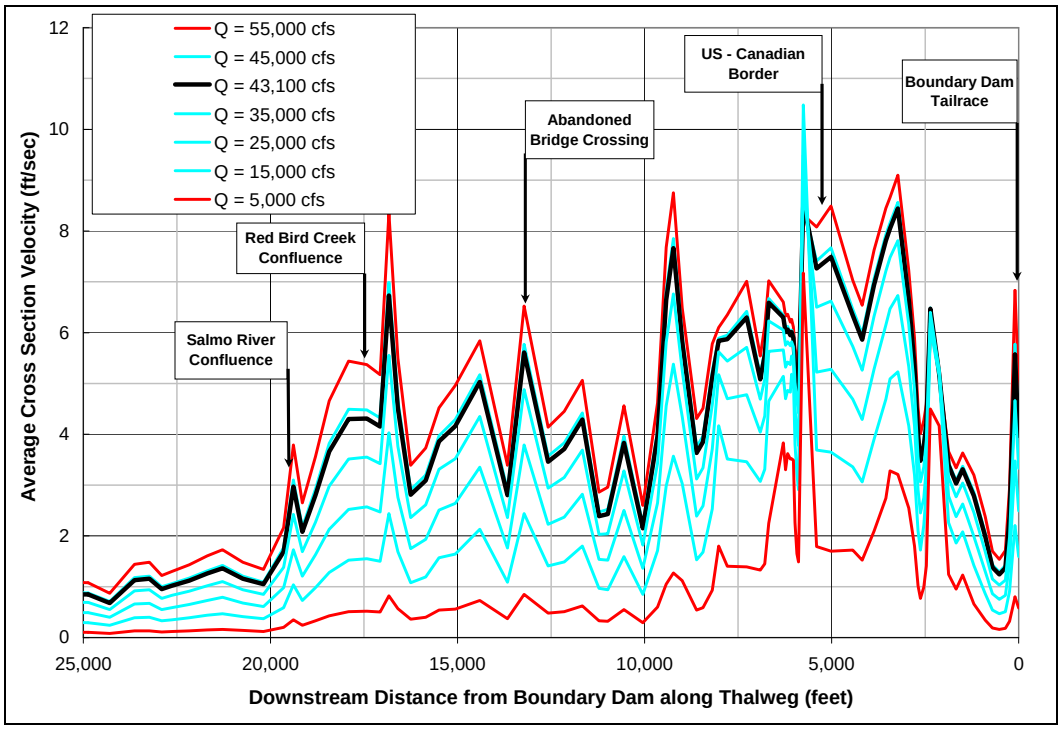


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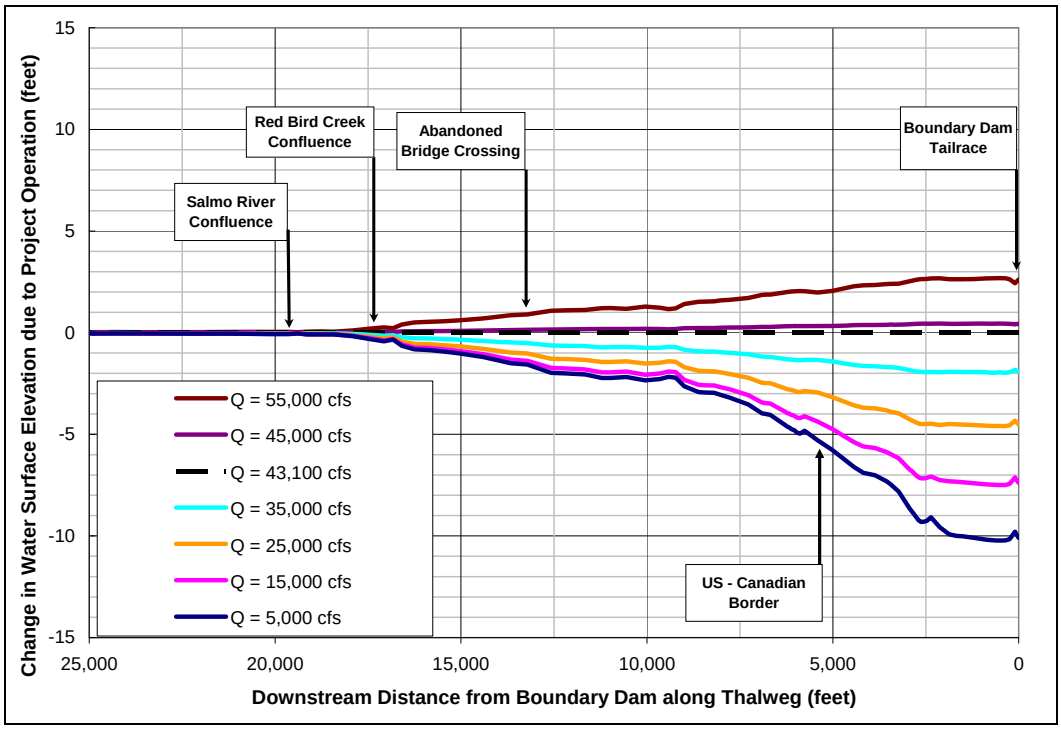


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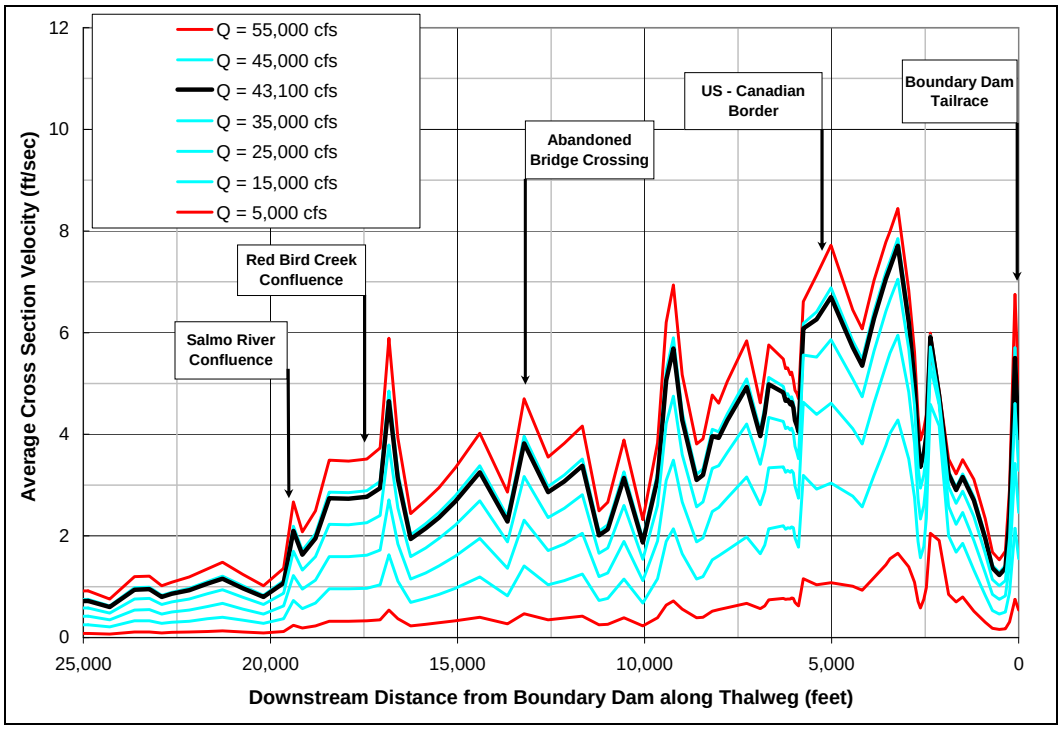


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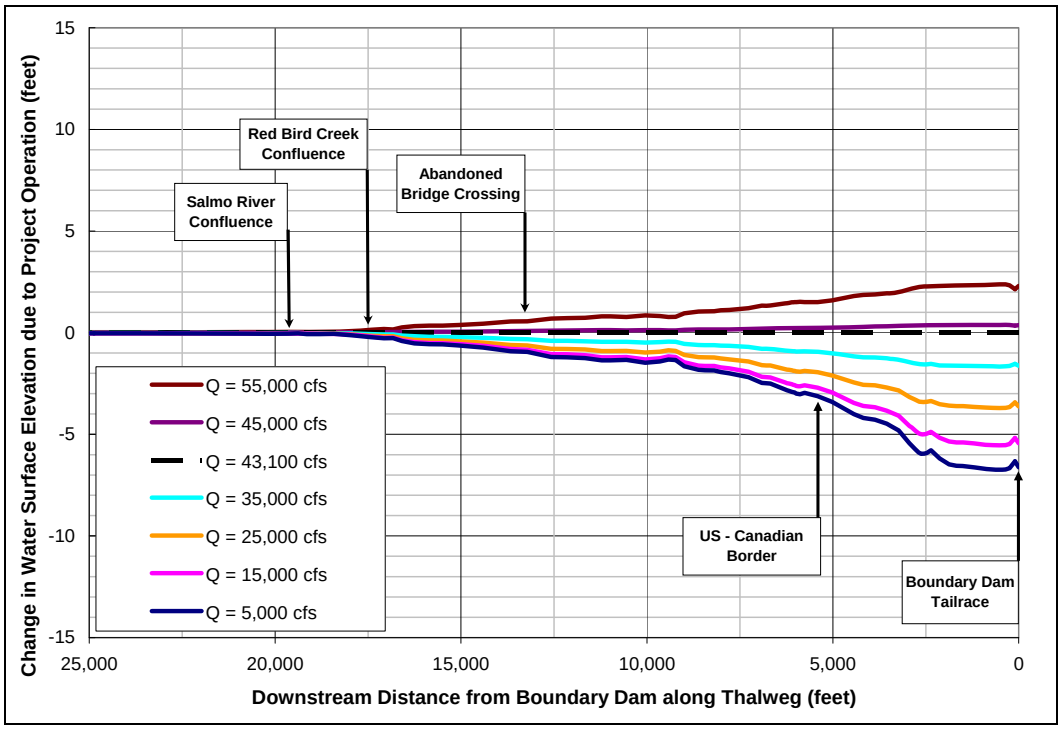


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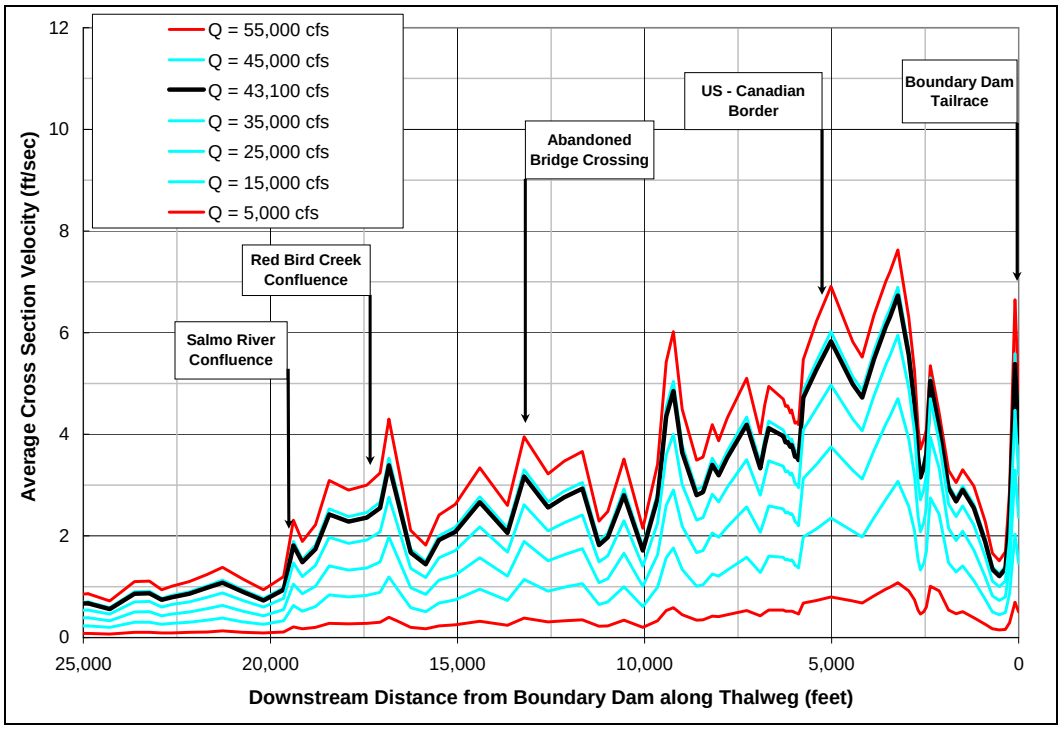


**Figure D-32.** Downstream hydraulic influence of Project operations on average cross section velocities relative to the condition associated with 1732.28 foot NAVD88 Seven Mile Dam forebay and 43,100 cfs Project inflow.

# Appendix 3: Fish Periodicity Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 3*

## *Fish Periodicity Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Mark Allen**
**Thomas R. Payne & Associates**
**(under contract to Tetra Tech)**

**March 2009**

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# Study 7 Appendix 3
# Fish Periodicity Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

This report presents final periodicity information for species of interest[1] in the Boundary Hydroelectric Project (Project) area. Species and life stages of interest for fish habitat modeling include the spawning, fry, juvenile, and adult life-stages of mountain whitefish (*Prosopium williamsoni*), bull trout (*Salvelinus confluentis*), westslope cutthroat trout (*Oncorhynchus clarki lewisi*), redband trout (*O. mykiss gairdneri*), smallmouth and largemouth bass (*Micropterus dolomieui* and *M. salmoides*), and a guild of cyprinid species (to represent forage for piscivorous species) that is dominated in Boundary Reservoir by northern pikeminnow (*Ptychocheilus oregonensis*) and peamouth (*Mylocheilus caurinus*), with lesser numbers of redside shiners (*Richardsonius balteatus*) and tench (*Tinca tinca*). Periodicity dates are also presented for spawning and fry life-stages of other fish species, including suckers (mostly largescale *[Catostomus snyderi]*), yellow perch (*Perca flavescens*), and sunfishes (mostly black crappie *[Pomoxis nigromaculatus]* and pumpkinseed *[Lepomis gibbosus]*), that may be susceptible to stranding during Project operations.

## 2 OBJECTIVES

The fish periodicity dates are intended to help guide the temporal application of fish HSI curves for habitat modeling, as well as to help assess the potential impacts of fluctuations in water surface elevation on the spawning, incubation, and fry life stages of several fish species. These periodicity dates were developed with reference to available information from literature sources, site-specific (Project area) fish observations, and professional experience, in order to characterize the full range of occupancy of each fish species by life stage. Each species and life-stages periodicity is defined as the temporal period when it is most abundant (i.e., the "peak" periods), or is expected to be present in observable numbers (i.e., the off-peak, or "shoulder" periods). By use of the periodicity dates, the relative daily proportion of fish (or fish nests) that may be impacted by surface fluctuations during peak and shoulder periods can also be estimated.

## 3 METHODS

The fish periodicity tables were derived by reference to three sources of information:
1) available literature in published journals, unpublished "gray" literature, and books; 2) site-specific capture and observation field data from Study 9, Fish Distribution, Timing, and

[1] The term "target species" specifically refers to native salmonids including bull trout, cutthroat trout, redband/rainbow trout and mountain whitefish. The target species as well as other species for which HSI curves were developed are species of interest. To simplify discussions, all species for which HSI curves were developed and WUA and ESI/PSI analysis were performed are collectively referred to as species of interest except when native salmonids are solely being discussed.

Abundance Study Final Report (SCL 2009a); and 3) personal communications from regional fish experts, including input from relicensing participants at two fish periodicity workgroup meetings (July 17 and August 27, 2008). Each of the species and life stage periodicity dates were discussed and reviewed at the workgroup meetings, with modifications made to specific dates based on the personal experience and local knowledge of relicensing participants.

Periodicity dates for spawning, incubation, and fry rearing were further divided into shoulder and peak periods. A summary of the species and life stages described in this appendix is found in Table 3.0-1. Note that periodicity dates are presented for bull trout fry; however, that species/life stage was not modeled because of high water temperatures in the Project area. Also, it should be noted that many of the species and life-stages utilized for the stranding and trapping analysis (Section 4.4 in the Study 7, Mainstem Aquatic Habitat Modeling Study Final Report [SCL 2009b]) were not utilized in the aquatic habitat modeling analysis (Section 4.9 in the Study 7 Final Report [SCL 2009b]). See Appendix 9 of the Study 7 Final Report for the list of species and life-stages of interest used for fish HSI and habitat modeling.

**Table 3.0-1**. List of species and life-stages included in the periodicity analysis.

| Species | Spawning | Incubation | Fry Rearing [6] |
|---|---|---|---|
| Mountain Whitefish[1] | Y | Y | Y |
| Bull Trout | Y | Y | N |
| Cutthroat Trout | Y | Y | Y |
| Redband Trout | Y | Y | Y |
| Smallmouth Bass[2] | Y | Y | Y |
| Sunfish spp.[3] | Y | Y | Y |
| Cyprinid Forage spp.[4] | Y | Y | Y |
| Yellow Perch | Y | Y | Y |
| Largescale Suckers[5] | Y | Y | Y |

Notes:
1 Whitefish spawning and incubation periodicity may change based upon data collected from whitefish spawning and incubation assessments that are being conducted in the Boundary Project area from November 2008 through January 2009.
2 Also intended to represent largemouth bass
3 Mostly black crappie and pumpkinseed
4 Mostly northern pikeminnow and peamouth
5 Few longnose suckers also present
6 Fry <55 mm, juvenile, and adults present year-round

The following sections detail information on literature sources, field data, and the final periodicity dates.

## 3.1. Literature

Pertinent literature was searched from published journal papers, unpublished "gray" literature (e.g., agency reports, Web-based reports, etc.), and books (e.g., regional fish books). Requests were made from among the SCL relicensing team as well as from agency relicensing participants

for any pertinent information (whether literature-based, data-based, or personal observations) relating to fish periodicity dates. Approximately 40 sources of literature-based information, as well as personal communications from relicensing participants and regional fish experts, were assessed for use in developing the final periodicity tables. These sources are listed in each species periodicity summary tables as well as in the references section of this appendix.

Each species-specific figure shows periodicity information for spawning, incubation, and fry rearing, followed by a table that contains the data and references. The figure legends identify the different line types, and each of the literature-based periodicities (the thin lines) are denoted by letters that correspond to the data source listed in the associated table. The thickest lines with diamond symbols and displayed dates are the final periodicities intended for use in the Project area. The periodicity dates shown here were not calculated using a mathematical formula, but instead were chosen based on the literature information (and site-specific data, described below) with greater weight given to actual capture data from geographically similar locations, and less weight to general literature reviews, which tend to cover broad geographic areas with broader life history characteristics. On each periodicity figure, the literature-based periodicities that immediately surround (above and below) the final Project periodicities were given most weight, whereas those lines farther from the interim line were given less weight.

In producing these periodicity figures, several assumptions and comments should be noted:

- Actual dates for literature data shown in the figures and tables are approximate, because many references refer to the initiation or conclusion of spawning, for example, as “mid-May”, which is interpreted for plotting purposes as May 15; in similar manner “late August” may be interpreted in the figures and tables as August 25, and so on.
- Spawning periodicities are based largely on literature dates; a limited number of site-specific spawning observations were made during the course of relicensing studies (described below).
- Not all listed life stages shown in the following figures are included in the habitat modeling in all study reaches. For example, spawning and incubation are not expected to occur for any trout species in the Project area, although spawning and incubation periodicities are shown for cutthroat and redband trout (but not for bull trout). Also, fry, juvenile, and adult rearing for redband trout are not known to occur in Boundary Reservoir, but are only intended for use in the Tailrace Reach. Consequently, some periodicities contained in this appendix may not be utilized for assessment of habitat or stranding impacts.
- Note that the peak and shoulder incubation times begin at the onset of peak and shoulder spawning periods, even though the incubation lines (dotted lines in figures) are only visible from the cessation of the spawning range.
- It is assumed that the division between “fry” and “juvenile” life stages for salmonids occurs at a length of approximately 55 millimeters (mm), which is consistent with most of the salmonid HSI curves and with National Oceanic and Atmospheric Administration fish screening criteria, and is largely based on rapid changes in habitat use as fish become less susceptible to predation, stranding, etc., and they more readily utilize deeper and swifter offshore habitats. For smallmouth bass, changes in microhabitat use from fry to juvenile life stages have been observed for fish over

60 mm, based on data from Pennsylvania (Allen 1996), Michigan (Monahan 1991), California (Studley et al. 1986), and West Virginia (Newcomb et al. 1995); therefore, a criterion length of 55 mm was also applied to define bass fry and juveniles. For cyprinid forage species (pikeminnows, peamouths, and redside shiners), periodicities are presented for fry (up to 55 mm) to assess stranding potential.

- The specific time at which a fish grows beyond the assigned length for "fry" into the "juvenile" class is rarely presented in literature; therefore, the ending dates for fry rearing in the figures and tables are highly approximate and were largely based on site-specific electrofishing data (described below) or from additional local expert or literature information.
- Periodicities are not presented for juvenile or adult life-stages under the assumption that those periodicities extend year-round, although not all life-stages may occur in the Project area. For slow growing, late-spawning, and/or repeat-spawning species (e.g., most non-salmonid species), fry periodicities also extend year-round.
- Bass periodicity dates were largely based on smallmouth information; periodicities for largemouth bass were assumed to be represented by smallmouth bass.

## 3.2. Field Data

Site-specific field data were acquired to assist the development of appropriate periodicity dates for the various fish species through the electrofishing and stranding and trapping surveys described in Study 9 (SCL 2009a). The actual site-specific data from the Study 9 efforts were plotted with the literature periodicities using different symbols to designate data based on electrofishing or trapping/stranding. The symbols were plotted on the Project periodicity line (the thick lines in the figures) according to the date of capture or observation and generally included the number of fish captured or observed. These site-specific observations were used to help select the starting and ending dates for the periodicities, as well as to determine the periods of peak abundance. For example, length-frequency plots were created for some species to help assess the approximate dates when most fry exceeded the 55 mm size class definition.

Additional site-specific field data used to develop the final periodicity curves included spring-time water temperature data from Boundary Reservoir, and seasonal growth data of trout fry from Boundary tributaries. The temperatures at which spawning is initiated by each species, as described in the available literature, was compared to site-specific water temperatures to validate the proposed spawning periodicity dates. The proposed dates for cutthroat trout spawning were assessed by back-calculating the expected date of fry emergence (based on seasonal fry growth data from local tributaries) and then subtracting literature-based incubation periods. Some periodicity figures may also contain field data from Boundary Reservoir collected by the Washington Department of Fish and Wildlife (McLellan and O'Conner 2001).

The final Project periodicity dates for each species and life-stage include peak and off-peak (or, shoulder) periods. The shoulder periods extend from first occurrence to the beginning of the peak period, and again from the conclusion of the peak period to the end of occurrence. The final peak and shoulder period dates are given in the table of final periodicity dates (Table 3.3-10).

The duration of the peak and shoulder periods (in days) was used to estimate the proportion of the population of each species and life-stage that might be impacted by fluctuations in water surface elevations, by assigning relative proportions to each period either by professional judgment or by reference to Study 9 (SCL 2009a) capture data. For example, the peak spawning periods for whitefish and smallmouth bass (two species of interest known to spawn in the Project area) were assumed to represent 70 percent of the spawning population, whereas the remaining 30 percent of the spawning population was assumed to spawn during the shoulder periods (Table 3.3-10). To estimate the percentage of the total population of spawners impacted each day, the duration of the peak spawning period was divided into 70 percent, so for instance, 44 days for smallmouth bass according to the peak periodicity dates divided into 70 percent gives an estimate of 1.6 percent of spawning bass per day during peak spawning. Likewise, an estimated 0.9 percent of spawning bass might be affected each day during the 33-day shoulder period. This 70:30 peak-to-shoulder ratio was assumed for all spawning species (and for incubation) due to a lack of sufficient site-specific data on spawning intensity in the Project area. Note that for non-mobile eggs the proportion of daily incubation is not considered independent on a daily basis, but is assessed in a cumulative manner according to procedures detailed in Section 4.9 of the Study 7 Final Report (SCL 2009b).

Site-specific data were available from Study 9 (SCL 2009a) to estimate the relative proportions of fry populations that were present during the peak and shoulder periods. The relative frequency of capture or observation was plotted for each species of fry (except bull trout fry, which were assumed to be absent in the Project area) according to sampling methodology (e.g., boat electrofishing, backpack electrofishing, seining and dip-netting, fyke netting, and dive counting in tributaries) by date. The relative proportion of fry captures or observations within the species-specific peak period was then estimated by eye, and the remaining proportion given to the shoulder periods (Table 3.3-10).

## 3.3. Final Periodicity Dates

The last process in developing the final periodicity dates involved presenting the proposed periodicities along with the supporting literature and field data to a panel of relicensing participants over the course of two meetings (July 17 and August 27, 2008), where consensus was reached on all final dates. Whitefish spawning and incubation assessments are being conducted in the Boundary Project area from November 2008 through January 2009. Based upon the data collected from these activities, spawning and incubation periodicity for whitefish may change. Supporting tables describing the literature sources are shown in Tables 3.3-1 to 3.3-9. Table 3.3-10 summarizes the final periodicity dates, as well as the duration (in days) and daily percentage of affected population, for each species and life stage.

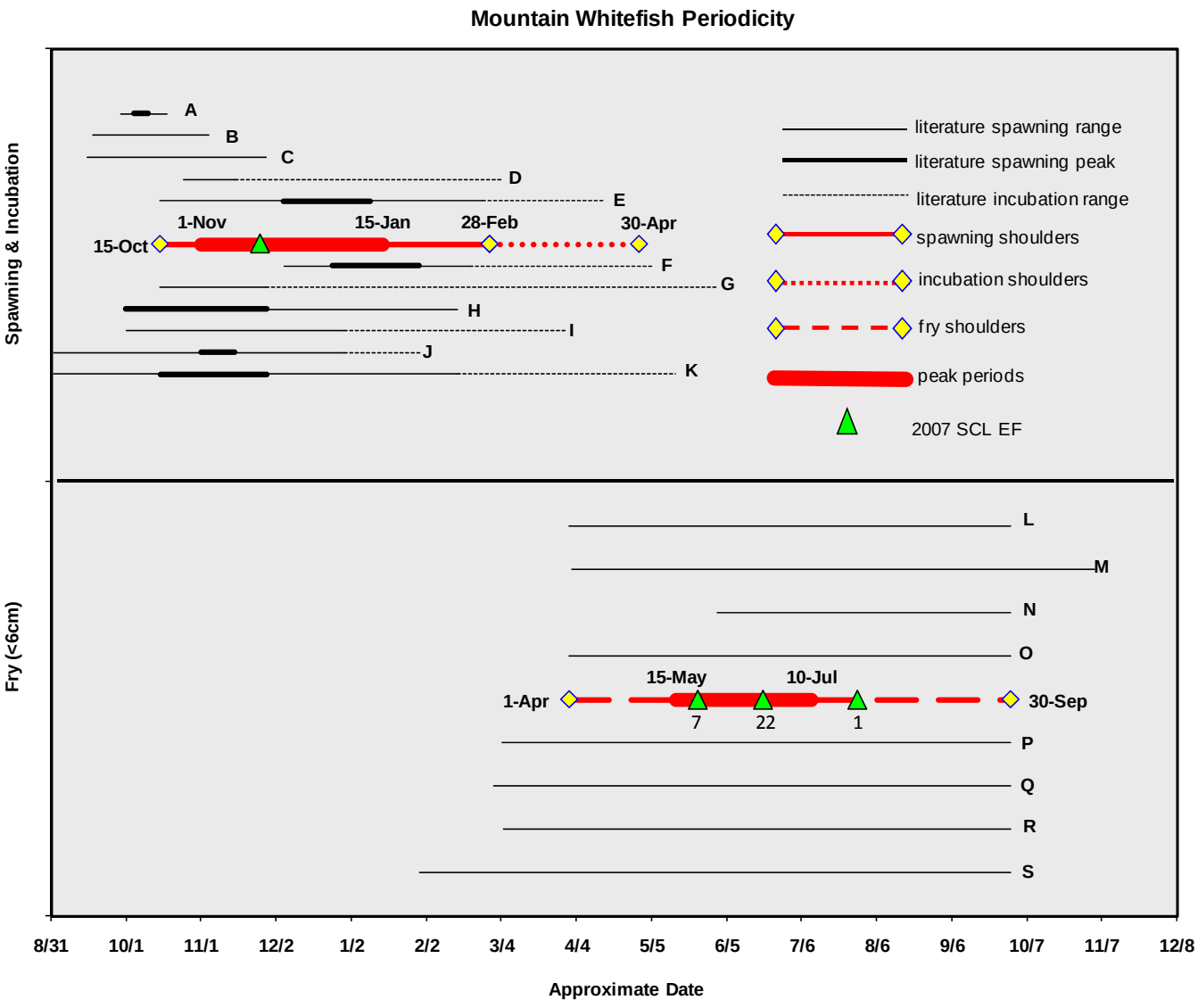


**Figure 3.3-1.** Boundary periodicity—mountain whitefish[1] (see following table for source data).

[1] Whitefish spawning and incubation periodicity may change based upon data collected from whitefish spawning and incubation assessments that are being conducted in the Boundary Project area from November 2008 through January 2009.

**Table 3.3-1.** Boundary periodicity—mountain whitefish.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Sheep R, AB | spawning | start | 29-Sep | 1.85 | 4-Oct | 1.85 | Thompson & Davies 1976 | Spawning at 32-46$^{o}$ F |
| A | Sheep R, AB | spawning | end | 18-Oct | 1.85 | 10-Oct | 1.85 | Thompson & Davies 1976 | |
| B | Red R, AB | spawning | start | 17-Sep | 1.80 | | | Golder 1999 | |
| B | Red R, AB | spawning | end | 4-Nov | 1.80 | | | Golder 1999 | |
| C | So Saskatch Basin streams | spawning | start | 15-Sep | 1.75 | | | Clipperton et al. 2003 | represents several South Saskatchewan Basin streams |
| C | So Saskatch Basin streams | spawning | end | 28-Nov | 1.75 | | | Clipperton et al. 2003 | |
| D | FW Fish of Canada | spawning | start | 25-Oct | 1.70 | | | Scott & Crossman 1998 | |
| D | FW Fish of Canada | spawning | end | 15-Nov | 1.70 | | | Scott & Crossman 1998 | |
| D | FW Fish of Canada | incubation | end | 5-Mar | 1.70 | | | Scott & Crossman 1998 | |
| E | Columbia R (Brilliant) | spawning | start | 15-Oct | 1.65 | 5-Dec | 1.65 | RL&L 2000 | |
| E | Columbia R (Brilliant) | spawning | end | 25-Feb | 1.65 | 10-Jan | 1.65 | RL&L 2000 | |
| E | Columbia R (Brilliant) | incubation | end | 15-Apr | 1.65 | | | RL&L 2000 | |
| F | Columbia&Kootenay R's | spawning | start | 5-Dec | 1.50 | 25-Dec | 1.50 | RL&L 1999,2000 | spawning from 33-46$^{o}$F, peaks ranged from 34-42$^{o}$F |
| F | Columbia&Kootenay R's | spawning | end | 20-Feb | 1.50 | 30-Jan | 1.50 | RL&L 1999,2000 | |
| F | Columbia&Kootenay R's | incubation | end | 5-May | 1.50 | | | RL&L 1999,2000 | |
| G | NF Clearwater R | spawning | start | 15-Oct | 1.45 | | | Pettit & Wallace 1975 | |
| G | NF Clearwater R | spawning | end | 28-Nov | 1.45 | | | Pettit & Wallace 1975 | |
| G | NF Clearwater R | incubation | end | 1-Jun | 1.45 | | | Pettit & Wallace 1975 | |
| H | Behnke's Salmonids | spawning | start | 1-Oct | 1.40 | 1-Oct | 1.40 | Behnke 2002 | may spawn into February in lakes with constant temperatures |
| H | Behnke's Salmonids | spawning | end | 15-Feb | 1.40 | 28-Nov | 1.40 | Behnke 2002 | |
| I | Daily lit review | spawning | start | 1-Oct | 1.35 | | | Daily 1971 | |
| I | Daily lit review | spawning | end | 30-Dec | 1.35 | | | Daily 1971 | |
| I | Daily lit review | incubation | end | 30-Mar | 1.35 | | | Daily 1971 | |
| J | Fish of WA | spawning | start | 1-Sep | 1.30 | 1-Nov | 1.30 | Wydoski & Whitney 2003 | spawning at 40-45$^{o}$ F |
| J | Fish of WA | spawning | end | 30-Dec | 1.30 | 15-Nov | 1.30 | Wydoski & Whitney 2003 | |
| J | Fish of WA | incubation | end | 30-Jan | 1.30 | | | Wydoski & Whitney 2003 | |
| K | Northcote lit review | spawning | start | 1-Sep | 1.25 | 15-Oct | 1.25 | Northcote & Ennis 1994 | |
| K | Northcote lit review | spawning | end | 15-Feb | 1.25 | 28-Nov | 1.25 | Northcote & Ennis 1994 | |
| K | Northcote lit review | incubation | end | 15-May | 1.25 | | | Northcote & Ennis 1994 | |
| L | Sheep R, AB | fry (<6cm) | start | 1-Apr | 0.90 | | | Thompson & Davies 1976 | |
| L | Sheep R, AB | fry (<6cm) | end | 30-Sep | 0.90 | | | Thompson & Davies 1976 | end date unknown, but fish averaged 81mm by end of year |
| M | Red R AB | fry (<6cm) | start | 2-Apr | 0.80 | | | Golder 1999 | |
| M | Red R AB | fry (<6cm) | end | 4-Nov | 0.80 | | | Golder 1999 | |
| N | NF Clearwater R | fry (<6cm) | start | 1-Jun | 0.70 | | | Pettit & Wallace 1975 | |
| N | NF Clearwater R | fry (<6cm) | end | 30-Sep | 0.70 | | | Pettit & Wallace 1975 | end date unknown, but fish averaged 86mm by September |
| O | Northcote lit review | fry (<6cm) | start | 1-Apr | 0.60 | | | Northcote & Ennis 1994 | |
| O | Northcote lit review | fry (<6cm) | end | 30-Sep | 0.60 | | | Northcote & Ennis 1994 | unknown end date |
| P | Daily lit review | fry (<6cm) | start | 4-Mar | 0.40 | | | Daily 1971 | |
| P | Daily lit review | fry (<6cm) | end | 30-Sep | 0.40 | | | Daily 1971 | end July fry mean length=55mm in Yellowstone River |
| Q | Behnke's Salmonids | fry (<6cm) | start | 1-Mar | 0.30 | | | Behnke 2002 | |
| Q | Behnke's Salmonids | fry (<6cm) | end | 30-Sep | 0.30 | | | Behnke 2002 | unknown end date |
| R | FW Fish of Canada | fry (<6cm) | start | 5-Mar | 0.20 | | | Scott & Crossman 1998 | |
| R | FW Fish of Canada | fry (<6cm) | end | 30-Sep | 0.20 | | | Scott & Crossman 1998 | unknown end date |
| S | Fish of WA | fry (<6cm) | start | 30-Jan | 0.10 | | | Wydoski & Whitney 2003 | eggs hatch 1+ months after spawning |
| S | Fish of WA | fry (<6cm) | end | 30-Sep | 0.10 | | | Wydoski & Whitney 2003 | unknown end date |

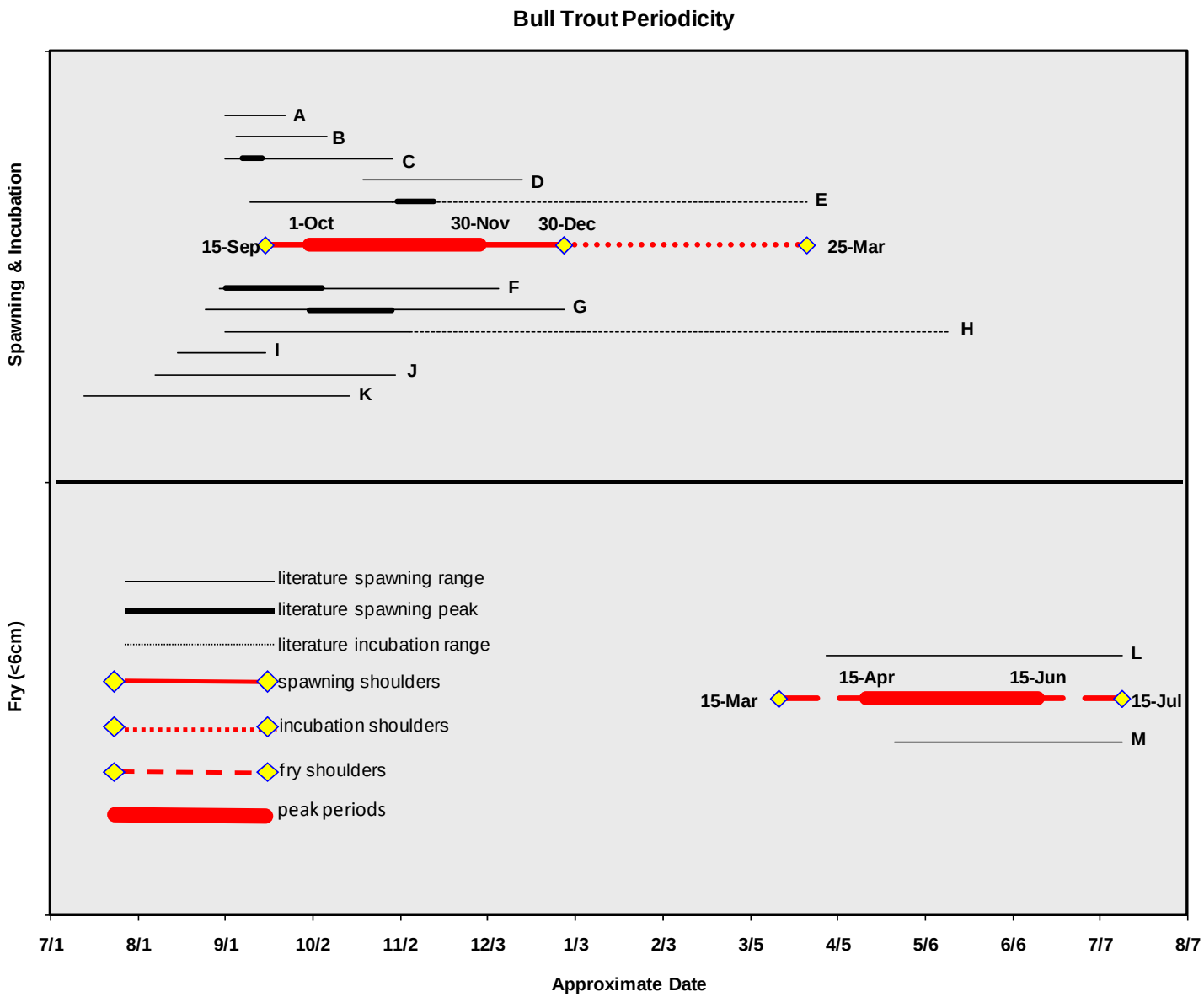


**Figure 3.3-2.** Boundary periodicity—bull trout (see following table for source data).

**Table 3.3-2.** Boundary periodicity—bull trout.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Goat R, BC | spawning | start | 1-Sep | 1.85 | | | Pillipow & Williamson 2004 | headwater tributary to Fraser River |
| A | Goat R, BC | spawning | end | 22-Sep | 1.85 | | | Pillipow & Williamson 2004 | |
| B | Rimrock Res & tribs | spawning | start | 5-Sep | 1.80 | 7-Sep | 1.75 | James & Sexauer 1997 | spawning peaked at 42-46$^{o}$ F |
| B | Rimrock Res & tribs | spawning | end | 7-Oct | 1.80 | 14-Sep | 1.75 | James & Sexauer 1997 | |
| C | Flathead Lake tribs | spawning | start | 1-Sep | 1.75 | | | Pratt 1992 | literature review, spawning as temperatures decreased to 48$^{o}$ F |
| C | Flathead Lake tribs | spawning | end | 30-Oct | 1.75 | | | Pratt 1992 | |
| D | Cedar R, WA | spawning | start | 20-Oct | 1.70 | 1-Nov | 1.65 | Reiser et al. no date | |
| D | Cedar R, WA | spawning | end | 15-Dec | 1.70 | 14-Nov | 1.65 | Reiser et al. no date | end date unknown, but new redds observed on 7 December |
| E | Columbia R (Brilliant) | spawning | start | 10-Sep | 1.65 | | | RL&L 2000 | |
| E | Columbia R (Brilliant) | spawning | end | 30-Oct | 1.65 | | | RL&L 2000 | |
| E | Columbia R (Brilliant) | incubation | end | 25-Mar | 1.65 | | | RL&L 2000 | |
| F | Yakima R, WA | spawning | start | 30-Aug | 1.45 | | | Craig 1997 | 6 Yakima basins, spawning as temperatures decreased to 48$^{o}$ F |
| F | Yakima R, WA | spawning | end | 7-Dec | 1.45 | | | Craig 1997 | |
| G | Fish of WA | spawning | start | 25-Aug | 1.40 | 1-Sep | 1.45 | Wydoski & Whitney 2003 | peak spawning as temperatures declined from 48-41$^{o}$ F |
| G | Fish of WA | spawning | end | 30-Dec | 1.40 | 5-Oct | 1.45 | Wydoski & Whitney 2003 | |
| H | FW Fish of Canada | spawning | start | 1-Sep | 1.35 | 1-Oct | 1.40 | Scott & Crossman 1998 | spawning began at temperatures ~46$^{o}$ F |
| H | FW Fish of Canada | spawning | end | 5-Nov | 1.35 | 30-Oct | 1.40 | Scott & Crossman 1998 | |
| H | FW Fish of Canada | incubation | end | 15-May | 1.35 | | | Scott & Crossman 1998 | |
| I | Rapid R, ID | spawning | start | 15-Aug | 1.30 | | | Schill et al. 1994 | |
| I | Rapid R, ID | spawning | end | 15-Sep | 1.30 | | | Schill et al. 1994 | |
| J | Goetz lit review | spawning | start | 7-Aug | 1.25 | | | Goetz 1989 | spawning begins as temperatures drop below 48$^{o}$ F |
| J | Goetz lit review | spawning | end | 31-Oct | 1.25 | | | Goetz 1989 | |
| K | Metolius R, OR | spawning | start | 13-Jul | 1.20 | 15-Aug | | Ratliff et al 1996 | spawning began as temperatures dropped below 48$^{o}$ F |
| K | Metolius R, OR | spawning | end | 15-Oct | 1.20 | 1-Oct | | Ratliff et al 1996 | |
| L | Flathead Lake tribs | fry (<6cm) | start | 1-Apr | 0.60 | | | Pratt 1992 | fry may remain in gravel up to 3 weeks prior to emergence |
| L | Flathead Lake tribs | fry (<6cm) | end | 15-Jul | 0.60 | | | Pratt 1992 | end date unknown |
| M | FW Fish of Canada | fry (<6cm) | start | 25-Apr | 0.40 | | | Scott & Crossman 1998 | |
| M | FW Fish of Canada | fry (<6cm) | end | 15-Jul | 0.40 | | | Scott & Crossman 1998 | unknown end date |

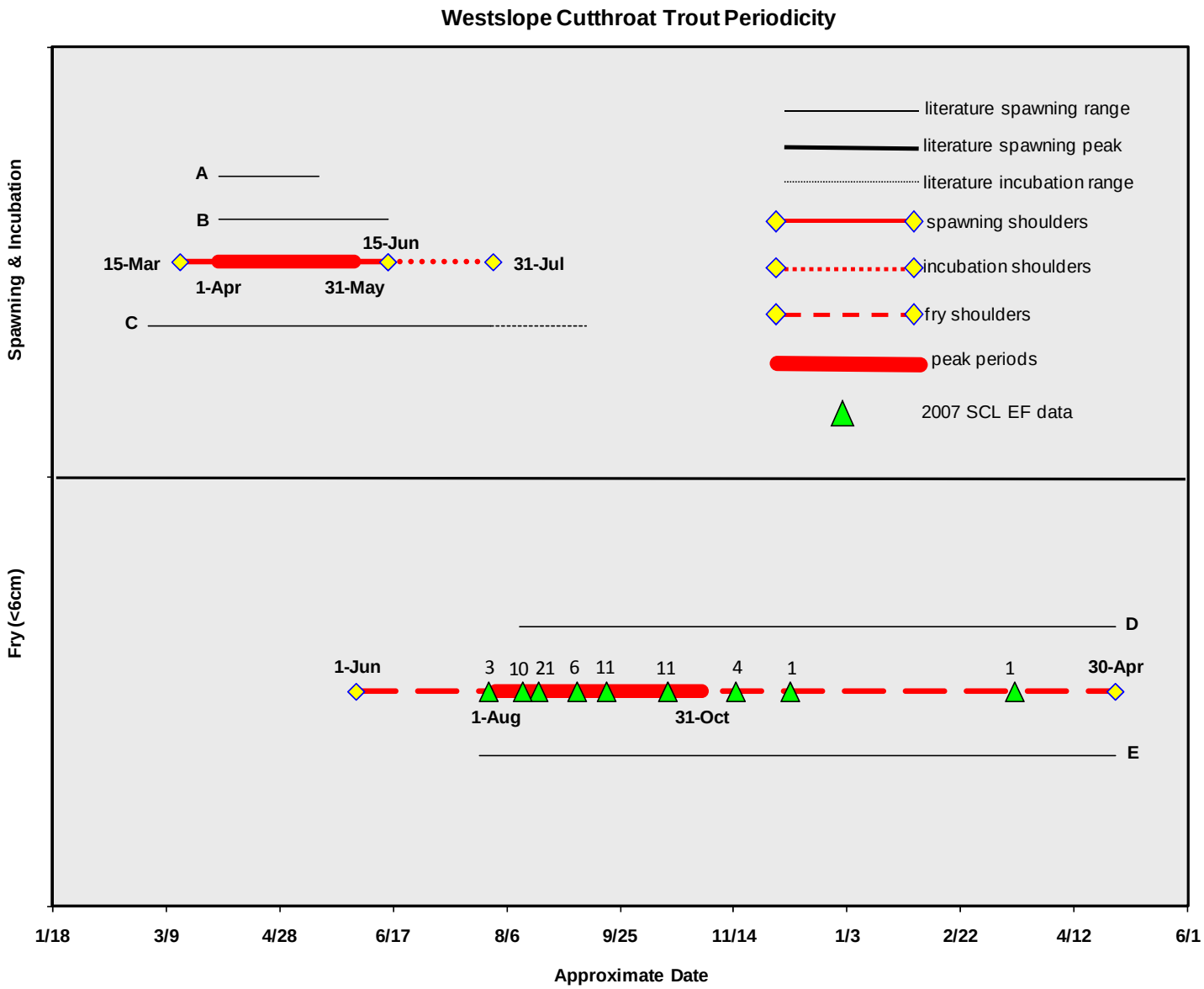


**Figure 3.3-3.** Boundary periodicity—westslope cutthroat trout (see following table for source data).

**Table 3.3-3.** Boundary periodicity—westslope cutthroat trout.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Fish of Alaska | spawning | start | 1-Apr | 1.70 | | | Morrow 1980 | |
| A | Fish of Alaska | spawning | end | 15-May | 1.70 | | | Morrow 1980 | |
| B | Behnke's Salmonids | spawning | start | 1-Apr | 1.60 | | | Behnke 2002 | spawning begins at 43-48$^{o}$ F |
| B | Behnke's Salmonids | spawning | end | 15-Jun | 1.60 | | | Behnke 2002 | 7-8 wks to emergence |
| C | Fish of WA | spawning | start | 1-Mar | 1.35 | | | Wydoski & Whitney 2003 | spawning at 43-63$^{o}$ F |
| C | Fish of WA | spawning | end | 30-Jul | 1.35 | | | Wydoski & Whitney 2003 | |
| C | Fish of WA | incubation | end | 10-Sep | 1.35 | | | Wydoski & Whitney 2003 | 6 wk incubation time added |
| D | Strawberry Res tribs, UT | fry (<6cm) | start | 12-Aug | 0.65 | | | Knight et al 1999 | Bonneville cutthroat |
| D | Strawberry Res tribs, UT | fry (<6cm) | end | 30-Apr | 0.65 | | | Knight et al 1999 | end date unknown |
| E | Northern ID streams | fry (<6cm) | start | 25-Jul | 0.35 | | | Griffith 1972 | first emergence of fry in northern Idaho tributaries over 2 years |
| E | Northern ID streams | fry (<6cm) | end | 30-Apr | 0.35 | | | Griffith 1972 | end date unknown |

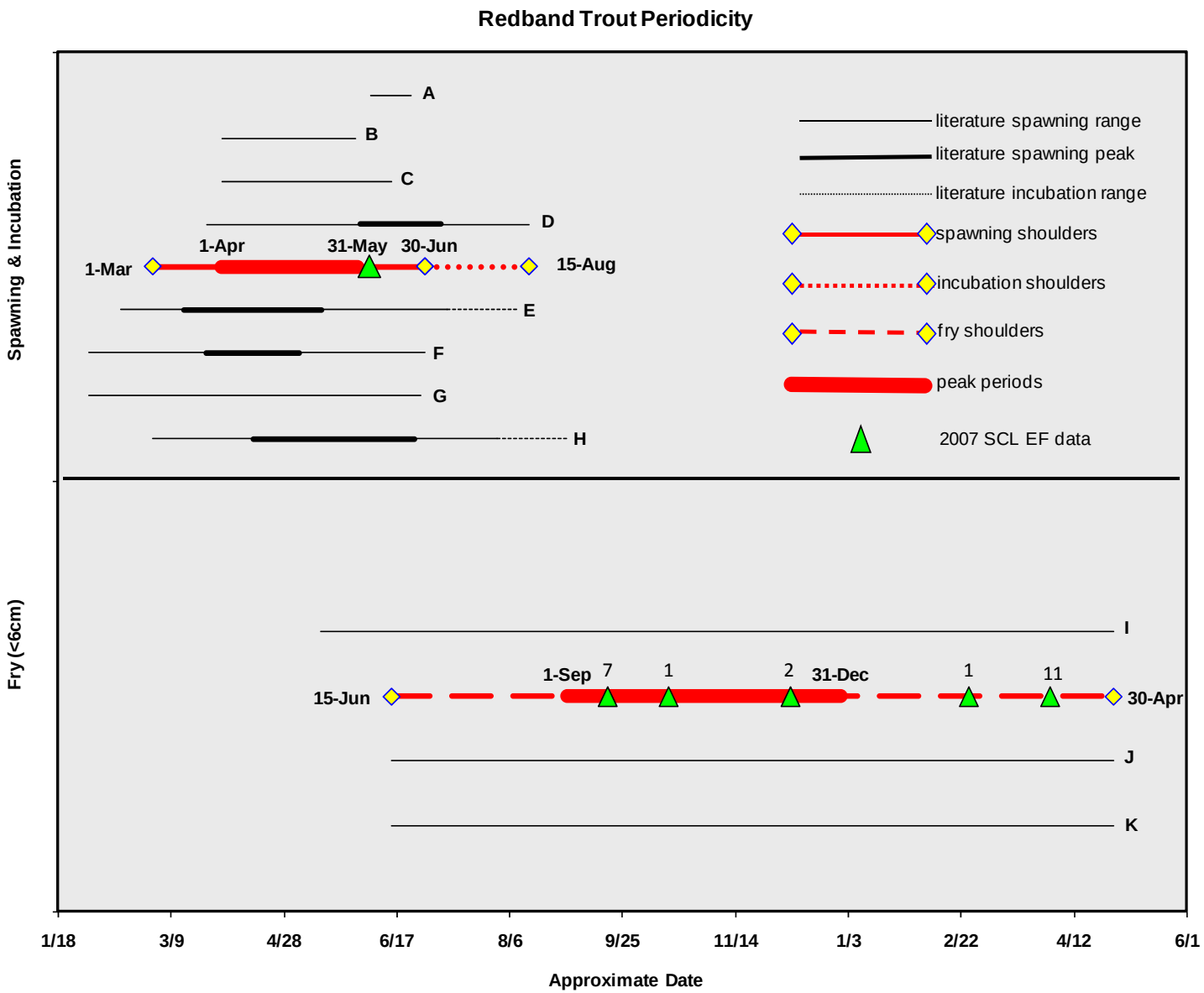


**Figure 3.3-4.** Boundary periodicity—redband trout (see following table for source data).

**Table 3.3-4.** Boundary periodicity—redband trout.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Montana stream | spawning | start | 6-Jun | 1.90 | | | Muhlfeld 2002 | |
| A | Montana stream | spawning | end | 24-Jun | 1.90 | | | Muhlfeld 2002 | |
| B | 11 Colorado streams | spawning | start | 1-Apr | 1.80 | | | Nehring & Anderson 1993 | |
| B | 11 Colorado streams | spawning | end | 30-May | 1.80 | | | Nehring & Anderson 1993 | |
| C | Oldman R, AB | spawning | start | 1-Apr | 1.70 | | | Fernet et al. 1990 | |
| C | Oldman R, AB | spawning | end | 15-Jun | 1.70 | | | Fernet et al. 1990 | |
| D | Deschutes R | spawning | start | 25-Mar | 1.60 | 1-Jun | 1.60 | Zimmerman & Reeves 2000 | our visual estimate of peak time |
| D | Deschutes R | spawning | end | 15-Aug | 1.60 | 7-Jul | 1.60 | Zimmerman & Reeves 2000 | |
| E | Columbia R (Brilliant) | spawning | start | 15-Feb | 1.40 | 15-Mar | 1.40 | RL&L 2000 | |
| E | Columbia R (Brilliant) | spawning | end | 10-Jul | 1.40 | 15-May | 1.40 | RL&L 2000 | |
| E | Columbia R (Brilliant) | incubation | end | 10-Aug | 1.40 | | | RL&L 2000 | |
| F | Fishes of WA | spawning | start | 1-Feb | 1.30 | 25-Mar | 1.30 | Wydoski & Whitney 2003 | |
| F | Fishes of WA | spawning | end | 30-Jun | 1.30 | 5-May | 1.30 | Wydoski & Whitney 2003 | |
| F | Fishes of WA | incubation | end | 20-Aug | 1.30 | | | Wydoski & Whitney 2003 | 6 wk incubation time added |
| G | Yakima R, WA | spawning | start | 1-Feb | 1.20 | | | Pearsons et al. 2003 | |
| G | Yakima R, WA | spawning | end | 28-Jun | 1.20 | | | Pearsons et al. 2003 | |
| H | FW Fish of Canada | spawning | start | 1-Mar | 1.10 | 15-Apr | 1.10 | Scott & Crossman 1998 | |
| H | FW Fish of Canada | spawning | end | 1-Aug | 1.10 | 25-Jun | 1.10 | Scott & Crossman 1998 | |
| H | FW Fish of Canada | incubation | end | 1-Sep | 1.10 | | | Scott & Crossman 1998 | |
| | Behnke's Salmonids | spawning | start | | | | | Behnke 2002 | spawning begins at 42-44$^{o}$ F |
| | Behnke's Salmonids | spawning | end | | | | | Behnke 2002 | |
| I | 11 Colorado streams | fry (<6cm) | start | 15-May | 0.65 | | | Nehring & Anderson 1993 | emergence began from early-Apr to late-June |
| I | 11 Colorado streams | fry (<6cm) | end | 30-Apr | 0.65 | | | Nehring & Anderson 1993 | end date unknown |
| J | FW Fish of Canada | fry (<6cm) | start | 15-Jun | 0.35 | | | Scott & Crossman 1998 | |
| J | FW Fish of Canada | fry (<6cm) | end | 30-Apr | 0.35 | | | Scott & Crossman 1998 | end date unknown |
| K | Lake Pond Oreille tribs | fry (<6cm) | start | 15-Jun | 0.20 | | | Pratt 1985 | fry start emerging in mid-June |
| K | Lake Pond Oreille tribs | fry (<6cm) | end | 30-Apr | 0.20 | | | Pratt 1985 | end date unknown |

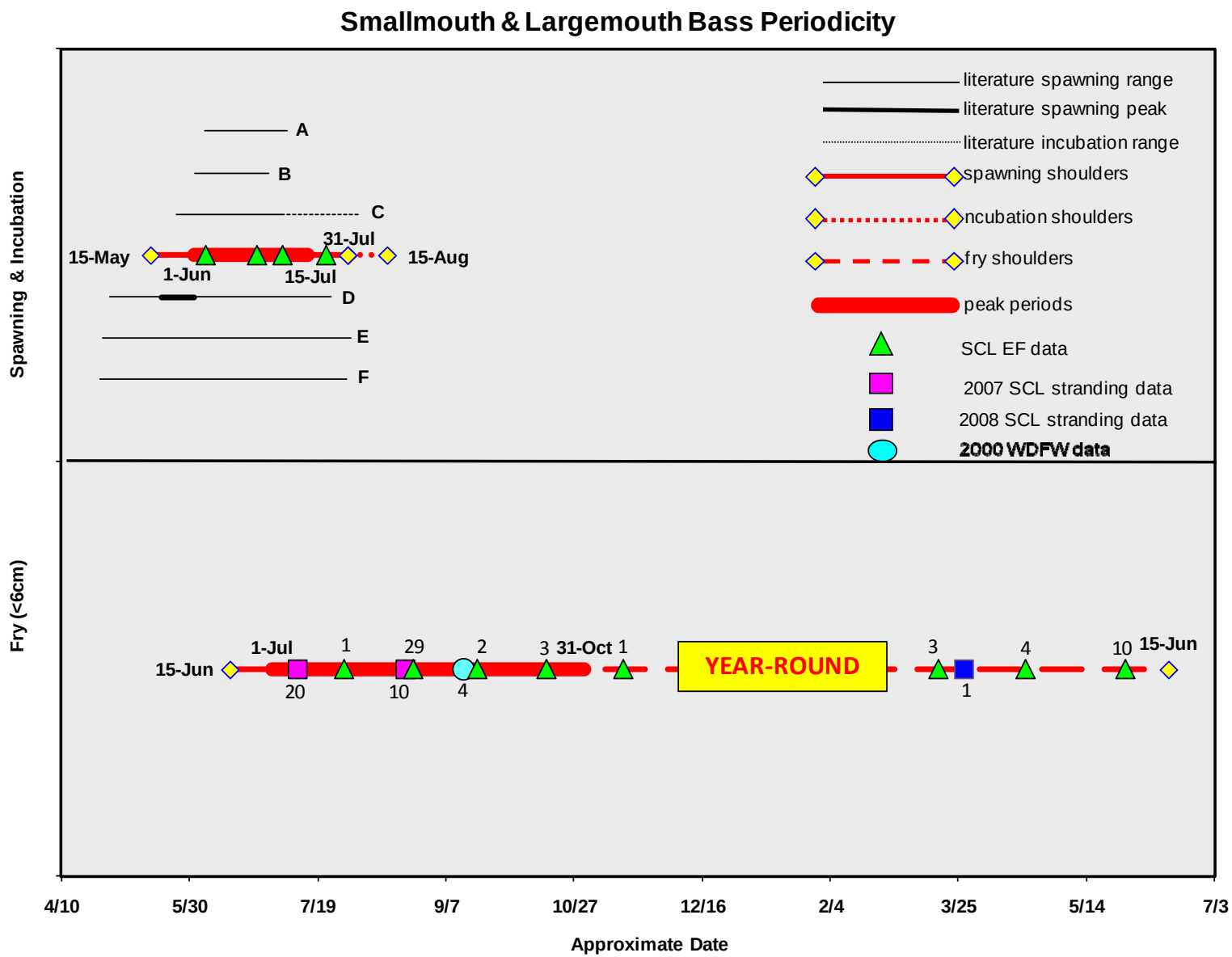


**Figure 3.3-5.** Boundary periodicity—smallmouth and largemouth bass (see following table for source data).

**Table 3.3-5.** Boundary periodicity—smallmouth and largemouth bass.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| **A** | Saskatchewan Lake | spawning | start | 5-Jun | 1.80 | | | Rawson 1945 | |
| **A** | Saskatchewan Lake | spawning | end | 7-Jul | 1.80 | | | Rawson 1945 | |
| **B** | Boundary Anglers PC's | spawning | 1 | 1-Jun | 1.70 | | | SCL 2007 | based on SCL angler interviews |
| **B** | Boundary Anglers PC's | spawning | end | 30-Jun | 1.70 | | | SCL 2007 | |
| **C** | FW Fish of Canada | spawning | start | 25-May | 1.60 | | | Scott & Crossman 1998 | spawning at 55-68$^{o}$ F (mostly at 61-65$^{o}$ F) |
| **C** | FW Fish of Canada | spawning | end | 5-Jul | 1.60 | | | Scott & Crossman 1998 | |
| **C** | FW Fish of Canada | incubation | end | 5-Aug | 1.60 | | | Scott & Crossman 1998 | dispersal ~3 wks after spawning |
| **D** | Snake R, Hells Canyon | spawning | start | 29-Apr | 1.40 | 19-May | 1.40 | Richter 2003 | 9-30 days from nest construction to swim-up |
| **D** | Snake R, Hells Canyon | spawning | end | 24-Jul | 1.40 | 1-Jun | 1.40 | Richter 2003 | |
| **E** | Columbia R | spawning | start | 26-Apr | 1.30 | | | Henderson & Foster 1957 | spawning initiated at 55-60$^{o}$ F |
| **E** | Columbia R | spawning | end | 1-Aug | 1.30 | | | Henderson & Foster 1957 | |
| **F** | Hanford Reach, Columbia R | spawning | start | 25-Apr | 1.20 | | | Montgomery et al. 1980 | |
| **F** | Hanford Reach, Columbia R | spawning | end | 30-Jul | 1.20 | | | Montgomery et al. 1980 | |

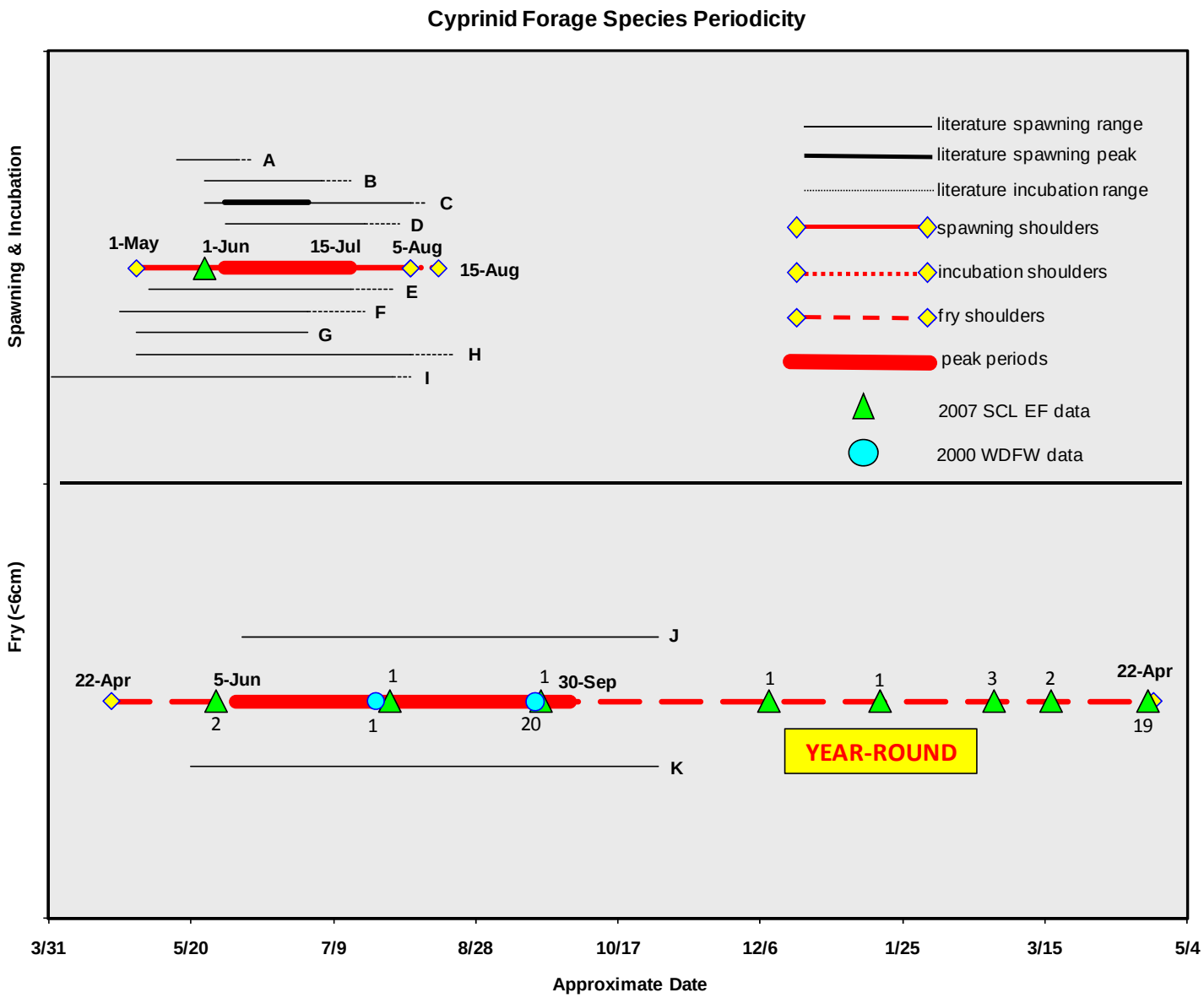


**Figure 3.3-6.** Boundary periodicity—cyprinid forage species (see following table for source data).

**Table 3.3-6.** Boundary periodicity—cyprinid forage species.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Fish of WA-Peamouth | spawning | start | 15-May | 1.75 | | | Wydoski & Whitney 2003 | spawning at 50-59$^{o}$ F |
| A | Fish of WA-Peamouth | spawning | end | 5-Jun | 1.75 | | | Wydoski & Whitney 2003 | |
| A | Fish of WA-Peamouth | incubation | end | 10-Jun | 1.75 | | | Wydoski & Whitney 2003 | |
| B | FW Fish Canada-Pikeminnow | spawning | start | 25-May | 1.70 | | | Scott & Crossman 1998 | |
| B | FW Fish Canada-Pikeminnow | spawning | end | 5-Jul | 1.70 | | | Scott & Crossman 1998 | |
| B | FW Fish Canada-Pikeminnow | incubation | end | 15-Jul | 1.70 | | | Scott & Crossman 1998 | |
| C | Fish of WA-Pikeminnow | spawning | start | 25-May | 1.65 | 1-Jun | 1.65 | Wydoski & Whitney 2003 | peak spawning at temperatures of 57-64$^{o}$ F |
| C | Fish of WA-Pikeminnow | spawning | end | 5-Aug | 1.65 | 30-Jun | 1.65 | Wydoski & Whitney 2003 | |
| C | Fish of WA-Pikeminnow | incubation | end | 10-Aug | 1.65 | | | Wydoski & Whitney 2003 | |
| D | Columbia R (Brilliant)-Pikeminnow | spawning | start | 1-Jun | 1.60 | | | RL&L 2000 | |
| D | Columbia R (Brilliant)-Pikeminnow | spawning | end | 20-Jul | 1.60 | | | RL&L 2000 | |
| D | Columbia R (Brilliant)-Pikeminnow | incubation | end | 1-Aug | 1.60 | | | RL&L 2000 | |
| E | Columbia R (Brilliant)-RS Shiner | spawning | start | 5-May | 1.45 | | | RL&L 2000 | used incubation start date to represent start of spawning |
| E | Columbia R (Brilliant)-RS Shiner | spawning | end | 15-Jul | 1.45 | | | RL&L 2000 | |
| E | Columbia R (Brilliant)-RS Shiner | incubation | end | 30-Jul | 1.45 | | | RL&L 2000 | |
| F | Columbia R (Brilliant)-Peamouth | spawning | start | 25-Apr | 1.40 | | | RL&L 2000 | |
| F | Columbia R (Brilliant)-Peamouth | spawning | end | 30-Jun | 1.40 | | | RL&L 2000 | |
| F | Columbia R (Brilliant)-Peamouth | incubation | end | 20-Jul | 1.40 | | | RL&L 2000 | |
| G | FW Fish Canada-Peamouth | spawning | start | 1-May | 1.35 | | | Scott & Crossman 1998 | |
| G | FW Fish Canada-Peamouth | spawning | end | 30-Jun | 1.35 | | | Scott & Crossman 1998 | |
| H | FW Fish Canada-Redside Shiner | spawning | start | 1-May | 1.30 | | | Scott & Crossman 1998 | |
| H | FW Fish Canada-Redside Shiner | spawning | end | 5-Aug | 1.30 | | | Scott & Crossman 1998 | |
| H | FW Fish Canada-Redside Shiner | incubation | end | 20-Aug | 1.30 | | | Scott & Crossman 1998 | |
| I | Fish of WA-Redside Shiner | spawning | start | 1-Apr | 1.25 | | | Wydoski & Whitney 2003 | spawning at 44-64$^{o}$ F |
| I | Fish of WA-Redside Shiner | spawning | end | 30-Jul | 1.25 | | | Wydoski & Whitney 2003 | |
| I | Fish of WA-Redside Shiner | incubation | end | 5-Aug | 1.25 | | | Wydoski & Whitney 2003 | eggs hatch in ~3-7 days at 70$^{o}$ F |
| J | Fish of WA-Pikeminnow | fry (<6cm) | start | 7-Jun | 0.65 | | | Wydoski & Whitney 2003 | swimming 1 week after hatching |
| J | Fish of WA-Pikeminnow | fry (<6cm) | end | 31-Oct | 0.65 | | | Wydoski & Whitney 2003 | end date unknown |
| K | Fish of WA-Peamouth | fry (<6cm) | start | 20-May | 0.35 | | | Wydoski & Whitney 2003 | eggs hatch in ~7-8 days |
| K | Fish of WA-Peamouth | fry (<6cm) | end | 31-Oct | 0.35 | | | Wydoski & Whitney 2003 | end date unknown |

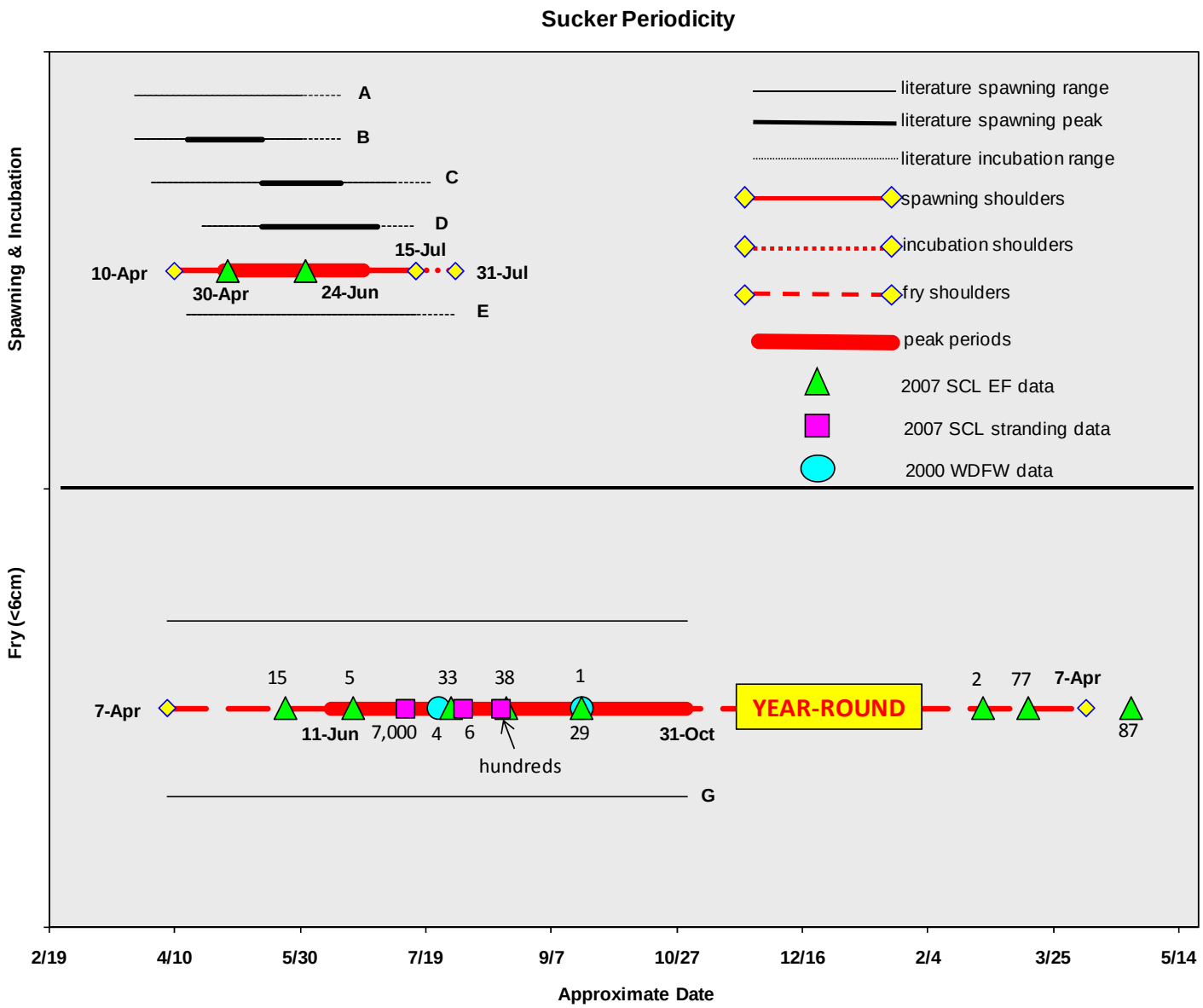


**Figure 3.3-7.** Boundary periodicity—largescale and longnose suckers (see following table for source data).

**Table 3.3-7.** Boundary periodicity—largescale and longnose suckers.

| | Periodicity Dataset | Species | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| A | Fish of WA | longnose sucker | spawning | start | 25-Mar | 1.90 | | | Wydoski & Whitney 2003 | spawning @ water temps >41$^{o}$ F |
| A | Fish of WA | longnose sucker | spawning | end | 31-May | 1.90 | | | Wydoski & Whitney 2003 | by late March temps in Boundary>41$^{o}$ F (5.0$^{o}$C) |
| A | Fish of WA | longnose sucker | incubation | start | 25-Mar | 1.90 | | | Wydoski & Whitney 2003 | eggs usually hatch in ~2-3 weeks |
| A | Fish of WA | longnose sucker | incubation | end | 15-Jun | 1.90 | | | Wydoski & Whitney 2003 | |
| B | FW Fish Canada | longnose sucker | spawning | start | 25-Mar | 1.80 | 15-Apr | 1.80 | Scott & Crossman 1998 | spawn in the "spring" when @ water temps >41$^{o}$ F |
| B | FW Fish Canada | longnose sucker | spawning | end | 31-May | 1.80 | 15-May | 1.80 | Scott & Crossman 1998 | by late March temps in Boundary>41$^{o}$ F (5.0$^{o}$C) |
| B | FW Fish Canada | longnose sucker | incubation | start | 25-Mar | 1.80 | | | Scott & Crossman 1998 | eggs usually hatch in ~14 days |
| B | FW Fish Canada | longnose sucker | incubation | end | 15-Jun | 1.80 | | | Scott & Crossman 1998 | |
| C | Fish of WA | largescale sucker | spawning | start | 1-Apr | 1.70 | 15-May | 1.70 | Wydoski & Whitney 2003 | in Pend Oreille when temps 46-55$^{o}$F(7.8-12.8$^{o}$F) |
| C | Fish of WA | largescale sucker | spawning | end | 7-Jul | 1.70 | 15-Jun | 1.70 | Wydoski & Whitney 2003 | |
| C | Fish of WA | largescale sucker | incubation | start | 1-Apr | 1.70 | | | Wydoski & Whitney 2003 | |
| C | Fish of WA | largescale sucker | incubation | end | 21-Jul | 1.70 | | | Wydoski & Whitney 2003 | |
| D | FW Fish Canada | largescale sucker | spawning | start | 21-Apr | 1.60 | 15-May | 1.60 | Scott & Crossman 1998 | |
| D | FW Fish Canada | largescale sucker | spawning | end | 30-Jun | 1.60 | 30-Jun | 1.60 | Scott & Crossman 1998 | |
| D | FW Fish Canada | largescale sucker | incubation | start | 21-Apr | 1.60 | | | Scott & Crossman 1998 | eggs usually hatch in ~14 days |
| D | FW Fish Canada | largescale sucker | incubation | end | 15-Jul | 1.60 | | | Scott & Crossman 1998 | |
| E | Foster Creek (Douglas Co.) | largescale sucker | spawning | start | 15-Apr | 1.40 | | | Vadas and Beecher 2007 | |
| E | Foster Creek (Douglas Co.) | largescale sucker | spawning | end | 15-Jul | 1.40 | | | Vadas and Beecher 2007 | |
| E | Foster Creek (Douglas Co.) | largescale sucker | incubation | start | 15-Apr | 1.40 | | | Vadas and Beecher 2007 | |
| E | Foster Creek (Douglas Co.) | largescale sucker | incubation | end | 31-Jul | 1.40 | | | Vadas and Beecher 2007 | assume 14 days |
| F | Fish of WA | largescale sucker | fry (<6cm) | start | 7-Apr | 0.70 | | | Wydoski & Whitney 2003 | 25 March + 14 days |
| F | Fish of WA | largescale sucker | fry (<6cm) | end | 31-Oct | 0.70 | | | Wydoski & Whitney 2003 | end date unknown |
| G | FW Fish Canada | largescale sucker | fry (<6cm) | start | 7-Apr | 0.30 | | | Scott & Crossman 1998 | 25 March + 14 days |
| G | FW Fish Canada | largescale sucker | fry (<6cm) | end | 31-Oct | 0.30 | | | Scott & Crossman 1998 | end date unknown |

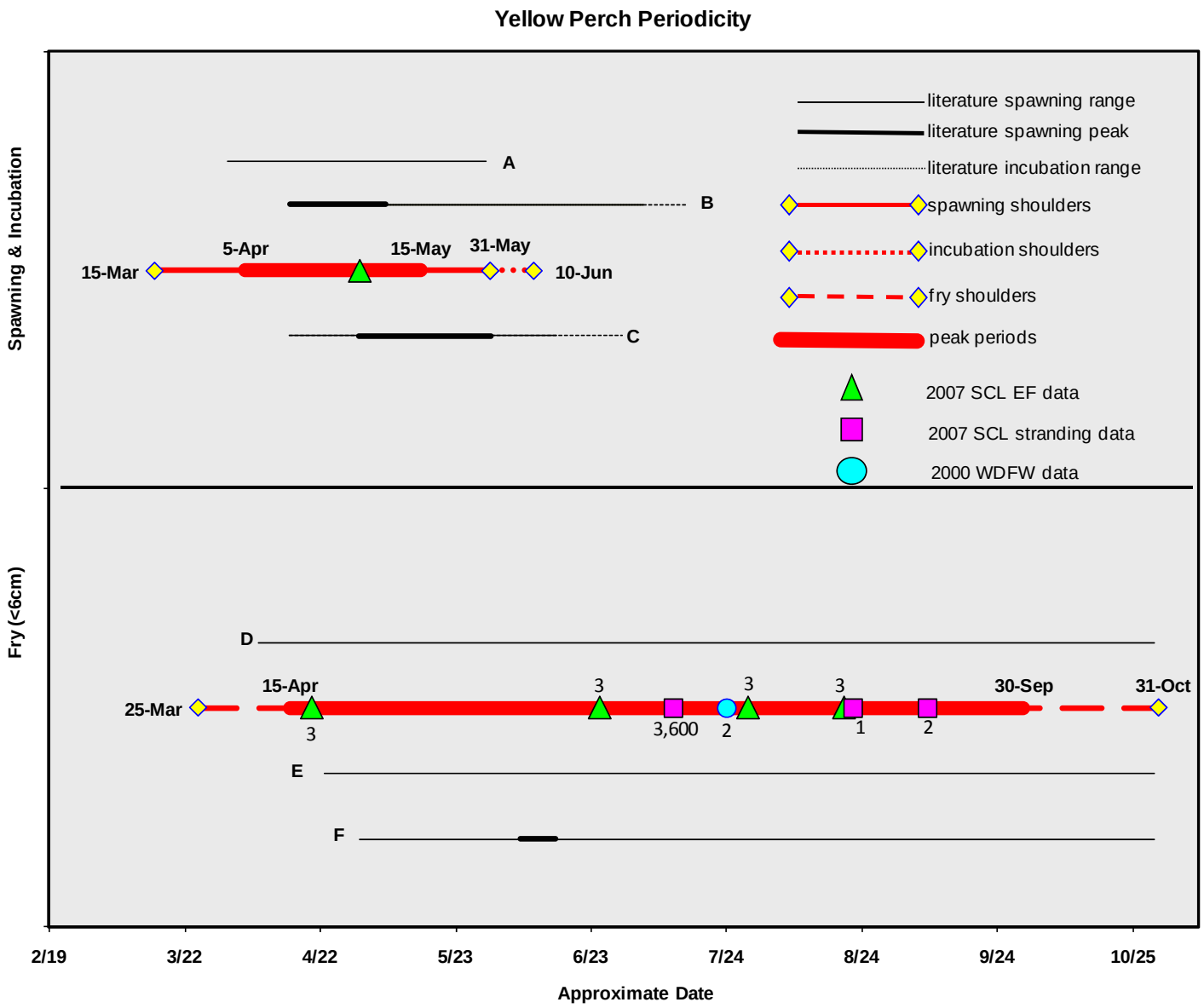


**Figure 3.3-8.** Boundary periodicity—yellow perch (see following table for source data).

**Table 3.3-8.** Boundary periodicity—yellow perch.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Fish of WA | spawning | start | 1-Apr | 1.75 | | | Wydoski & Whitney 2003 | spawning @ water temps of 45-52$^{o}$ F |
| A | Fish of WA | spawning | end | 30-May | 1.75 | | | Wydoski & Whitney 2003 | |
| B | FW Fish Canada | spawning | start | 15-Apr | 1.65 | 15-Apr | 1.65 | Scott & Crossman 1998 | spawning @ water temps of 44-54$^{o}$ F |
| B | FW Fish Canada | spawning | end | 5-Jul | 1.65 | 7-May | 1.65 | Scott & Crossman 1998 | |
| B | FW Fish Canada | incubation | start | 15-Apr | 1.65 | | | Scott & Crossman 1998 | eggs hatch in ~8-10 days, but may be as long as 27d @of 47$^{o}$ F |
| B | FW Fish Canada | incubation | end | 15-Jul | 1.65 | | | Scott & Crossman 1998 | by mid-May temps in Boundary>55$^{o}$ F |
| C | Holter/Hauser Reservoirs, MT | spawning | start | 15-Apr | 1.35 | 1-May | 1.35 | EA 1992 | spawning initiated at 43-48$^{o}$F, peaked at 45-57$^{o}$F |
| C | Holter/Hauser Reservoirs, MT | spawning | end | 15-Jun | 1.35 | 31-May | 1.35 | EA 1992 | |
| C | Holter/Hauser Reservoirs, MT | incubation | start | 15-Apr | 1.35 | | | EA 1992 | |
| C | Holter/Hauser Reservoirs, MT | incubation | end | 30-Jun | 1.35 | | | EA 1992 | |
| F | Holter/Hauser Reservoirs, MT | fry (<6cm) | start | 1-May | 0.20 | 7-Jun | 0.20 | EA 1992 | first fry (post-larvae) captured |
| F | Holter/Hauser Reservoirs, MT | fry (<6cm) | end | 30-Oct | 0.20 | 15-Jun | 0.20 | EA 1992 | peak fry (post-larvae) 2nd-3rd wks of June, end date unknown |
| D | Fish of WA | fry (<6cm) | start | 8-Apr | 0.65 | | | Wydoski & Whitney 2003 | eggs usually hatch in ~8-10 days |
| D | Fish of WA | fry (<6cm) | end | 30-Oct | 0.65 | | | Wydoski & Whitney 2003 | end date unknown |
| E | FW Fish Canada | fry (<6cm) | start | 23-Apr | 0.35 | | | Scott & Crossman 1998 | eggs usually hatch in ~8-10 days |
| E | FW Fish Canada | fry (<6cm) | end | 30-Oct | 0.35 | | | Scott & Crossman 1998 | end date unknown |

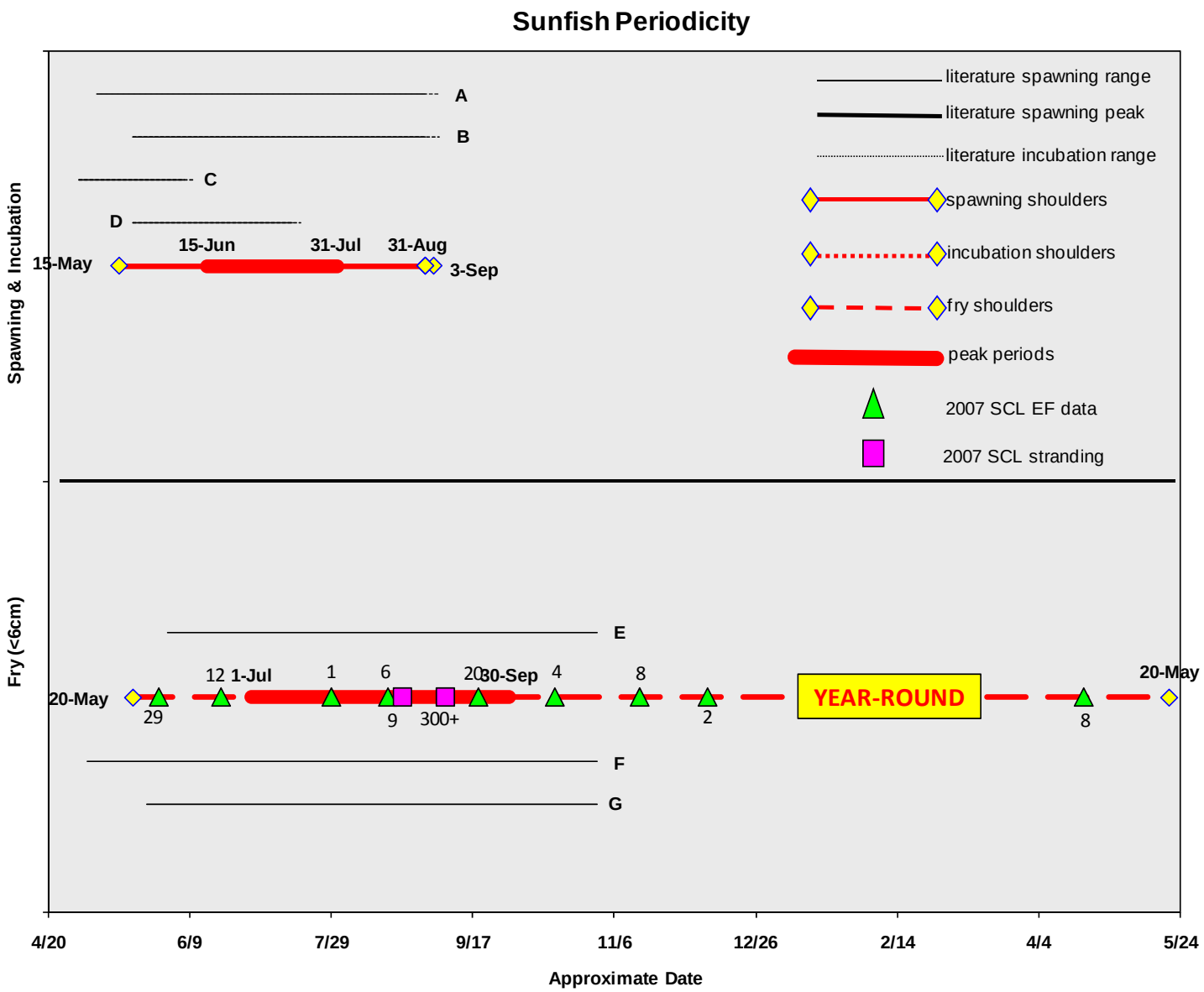


**Figure 3.3-9.** Boundary periodicity—sunfish spp. (see following table for source data).

**Table 3.3-9.** Boundary periodicity—sunfish spp.

| | Periodicity Dataset | Lifestage | | Range | code | Peak | code | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| A | Fish of WA | pumpkinseed-spwn | start | 7-May | 1.90 | | | Wydoski & Whitney 2003 | spawning @ temps 61-73°F |
| A | Fish of WA | pumpkinseed-spwn | end | 31-Aug | 1.90 | | | Wydoski & Whitney 2003 | |
| A | Fish of WA | pumpkinseed-inc | start | 7-May | 1.90 | | | Wydoski & Whitney 2003 | eggs hatch in 3+ days @ 82°F; longer at cooler temps |
| A | Fish of WA | pumpkinseed-inc | end | 5-Sep | 1.90 | | | Wydoski & Whitney 2003 | |
| B | FW Fish Canada | pumpkinseed-spwn | start | 20-May | 1.80 | | | Scott & Crossman 1998 | spawn at temps ~68° F |
| B | FW Fish Canada | pumpkinseed-spwn | end | 31-Aug | 1.80 | | | Scott & Crossman 1998 | |
| B | FW Fish Canada | pumpkinseed-inc | start | 20-May | 1.80 | | | Scott & Crossman 1998 | eggs hatch in 3+ days @ 82.4°F; longer at cooler temps |
| B | FW Fish Canada | pumpkinseed-inc | end | 5-Sep | 1.80 | | | Scott & Crossman 1998 | |
| C | Fish of WA | blk crappie-spwn | start | 1-May | 1.70 | | | Wydoski & Whitney 2003 | spawn May or early June at temps 58-64°F |
| C | Fish of WA | blk crappie-spwn | end | 7-Jun | 1.70 | | | Wydoski & Whitney 2003 | |
| C | Fish of WA | blk crappie-inc | start | 1-May | 1.70 | | | Wydoski & Whitney 2003 | eggs usually hatch in 2-3 days @ 65°F |
| C | Fish of WA | blk crappie-inc | end | 10-Jun | 1.70 | | | Wydoski & Whitney 2003 | |
| D | FW Fish Canada | blk crappie-spwn | start | 20-May | 1.60 | | | Scott & Crossman 1998 | spawn during late spring/early summer when temps 66-68°F |
| D | FW Fish Canada | blk crappie-spwn | end | 15-Jul | 1.60 | | | Scott & Crossman 1998 | |
| D | FW Fish Canada | blk crappie-inc | start | 20-May | 1.60 | | | Scott & Crossman 1998 | eggs usually hatch in 3-5 days |
| D | FW Fish Canada | blk crappie-inc | end | 18-Jul | 1.60 | | | Scott & Crossman 1998 | |
| E | Box Canyon Reservoir | fry (<6cm) | start | 1-Jun | 0.65 | | | Bennett and Liter 1991 | captured 1 inch pumpk fry in the "spring" of 1989&90 |
| E | Box Canyon Reservoir | fry (<6cm) | end | 31-Oct | 0.65 | | | Bennett and Liter 1991 | captured 1 inch pumpk fry in the "fall" of 1989&90 |
| F | Fish of WA | fry (<6cm) | start | 4-May | 0.35 | | | Wydoski & Whitney 2003 | 1 May + 3 days |
| F | Fish of WA | fry (<6cm) | end | 31-Oct | 0.35 | | | Wydoski & Whitney 2003 | end date unknown |
| G | FW Fish Canada | fry (<6cm) | start | 25-May | 0.25 | | | Scott & Crossman 1998 | 20 May + 5 days |
| G | FW Fish Canada | fry (<6cm) | end | 31-Oct | 0.25 | | | Scott & Crossman 1998 | end date unknown |

**Table 3.3-10.** Boundary periodicity dates for all species, including the duration, relative proportion, and daily percentage of affected population in peak and shoulder periods.

| Activity | | Whitefish[1] | Bull Trout | Cutthroat Trout | Redband Trout | Bass | Sunfish | Cyprinids | Yellow Perch | Suckers |
|---|---|---|---|---|---|---|---|---|---|---|
| Spawning range | start | 10/15 | 9/15 | 3/15 | 3/1 | 5/15 | 5/15 | 5/1 | 3/15 | 4/10 |
| | stop | 2/28 | 12/31 | 6/15 | 6/30 | 7/31 | 8/31 | 8/5 | 5/31 | 7/15 |
| Spawning peak | start | 11/1 | 10/1 | 4/1 | 4/1 | 6/1 | 6/15 | 6/1 | 4/5 | 4/30 |
| | stop | 1/15 | 11/30 | 5/31 | 5/31 | 7/15 | 7/31 | 7/15 | 5/15 | 6/24 |
| Incubation range | start | 10/15 | 9/15 | 3/15 | 3/1 | 5/15 | 5/15 | 5/1 | 3/15 | 4/10 |
| | stop | 4/30 | 3/25 | 7/31 | 8/15 | 8/15 | 9/3 | 8/15 | 6/10 | 7/31 |
| Incubation peak | start | 11/1 | 10/1 | 4/1 | 4/1 | 6/1 | 6/15 | 6/1 | 4/5 | 4/30 |
| | stop | 3/17 | 2/22 | 7/16 | 7/16 | 7/30 | 8/3 | 7/25 | 5/25 | 7/10 |
| Fry range | start | 4/1 | 3/15 | 6/1 | 6/15 | all | all | all | 3/25 | all |
| | stop | 9/15 | 7/15 | 4/30 | 4/30 | year | year | year | 10/31 | year |
| Fry peak | start | 5/15 | 4/15 | 8/1 | 9/1 | 7/1 | 7/1 | 6/5 | 4/15 | 6/11 |
| | stop | 7/10 | 6/15 | 10/31 | 12/31 | 10/31 | 9/30 | 9/30 | 9/30 | 10/31 |
| Spawning shoulder | # days | 61 | 47 | 32 | 61 | 33 | 62 | 52 | 37 | 41 |
| Spawning peak | # days | 75 | 60 | 60 | 60 | 44 | 46 | 44 | 40 | 55 |
| Incubation shoulder | # days | 61 | 47 | 32 | 61 | 33 | 62 | 52 | 37 | 41 |
| Incubation peak | # days | 136 | 144 | 106 | 106 | 59 | 49 | 54 | 50 | 71 |
| Fry shoulder | # days | 110 | 61 | 242 | 198 | 242 | 274 | 248 | 52 | 223 |
| Fry peak | # days | 57 | 62 | 92 | 122 | 123 | 91 | 117 | 169 | 142 |
| Spwn / Incub shoulder: | % of pop | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Spwn / Incub peak: | % of pop | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| Fry shoulder: | % of pop | 0.1 | n/a | 0.2 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.3 |
| Fry peak: | % of pop | 0.9 | n/a | 0.8 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 0.7 |
| Spawning shoulder | %/day | 0.5% | 0.6% | 0.9% | 0.5% | 0.9% | 0.5% | 0.6% | 0.8% | 0.7% |
| Spawning peak | %/day | 0.9% | 1.2% | 1.1% | 1.1% | 1.6% | 1.5% | 1.6% | 1.7% | 1.3% |
| Incubation shoulder | %/day | 0.5% | 0.6% | 0.9% | 0.5% | 0.9% | 0.5% | 0.6% | 0.8% | 0.7% |
| Incubation peak | %/day | 0.5% | 0.5% | 0.7% | 0.7% | 1.2% | 1.4% | 1.3% | 1.4% | 1.0% |
| Fry shoulder | %/day | 0.1% | n/a | 0.1% | 0.2% | 0.1% | 0.1% | 0.0% | 0.2% | 0.1% |
| Fry peak | %/day | 1.6% | n/a | 0.9% | 0.6% | 0.7% | 0.9% | 0.8% | 0.5% | 0.5% |

Note:
Whitefish spawning and incubation periodicity may change based upon data collected from whitefish spawning and incubation assessments that are being conducted in the Project area from November 2008 through January 2009.

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# Appendix 4: Stranding and Trapping Analysis Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habit Modeling*

## *Appendix 4*

## *Stranding and Trapping Analysis*

## *Final Report*

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# Study 7 Appendix 4
# Stranding and Trapping Analysis
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

Appendix 4 presents the development of the stranding and trapping analyses. Though they are similar, they are two separate analyses. Both analyses determine indices that represent the potential negative influence on fish as water level recedes either from Boundary Hydroelectric Project (Project) operations or reduction in inflow to the Project, resulting in the fish being isolated from the mainstem flow. The latter influence can be a result of operation of upstream projects, natural recession of the hydrograph, or a combination of both. Stranding involves the beaching of fish as the water levels recedes and is typically associated with low gradient shoreline areas or cover conditions that result in fish remaining in an area as it is dewatered. Mortality occurs in stranding as fish are left beached on the dewatered shoreline. Trapping is the retention of fish in pools formed by depressions as the water level recedes. Stress and potential mortality to trapped fish occur from several mechanisms including temperature fluctuations, reduction in dissolved oxygen, predation, and stranding as the water in the pool infiltrates into the substrate. Both the stranding and trapping analyses utilize results of hourly water surface elevation determinations from the Hydraulic Routing Model (HRM) (Appendix 2 and Sections 4.2 and 5.2 of Study 7, Mainstem Aquatic Habitat Modeling Study Final Report [SCL 2009a]) to track water level fluctuations and calculate numerical indices representing the potential for stranding and the potential for trapping of aquatic organisms.

The development of the stranding and trapping analysis involved three main areas: defining the modeling approach, performing the field data collection, and development of factors to be utilized in the calculation of the indices. The initial effort was the data collection performed in 2007. This allowed a better understanding of the conditions and processes important to stranding and trapping in the study area. Based on the 2007 efforts and general stranding and trapping concepts, the equations for determining the stranding and trapping indices were developed along with provisional values for the associated factor values. A data collection program to provide information to refine provisional estimates of the factor values was developed. The data collection effort was conducted from March through August 2008. The factors were developed from this data and approved by the relicensing participants through a series of meetings. These are the factors that were used in the determination of the stranding and trapping indices.

In 2007, initial investigations of trapping and stranding conditions conducted through field reconnaissance and review of aerial photographs and the bathymetric mapping indicated there were distinct regions within the study area where areas for potential stranding and trapping were concentrated. This resulted in dividing the study area into 23 regions (see Section 4, Figure 4.1-1). References to these regions are made throughout this appendix when discussing locations of specific stranding or trapping areas.

## 2 OBJECTIVES

The goal of the stranding and trapping effort is determination of numerical indices representing the potential for stranding and trapping of aquatic organisms. More specifically, the effort was targeted to evaluating the stranding and trapping potential for juvenile fish. The stranding and trapping indices provided a relative quantification between operations scenarios of the potential for stranding and trapping of aquatic organisms. The procedures were not intended to estimate the actual number of fish that may experience mortality from stranding or trapping. Specific objectives of the effort were:

- Develop the modeling approach for calculating the stranding and trapping indices. This included the following:
    - Develop equations to calculate indices reflecting the relative quantification of stranding and trapping potential for juvenile fish under operations scenarios.
    - Develop the modeling procedures for calculating the stranding and trapping indices.
- Identify provisional values for factors in the index equations.
- Collect field data to support the development of the stranding and trapping index equations and the determination of the factors within the equations.
- Apply the data collected to determine the values of the stranding and trapping equations.

## 3 MODELING APPROACH AND PROVISIONAL FACTORS

The approach to the trapping and stranding analyses was similar to other analyses involving the evaluation of the effects of water surface elevation fluctuations in the varial zone. These other analyses include the evaluation of indices for macrophytes, benthic macroinvertebrates (BMI), and periphyton. As with the other indices, the stranding and trapping indices utilized results of the Scenario Tool and the HRM to determine the water surface elevation on an hourly basis to evaluate conditions throughout the mainstem habitat modeling study area.

The stranding and trapping analyses followed a similar approach; however, there were two differences. First, the stranding and trapping analyses only tracked the period of dewatering (stranding) or the period of disconnection (trapping). Fish were assumed to return to potential stranding and trapping areas shortly after the water surface elevation rises to once again inundate/connect the areas. Secondly, stranding and trapping indices were not treated as values that are summed on an hourly basis. Stranding and trapping were viewed as a series of events or cycles. Therefore, the results were computed at the end of a cycle based on the duration of the cycle, then these results are summed over the series of cycles. A cycle starts when a stranding area becomes dewatered or a trapping area becomes disconnected from the mainstem. A cycle ends when a stranding area becomes inundated or a trapping area becomes reconnected to the mainstem. Each cycle is represented by a single index value computed at the end of the cycle rather than a summation of hourly values calculated over the cycle. A cycle may be as short as an hour or may last many days. The distinction between discrete hourly values for the macrophyte, periphyton, and BMI versus a single value per cycle for stranding and trapping was made because, in the former case, the hourly indices represent the relative state of the biota of

interest on an hourly basis whereas the stranding and trapping indices represent the overall potential for stranding and trapping at the completion of a cycle.

Stranding and trapping were separate analyses in Study 7. The distinction is stranding results in immediate beaching of fish as the water level recedes, whereas trapping involves fish being retained in pools as the flow recedes. In the case of stranding, mortality happens quickly from the fish being beached. In the case of trapping, fish may survive for hours or days in the trapping pools and mortality may be the results of thermal stress, low oxygen, predation, or stranding from dewatering of the pool. For both the stranding and trapping analyses, ramping rates were not directly incorporated as a factor in the calculation of the indices. Strong relationships between ramping rate and incidence of trapping were not consistently demonstrated in previous studies (Hunter 1992; Higgins and Bradford 1996; R.W. Beck and Associates 1989). Ramping rates were determined for historic wet, dry, and average years as part of the downramping analysis including the exceedance of specific hourly rates ranging from 2 inches per hour to over 12 inches per hour (Appendix 5 and Sections 4.5 and 5.5 of the Study 7 Final Report [SCL 2009a]). The results of both indices can be reviewed along with the reported ramping rates associated with a specific hydrologic condition or operations scenario.

In conducting the evaluation of stranding and trapping potential, periodicity for each of the fish species of interest is an important factor. The potential for stranding and trapping of a specific fish species depends on the presence in the system of lifestage(s) susceptible to stranding and trapping, and the likelihood that the susceptible life stages would be utilizing the areas with stranding and trapping potential. The results for the development of the periodicity table are presented in Appendix 3 and Section 5.3.1 of the Study 7 Final Report (SCL 2009a). The results of fish distribution studies (Study 9, Fish Distribution, Timing, and Abundance Study Final Report [SCL 2009b]) also assisted in evaluating the results of the stranding and trapping analysis by indicating areas in which species of interest may be more abundant. Because the stranding and trapping indices were calculated at each habitat transect location within the HRM, there was a high level of spatial resolution to the indices. This helped in evaluating and interpreting the results of the stranding and trapping indices developed.

The indices for stranding and trapping are based on equations that relate physical characteristics of the stranding and trapping sites to the potential for stranding and trapping to occur. The information for the physical site characteristics were derived from the bathymetry and mapping through the application of a Geographic Information System (GIS). The index equations have physical factors related to site area, depth, and cover conditions. The observations and data collected during the stranding and trapping field surveys assisted in developing the ratings for several of these factors. The following paragraphs present the two indices, their factors, and initial estimates for factor values (provisional values). The trapping index is presented first because its formulation has more factors than the stranding index and covers the concepts that are also proposed for stranding.

## 3.1. Stranding

The stranding equation is simpler than the trapping equation. The primary differences are the lack of the duration of trapping and the contributing basin area factors. A duration associated with the stranding factor is not needed because it is assumed that the 1-hour time interval for

modeling is sufficient to cause mortality to the vast majority of fish that become stranded. The contributing basin factor was not included because fish can readily pass across the stranding areas and would not typically have a tendency to concentrate as they would with the depressions of the trapping areas. Therefore, the area upgradient from the stranding location was not believed to influence the potential for stranding. The resulting equation for stranding is:

$$SI = A_S * C_S$$

Where:

$SI$ = stranding index
$A_S$ = stranding area in square feet
$C_S$ = cover factor for stranding

Figure 3.1-1 provides a conceptual sketch of a trapping area, both in plan and section view, which will help in defining several of the above factors.

### 3.1.1. Stranding Index – SI

The stranding index is calculated once for each stranding event. It was decided that there would not be a time component (duration) to stranding. It was assumed that the 1-hour time interval of the modeling is sufficient to cause mortality for the vast majority of fish stranded for this length of time. It was also assumed that once the stranding area is again inundated, it reaches its full potential for stranding; i.e., the fish population is replenished. This is a conservative assumption, particularly in the winter when juvenile fish movement is less because they may hide in coarse substrate during daylight hours. Based on this assumption, it is not necessary to track potential residual fish from survival or model repopulation of the stranding area over time.

The SI is calculated for each 1-foot elevation band. Elevation bands are assigned to the nearest habitat transect in the HRM for the purpose of calculating an area and for defining the hourly water surface elevation used to determine whether the stranding area is inundated or dewatered. The factors on the right hand side of the equation are defined for each 1-foot elevation band within the range of Project operations. A set of elevation bands is assigned within each Region for the purpose of calculating the stranding index.

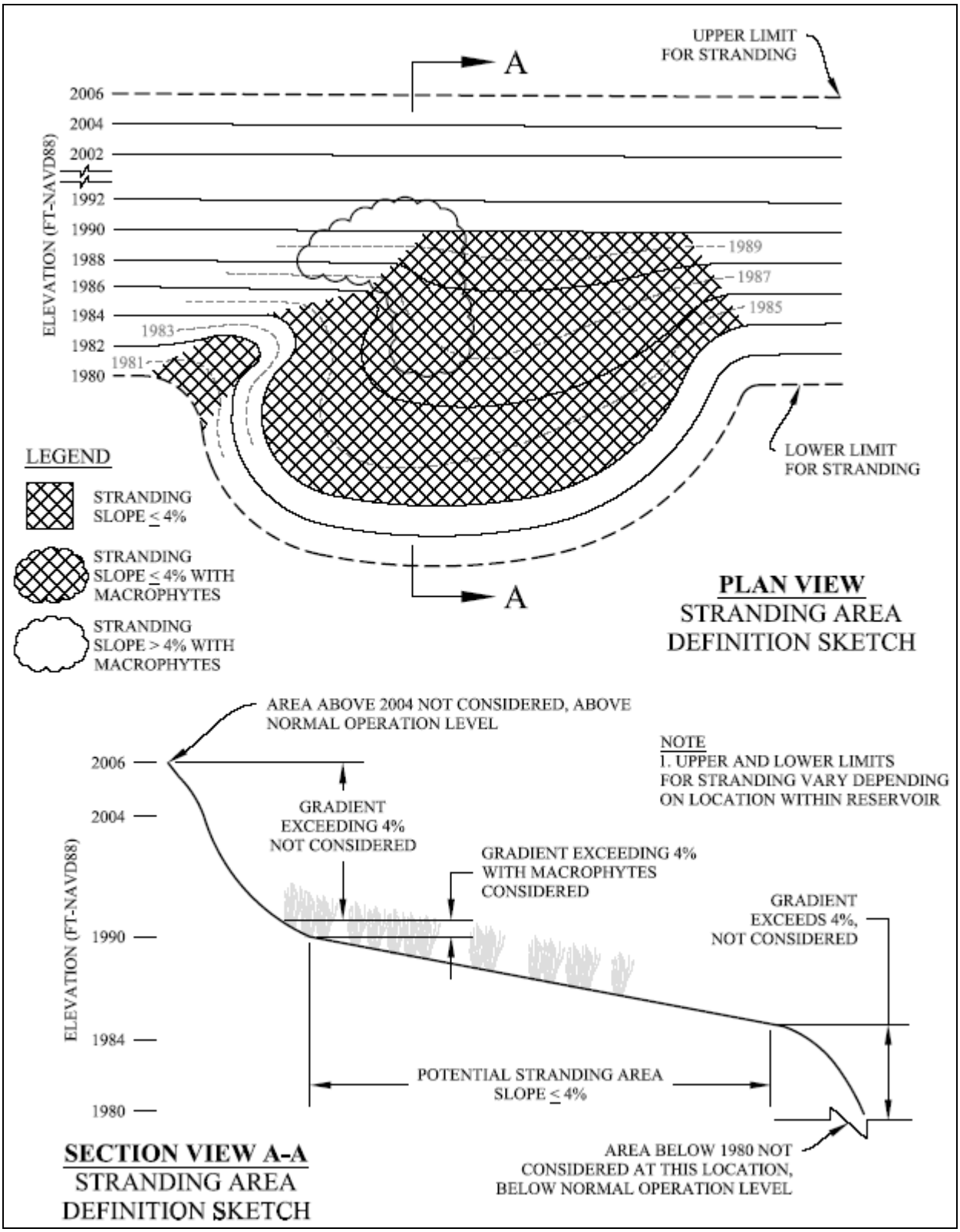


**Figure 3.1-1.** Conceptual sketch of stranding area, plan and section views.

### 3.1.2. Area of Stranding – $A_S$

Stranding areas are defined as areas with a slope of 4 percent or less, excluding depression areas that have already been included in the trapping area analysis. Stranding areas are also defined as areas where cover poses a potential for stranding regardless of slope. Inclusion of cover as potential stranding on slopes greater than 4 percent is based on field observations in 2007, which indicated that where macrophytes occurred, there was likely to be stranding. The 2008 data collection effort was used to investigate the influence of cover on stranding, and the results are reflected in the final factors presented in Section 6.

Specific stranding zones are defined at 1-foot elevation intervals to allow for tracking of dewatering of stranding areas as the water surface elevation rises and falls. Stranding zones are assigned to each mainstem habitat transect and correspond to the length of the mainstem assigned during the transect weighting (see Section 4.1.1 of Study 7 Final Report [SCL 2009a]). The unit for stranding area is square feet.

The stranding area within each elevation band for each mainstem habitat transect was determined from the bathymetry using GIS tools. Only potential sites of contiguous areas of 1,000 square feet or greater were considered in the stranding analysis. Setting the minimum stranding area at 1,000 square feet eliminates narrow bands of flat slopes, which pose minimal stranding risk due to the short distance to deeper water. Additionally, setting the area at 1,000 square feet aids in highlighting the areas having broad low gradient bars that pose the greatest stranding risk in Boundary Reservoir. Several elevation bands may make up the 1,000-foot minimum as long as they are connected to each other. Similar to the logic for applying the trapping area directly as a factor in the trapping index calculation, it was assumed that the potential presence of fish in a stranding elevation band is directly proportional to the area of the elevation band.

### 3.1.3. Cover Factor – $C_S$

The stranding cover factor represents the influence of aquatic macrophytes on the potential for stranding. In establishing the provisional cover factor values, if aquatic macrophytes are not present on a potential stranding slope of 4 percent or less, then this factor is neutral and set to a value of 1.0. If aquatic macrophytes are present on a slope of greater than 4 percent, the provisional value is set at 2.0. This is double the potential for stranding on a slope of 4 percent or less without aquatic macrophytes. This is based on general observations from 2007 that macrophyte beds appear to have a higher potential for stranding than the open lower gradient areas. Setting the provisional value at 3.0 for the low gradient areas with macrophytes is based on the potential for even greater stranding risk on these flatter areas with macrophytes. For slope greater than 4 percent without macrophyte cover, the stranding potential is considered minimal and the provisional value is set at 0.0. The provisional values for the cover factor are listed below in Table 3.1-1.

**Table 3.1-1.** Provisional values for the cover factor in the stranding analysis.

| Gradient | Macrophytes Presence | Cover Factor |
|---|---|---|
| ≤ 4% | No | 1.0 |
| ≤ 4% | Yes | 3.0 |
| > 4% | No | 0.0 |
| > 4% | Yes | 2.0 |

Substrate was considered in development of the cover factor, but was not included in the provisional values. This is based on field observations indicating that macrophytes are by far the most important factor and that typically, only the large cobble and larger substrate are considered to appreciably influence stranding. There are only a few locations in the project area where cobble or larger size substrate exist. Based on the observations in 2007, limited areas of such substrate may exist in the first mile below Box Canyon Dam (Region 18) along the irregular left bank bars, in the "Islands" area (Region 10), and the right bank tailrace bar near the hydraulic control just upstream of the border (Tailrace Region).

## 3.2. Trapping

The equation for determining the trapping index was presented several times at Fish and Aquatic Workgroup meetings including October17, 2007; February 28, 2008; and July 7, 2008. Final approval on the approach was reached after October 1, 2008, workgroup meeting.
The equation for computing the trapping index has been formulated as:

$$TI = A_T * B_T * T_T(D) * C_T$$

Where:

- $TI$ = trapping index
- $A_T$ = trapping area (square feet)
- $B_T$ = contributing basin factor
- $T_T(D)$ = duration of trapping factor
- $C_T$ = cover factor representing the influence of macrophytes and other cover

In the above equation, there are two basic types of factors. The factors $A_T$, $B_T$, and $C_T$ represent the risk that fish will be trapped in the pool. The larger these factors, the higher the potential for trapping fish in the pool. The fourth factor, $T_T(D)$, represents the potential for mortality of fish trapped in a pool once it becomes isolated from the mainstem. It is the ratio of fish mortalities to total fish trapped. The trapping factors are not species-specific. The results of the trapping index calculations require review of fish periodicity to determine if species of interest and associated life stages susceptible to trapping are present during a particular period.

Figure 3.2-1 provides a conceptual sketch of a trapping area, both in plan and section view to help in defining several of the above factors. The remainder of the section provides a description of each of the factors and provisional values.

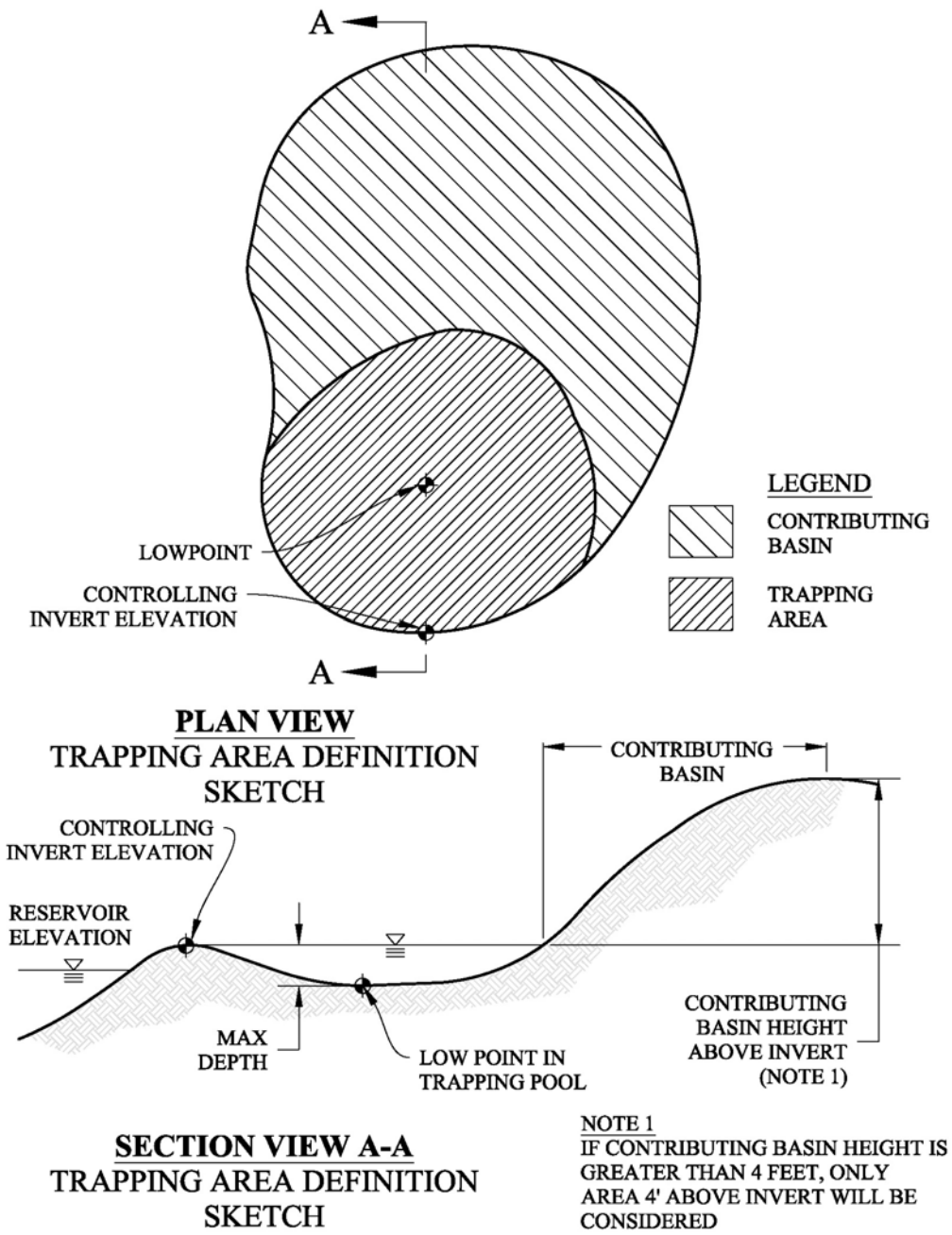


**Figure 3.2-1.** Conceptual sketch of trapping area, plan and section views.

### 3.2.1. Trapping Index – TI

The trapping index is calculated once per trapping event and represents the likelihood that fish will be trapped in the pool when the pool becomes disconnected from the mainstem flow, and the potential for fish mortality that is dependent on the duration of the trapping event. The TI is calculated for each individual trapping depression. Consequently, the factors on the right hand side of the equation are defined for individual trapping pools. Each pool has an effective elevation assigned to its outlet, which allows for determination of trapping duration based on application of the hourly elevations available from the HRM and the mainstem habitat transect closest to controlling water surface for the trapping pool outlet.

The index is calculated once per trapping event because it is a representation of the potential for mortality that is dependent on the length of the trapping event. It is only necessary to calculate the index at the end of the event, not at intermediate points. The duration of trapping is the total time between disconnection of the trapping site and reconnection to the mainstem. It is also assumed that once the trapping area is reconnected, it reaches its full potential for trapping within the one hour that elapses before the next time interval. This assumption represents a 100 percent recolonization within one hour. The assumption is conservative in that a species of interest may require some time (days to weeks) to recolonize trapping areas. However, because of this simplifying assumption, it is not necessary to track the survival and dispersal of residual fish or to model the repopulation of a trapping area over time.

### 3.2.2. Trapping Area – $A_T$

The trapping area factor is the actual area of the depression or pool in square feet. GIS tools have been used to identify each depression and determine its area and several other parameters. In using the area of the depression directly as a factor, it is assumed that the potential presence of fish in a trapping area is directly proportional to the area of the depression. This is the area of the depression or pool that is below the "effective outlet elevation." The effective outlet elevation is used to account for the influence of a mat of macrophytes causing the outlet to be effectively disconnected from the mainstem at an elevation above the actual outlet invert. A value of 0.5 foot was added to the outlet invert elevation if macrophytes were present. Additionally, a marginal depth of 0.1 foot for clear outlets was added to the outlet elevation to account for minimum depth at which fish will still utilize the outlet.

The area of trapping along with the associated outlet invert elevation, with modifications for the effective outlet elevation, are determined from the bathymetry utilizing GIS analysis tools. The trapping areas were based on the area below the effective outlet elevation. Depressions with areas of less than 100 square feet were not considered in the trapping analysis.

### 3.2.3. Contributing Basin Factor – $B_T$

This factor accounts for the area that drains into the trapping basin as the mainstem recedes that is above the effective outlet elevation. The area that can potentially contribute fish to be trapped includes not only the area of the depression ($A_T$), but also the areas draining into the depression above the effective outlet elevation. The provisional assumption was that this factor would be used to account for the contributing basin area up to a limit of 4 feet above the effective outlet

invert. The contributing basin factor would be set equal to the ratio of the contributing area divided by the trapping area. If the ratio is above 3.0, the factor is set to a maximum 3.0. The resulting contributing basin provisional factors are provided in Table 3.2-1.

**Table 3.2-1.** Provisional values for contributing basin area factor in the trapping analysis.

| Ratio: Basin Area/$A_T$ | Contributing Basin Factor |
|---|---|
| 1.0 | 1.0 |
| 1.5 | 1.5 |
| 2.0 | 2.0 |
| 2.5 | 2.5 |
| 3.0 | 3.0 |
| >3.0 | 3.0 |

The provisional setting of the factor equal to the ratio of the contributing basin area to the trapping pool area is based on the assumptions that the presence of fish is proportional to the area and that most of the fish in the contributing area will pass through the actual depression area before leaving the site as the reservoir elevation falls. By setting the ratio equal to the area ratio, the assumption is made that fish in the contributing area are as likely to be trapped as those in the actual depression. Therefore, this factor is set conservatively high, because some portion of the contributing basin may drain without passing through the depression area. By setting the upper limit of the factor at 3.0 and the elevation above the effective outlet at 4 feet, there is recognition that the contributing basin concept has limits both laterally and vertically.

The proposed setting of the factor equal to the ratio is based on the assumptions that the presence of fish is proportional to the area and that most of the fish in the contributing area will pass through the actual depression area before leaving the site as the reservoir elevation falls. By setting the ratio equal to the area ratio, the assumption is made that fish in the contributing area are as likely to be trapped as those in the actual depression. Therefore, this factor is set conservatively high, because some portion of the contributing basin may drain without passing through the depression area. By setting the upper limit of the factor at 3.0 and the elevation above the effective outlet at 4 feet, there is recognition that the contributing basin concept has limits both laterally and vertically.

A variety of factors besides the size of the contributing basin may affect fish density in trapping pools. For example, the natural variability of fish distribution and abundance independent of the drainage basin may obscure a relationship between fish density and catchment area. In addition, differences in sampling efficiency between sampling methods and among different pools and seasons may limit the ability to refine this modeling assumption.

### 3.2.4. Duration of Trapping Factor – $T_T(D)$

The duration of trapping factor is incorporated to account for the temporal aspect of the potential for fish mortality as the duration that a pool is isolated increases. A variety of factors can contribute to the mortality rate as the duration the outlet has been dewatered increases, including:

temperature change (heating in summer or cooling/freezing in winter), lowering of dissolved oxygen, predation, and dewatering of the pool by seepage. The depth of the pool can influence how quickly these mechanisms result in trapped fish mortality. Therefore, the provisional assumption was to have three separate depth-based curves to define the factor. Each curve represents the increase in mortality as the duration of isolation increases for a range of maximum pool depths.

The provisional relationships for both summer and winter conditions are presented in Figure 3.2-2. The summer conditions relationship is presented in tabular form in Table 3.2-2. As shown in this table, for pool depths greater than 2 feet, full mortality is reached in 48 hours; for pool depths between 1 and 2 feet, full mortality is reached in 36 hours; and for pool depths less than 1 foot, full mortality is reached in 24 hours. These provisional values were developed in 2007 based on professional judgment prior to collecting actual data in 2008 to relate fish mortality to duration of trapping at Boundary Reservoir.

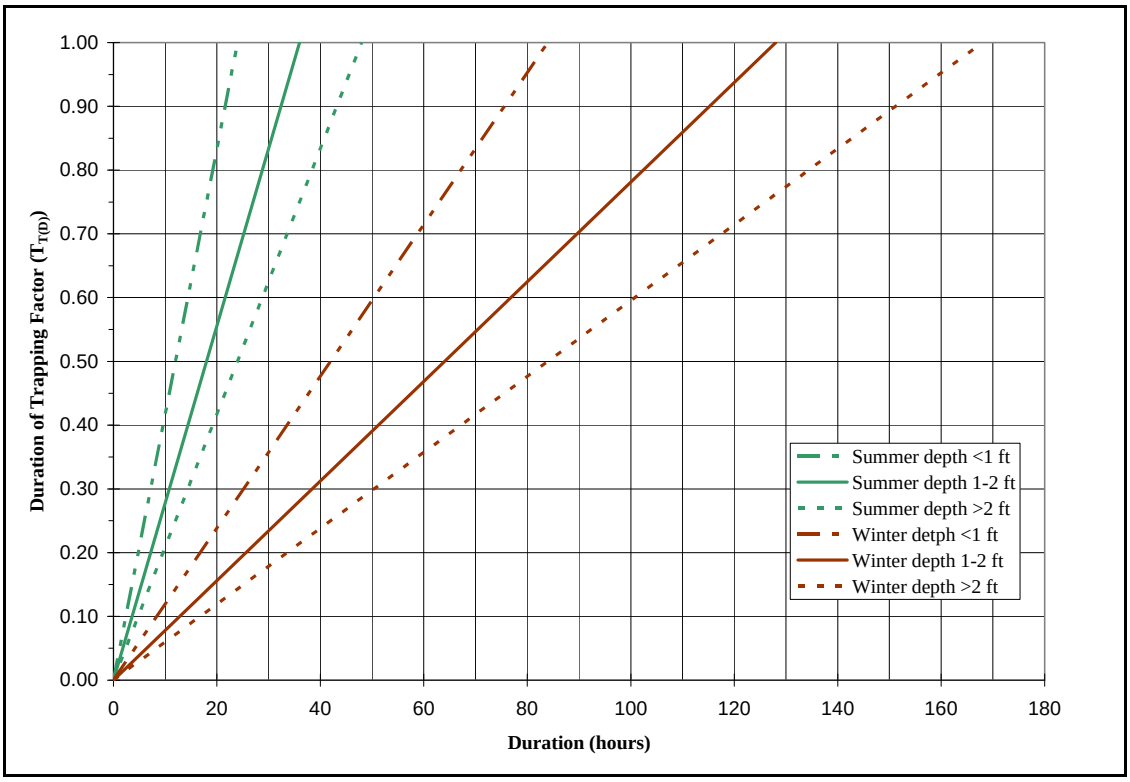


**Figure 3.2-2.** Provisional relationship for duration of trapping factor for summer and winter conditions in the trapping analysis.

**Table 3.2-2.** Provisional values for duration of trapping factor ($T_T$[D]) for summer conditions in the trapping analysis.

| Depth < 1 foot | | Depth 1 to 2 feet | | Depth > 2 feet | |
|---|---|---|---|---|---|
| **Hours** | **$T_T$(D)** | **Hours** | **$T_T$(D)** | **Hours** | **$T_T$(D)** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 6 | 0.25 | 9 | 0.25 | 12 | 0.25 |
| 12 | 0.50 | 18 | 0.50 | 24 | 0.50 |
| 18 | 0.75 | 27 | 0.75 | 36 | 0.75 |
| 24 | 1.0 | 36 | 1.0 | 48 | 1.0 |

For winter months, the provisional "greater than 2 feet curve" was adjusted from the provisional summer curve to have a 168-hour (1-week) period for reaching a factor of 1.0. The other two depth curves were adjusted for winter in a similar manner by maintaining the same ratio of 3.5 (168 to 48 hours). The resulting provisional duration of trapping factors for winter conditions, along with the summer factors, are shown in Figure 3.2-2 and listed in Table 3.2-3.

**Table 3.2-3.** Provisional values for duration of trapping factor ($T_T$[D]) for winter conditions in the trapping analysis.

| Depth < 1 foot | | Depth 1 to 2 feet | | Depth > 2 feet | |
|---|---|---|---|---|---|
| **Hours** | **$T_T$(D)** | **Hours** | **$T_T$(D)** | **Hours** | **$T_T$(D)** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 21 | 0.25 | 32 | 0.25 | 42 | 0.25 |
| 42 | 0.50 | 64 | 0.50 | 84 | 0.50 |
| 63 | 0.75 | 96 | 0.75 | 126 | 0.75 |
| 84 | 1.0 | 128 | 1.0 | 168 | 1.0 |

### 3.2.5. Cover Factor - $C_T$

The cover factor represents the influence of cover on the potential for trapping of fish in disconnected depressions. A variety of cover conditions had initially been considered and discussed for application in determining this factor, including macrophytes, LWD, and coarse substrate. The provisional cover factor considered the presence of macrophytes only as a contributing condition. LWD was excluded because its occurrence is relatively rare compared to macrophytes and was considered a secondary influence. Substrate was not considered in the provisional cover factor because there is limited cobble in gently sloping areas associated with trapping pools. However, Region 10 is primarily cobble and coarse gravel containing several significant pools that appear to have been created by past gravel mining activities. Region 10 was included in the trapping surveys to investigate this aspect of trapping.

The provisional cover factor for the trapping analysis accounting for the presence of macrophytes is provided in Table 3.2-4. The macrophyte factor is used only during periods when the macrophytes are present. For other periods, the value is set to 1.0.

**Table 3.2-4.** Provisional values for the cover factor ($C_T$) in the trapping analysis.

| Percent Macrophytes | Designation | $C_T$ Factor |
|---|---|---|
| None | None | 1.0 |
| < = 25 | Sparse | 1.5 |
| > 25 | Abundant | 3.0 |

## 3.3. Hydraulic Model Integration

The HRM is a key element of the stranding and trapping analyses. It is used to determine water surface elevations on an hourly time step along the entire study area. The hourly water surface elevations provide the basis for identifying when a stranding or trapping site becomes dewatered or disconnected from the mainstem channel as well as the duration. The HRM was run for the historic wet, dry, and average years and will be run for each operations scenario. The HRM provides a series of hourly water surface elevations associated with each hydrologic condition or scenario at each habitat transect.

The HRM includes 49 habitat transects from Boundary Dam to the Box Canyon tailrace and 14 habitat transects form Boundary Dam to Red Bird Creek. The HRM calculates the water surface elevation at each of these transects for each hourly time interval. The water surface elevations at a transect provide the estimate of the water surface elevation at adjacent stranding and trapping areas.

The hourly water surface elevations from the hydraulic routing model are used slightly differently depending on whether the information is being used for the calculation of the stranding index or the trapping index. This is due to the differences in spatial representation of the stranding areas versus the trapping areas and in the definition of the elevation used to represent the hydraulic connection with the mainstem. Separate descriptions of the use of the hydraulic routing model results are provided for stranding and trapping.

### 3.3.1. Stranding

As presented in Section 3.1.2, the stranding areas identified from the bathymetry using GIS were divided into zones of 1-foot elevation increments. The 1-foot increments were set at even feet. The elevation chosen to represent a stranding zone was the vertical midpoint between the limits of the zone. For example, a zone defined by the 1,986-foot NAVD 88 (1,982 feet NGVD 29)[1]

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

contour as its lower limit and the 1,997 feet NAVD 88 (1,983 feet NGVD 29) contour as its upper limit will be represented by an elevation of 1,986.5 (1,982.5 feet NGVD 29). The elevation of 1,986.5 feet NAVD 88 (1,982.5 feet NGVD 29) is compared against the water surface elevation from the nearest habitat transect to identify whether the elevation zone is inundated or dewatered. If the water surface elevation is equal to or above 1,986.5 feet NAVD 88 (1,982.5 feet NGVD 29), the zone between 1,986 and 1,987 feet NAVD 88 (1,982 and 1,983 feet NGVD 29) is considered to be inundated, and if the water surface is below 1,986.5 feet NAVD 88 (1,982.5 feet NGVD 29), the zone is considered to be dewatered.

For each hourly time increment, the hourly elevation from the HRM for the representative cross section is compared against the midpoint elevations for each stranding zone to determine which stranding zones become dewatered during the current time increment. When the HRM indicates an elevation zone becomes dewatered, a stranding cycle begins and the stranding index is computed for the elevation zone for that hour. The computed stranding index is added to the sum of the stranding indices from all previous stranding cycles for the elevation zone. For this procedure, the stranding index is cumulative over the entire modeling period, with each stranding event contributing once to the total.

The stranding index is calculated only once within an elevation zone during a stranding cycle. Therefore, the elevation zone can remain dewatered for additional hours or even days, but the cumulative stranding index for the elevation zone for the modeling period does not increase until a new stranding cycle is initiated. A new cycle is not initiated until the stranding elevation zone once again becomes inundated and is subsequently dewatered. The stranding index is only increased during the initial hour of a stranding cycle because the assumption was made that 1 hour is sufficient to cause mortality to the vast majority of fish stranded. Therefore, until the elevation zone is inundated again, there are no surviving fish present that would result in additional mortality as the duration of dewatering increases.

Table 3.3-1 summarizes the four possible combinations of current and previous dewatering and inundation conditions and action the stranding modeling procedure takes.

**Table 3.3-1.** Action taken in the stranding index calculation based on current and previous hour inundation and dewatering states.

| **Inundation/Dewatering State** | | **Action Taken in Stranding Calculation** |
|---|---|---|
| **Previous Hour** | **Current Hour** | |
| Inundated | Dewatered | Stranding event starts, stranding index is calculated and summed to previous index total, zero out inundation flag, proceed to next hour |
| Dewatered | Dewatered | Stranding event continues, stranding index does not change, proceed to next hour |
| Dewatered | Inundated | Stranding event is over, reset inundation flag to 1, stranding index does not change, proceed to next hour |
| Inundated | Inundated | Stranding index does not change, proceed to next hour |

Several modeling assumptions were incorporated into the stranding model formulation. The assumptions were presented to and agreed upon by the relicensing participants on September 11, 2008. These assumptions are listed below.

- Stranding areas of less than 1,000 square feet are considered in the stranding analysis.
- After a period of isolation from the mainstem, recolonization of a stranding area is assumed to occur within the first hour of reinundation by the mainstem.
- Downramping rates are not incorporated into the stranding index equation. Ramping rates are determined for mainstem habitat transects and averaged by reach under operations scenarios as part of the concurrent but separate downramping analysis.
- Species-specific stranding factors were not developed. Interpretation of the calculated stranding index for various times of the year requires reviewing fish periodicity to determine if species of interest and associated life stages susceptible to stranding are present.

### 3.3.2. Trapping

The trapping pools were identified from the bathymetry using GIS tools. The effective outlet elevation was set at either 0.5 foot or 0.1 foot above the outlet invert of the trapping pool based on the presence or absence of macrophytes, respectively. Each trapping pool was assigned a cross section from the hydraulic routing model to determine the hourly water surface elevations adjacent to the trapping area. Trapping areas within a region were assigned to the habitat transect which best represents the water surface elevations in that region.

For each trapping pool, the area, effective outlet elevation, maximum depth, contributing basin factor, and cover factor were tabulated. For each hourly time increment, the hourly elevation from the HRM for the representative habitat transect are compared against the effective outlet elevation for each trapping pool to determine whether a trapping pool is connected or disconnected from the mainstem. When a trapping area becomes disconnected during an hourly interval, a trapping event has been initiated and the trapping model starts tracking the duration of the trapping event. For each hourly interval the trapping pool remains dewatered, i.e., the water surface elevation in the mainstem remains below the effective outlet elevation, an hour is added to the duration of trapping. Once the water surface elevation in the mainstem rises above the effective outlet elevation of the trapping pool, the trapping event ends and the duration is not increased by an hour. At the end of the trapping event, the total duration of the event and the maximum pool depth are used to derive the duration of trapping factor. The trapping index for the trapping event is calculated by multiplying the duration of trapping factor by the other associated trapping factors. This trapping index value is added to the previously summed trapping index value for the given trapping area. Table 3.3-2 summarizes the four possible combinations of current and previous disconnected and connected conditions and the action the trapping modeling procedure takes.

**Table 3.3-2.** Action taken in the trapping index calculation based on current and previous hour inundation (connected) and dewatering (disconnected) states.

| Inundation/Dewatering State | | Action Taken in Trapping Calculation |
|---|---|---|
| **Previous hour** | **Current hour** | |
| Connected | Disconnected | Trapping event starts, trapping duration is set at one hour, zero out connection flag, proceed to next hour. |
| Disconnected | Disconnected | Trapping event continues, one hour is added to duration of trapping, proceed to next hour. |
| Disconnected | Connected | Trapping event is over, reset connection flag to 1, duration of trapping factor is determined based on duration of trapping from previous hour and the maximum pool depth, the trapping index for the trapping event is calculated by multiplying the duration of trapping by the other trapping factors, add current trapping index to previous sum of trapping indices for the trapping area, proceed to next hour. |
| Connected | Connected | Trapping index does not change, proceed to next hour. |

Several modeling assumptions are incorporated in the trapping model formulation. The assumptions were presented to and agreed upon by the relicensing participants on October 1, 2008. These assumptions are listed below.

- When calculating when a trapping pool becomes isolated from the mainstem channel, 0.5 foot was added to the outlet invert elevation if macrophytes are present.
- For outlets free of macrophytes, 0.1 foot was added to the outlet invert elevation to account for minimum depth at which fish will still utilize the outlet to access the mainstem flow.
- Depressions with areas of less than 100 square feet were not considered in the trapping analysis.
- After a period of isolation from the mainstem, recolonization of a trapping pool is assumed to occur within the first hour of the pool being reconnected to the mainstem.
- Downramping rates are not incorporated into the trapping index equation. Ramping rates are determined for mainstem habitat transects and averaged by reach under operations scenarios as part of the concurrent but separate downramping analysis.
- Species-specific trapping factors are not developed. Interpretation of the calculated trapping index for various times of the year require reviewing fish periodicity to determine if species of interest and associated life stages susceptible to trapping are present.

## 3.4. Determination of Parameters for Stranding and Trapping Analyses

Detailed mapping of potential stranding and trapping areas was developed from the bathymetry of the Boundary Reservoir and tailrace using ArcGIS (version 9.2). The resulting maps serve two primary purposes. The first purpose is to aid field efforts in locating and characterizing areas where fish may become stranded or trapped during reduction in water surface elevations. The second purpose is to provide an accurate basis for characterizing the stranding and trapping areas to conduct the modeling effort. Use of the GIS system allowed for the incorporation of

both physical and biological conditions on a geographic basis to determine the characteristics of the stranding and trapping areas. Information in addition to the bathymetry, e.g., the macrophyte mapping, can be overlaid on the stranding and trapping maps to further aid in the development of the site characteristics. Many of the site characteristics that are used to develop the stranding and trapping parameters and to link with the HRM are developed from the mapping through application of the GIS tools. A full presentation of the development of the stranding and trapping maps and model parameters is presented in Appendix 1c.

An example of one of the stranding and trapping maps is provided in Figure 3.4-1. All 23 stranding and trapping region maps are provided in Attachment A of Appendix 1c. Figure 3.4-2 provides an example of an overlay of the macrophyte mapping. This mapping is used to determine the percentage of the stranding or trapping area with aquatic macrophytes present. In the case of trapping, the presence of cobble substrate was also evaluated from the GIS database for each trapping pool. Figure 3.4-3 provides an enlargement to illustrate the detail provided by the mapping for specific stranding and trapping areas.

Table 3.4-1 provides an overview of the basis for development of various site characteristics and factors used in the stranding and trapping analysis. This table lists the various parameters and factors and identifies whether they are developed directly from GIS, derived from GIS-based parameters, or determined using HRM and GIS-based parameters. In the latter two cases, the GIS parameters that provide the basis for the determination are identified by their table ID numbers. A parameter developed directly from GIS is a physical characteristic determined directly using the GIS tools that analyze the bathymetry and other spatial data such as macrophyte and substrate mapping. Examples of parameters derived directly from GIS are the stranding area and trapping area. An example of a parameter derived from GIS-based parameters is the stranding cover factor. The presence of mapped macrophytes is used to look up the cover factor which varies depending on the time of year (periodicity) and the slope of the trapping areas. The actual values of the stranding and trapping factors used in each region in the application of the models are provided in Appendix 1c, Attachments B and C.

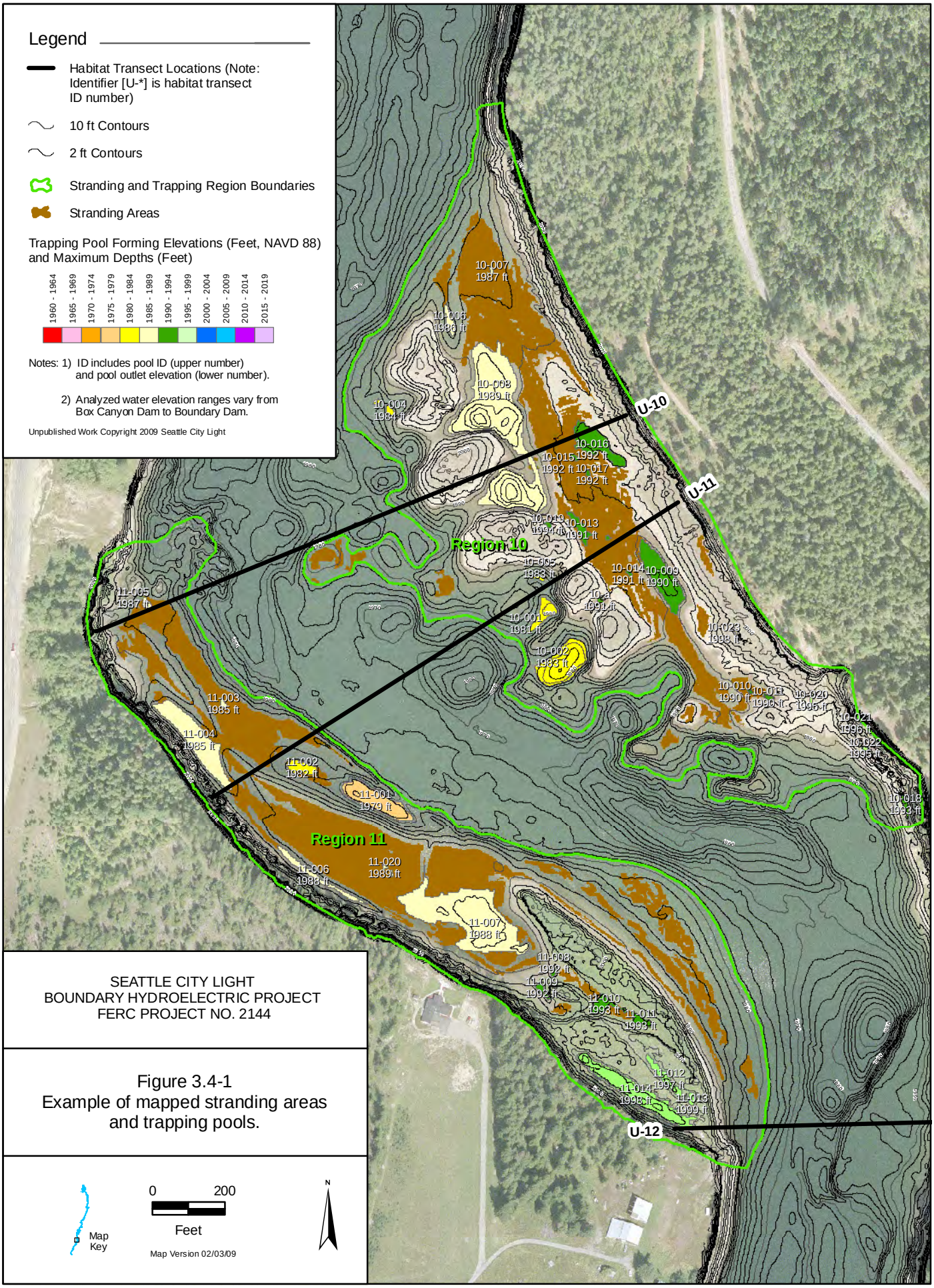


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Figure 3.4-1
Example of mapped stranding areas and trapping pools.

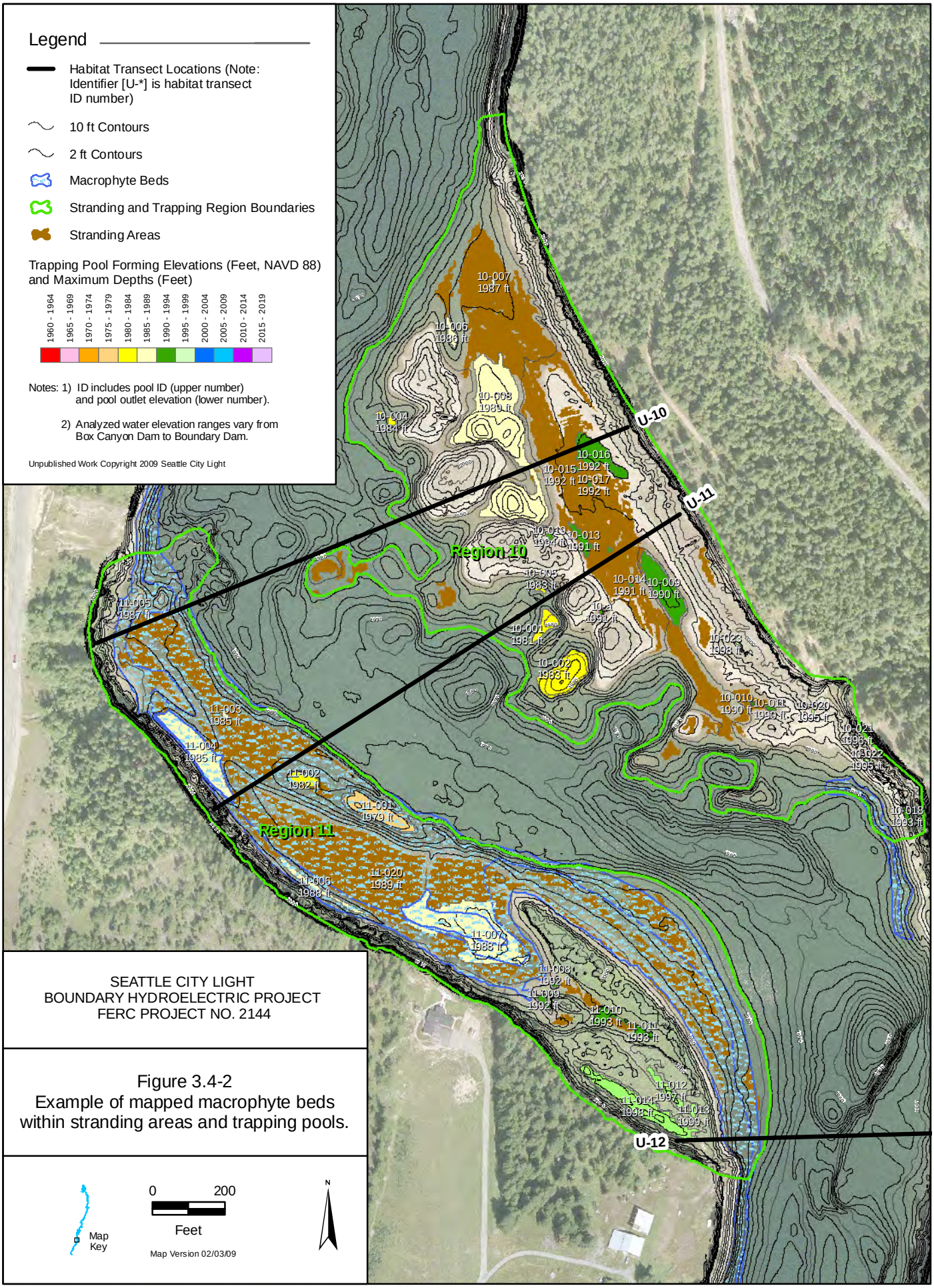


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Figure 3.4-2
Example of mapped macrophyte beds within stranding areas and trapping pools.

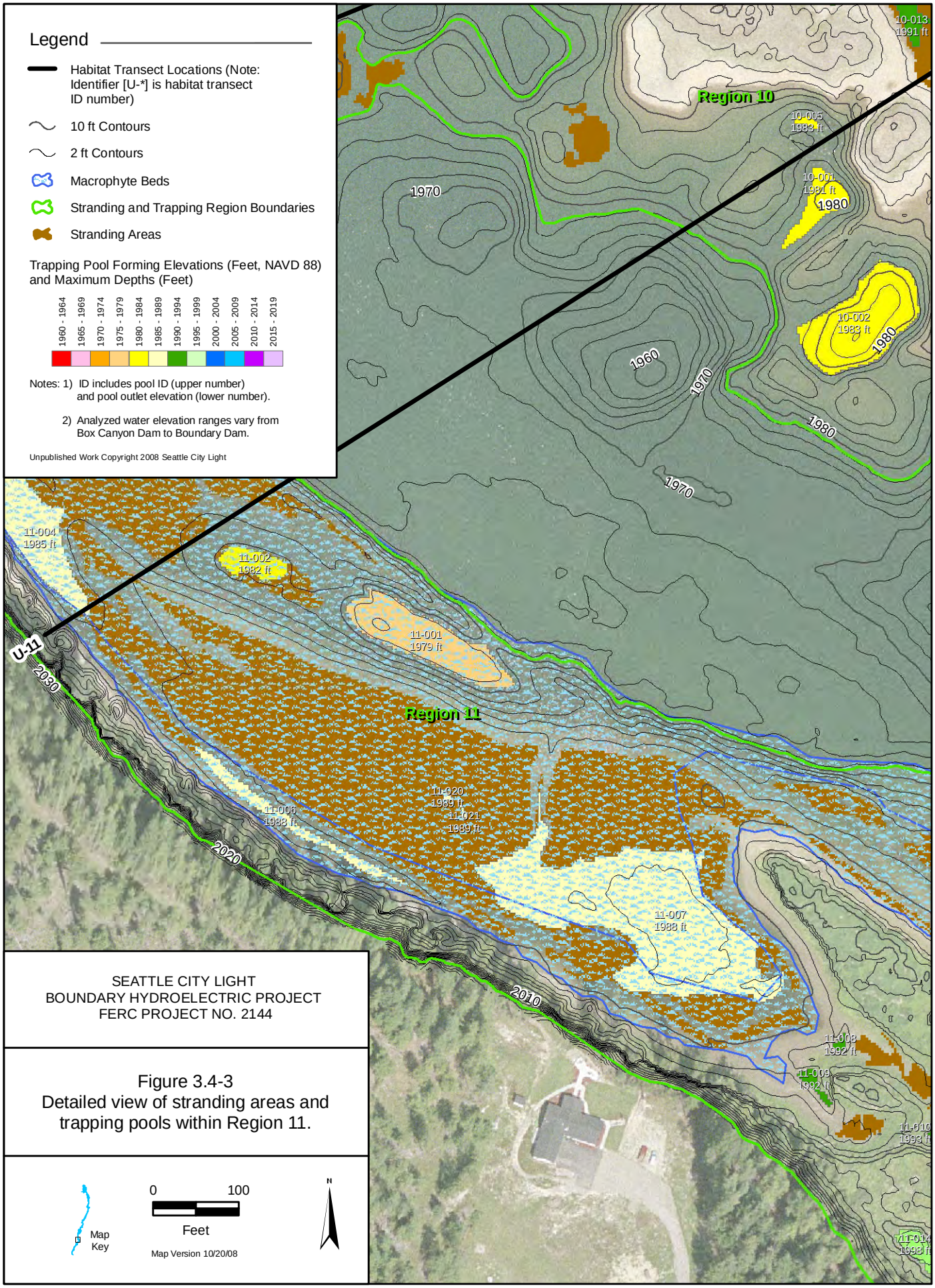


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Figure 3.4-3
Detailed view of stranding areas and trapping pools within Region 11.

**Table 3.4-1.** Summary of stranding and trapping parameters and factors with information basis for their development.

| ID No. | Parameter/Factor (units) | Determination Source | | |
|---|---|---|---|---|
| | | Directly from GIS | Based on GIS Parameter (ID No.) | From Application of the HRM |
| 1 | Trapping area (square feet) | Y | --- | --- |
| 2 | Outlet elevation - trapping (feet NAVD 88) | Y | --- | --- |
| 3 | Effective outlet elevation - trapping (ft NAVD 88) | N | 2,5 | --- |
| 4 | Substrate type - trapping | Y | --- | --- |
| 5 | Duration - trapping (hours) | N | 6 | Y |
| 6 | Mapped macrophytes (Y/N) trapping | Y | --- | --- |
| 7 | Cover factor - trapping (macrophytes or cobble) | N | 6 | --- |
| 8 | Mapped macrophytes (Y/N) | Y | --- | --- |
| 9 | Stranding slope (percent) | Y | --- | --- |
| 10 | Stranding area (square feet) | Y | 8,9,10 | --- |
| 11 | Cover factor for stranding | N | 8,9 | --- |
| 12 | Elevation of stranding area (feet NAVD 88) | Y | --- | --- |
| 13 | Hourly water surface elevation (feet NAVD 88) | N | --- | Y |
| 14 | Inundation and dewatering - stranding | N | 12 | Y |

Notes:
HRM – hydraulic routing model
GIS – geographic information system

# 4 FIELD DATA COLLECTION METHODS

Data collection efforts in support of the stranding and trapping analysis were conducted in both 2007 and 2008. The 2007 efforts concentrated on gaining an understanding of stranding and trapping conditions throughout the study area. This included determining areas with the greatest potential for stranding and trapping which were designating the stranding and trapping regions. It also involved identifying the processes and conditions that contribute to stranding and trapping within the study area. This information was utilized to develop the modeling approach to the stranding and trapping analyses and design the data collection efforts conducted in 2008 to support determination of the factors and their associated values.

## 4.1. 2007 Stranding and Trapping Survey Efforts

Stranding and trapping field data supply information on the characteristics of stranding and trapping sites, location, species, and life stage of fish species that become stranded or trapped. The following section describes the action taken in 2007 to initially identify potential sites, the use of detailed bathymetry maps that show selected slope, pool sizes, pool depth and elevations, and field measurements taken for both physical and biological information to characterize conditions which may have caused fish to become stranded or trapped.

### 4.1.1. Reconnaissance Survey

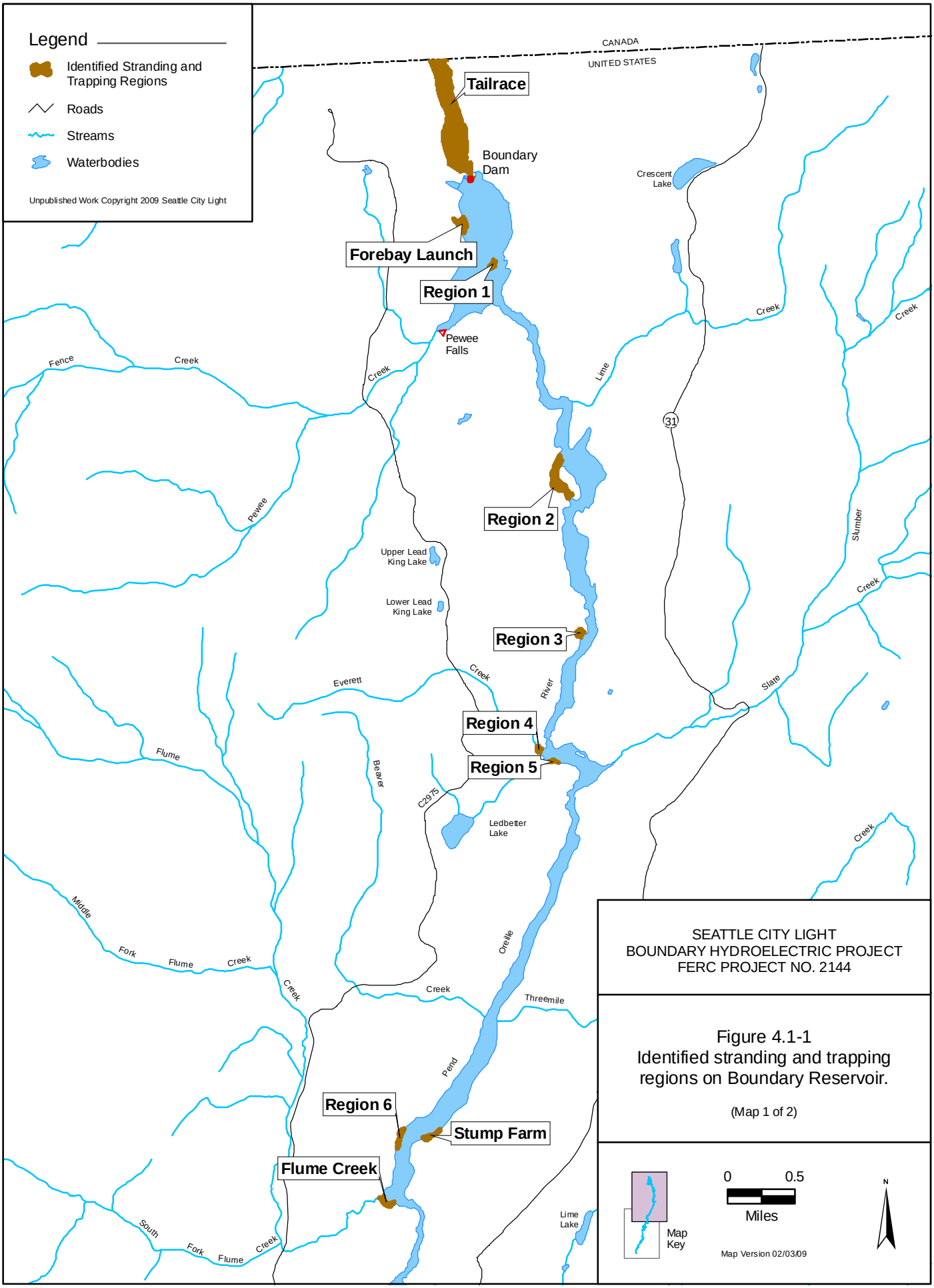
Suitable regions for study were initially selected by a three-person reconnaissance survey on June 21, 2007, with an understanding of the local habitat conditions previously acquired through conducting field surveys of fish distribution, timing, and abundance (SCL 2009b). Additionally, the study considered a local resident's report of where fish stranding and trapping had occurred in the past or habitat area with fish stranding and trapping potential. The survey crew included staff with extensive knowledge and experience of stranding and trapping habitat characteristics from multiple studies conducted in similar regions of the Pacific Northwest, and staff familiar with the reservoir and tailrace. This survey was conducted prior to the start of sampling in 2007 to identify areas with the potential to strand or trap fish during flow or water surface elevation reductions.

### 4.1.2. Region Identification and Associated Areas

Regions with physical and habitat characteristics likely to result in stranding or trapping were identified for sampling by integrating the results of the reconnaissance survey and local knowledge with aerial photographs and bathymetric maps. Regions selected for sampling met one of the following criteria:

- Encompassed pools that were expected to isolate as reservoir levels drop during Project operations,
- Exhibited low gradient shoreline profiles (e.g., primarily less than 4 percent), or
- Contained coarse substrate or other cover such as submerged macrophytes that could potentially strand or trap fish.

Based on the results from the reconnaissance survey and the criteria described above, 18 regions in the reservoir were identified that posed the largest risk to strand or trap fish. These included 6 regions in the lower reservoir (Canyon and Forebay reaches) and 12 regions in the upper reservoir. During sampling, 4 other regions were identified and sampled that had not been initially noted during the reconnaissance survey in June. A fifth additional region was identified in the Tailrace Reach upstream of the border. Figure 4.1-1 presents the location of all 23 regions. Areas from the GIS mapping of each identified region are provided in Table 4.1-1. Overall, based on the GIS analysis, 93 percent of the stranding area and 95 percent of the trapping area is located upstream of Metaline Falls in the Upper Reservoir Reach. The Canyon Reach has the next largest portion of stranding and trapping areas at approximately 4 percent each. The Forebay and the Tailrace reaches each have about 0.5 percent of the trapping area. In terms of stranding area, the Forebay Reach has about 2 percent and the Tailrace Reach about 1 percent.


Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
CANADA
UNITED STATES
Tailrace
Boundary Dam
Crescent Lake
Forebay Launch
Region 1
Pewee Falls
Fence
Creek
Creek
Lime
Creek
Creek
31
Pewee
Region 2
Slumber
Upper Lead King Lake
Lower Lead King Lake
Creek
Region 3
Everett
Creek
River
Slate
Region 4
Region 5
Flume
Beaver
C2975
Ledbetter Lake
Creek
Middle
Fork
Flume
Creek
Creek
Creek
Threemile
Orville
Pend
Region 6
Stump Farm
Flume Creek
Lime Lake
South
Fork
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 4.1-1
Identified stranding and trapping regions on Boundary Reservoir.
(Map 1 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
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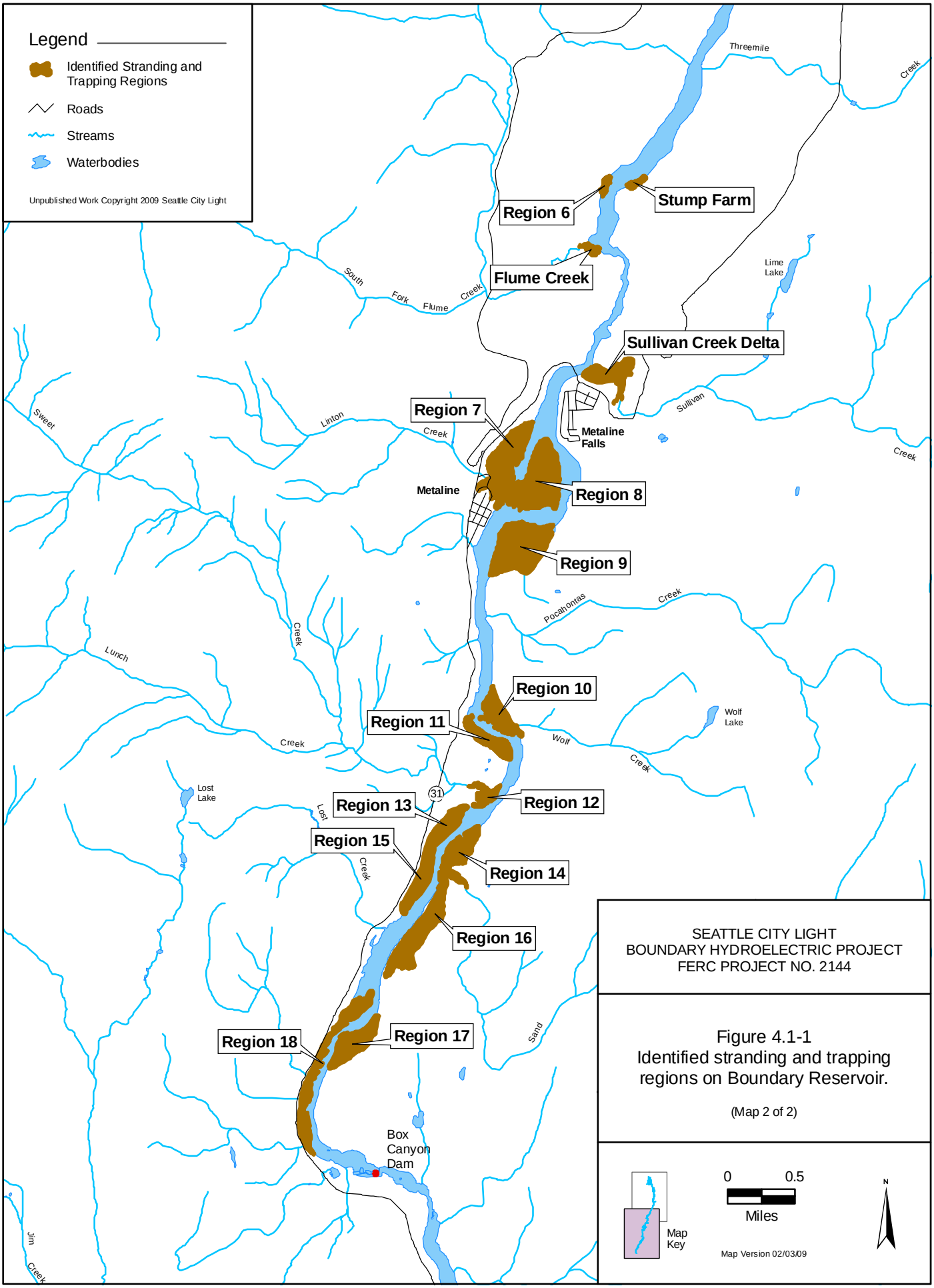
Legend
Identified Stranding and Trapping Regions
Roads
Streams
Waterbodies
Unpublished Work Copyright 2009 Seattle City Light
Threemile
Creek
Stump Farm
Region 6
Flume Creek
South
Fork
Flume
Creek
Lime Lake
Sullivan Creek Delta
Sullivan
Creek
Sweet
Linton
Creek
Region 7
Metaline Falls
Metaline
Region 8
Region 9
Pocahontas
Creek
Creek
Lunch
Region 10
Region 11
Wolf Lake
Wolf
Creek
Creek
Lost Lake
31
Region 13
Region 12
Lost
Region 15
Creek
Region 14
Region 16
Sand
Region 18
Region 17
Box Canyon Dam
Jim
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 4.1-1
Identified stranding and trapping regions on Boundary Reservoir.
(Map 2 of 2)
Map Key
0
0.5
Miles
Map Version 02/03/09
N

**Table 4.1-1.** Approximate areas of identified stranding and trapping regions (total stranding area = 9,629,00 $ft^2$, total trapping area = 2,221,000 $ft^2$).

| Reach | Region | Total Stranding Area within Region ($ft^2$) | Total Number of Trapping Pools within Region | Total Trapping Area within Region ($ft^2$) |
|---|---|---|---|---|
| Tailrace | Tailrace | 127,873 | 17 | 10,629 |
| Forebay | Forebay Launch | 150,800 | 4 | 11,142 |
| | 1 | 62,642 | 1 | 189 |
| Canyon | 2 | 248,363 | 20 | 81,669 |
| | 3 | 18,405 | 1 | 108 |
| | 4 | 13,628 | 3 | 2,169 |
| | 5 | 42,845 | 1 | 135 |
| | Stump Farm | 28,321 | 1 | 153 |
| | 6 | 4,576 | 5 | 1,980 |
| | Flume Creek | 11,559 | 2 | 1,809 |
| Upper Reservoir | Sullivan Creek | 244,138 | 63 | 99,657 |
| | 7 | 407,994 | 40 | 269,793 |
| | 8 | 2,521,424 | 217 | 677,155 |
| | 9 | 2,227,835 | 121 | 252,558 |
| | 10 | 193,775 | 24 | 86,055 |
| | 11 | 847,881 | 16 | 83,979 |
| | 12 | 12,177 | 22 | 15,417 |
| | 13 | 391,009 | 35 | 49,374 |
| | 14 | 389,839 | 41 | 99,045 |
| | 15 | 569,991 | 22 | 52,182 |
| | 16 | 91,409 | 139 | 317,925 |
| | 17 | 583,908 | 61 | 40,248 |
| | 18 | 438,874 | 63 | 67,770 |

### 4.1.3. 2007 Stranding and Trapping Surveys

Seven stranding and trapping surveys were conducted between July 11 and September 8, 2007. Surveys on July 11 and 12 were reconnaissance level surveys conducted during an unusual summer drawdown event that occurred at the request of another licensing study. The July survey did not collect the same level of information obtained during later sampling efforts. Habitat information was collected during the surveys conducted between August 3 and September 8. Stranding and trapping regions were accessed by boat for all surveys except for August 22, when regions were accessed by foot from nearby roadways due to low water elevations that caused difficulties with boat launching and loading. The dates of these surveys, along with the stranding and trapping regions surveyed, are presented in Table 4.1-2.

**Table 4.1-2.** Stranding and trapping survey dates and regions sampled, July to September 2007.

| Survey Date | Stranding and Trapping Regions Sampled |
|---|---|
| July 11 | 7, 8, 10 |
| July 12 | Sullivan Creek Delta, 11, 13, 14, 15, 16, 17, Boundary Tailrace |
| August 3 | 10, 12, 13, 14, 16, 17, 18 |
| August 22 | 7, 8, 9, 11, 15 |
| September 7 | 1, 2, 3, 4, 5, 6, Stump Island, Flume Creek Mouth |
| September 8 | Forebay Launch, 10, 14, 15, 16, 17 |

Stranding and trapping surveys were conducted both during and following a significant drop in water surface elevation. Crews consisted of two personnel. Upon arrival on site, the field crew surveyed the entire region to identify pools and stranding areas. During surveys in August, pools and stranding areas were marked on aerial photographs. By September, preliminary versions of the bathymetric maps were completed, and a combination of these maps and aerial photographs was used to record the locations of trapping pools and stranding areas observed during surveys conducted in September. The pools and stranding areas were then surveyed, and stranded or trapped fish within these areas were documented. The habitat characteristics recorded by field crews at each region are described in Section 4.1.3.1. Stranded and trapped fish were either captured by dip net or collected by hand, and life history information was recorded (described in Section 4.1.3.2).

#### *4.1.3.1. Habitat Data Collection*

The general observed habitat characteristics of each region were reported. For many regions, information was reported on specific locations or sites within a region. This included specific pools for trapping and slope areas relating to stranding. The field crews recorded the following habitat characteristics at most stranding or trapping regions and at certain specific sites within each region surveyed:

- Approximate area of the site drawn on aerial photographs or detailed bathymetry maps;
- Stranding or trapping condition (e.g., stranding, trapping then stranding, trapping only);
- Size of exposed substrate as measured by the modified Wentworth method (Cummings 1962);
- Exposed substrate parameters (including embeddedness, angularity, and compaction);
- Slope at one or more locations within a region, and slope length measured (distance between crew members recording slope);
- Mainstem and isolated pool water temperatures (using hand-held calibrated thermometers accurate to ± 1°C);
- Maximum pool depth at time of sampling; and
- Estimated area and available cover of each trapping pool or stranding area after disconnecting from the reservoir.

One of the primary objectives during stranding and trapping surveys was to identify the stranding and trapping mechanisms observed at each site. Factors that can affect the risk of stranding include low gradients, substrate characteristics, and presence of aquatic macrophytes. Factors that affect the likelihood and severity of trapping include elevation drop, size and depth of the isolated feature, the bathymetry surrounding the feature, and the presence of macrophytes.

All trapping areas have the potential to eventually strand fish as water drains from the entrapment, whereas stranding areas typically strand fish concurrently with the receding river water if they do not immediately vacate the area being dewatered.

Available cover types recorded for each trapping pool and stranding area after isolation from the mainstem reservoir include shallow pool, deep pool, large and small woody debris, interstices, terrestrial vegetation, and aquatic vegetation. In potential stranding and trapping areas, substrate and cover were sometimes moved to look for affected fish, but detailed surveys were not made.

#### *4.1.3.2. Fish Life History Information*

Fish collected during the reservoir level reduction surveys were processed for the following life history information:

- Species
- Length (mm)
- Life stage
- Habitat association, such as isolated pool, interstices, and side channel
- Overall fish health

## 4.2. 2008 Stranding and Trapping Survey Efforts

The goal of the 2008 stranding and trapping surveys was not to estimate the total number of fish stranded or trapped in the Project area. The 2008 field surveys effort focused on collecting data that could be used to develop the provisional factors associated with stranding and trapping indices for use in the modeling effort. Stranding and trapping surveys during 2008 were conducted during periods of normal Project operations and following atypical drawdown events conducted to support relicensing studies. The median daily change in reservoir water surface elevation during the period 1987 to 2005 was 7 feet measured at the Boundary Dam forebay (R2 2008). Daily changes in water surface elevations are greater in the fall, winter, and spring months, and less during the summer months when SCL implements a voluntary constraint on pool level fluctuations. During 2008, stranding and trapping surveys were conducted following periods of typical Project operations in March, April, May, July, and August. In addition, stranding and trapping surveys were conducted following a July drawdown event where the change in water surface elevation at the Boundary forebay was approximately 16 feet, and following an August drawdown event where the change in water surface elevations was approximately 14 feet.

### 4.2.1. 2008 Stranding Surveys

Stranding surveys consisted of visual counts of the number of fish stranded along relatively low gradient shoreline areas of the stranding sites after a reduction in reservoir pool elevation. Stranding surveys were conducted using several different methods.

Upon arrival by the two-man survey crew, the size of the potential stranding area at the time was visually estimated as small or large. For smaller stranding areas (generally areas of less than 2,000 square feet) with little or no aquatic vegetation, the entire stranding area was surveyed by the crews walking methodically along the entire survey area looking for stranded fish laying on the surface. Following the survey, the area was measured so that a surface area of the survey site could be calculated.

In areas where the available stranding area appeared to cover more than 2,000 square feet, surveys were conducted within a subsample of the entire stranding area by surveying along oblique transect lines. Surveyors walked along a transect line running obliquely through the recently dewatered varial zone starting from the obvious high water mark to the current pool level. The search zone along each transect was limited to 6 feet (3 feet on either side of the surveyor's path). If the length of the survey area allowed, additional oblique paths could be added resulting in a "zigzag" pattern of search for stranded fish through stranding area. The length of each survey transect or oblique search line was measured so that the total search area could be calculated. The survey goal using this transect method was a minimum of 300 feet, or 1,800 $ft^2$ per stranding site (300-foot transect by 6-foot search width).

In cobble and boulder substrate areas where stranded fish could potentially be caught within interstitial spaces, a 1 square foot area beneath the surface layer of substrate was excavated and inspected for every three steps of the survey (or approximately one subsurface inspection for every 10 feet of survey distance). The stranding survey transect search width area goal was 6 feet (3 feet on either side of the survey path). This equated to a subsurface/interstitial space inspection of approximately one square foot for every 60 square feet of surface area surveyed. This subsurface-to-surface area subsampling ratio was true for both the entire area and transect methodologies.

Macrophytes are aquatic plants, growing in or near water that are emergent, submergent, or floating. Macrophytes are beneficial for lake fish populations by virtue of the cover they provide to smaller life stages. However, as these areas become exposed, they can pose a greater risk of stranding fish that utilize that cover. In stranding areas covered with dense aquatic vegetation, a subsample of the area below the surface layer of weeds was inspected to account for stranded fish that are not visible on the macrophyte surface layer. Surveyors inspected a 1-meter by 1-meter square plot systematically located every ten steps along the survey transect line (or approximately one detailed inspection for every 30 feet of survey distance). The entire depth of emergent macrophyte areas were inspected at each subsample plot. Effort was made to keep the subsamples within the 6-foot transect search width. The subsample consisted of searching the entire depth of the vegetative mat within the square meter plot. A minimum of 10 non-overlapping square-meter subsamples were collected at each aquatic vegetated stranding area.

On the few occasions when a stranding area was visited more than once during a single stranding episode, markers were left in place to ensure that subsequent surveys did not overlap areas previously surveyed.

Information recorded during the stranding surveys included the following:

- Date of survey
- Time of survey (used to determine pool elevation at time of the survey)
- Survey region
- GPS or map position at start and end points of surveys
- Type of methodology employed (whole area or transect)
- Length of transect line
- Type of dominant substrate or cover of the survey area or transect
    - Fines (composed of mud, clay, or fine sand; substrates <0.125 inch in diameter),
    - Gravels (composed of materials ranging from coarse sand to medium gravels; substrates 0.125 to 3.0 inches in diameter),
    - Coarse materials (large gravels, cobbles, or boulders; substrates >3.0 inches in diameter), and
    - Aquatic macrophytes (rooted aquatic vegetation)
- Fish species and size (total length) for all stranded fish found during surveys
- Type of habitat associated with stranded fish (fine, gravel, cobble, macrophyte) and location of stranded fish (surface or subsurface)
- Incidental observations of stranded fish that might be observed in the area but not on the survey transect

### 4.2.2. 2008 Trapping Surveys

The 2008 field efforts concentrated on estimating the risk of fish being trapped in various pools and the mortality associated with specific trapping episodes. The effort was focused on estimating the density of fish trapped and the ratio of live to dead fish in each of the trapping survey pools during each survey. Secondary information collected during the surveys included estimating the relative species composition and life history stages of fish within the trapping pools. Trapped fish are fish that remain behind in isolated pool areas as the water recedes. Once trapped, these fish are subjected to increased risk of mortality by deteriorating water quality (higher water temperatures and lower dissolved oxygen levels) within the trapping pool and possibly secondary stranding within the confines of the trapping pool zone as water evaporates or drains through the substrate. All dead fish found within the confines of the mapped trapping pool zones (even if stranded after being trapped) were considered trapping mortalities.

All GIS-identified trapping pools were entered in a database that included pool location, size, maximum residual depth, and the controlling outlet invert elevation. Prior to surveys, the crews determined the expected reservoir level for the survey period (from USGS real-time gage data and water surface profiles generated by the HRM) and using the trapping pool database, identified trapping pools that were likely to be isolated during their survey period. Only pools that were physically isolated from the mainstem flow were surveyed.

Once on site, the survey crew located the trapping pool and confirmed whether it was isolated from the mainstem flow (pool connectivity status). If it was determined that the pool was still connected to the reservoir and that fish could still emigrate from the pool, no survey was done at that pool and the next pool was inspected. If a pool was judged to be functionally isolated from the reservoir, a survey was conducted. Trapping surveys were conducted using several different methods.

#### *4.2.2.1. Entire Trapping Pool Survey*

If the isolated trapping pool was judged to be small enough or was shallow and lacked significant macrophyte cover, the entire pool was surveyed. The trapping pool area included all portions of the pool below the controlling outlet invert elevation, even if this area was dewatered at the time of the survey. The pool was inspected and number of live and dead fish by size class was visually estimated. This served as the total fish density and mortality estimates. To make an estimate of the relative species abundance and size distribution of trapped fishes, a subsample of live and dead fish were collected in selected pools using seines, dip nets, or backpack electroshocker. Captured fish were identified to species (or to family for larval fishes) and a subsample of at least 30 specimens was measured. The time of the survey was recorded so that using the HRM the time of pool isolation, and thus the duration of pool isolation at the time of the survey, could be estimated.

#### *4.2.2.2. Transect Based Pool Surveys*

If the isolated trapping pool was judged to be too large or too deep and/or contained significant macrophyte cover, surveys were conducted along one or more transects through the pool. Based upon the configuration of the pool, one of two transect orientations were used. For large and wide pools, several cross sectional transects were located along the perpendicular axis of the pool. For relatively narrow pools, a single transect was oriented along the long axis of the pool. Regardless of the orientation, all transects began and ended at the controlling outlet invert elevation, even if this area was dewatered at the time of the survey. The number of live and dead fish was visually estimated at square meter plots systematically located along each transect and combined counts served as the fish density and mortality estimates. At each plot, fish were tallied by size class. Fish population sub-sampling data were collected similar to that described in the whole-pool surveys. As described for the whole-pool counts, the time of the survey was recorded so that using the HRM the time of pool isolation and thus the duration of pool isolation at the time of the survey could be estimated and used to generate a mortality estimate for given duration of trapping event.

#### *4.2.2.3. Pool Survey Data*

Information recorded during the trapping surveys consisted of the following:

- Date of survey;
- Time of survey (used in conjunction with HRM to determine how long pool had been isolated at time of survey);
- Survey region;

- Trapping pool ID;
- Water temperature (and time) in the mainstem flow near survey region prior to survey;
- Pool water temperature (and time);
- Pool connectivity status (disconnected; wetted but emigration impeded by depth or macrophytes; pool still connected, emigration likely [no further survey]);
- Pool depth at time of survey;
- Type of methodology employed (whole area or transect);
- Number and size of subplots measured along the transect;
- Estimate of size of pool at time of survey;
- Pool substrate and cover types (aquatic macrophytes or grasses rated as low, moderate or high based on biomass);
- Fish species encountered (0 for no fish);
- Lengths of measured fish (live or dead);
- Visual estimates of abundance by size class (<40 mm, 40-60 mm, 61-120 mm, >120 mm) for live fish in trapping pool or in trapping pool subplots;
- If large numbers of dead fish were observed, visual estimates of abundance by size class (<40 mm, 40-60 mm, 61-120 mm, >120 mm) for dead fish in trapping pool or in trapping pool subplots; and
- Incidental observations/notes (including observations of any fish mortality not recorded as part of the formal trapping pool surveys)

Substrate/cover categories were identical to those used in the stranding surveys and consisted of the following:

- Fines (composed of mud, clay, or fine sand; substrates <0.125 inches in diameter);
- Gravels (composed of materials ranging from coarse sand to medium gravels; substrates 0.125 to 3.0 inches in diameter);
- Coarse materials (large gravels, cobbles, or boulders; substrates >3.0 inches in diameter);
- Submerged aquatic "macrophytes" (rated as low, moderate or high based on biomass); and
- Grasses (includes emergent vegetation and upland vegetation rates as low, moderate or high based on biomass).

Observations on pool substrate and vegetative cover (macrophytes or grasses) presence were recorded so that mortality estimates could be stratified by these pool characteristics. As was the case with stranding surveys, "grasses" was added as a vegetation cover category in 2008 as high flows started to inundate areas covered by vegetation other than aquatic macrophytes.

#### *4.2.2.4. Pool Outlet Invert Elevation Surveys*

During the spring and summer of 2008, elevation surveys were conducted to provide a comparison of elevations obtained from conventional surveys (automatic level and rod) with those from GIS analysis of the light detection and ranging (LiDAR) and bathymetry–based

mapping. The purpose of the effort was to assess the accuracy of the trapping pool outlet elevations developed from the GIS. The outlet elevations are used in the trapping model to identify the time at which a trapping pool becomes isolated from the mainstem and later reconnected to the mainstem. Determination of the time at which a pool becomes isolated is accomplished by comparing hourly water surface elevations produced by the HRM with the outlet elevations. The trapping pool outlet elevation influences whether the pool will become isolated during a downramping or flow recession event and the duration of isolation, or in other words, how long fish are trapped in a pool.

The outlet invert elevation survey locations were selected in coordination with the modeling group and stranding and trapping field survey team. The pools were selected to survey as many of the pools used for data collection as possible with an emphasis on obtaining outlet invert elevations at the most important pools. Pools outlet invert elevations were surveyed over a range of elevations in the Upper Reservoir.

The measurements were performed by a two-person or three-person crew separate from the stranding and trapping surveys. The field activities involved surveying outlet invert elevations with standard surveying equipment (e.g., automatic level, tripod and rod) and in the case that the pools were still connected, the invert depth relative to the river elevation. In addition, the adjacent river water surface elevation was surveyed. In most cases, the bottom elevation of the pool was also surveyed to provide an additional check on the accuracy of the GIS-derived elevations. The date and time of each survey was recorded. The survey results have been compared to the data from the bathymetric and LiDAR mapping to determine the accuracy of the GIS based elevation data (Section 5.2.2.1).

#### *4.2.2.5. Monitoring Pool Depth Reduction in Isolated Pools*

A separate task conducted in 2008 was investigating the rate at which isolated pools and side channels dewater. This involved the deployment of up to 10 stage recorder stations in a subset of trapping pools. The locations were determined during the reconnaissance site visit and through coordination with the trapping survey crews. Outlet invert elevations were surveyed at all pools with pressure transducers installed. In addition, the pool bottom elevation, the elevation of the pressure transducer sensor and the elevation of the mainstem water surface adjacent to the trapping pool were surveyed. Pools were selected to cover a range of pool conditions including variable depths, substrate type, and relative elevations. The physical characteristics of each pool were recorded at the time of transducer installation.

## 5 RESULTS OF STRANDING AND TRAPPING SURVEYS

This section presents the results stranding surveys and trapping surveys conducted in 2007 and 2008. The 2007 surveys were utilized to better understanding stranding and trapping conditions in the study area and to design the 2008 surveys. The 2008 surveys were utilized to develop the stranding and trapping factors (Section 6).

## 5.1. 2007 Survey Results

Surveys of stranding and trapping habitat and fish observations occurred over a variety of reservoir elevations during the summer of 2007. Figure 5.1-1 shows typical elevations in the upper and lower reservoir over the period of the 2007 surveys. The figure shows hourly elevations which, for existing Project operations, vary several feet during 24 hours. Elevations in the lower reservoir (below Metaline Falls) were lower than the upper reservoir (above Metaline Falls) due to influence of Metaline Falls on water-surface elevations.

The reconnaissance surveys conducted from July 11 to 12 occurred after a sharp and extended drop in reservoir level, preceded by a long period of higher reservoir elevation. This elevation drop and hold was because of another specific licensing study needed to survey at lower elevations and is not typical of existing Project operations. The August 3 survey was during fluctuations in water surface elevation more typical of existing Project operations. The surveys conducted on August 22, September 7, and September 8, 2007, also occurred during requested changes to Project operations for other licensing studies. Surveys during these large drops in elevation allowed for observations of many stranding and trapping habitat areas, that for normal summer operations, would rarely be dewatered or stay dewatered for the extended periods. However, because of the magnitude of the drawdowns and the extended duration, the surveys were not conducted during typical Project operations.

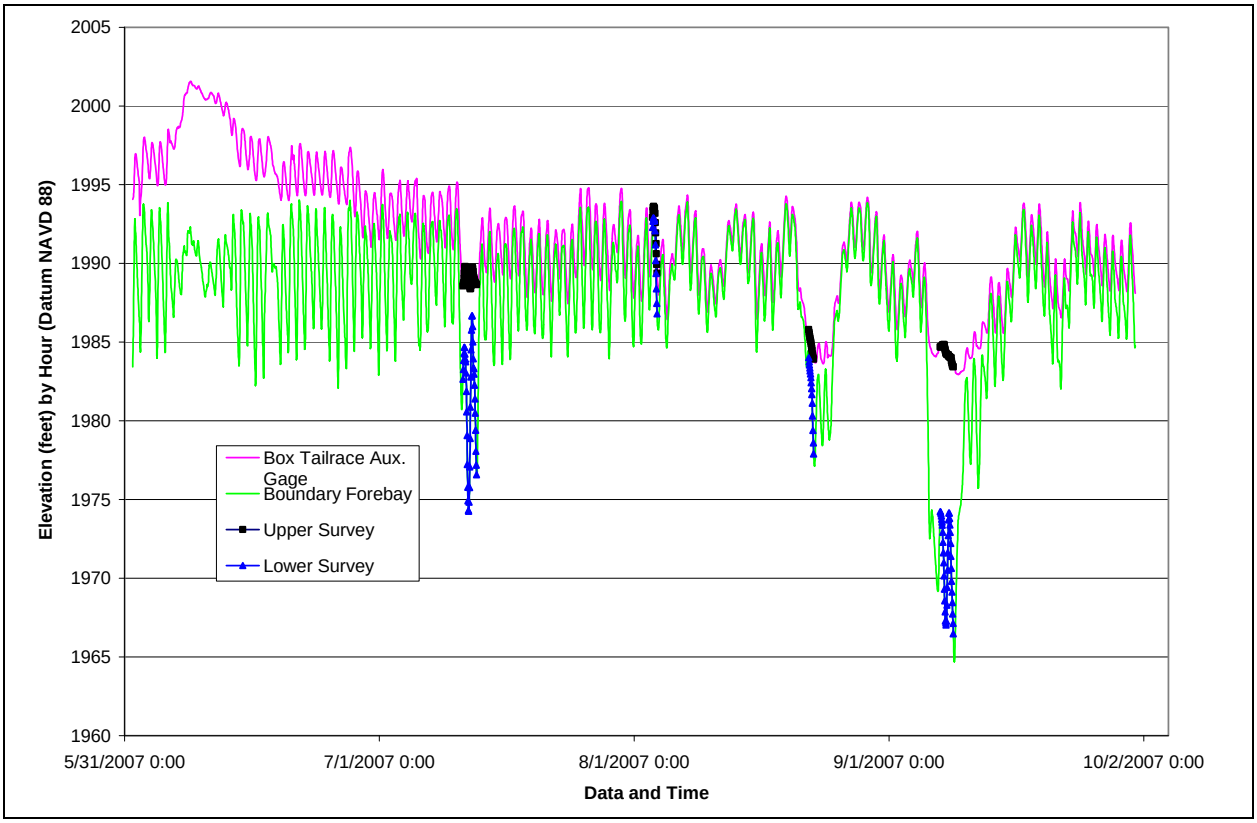


**Figure 5.1-1.** Boundary Reservoir hourly elevation at Box Canyon Tailrace USGS auxiliary gage and Boundary forebay (NAVD 88) (June 1 to September 30) showing elevations on dates of reconnaissance and regular stranding and trapping surveys in 2007.

### 5.1.1. General Description of Stranding and Trapping Regions Surveyed

A general description for each of the 23 stranding and trapping regions is provided in Attachment A. These descriptions were compiled from field observations made during the various surveys conduced in July, August, and September of 2007. The descriptions include the overall physical characteristics as well as observations of stranded or trapped fish. Additional information on stranded and trapped fish during the 2007 surveys is presented in Section 5.1.2.

### 5.1.2. Fish Observations and Life History Information

Of the 23 regions surveyed, stranded or trapped fish were not observed at 10 of the regions. The remaining 12 regions had from 2 to approximately 6,400 fish observed as either stranded or trapped between the July through September surveys. Ten different species of fish were identified during these surveys. The dominant species were sucker species (mostly largescale), yellow perch, black crappie, and bass (mostly smallmouth). Only one juvenile salmonid (139 mm) was observed among the approximately 30,000 fish observed during the 2007 surveys. Young-of-the-year fish (≤80 mm) were the most abundant life stage observed, although at certain locations and times juvenile sucker species (81–133 mm), bass species (81–155 mm), yellow perch (81–220 mm), tench (96 mm) and redside shiner (131 mm) were documented. Low numbers of adult smallmouth bass, largescale sucker, and bullhead species were also observed (all <330 mm). Numbers and percents indicated are coarse approximations, as in many cases numbers were estimated by eye and species identification could not be determined at the time of the observations.

#### *5.1.2.1. July 2007 Reconnaissance Survey*

Fish observations and life history information collected during reconnaissance-level surveys on July 11-12, 2007, are summarized by period in Figure 5.1-2 and number by region in Figure 5.1-3. These July data were collected during an unusual extended drawdown event specifically scheduled for relicensing studies that normally would not occur for existing Project operations at this time of year. The numbers shown in the figure are not exact by site, because some values were approximations. The data includes over 16,000 fish that were observed to be either stranded or trapped at the time of the survey. Highest numbers were observed in Regions 14 and 16 in the Upper Reservoir Reach (Figure 5.1-3). Of these numbers, about 70 percent were mortalities. The vast majority of fish observed in July were young-of-the-year suckers (most <50 mm), approximately 70 percent of all fish (Figure5.1-2). Yellow perch accounted for a little over 20 percent and bass species less than 10 percent of all stranded or trapped fish observed during July. Few other species were observed during July surveys. Regions in the lower reservoir were not surveyed at this time.

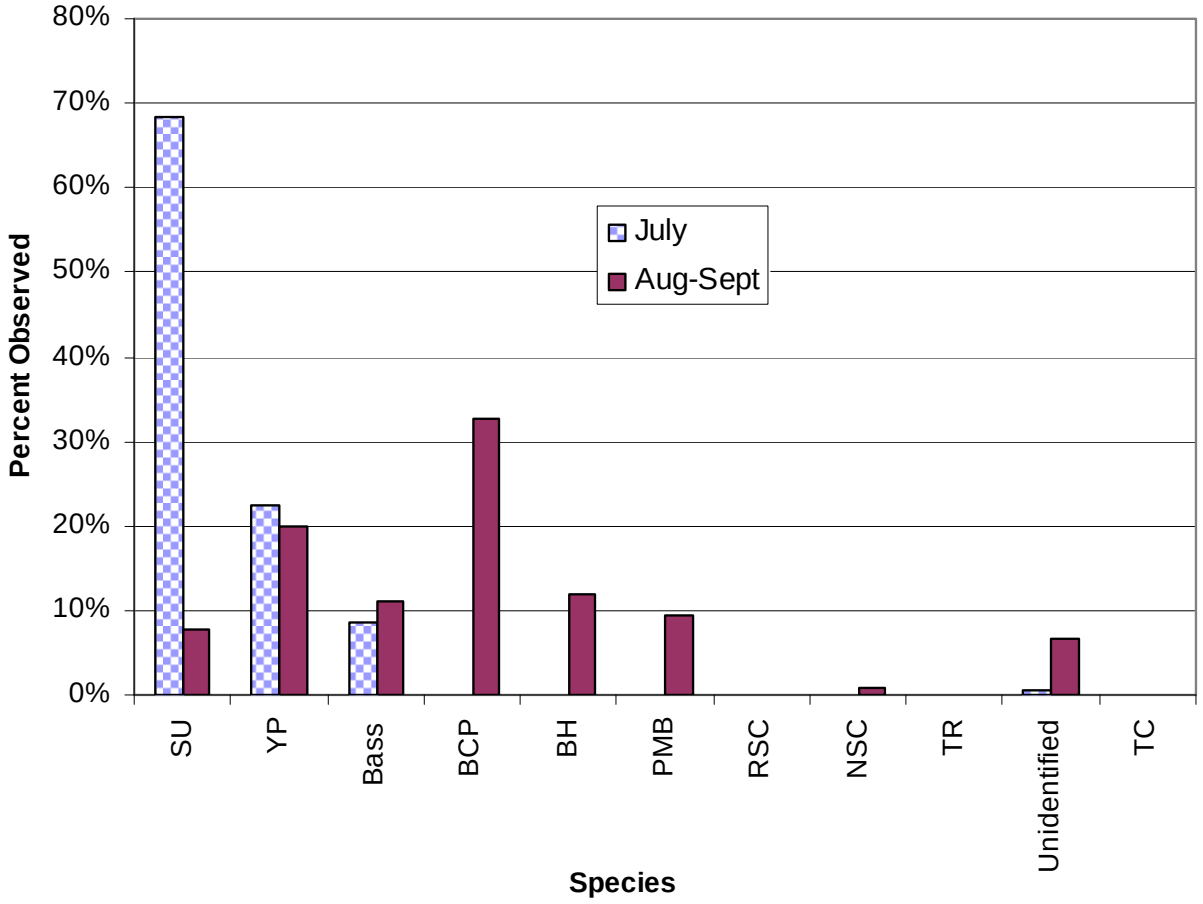


**Figure 5.1-2.** Approximate portion of fish species observed during stranding and trapping surveys in July, August, and September 2007 in Boundary Reservoir.

Notes:
Abbreviations: SU = sucker spp., YP = yellow perch, Bass = bass spp., BCP = black crappie, BH = bullhead spp., PMB = pumpkinseed, RSC = redside shiner, NSC = northern pikeminnow, TR = undetermined trout species, TC = tench.

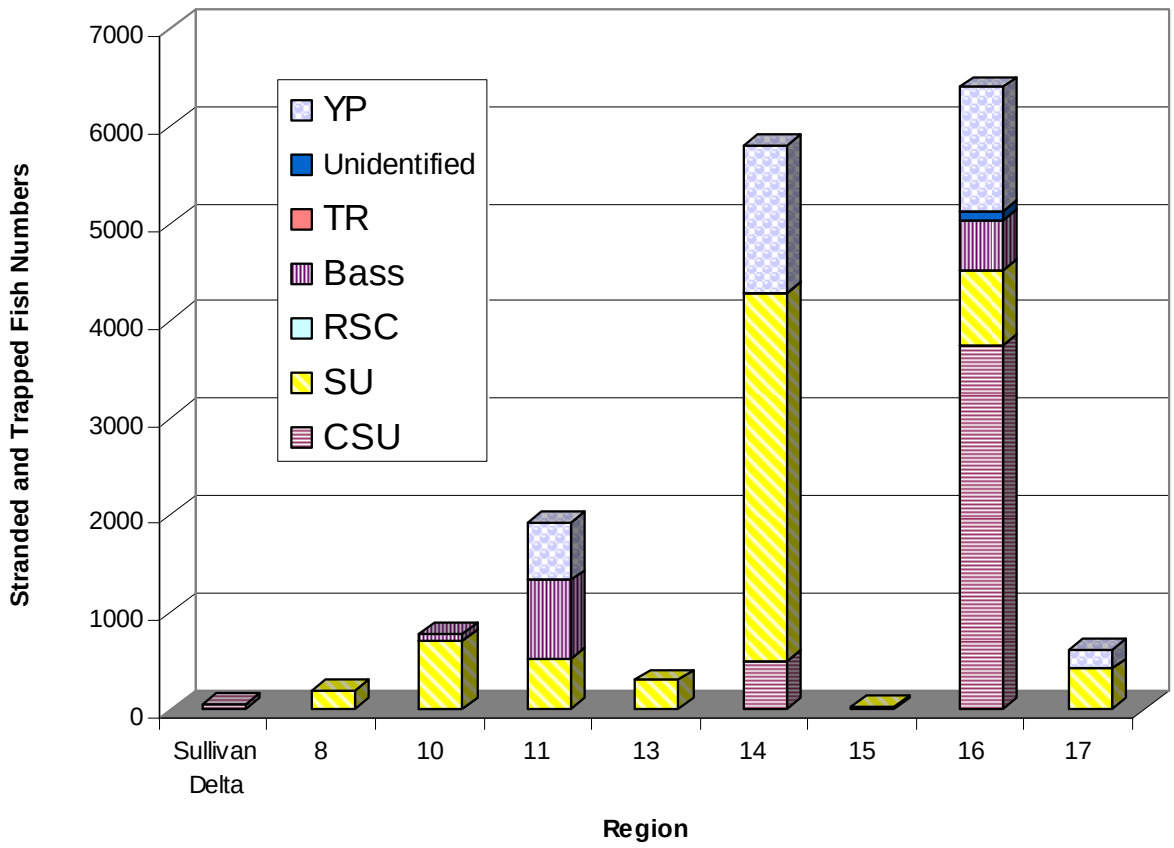


**Figure 5.1-3.** Summary of stranded and trapped fish observed on July 11 and 12, 2007, during reconnaissance surveys.

Notes:
Abbreviations: YP = yellow perch, TR = undetermined trout spp., SMB = smallmouth bass, RSC = redside shiner, SU = sucker spp., CSU = largescale sucker.

### *5.1.2.2. August and September 2007 Stranding and Trapping Surveys*

Fish observations collected during stranding and trapping surveys between August and September are summarized by region in Figure 5.1-4. Salmonids were not observed during August or September and the majority of stranded or trapped fish were young-of-the-year. Due to time constraints and conditions during surveys, when large numbers of stranded and trapped fish were encountered, estimates were recorded. However, some general assumptions about the estimates were made to obtain general characteristics of numbers observed stranded or trapped in August and September. During this period, approximately 14,200 stranded or trapped fish were observed, of which approximately 70 percent were mortalities. Similar to July, high numbers were observed in Region 14 in the Upper Reservoir Reach, but also in Region 2 in the Canyon Reach of the lower reservoir, which was not surveyed in July. Of all fish observed, the most abundant was black crappie at approximately 33 percent (Figure 5.1-2). Yellow perch (approximately 20 percent) remained abundant in shallow water areas where stranding and

trapping occurred. Bass were also abundant and the number of sucker young-of-the-year observed in August and September was substantially lower than numbers observed in July. Additional species observed in August and September but not observed in July were bullhead, pumpkinseed, and northern pikeminnow. The obvious increase in overall Centrarchids during these months is from the increase of young-of-the-year of these species being present in August and September when they had not been in early July.

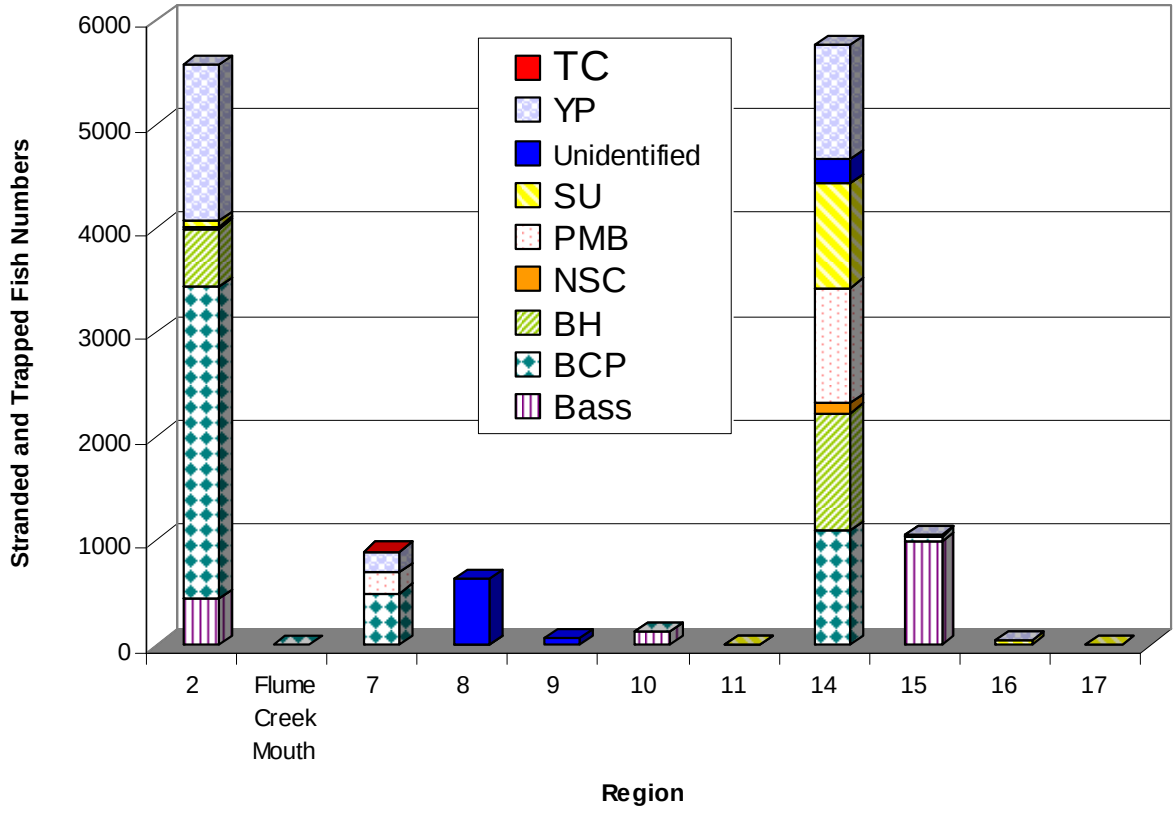


**Figure 5.1-4.** Summary of stranded and trapped fish observed between August 3 and September 8, 2007 during stranding and trapping surveys.

Notes:
Abbreviations: TC= tench, YP = yellow perch, SU = sucker spp., PMB = pumpkinseed, NSC = northern pikeminnow, BH = bullhead spp., BCP = black crappie, Bass = bass spp.

### 5.1.3. Duration of Flow Reductions

An approximate duration of reduction (hours) before the onset of each survey was calculated based on daily mean reservoir elevation from the USGS water gage station below Box Canyon Dam and is provided in Table 5.1-1. The values shown are approximate, as duration of dewatering varies with location along the reservoir and could be longer for sites below Metaline Falls and for sites at higher elevations.

**Table 5.1-1.** Approximate duration of reduction prior to each survey date, July 11 to September 9, 2007.

| Stranding and Trapping Survey Date | Duration of Reduction Prior to Survey (hours) |
|---|---|
| 11 July | 24 |
| 12 July | 48 |
| 3 August | 4 |
| 22 August | 36 |
| 7 September | 72 |
| 8 September | 88 |

### 5.1.4. Summary of 2007 Results

Over the course of the stranding and trapping surveys on Boundary Reservoir and Tailrace Reach, several factors influencing fish stranding and trapping were observed. These factors include duration and magnitude of elevation reductions, aquatic macrophyte growth, substrate characteristics, slope, and size and depth of pools.

The highest rates of trapping were observed at regions with side channel habitats. Side channels with high rates of trapping were observed at Regions 2, 7, 11, 14, and 16 (Figures 5.1-3 and 5.1-4). During surveys at these regions, the side channels had large areas and contained high concentrations of aquatic macrophytes that provided cover for juvenile fish. As water surface elevations receded, the side channels isolated and trapped fish. Trapping was also observed at Regions 8, 10, and 14 in areas with gradual gradients dominated by gravel and cobble substrates that drained into several pools. Trapping rates observed at these regions were less significant than regions with side channel habitats and trapping areas with high concentrations of aquatic macrophyte growth.

High rates of stranding occurred at Regions 2 and 14 during extended drawdown events. These regions contained areas with gradual gradients and high concentrations of aquatic macrophyte growth.

Results from the Study 9 Final Report (SCL 2009b) show that very few native salmonids were observed in the reservoir, and that juvenile mountain whitefish represent the majority of native salmonids captured in the reservoir and tailrace. Young-of-the-year mountain whitefish were first captured in May 2007, peaked in June, but were rarely captured from July to September 2007. Also young-of-the-year mountain whitefish grew rapidly as all mountain whitefish captured after June were 82 mm or larger. The larger size would likely have reduced their potential to be found in shallow water regions where stranding and trapping was most likely to occur. When stranding and trapping surveys were conducted between July and September 2007, small mountain whitefish were absent from reservoir sampling during Study 9 field sampling; however, some juveniles, all greater than 80 mm, entered the reservoir from tributaries in July 2007. Habitat conditions with the highest catch rates of all mountain whitefish consisted of moderately sloped areas dominated by gravel and cobbles (SCL 2009b). These data suggest that stranding during the late spring and early summer is the highest risk to young-of-the-year and juvenile mountain whitefish as a result of Project operations.

During the stranding and trapping surveys in 2007, only one juvenile salmonid was observed. This fish was documented at Region 14 on July 12, but could only be identified as a trout species due to its advanced stage of decomposition. The fish was found in emergent aquatic macrophytes (horsetails) in a side channel area of Region 14, a habitat type that would likely only be watered during spring high flows. Plotting the GPS coordinates of the fish on the bathymetry layer, the estimated elevation of the location was about 1,991 to 1,992 feet NAVD 88 (1,987 to 1,988 feet NGVD 29). The drawdown that occurred beginning July 10 had water elevations at the Box Canyon auxiliary gage drop from a high the day before of about 1,995 feet down to about 1,990 feet and remained at 1,990 feet or lower for the next 2 days. However, during the preceding week, water surface elevations at the gage had daily fluctuations between 1,995 and 1,991 feet NAVD 88 (1,991 to 1,987 feet NGVD). While the large drawdown that occurred on July 10 seems to be the most likely cause of the trout stranding, the fish could have been stranded earlier during the daily drawdowns.

For the water surface elevation and operational conditions examined, stranding and trapping was documented for non-salmonid sport fish and important prey species, including sucker spp., smallmouth bass, largemouth bass, yellow perch, black crappie, pumpkinseed, and bullhead spp. Sucker species, noted as likely larval fish, dominated observations in the June reconnaissance surveys, and accounted for the vast majority of the fish observed in July, with the Centrarchids and bullheads being more common in the August and September sampling. This indicates that there is a higher risk of stranding and trapping on the early life stages of many of these species during the summer months. However, the number of trapped and stranded fish observed were likely influenced by the unusually large and extended drawdowns during early July, late August, and September that were implemented as part of project relicensing studies rather than typical operations during this period.

#### *5.1.4.1. Duration and Magnitude of Elevation Reductions*

The approximate duration of elevation reductions prior to surveys ranged from 4 hours on August 3 to 88 hours on September 8. The number of fish stranded or trapped increased rapidly as the duration of the elevation reduction increased. On August 3, stranded and trapped fish were not observed as a result of the reduction that occurred that day. Alternately, stranded and trapped fish numbers observed increased substantially for all reductions that lasted 24 hours or longer. Stranding and trapping areas that reconnect to the mainstem and inundate during diel flow fluctuations drain over extended drawdowns and have an increased risk of stranding and trapping. The magnitude of the reductions at these times also contributed to the numbers observed, as some sites within the surveyed regions that infrequently dewater had dewatering events during these extended drawdown periods.

#### *5.1.4.2. Aquatic Macrophytes*

The highest rates of stranding and trapping occurred in areas with high concentrations of aquatic macrophyte growth. As water elevations receded, dewatering aquatic macrophytes restricted, and in some areas, prevented fish movement out of the stranding and trapping sites. Therefore, the presence and concentration of aquatic macrophytes has a direct correlation on stranding and

trapping rates. Macrophyte habitat is abundant in the upper reservoir regions, while only occurring in limited sites in the lower reservoir.

#### *5.1.4.3. Substrate Characteristics and Slope*

The mean Modified Wentworth category for the substrate recorded at all regions ranged from 1.0 to 5.0, from silt to large gravel (18 to 32 mm). Substrate embeddedness, angularity, and compaction for the majority of regions remained low. The embeddedness and angularity at Region 12 was moderate, as well the compaction at Region 13. Substrate parameters that pose the highest risk of interstitial stranding include low embeddedness and compaction and high angularity. Gravel and cobble substrates also pose greater risks of interstitial stranding than fines and sand. These conditions were rare in the study area as most (likely more than 95 percent of all observed stranded fish) occurred in macrophytes. The highest rates of interstitial stranding (not associated with aquatic macrophytes) occurred at Region 10, which was dominated by gravel and cobble substrate with low embeddedness and compaction. Low rates of interstitial stranding were also documented at Regions 8, 15, 16, and 17.

Slopes recorded during the surveys ranged from 1 to 25 percent. The relatively low number of slopes taken over the course of the surveys cannot be considered representative of gradients present at each region. At higher reservoir elevations, gradients observed at stranding and trapping sites tended to be steeper, and as pool elevation decreased at each region, gradients became more gradual. Areas with gradual gradients experience higher rates of dewatering, which leads to increased rates of stranding and trapping. As areas with gradual gradients dewater, aquatic macrophytes become exposed and pools start to form.

#### *5.1.4.4. Depth and Size of Pools*

At the point of isolation from the mainstem reservoir, larger pools have greater amounts of habitat availability and therefore pose higher risks of trapping. As larger pools dewater and shrink in size, they tend to split into small pools and concentrate trapped fish. Pools with greater depths can support fish for longer periods of time during flow reductions, as they hold water for longer durations and moderate temperature and dissolved oxygen changes, especially during warm climatic periods.

## 5.2. 2008 Survey Results

Stranding and trapping surveys conducted in 2008 were designed to support finalization of the factors used in the stranding and trapping index equations and determination of factor values (or curves). The stranding and trapping field data collection effort was conducted from March 3, 2008, through August 19, 2008. In the period from May 7, 2008 through July 16, 2008, no stranding and trapping surveys were conducted due to high runoff. Once the mainstem flow started to recede to the point that stranding area and trapping pools were being exposed, the surveys were resumed. Stranding area and trapping pool surveys were conducted during normal Project operations as well as two atypical reservoir drawdown events. The drawdown events occurred from July 21 to July 24, 2008, and from August 18 to August 19, 2008.

### 5.2.1. 2008 Stranding Survey Results

During 2008, stranding survey were conducted at 175 transects representing nearly 406,000 square feet. Table 5.2-1 present a summary of the stranding surveys by month. Though 50 transect surveys were conducted in March, April, and May, only one stranded fish was observed in the stranding areas surveyed. The total number of beached fish estimated during the 2008 surveys was 1,203. Table 5.2-1 also presents, by month, the average density of stranded fish. The average density for the fiver months ranged from 0.00 fish per square feet in April and May to 5.19 stranded fish per square feet in July. The month with the next highest density of stranded fish was in August at 4.33 fish per square feet. The complete 2008 stranding survey data are presented in Table B-1 of Attachment B.

**Table 5.2-1.** Summary of fish stranding surveys conducted in 2008.

| Month | Number Transects Surveyed | Total Area Surveyed (sq. ft.) | Total Beached Fish Estimated | Total Average Density (Beached fish per 1,000 sq. ft.) |
|---|---|---|---|---|
| March | 25 | 97,840 | 1 | 0.01 |
| April | 20 | 42,860 | 0 | 0.00 |
| May | 5 | 13,500 | 0 | 0.00 |
| July | 76 | 133,590 | 693 | 5.19 |
| August | 49 | 117,870 | 510 | 4.33 |
| **Total** | **175** | **405,660** | **1,203** | **2.97** |

**Table 5.2-2.** Summary of stranding transects surveyed by month and vegetation type.

| Month | Number of Transects Surveyed by Vegetation Cover Type (Mac. = Submerged Aquatic Macrophytes) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Low Mac. | Moderate Mac. | High Mac. | Low Grass | Moderate Grass | High Grass | No Vegetation |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 25 |
| April | 6 | 0 | 0 | 0 | 0 | 0 | 14 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| June | NA | NA | NA | NA | NA | NA | NA |
| July | 21 | 9 | 9 | 12 | 9 | 0 | 16 |
| August | 25 | 3 | 5 | 0 | 0 | 1 | 15 |
| Total | 52 | 12 | 14 | 12 | 9 | 1 | 75 |

Table 5.2-2 lists the number of transects surveyed for each vegetation cove type. This information is provided by months. Originally, the only vegetation type to be considered was submerged aquatic macrophytes (referred to as “macrophytes”). However, because of the high flows in 2008, some of the surveys conducted during the recession limb of the runoff hydrograph were conducted in higher elevations where grass and other freestanding vegetation such as sedges were present. This vegetation was distinguished from macrophytes, since it does not

compress in a mat as the water receded as macrophytes do, but rather stays upright. Therefore, it does not pose the same stranding potential as fish do not become trapped in the freestanding vegetation.

Table 5.2-3 presents the number of stranded fish observed by vegetation type and months. Reviewing this table it appears that the high rates of stranding occur in all three macrophyte cover level as well as low grasses. However, the low macrophyte category represents a much larger area of transects surveyed since the macrophyte growth in 2008 was slowed by the extended runoff. When the stranding observations are expressed in terms of density, obtained by dividing the number of beached fish by the area of the transects surveyed, a truer picture of the influence of cover on stranding potential is achieved. Table 5.2-4 lists the density of stranded fish by cover type and month.

**Table 5.2-3.** Number of stranded fish observed by month and vegetation type.

| Month | Number of Beached Fish by Vegetation Cover Type (Mac. = Submerged Aquatic Macrophytes) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Low Mac.** | **Moderate Mac.** | **High Mac.** | **Low Grass** | **Moderate Grass** | **High Grass** | **No Vegetation** |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | NA | NA | NA | NA | NA | NA | NA |
| July | 141 | 191 | 58 | 247 | 6 | 0 | 50 |
| August | 93 | 202 | 198 | 0 | 0 | 2 | 15 |
| Total | 234 | 393 | 256 | 247 | 6 | 2 | 66 |

**Table 5.2-4.** Density of stranded fish observed by month and vegetation type.

| Month | Density of Beached Fish by Vegetation Cover Type (Mac. = Submerged Aquatic Macrophytes) (fish per 1,000 sq. ft.) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Low Mac.** | **Moderate Mac.** | **High Mac.** | **Low Grass** | **Moderate Grass** | **High Grass** | **No Vegetation** |
| March | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| April | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| May | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| June | NA | NA | NA | NA | NA | NA | NA |
| July | 2.85 | 9.61 | 21.1 | 11.1[1] | 0.49 | 0.00 | 1.86 |
| August | 1.67 | 44.9 | 11.4 | 0.00 | 0.00 | 0.77 | 0.40 |
| Total | 1.95 | 16.1 | 12.7 | 11.1 | 0.49 | 0.77 | 0.32 |

Note:
1 The density of 11.1 fish per 1,000 sq. ft. includes area in Region 17 with high stranding rates to be addressed as a special case.

Reviewing the densities, it appears that the greatest stranding potentials are associated with moderate macrophyte, high macrophyte and low grass cover types. Since it was counterintuitive that the low grass would have this high stranding potential, the data were investigated further and it was found that there were two transects in Region 17 with very high stranding numbers that skewed this information. Discussions of these transects with the field crew members conducting the survey and reviewing the bathymetry revealed that this is a very low gradient location (about 1 percent) where considerable area above it drains into and then across (Figure 5.2-1). Based on this information, it was decided to remove this portion of the Region 17 transect data from the low grass category and analyze it as its own "condition." It was also decided that the three grass categories would be combined with the no vegetation category and analyzed as one cover type referred to as "without macrophytes." The moderate and high macrophyte cover categories exhibited similar stranding densities and it was also decided to combine these two cover conditions. These decision was discussed with the relicensing participants during the August 28 and September 11, 2008 WebEx teleconferences and they agreed with this approach. Another decision agreed upon by the relicensing participants during concerning analysis of the data was to only utilize the data from July and August in developing the factors. The stranding factor determination presented in Section 6.1 reflects these decisions on utilizing the results of the 2008 stranding area surveys.

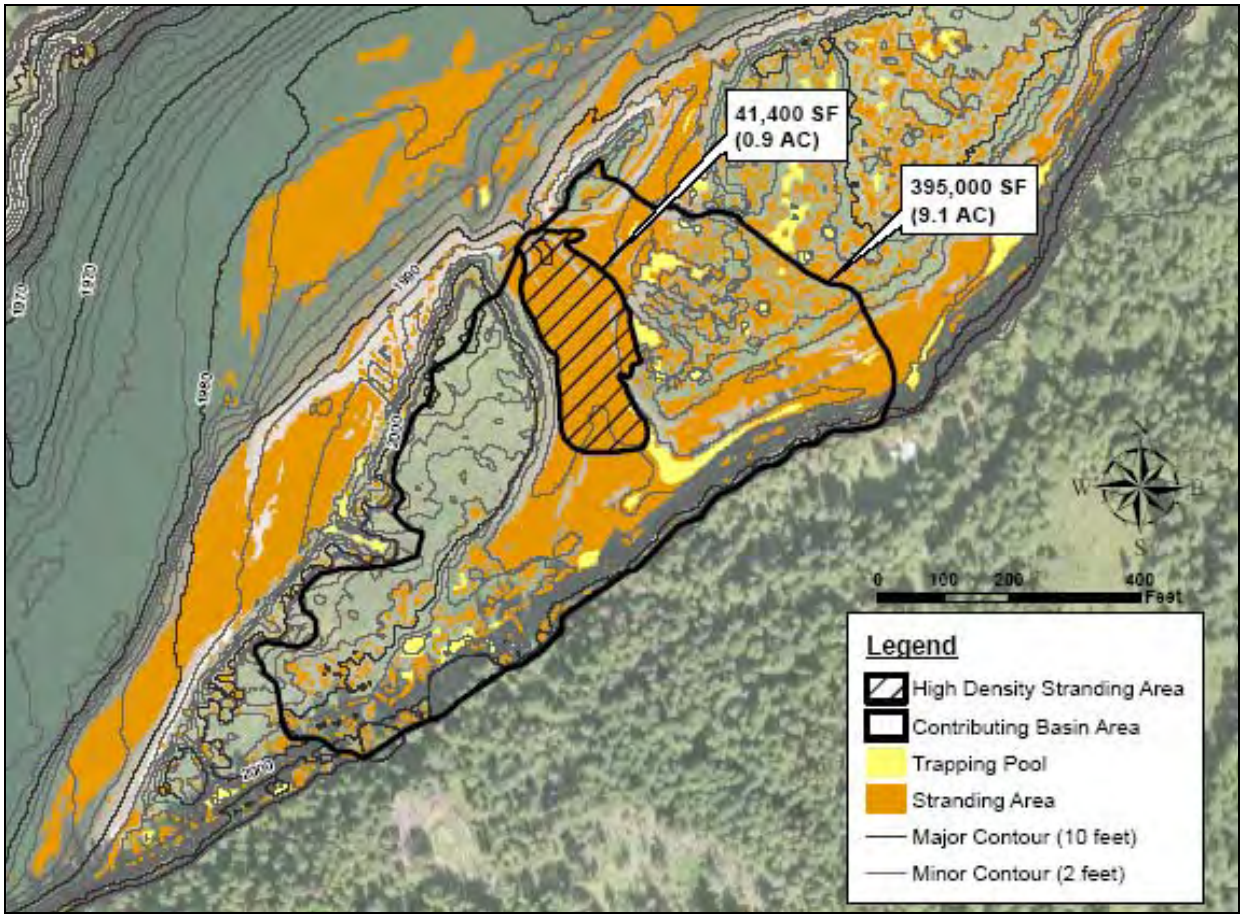


**Figure 5.2-1.** Location of high density stranding area in Region 17 and associated contributing basin area.

The species composition of the fish observed in the 2008 stranding survey is presented in Table 5.2-5. The vast majority of fish identified during the 2008 stranding surveys were Catostomids and cyprinids representing 92 percent of the beached fish in July and 82 percent of the beached fish in August. Centrarchids were the next most abundant fish in August at 12 percent Followed by Percids at 6 percent. In July the proportion of Percids and Centrarchids were equal at 3 percent. A small proportion of the stranded fish in July were Ictalurids at 2 percent. The only other group of fish identified during the stranding surveys was Esocids at less than 1 percent. No salmonids were observed during the 2008 stranding surveys.

**Table 5.2-5.** Approximate species composition of fish observed during the 2008 stranding surveys.

| Month | Catostomids & Cyprinids | Centrarchids | Percids | Ictalurids | Esocids | Cottids |
|---|---|---|---|---|---|---|
| March | 0% | 0% | 100% | 0% | 0% | 0% |
| April | 0% | 0% | 0% | 0% | 0% | 0% |
| May | 0% | 0% | 0% | 0% | 0% | 0% |
| July | 92% | 3% | 3% | 2% | 0% | 0% |
| August | 82% | 12% | 6% | 0% | 0% | 0% |
| **Total** | **88%** | **6%** | **4%** | **1%** | **<1%** | **0%** |

Additional data on the species and life stages collected during the stranding surveys are presented in the Study 9 Final Report (SCL 2009b). These data are not presented in Study 7 because the stranding factor development and analysis are not species specific. However, these data were used in developing the periodicity information presented in Sections 5.3 of the Study 7 Final Report (SCL 2009a). Periodicity information is used in interpretation of the potential for various fish species and lifestages potentially stranded throughout the year.

### 5.2.2. 2008 Trapping Survey Results

Trapping pool surveys were conducted in over 100 individual trapping pools. Over 40 of the pools were surveyed multiple times. A total of 228 pool surveys were conducted across 178 pool drawdown events. A pool drawdown event is a survey or a set of multiple surveys conducted at a pool during a single drawdown cycle. A pool may be surveyed multiple times during a single drawdown event. Table 5.2-6 presents a summary of the trapping survey effort by month including the number of pool drawdown events, pool area covered by the surveys, total fish mortalities estimated, total fish estimated (includes live and dead fish), the average density and total average densities. The average density is based on the mean of the drawdown events in a category. Total average density is determined by dividing the total number of fish estimated for all drawdown events in a category by the total area of trapping pools in the category.

**Table 5.2-6.** Summary of fish trapping surveys conducted in 2008.

| Month | Number of Pool Drawdown Events | Total Area Surveyed (sq. ft.) | Total Fish Mortalities Estimated | Total Fish Estimated | Total Average Density (Fish mortalities per 1,000 sq. ft.) | Total Average Density (Total fish per 1,000 sq. ft.) |
|---|---|---|---|---|---|---|
| March | 24 | 127,490 | 2 | 2 | 0.02 | 0.02 |
| April | 18 | 75,460 | 1 | 6 | 0.01 | 0.08 |
| May | 8 | 30,222 | 0 | 3 | 0.00 | 0.10 |
| July | 88 | 248,407 | 7,678 | 108,460 | 31 | 436 |
| August | 40 | 372,315 | 10,295 | 125,077 | 28 | 335 |
| **Total** | **178** | **853,894** | **17,976** | **233,548** | **21.05** | **273.51** |

In reviewing Table 5.2-6, it is evident that very few fish are subjected to trapping during the late winter and early spring. This is primarily the result of smaller fish not being present in the system during this time of year and/or not occupying the shallow shoreline areas that would expose them to the trapping pools. A total of 11 fish were observed trapped during the period of early March through early May 2008 with only 3 of these observations being mortalities. In contrast, during July and August 2008, an estimated 230,000 fish were trapped in the pools with a corresponding estimate of nearly 18,000 mortalities. For this reason, much of the analysis of the trapping factors is based on observations collected during July and August, including the atypical drawdown events of July 21 and August 18, 2008.

Table 5.2-7 presents the species composition for trapped fish by month. During the period of high trapping potential, July and August 2008, the vast majority of trapped fish were Catostomids and cyprinids. The next most abundant group was Centrarchids followed by Percids. No salmonids were observed during the 2008 trapping or stranding surveys.

**Table 5.2-7.** Approximate species composition of fish observed during the 2008 trapping pool surveys.

| Month | Catostomids & Cyprinids | Centrarchids | Percids | Ictalurids | Esocids | Cottids |
|---|---|---|---|---|---|---|
| March | 0% | 50% | 50% | 0% | 0% | 0% |
| April | 0% | 0% | 50% | 25% | 0% | 25% |
| May | 0% | 0% | 100% | 0% | 0% | 0% |
| July | 80% | 15% | 5% | <1% | <1% | 0% |
| August | 97% | 3% | 0% | 0% | 0% | 0% |
| **Total** | **84%** | **12%** | **4%** | **<1%** | **<1%** | **<1%** |

The trapping survey field data are presented in Table C-1 in Attachment C. The data presented in this table were used to develop the trapping factor values. Additional data collected in 2008 on the species and lifestages collected during the trapping surveys are presented in Study 9 (SCL 2009b). These data are not presented in Study 7, since the trapping analysis is not species specific. However, these data were used in developing the periodicity presented in Section 5.3 of

the Study 7 Final Report (SCL 2009a). The periodicity information is used in interpretation of the potential for various fish species and lifestages to be trapped throughout the year.

#### *5.2.2.1. Pool Outlet Invert Elevation Surveys*

During the spring and summer of 2008, elevation surveys were conducted to provide a comparison of elevations obtained from conventional surveys (automatic level and rod) with those from GIS analysis of the LiDAR and bathymetry based mapping. The purpose of the effort was to assess the accuracy of the trapping pool outlet elevations developed from the GIS. The outlet elevations are used in the trapping model to identify the time at which a trapping pool becomes isolated from the mainstem and later reconnected to the mainstem. The outlet elevations at 70 pools were surveyed using conventional automatic levels and survey rods to points of known elevation. In addition, the bottom elevations for 67 of these pools were also surveyed. This provided a total of 137 surveyed elevations to compare with elevations determined from GIS. Selection of trapping pools for elevation surveys were based on several factors including survey pools that had fish trapping surveys, survey pools across a range of elevations, concentrate surveys on the larger pools, and concentrate on pools in the areas with the most significant fish trapping being observed by the fish trapping survey crews.

To quantify the differences between the elevations in the GIS mapping and the field-surveyed elevations, statistics for the differences were developed and are provided in Table 5.2-8. The average elevation difference between the field survey and the bathymetry is -0.5 foot with a standard deviation of 0.7 foot and a range of 2.2 to -1.8 feet. For the LiDAR data, the mean difference is -1.7 feet, with a standard deviation of 0.8 foot and a range 1.3 to -3.4 feet. The variation for both data sets is similar with standard deviations within 0.1 foot of each other and with the ranges each spanning a similar distance, 4 feet for the bathymetry and 4.7 feet for the LiDAR. In both cases, approximately 50 percent of the points are within the ±0.5 of the mean elevation difference.

**Table 5.2-8.** Comparison between elevations based on GIS mapping and elevations based on field surveys (negative elevations indicate GIS based elevations are lower than field surveyed).

| Parameter | Elevation Differences by Source for GIS Elevations | |
|---|---|---|
| | **Areas with Bathymetric Survey** | **Areas with LiDAR Survey** |
| Maximum Difference (ft) | 2.2 | 1.3 |
| Minimum Difference (ft) | -1.8 | -3.4 |
| **Average Difference (ft)** | **-0.5** | **-1.7** |
| Median Difference (ft) | -0.7 | -1.6 |
| Standard Deviation (ft) | 0.7 | 0.8 |
| Number of Observations | 86 | 51 |

To take advantage of the field surveyed elevations and the comparison with the GIS mapping, several actions were taken. These included the following:

- All trapping pools with field surveyed outlet or low point elevations utilized the field surveyed elevations for modeling of the trapping index and determination of the duration of isolation for the trapping surveys.
- All trapping pools that had outlet or bottom elevations determined by bathymetry and do not have field surveyed elevations, had 0.5 foot subtracted from the outlet and bottom elevations determined by GIS.
- All trapping pools that had outlet or bottom elevations determined by LiDAR and do to have field surveyed elevations, had 1.7 feet subtracted from the outlet and bottom elevations determined by GIS.

Through the combination of the field surveys and the available GIS mapping, the trapping pool outlet determinations provide for accurate determination of the fish trapping index under the range of operations scenarios to be investigated. This conclusion is based on several factors including the following:

- Within the fluctuation zone between 1,986 and 1,998 feet NAVD 88 (1,982 and 1,994 feet NGVD 29) nearly 50 percent of the area of trapping pools is controlled by outlets that elevations were field surveyed.
- The three one-foot elevation bands with the largest trapping pool areas within the elevation range from 1,986 to 1,998 feet NAVD 88 (1,982 and 1,994 feet NGVD 29) are 1,986, 1,989 and 1,992 feet NAVD 88 (1,982, 1,985, and 1,988 feet NGVD 29) which have field surveyed elevations for outlets controlling 67, 75, and 33 percent of the trapping pool area, respectively.
- The portion of the GIS mapping in which field verification surveys of elevations were not possible are within the range in which the GIS mapping was developed from bathymetry. The bathymetry has the least deviation from the field survey with the average elevation difference between the field surveys and GIS mapping of -0.5 foot.
- The trapping pools are spread across a wide range of elevations with significant numbers and area of pools in each elevation range. This combined with the majority of the larger trapping pools having elevation surveys means that random errors in the remaining unsurveyed outlet elevations will not greatly alter the distribution of pools between elevation zones.
- The field surveys allowed determination of elevation corrections to more accurately model and characterize pool outlet elevations for determination of the trapping index.

#### *5.2.2.2. Monitoring Pool Depth Reduction in Isolated Pools*

Between April 30, 2008 and August 19, 2008, pressure transducers were deployed at 20 trapping pools in the Upper Reservoir Reach. The instruments were deployed in order to monitor changes in trapping pool elevations in response to water surface elevation fluctuations in the Pend Oreille River. The period over which recordings were taken varied from 1.2 to 31 days. Over the entire program, data representing 252 days of trapping pool water surface elevations were collected. Data were collected at 16 pools with fine substrate and 4 pools with coarse gravel and cobble substrate.

An example of a plot of the data collected at trapping pool 10-016 in Region 16 is provided in Figure 5.2-2. The plot shows the pool stage from July 21, 2008 through August 16, 2008 along with the estimated water surface elevation of the Pend Oreille River based on results of the HRM. The figure includes horizontal lines representing the elevation of the pool inlet and the deepest point (invert) in the pool. The plots shows the pool going dry over the period of July 21 into July 22 in approximately 20 hours after the mainstem elevation dropped below the pool inlet elevation of 1,991.75 feet NAVD 88 (1,987.72 feet NVGD 29). This was during the first of three drawdown events conducted for performing the thermal plume data collection on the tributary deltas. The pool then continued to respond to mainstem water surface elevation fluctuations, but did not approach going dry again until August 5. From August 5 through the end of the recording on August 16, the pool went dry or nearly dry eight times. It is significant to note that once the pool is disconnected, the rate at which it drains into the substrate is somewhat constant, based on the straight line with consistent slope during each period of pool draining. The drain rate may be initially slower, until the mainstem water surface elevation drops several feet below the inlet elevation.

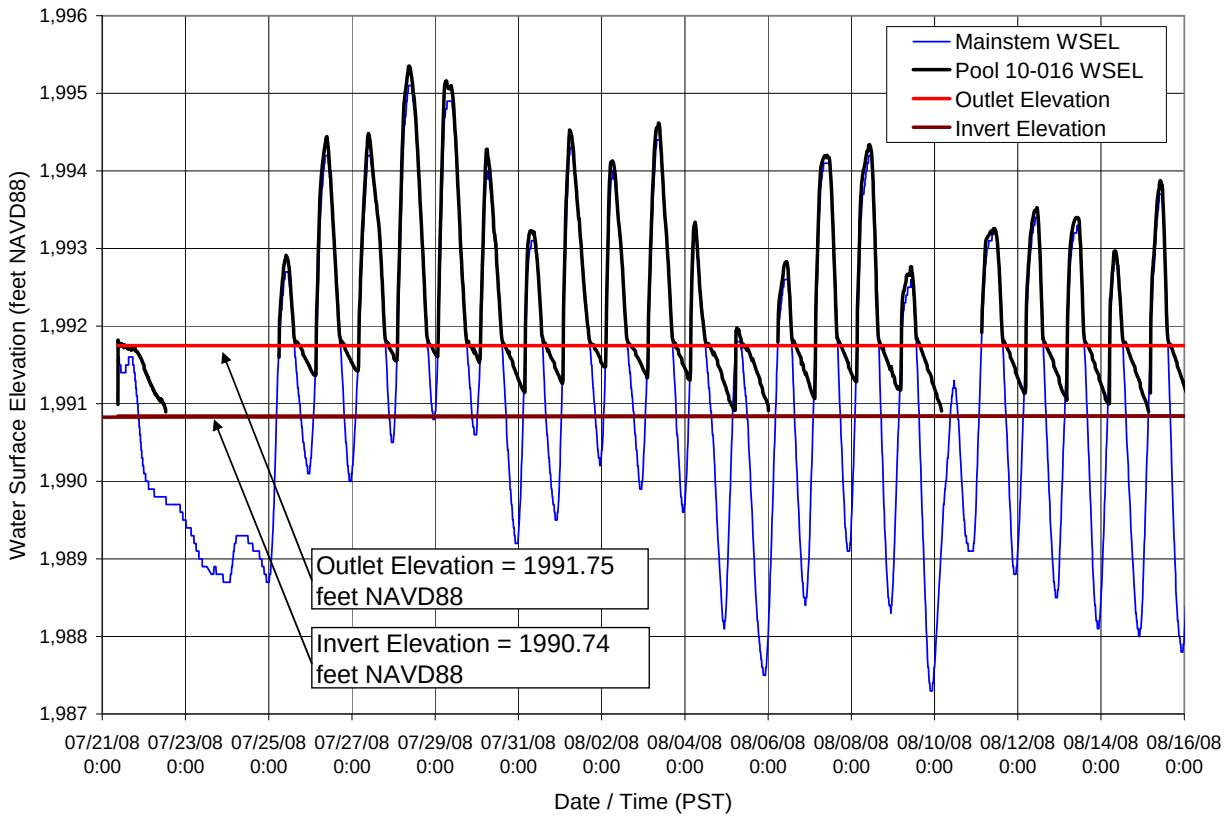


**Figure 5.2-2.** Example stage recordings from pressure transducer deployed at trapping pool 10-016 in Region 10, July 21 though August 16, 2008.

The data from the other 19 pool stage recorders were plotted up in a similar manner and reviewed. In most cases, the plots revealed site specific information about the individual pool; however, the information was too specific and variable to apply across a specific pool type. For example, the draining behavior of pool 10-016 just discussed was not similar for all pools in cobble substrate. Other pools did not drain as quickly, possibly due to connection to groundwater or localized inflow from bank storage. Additionally, it is suspected that distance from the mainstem may play a role in the period required for a pool in coarse substrate to drain. The results from the pools in fine material were even more variable. Some of the pools did not drain at all once disconnected and appear to be receiving inflow from groundwater. Other pools in fine substrate drained at rates similar to that shown for 10-016. The pool stage data helped in understanding some of the mechanisms influencing the rate at which the pools drain, but because of the variability and many factors involved, it could not be applied directly to development of the trapping pool duration of trapping ($T_T$[D]) factor values.

# 6 FINAL STRANDING FACTORS AND FINAL TRAPPING FACTORS

This section presents the development of both the final values for the stranding factors and the final trapping factors. These factor values were applied to the modeling approach detailed in Section 3 to produce the stranding and trapping modeling results presented in Section 7. The effort involved analyzing the 2008 stranding area and trapping pool data to adjust the provisional factor values.

The development of the final factor values included interaction with the relicensing participants. The analysis of the stranding area data and potential adjustments to the provisional factors were presented to the relicensing participants during a WebEx teleconference on August 28, 2008. A follow-up memo with final recommendations for stranding factors was developed after the August 28, 2008, WebEx and discussed during a second WebEx teleconference held on September 11, 2008. During the September 11 WebEx, the relicensing participants agreed to the recommended factors presented.

A similar process was conducted to reach agreement with the relicensing participants on the trapping factors. A WebEx teleconference was held on October 1, 2008, in which a memo detailing the development of the final factors and the actual recommendations for the final factors was presented to the relicensing professionals. The relicensing participants tentatively agreed to the factors as recommended and provided their final agreement in an October 10, 2008, telephone call to Al Solonsky of SCL. The material in this section, including the final factors, is derived from the memos and presentations made to and agreed upon by the relicensing participants during the process just described.

## 6.1. Development of Final Stranding Factor Values

There are two factors in the stranding equation: the stranding area factor $A_s$ and the stranding cover factors ($C_s$). This section presents the determination of the stranding factors utilizing the data collected in the summer of 2008 and summarized in Section 5.2.1 and listed in detail in Attachment B.

### 6.1.1. Stranding Area Factor – $A_S$

The development of the stranding factor values utilized comparison of stranding densities for various groupings of conditions potentially influencing stranding to develop the appropriate set of factors and their values to be used in the stranding analysis. The density of fish stranded in low gradient areas less than 4 percent or in areas with gradients greater than 4 percent with macrophytes was determined by dividing the number of stranded fish in a transect by the area represented by the transect. By comparing the densities of stranded fish between various stranding area conditions, the relative potential for stranding for each condition was determined. In this process, it was a basic assumption that the potential to strand fish is directly proportional to the surface area of the pool when it becomes isolated from the mainstem flow. Therefore, the stranding area factor remained unchanged from the provisional recommendation of being set equal to the area of the stranding location in square feet.

### 6.1.2. Stranding Cover Factor – $C_S$

The cover factor represents the influence of cover on the risk of fish being stranded in low gradient areas (slope ≤ 4 percent) or higher gradient areas (slope > 4 percent) where cover conditions influence the potential for stranding. Based on the 2007 stranding and trapping surveys, it was believed that the presence of submerged macrophytes (referred to as macrophytes) greatly influenced the risk of both stranding and trapping. Consequently, the provisional stranding factors reflected an increasing potential for trapping as the level of macrophyte cover increased. The review of the 2008 survey results presented in Section 5.2.1 confirmed the earlier observations. This section presents the development of the stranding cover factor values based on the vegetation cover. This includes a value for slopes greater than 4 percent and the separate value developed for the high density stranding area in Region 17. Macrophyte periodicity was also incorporated into cover factor values and is presented in this section.

As indicated in the discussion of the overall data collection for 2008, the stranding survey results from the months of July and August were used to develop the stranding factor values. The data from March, April, and May were not included as only one stranded fish was observed. Two other decisions were made concerning use of the 2008 data. It was decided to combine cover types into a total of three, represented as without macrophytes, low macrophytes and moderate to high macrophytes. It was also decided to treat the high density stranding area in Region 17 as a separate case from the other stranding areas and develop its own factor.

#### *6.1.2.1. Cover Factor for Slopes Less Than or Equal to 4 Percent*

The density of beached fish using the three cover types and excluding the data from the high density area in Region 17 are provided in Table 6.1-1. The average densities are reported two ways, as transect and as total. The transect density was determined by summing the densities from each transect in a category and dividing by the number of transects in that category. The total average density was determined by dividing the total number of beached fish in a category by the total area in a category. The total average density values were used in determining the stranding cover factor values. The total average density was selected as a better representation of

the overall stranding conditions since the transect-based average density equally weighted transects of different sizes whereas the total average density accounts for the size of the transects.

**Table 6.1-1.** Summary of July and August 2008 stranding area surveys categorized by three cover conditions, excluding high density stranding area in Region 17.

| Condition | No. of Transects | Area (1,000 sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Transect | Total |
| Moderate to High Macrophyte | 26 | 44.53 | 0 | 650 | 86.7 | 14.57 |
| Low Macrophyte | 46 | 105.12 | 0 | 20 | 2.49 | 2.23 |
| Without Macrophytes | 51 | 94.61 | 0 | 37 | 1.43 | 0.99 |

The cover factor values were determined by taking the total average densities and dividing by the lowest density. In this case, the lowest density was represented by the without macrophyte condition at 0.99 beached fish per 1,000 square feet. The resulting calculations are presented below.

- Without macrophytes = 0.99 / 0.99 = 1
- Low macrophyte = 2.23 / 0.99 = 2.25 (Round to 2)
- Moderate to high macrophytes = 14.57 / 0.99 = 14.72 (Round to 15)

This set of factor values includes separate values for areas without macrophytes, value of 1, and low macrophytes, value of 2. Based on discussion with the relicensing participants during the September 11, 2008 call, it was decided that the low macrophyte condition factor value applies to periods of the year when macrophytes are present but are not near their peak biomass. The moderate to high factor of 15 applies to the period of the year with peak macrophyte biomass. In addition, all mapped macrophyte areas are considered in the moderate to high category during the peak period of biomass and represented by the low macrophyte factor during the off peak or shoulder season. There is not a distinction made between the mapped densities of macrophytes within a bed. This approach for defining the cover conditions was adopted for the following two reasons:

- Until macrophytes reach a substantial level of biomass, they do not lay down into a "mat" when the reservoir water surface elevation drops. When macrophytes create a mat they tend to greatly increase the risk of fry stranding. When macrophytes are in an early growth period, fry have been observed beached, but the numbers are much less than observed in later growth stages.
- For the stranding field work, macrophytes were rated as to their level of cover based on whether they presented a solid mat when dewatered. However, when macrophyte distribution was mapped, the density of macrophytes was recorded based on the stem densities. It is difficult to quantify the relationship between cover levels identified in the stranding surveys and those identified in the macrophyte mapping effort. Therefore, all mapped macrophytes are treated the same within a growth stage period.

Areas mapped as containing macrophytes during 2007 (dry year), also contained macrophytes in 2008 (wet year); however, the density and level of macrophyte growth were typically higher in 2007. In recognition of the year to year variation in macrophyte growth, areas mapped as containing low, moderate or high macrophyte growth were considered to contain macrophytes and present a higher risk of fry stranding than areas without macrophytes. Low macrophytes were considered to be related to the timing of macrophyte growth rather than stem density. During the period of initial macrophyte growth, the factor associated with the low macrophyte density will be applied. The application of the stranding factors previously determined requires the identification of macrophyte periodicity, which is presented in Section 6.1.2.6.

#### *6.1.2.2. Potential Influence of Substrate on Cover Factor*

The potential for substrate to influence the stranding cover factor was also evaluated. The data were stratified by the substrate conditions consisting of fines, gravels and cobble. The results are presented in Table 6.1-2. Reviewing this information, there were no clear patterns in the density associated with the three substrate types. The differences in densities were dominated by the vegetative cover condition and not substrate type. Therefore, it was decided to not consider substrate in the stranding cover factor.

**Table 6.1-2.** Summary of stranding densities for July and August stratified by substrate type and cover, excluding Region 17 high density stranding area.

| Condition | | Number of Transect | Density (Fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Transect Average | Total Average |
| Substrate | Vegetation | | Low | High | | |
| Fines | Mod/High Mac | 24 | 0.0 | 650.3 | 90.5 | 12.6 |
| | Low Mac | 40 | 0.0 | 20.4 | 2.1 | 2.0 |
| | W/out Mac, | 24 | 0.0 | 6.7 | 1.5 | 1.4 |
| Gravel | Mod/High Mac | 1 | 54.9 | 54.9 | 54.9 | 54.9 |
| | Low Mac | 6 | 0.0 | 17.5 | 4.8 | 4.8 |
| | W/out Mac | 19 | 0.0 | 0.8 | 0.1 | 0.1 |
| Cobble | Mod/High Mac | 1 | 28.2 | 28.2 | 28.2 | 28.2 |
| | Low Mac | 0 | NA | NA | NA | NA |
| | W/out Mac | 8 | 0.0 | 1.5 | 0.4 | 0.5 |

#### *6.1.2.3. Cover Factor for Steep Slopes with Macrophytes*

The potential for macrophytes on steep slopes to contribute to stranding was also investigated during the 2008 surveys. A total of 9 stranding transects were surveyed on slopes greater than 4 percent with macrophytes in the moderate to high condition. Table 6.1-3 summarizes this data along with the results of the 17 stranding surveys performed on slopes less than 4 percent with moderate to high macrophyte cover. The ratio of total average densities for the stranding areas with moderate to high macrophytes on slopes less than or equal to 4 percent to those greater than 4 percent is 19.7 divided by 6.4, which equals approximately 3. Therefore, the cover factor

value of 15 for the high to moderate macrophyte condition was divided by 3 to produce the cover factor value of 5 for slopes greater than 4 percent with moderate to high macrophyte coverage.

**Table 6.1-3.** Summary of stranding densities for July and August comparing results fro moderate to high macrophyte cover for slopes of less than or equal to 4 percent and slope greater than 4 percent.

| Condition | | | Number of Transects | Density (Fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Range | | Transect Average | Total Average |
| Slope | Veg | Substrate[1] | | Low | High | | |
| ≤ 4% | Mod/High | All (1C/1G/15F) | 17 | 0.0 | 371.6 | 50.2 | 19.7 |
| > 4% | Mod/High | Fines | 9 | 0.0 | 650.3 | 155.6 | 6.4 |

Note:
1 C = Cobble substrate, G = Gravel substrate, F = Fine Substrate

### *6.1.2.4. Cover Factor Value for Region 17 High Density Stranding Area*

A high density of fry was observed beached in a portion of Region 17 following a drop in reservoir water surface elevation during July 22, 2008 field surveys. The area was notable because it had a combination of conditions that were not typical of other potential stranding sites in Boundary Reservoir. These data were excluded when computing cover factor values presented for the rest of the region. An August 29, 2008, e-mail from Doug Robison (Washington Department of Fish and Wildlife [WDFW]) indicated that Hal Beecher (WDFW instream flow specialist) and he had discussed their preferences and jointly recommended that the Region 17 outlier data not be discarded but incorporated into the analysis in some form, perhaps by using a separate weighting factor for the area of high density stranding in Region 17. However, the data were used to develop a site cover factor value for this particular area of Region 17.

Figure 5.2-1, previously presented, shows an outline of the high density stranding area, which consists of a low gradient area of approximately 41,400 square feet (0.9 acre) lying primarily between the elevations of 1,990 and 1,993 feet NAVD 88 (1,986 and 1,989 feet NGVD 29). The figure also shows an outline of the area that eventually drains across the stranding area as water surface elevations recede. This contributing basin area totals 395,000 square feet (9.1 acres) or about 10 times larger than the delineated high density stranding area. The topographic configuration of this stranding area and large amount of contributing basin result in the high stranding densities recorded on July 22, 2008. The area also supports a dense stand of emergent, single stem vegetation, (i.e., horsetail [*Equisetum spp.*]), but does not contain the beds of submerged macrophytes typical of other high density stranding areas.

The combination of emergent vegetation, large contributing basin area funneling down through a low gradient stranding area creates a high potential for fry stranding at this site, even without the presence of submerged macrophytes. The approach chosen to account for the conditions in the high fry stranding area of Region 17 was to develop a site specific factor value based on the observation data collected along transects at this site on July 22, 2008. As with the development of the other cover weighting factors, the density of beached fish was determined based on the

transect area and number of beached fish. Transect 3 had 20 beached fish in a sample area of 4,500 square feet and transect 4 had 206 beached fish in a sample area of 2,700 square feet. This produces a total average density of 226 beached fish in 7,200 square feet, or 31 fish per thousand square feet. The total average density for the without macrophyte condition was 0.99 fish per square foot (Table 6.1-1). To normalize the density for the special stranding area in Region 17, as was the procedure for the other conditions, the total average density was divided by 0.99. The result is 31.3, which was rounded to 30. The 41,400 square foot high density stranding area in Region 17 was modeled with a site specific value for the cover factor ($C_s$) of 30. Because the high stranding factor is in an area without macrophytes and not related to the presence of macrophytes, the factor of 30 applies to all seasons.

In summary, cover factor values were developed for combinations of cover conditions to support efforts to analyze potential fish stranding. The two primary conditions contributing to potential fish stranding are flat channel bed features of less than 4 percent gradient and the presence of macrophytes. The cover factor values were developed using the results of site-specific surveys of potential stranding regions identified in 2007. Beached fish were observed in areas that contained macrophytes, whereas few beached fish were observed in areas without macrophytes. Those areas without macrophytes that contained beached fish had a bed gradient of less than 4 percent. Those areas that contained macrophytes and were less than 4 percent gradient had 15 times the number of beached fry than areas of less than 4 percent gradient without macrophytes. The resulting cover factor values for the fish stranding analysis and the initially proposed provisional are provided in Table 6.1-4.

**Table 6.1-4.** Provisional and final values for the cover factor ($C_S$) in the stranding analysis.

| **Provisional Cover Factor** | |
|---|---|
| **Cover Description** | **$C_S$ Factor** |
| ≤ 4% Gradient without macrophytes | 1.0 |
| ≤ 4% Gradient with macrophytes | 3.0 |
| > 4% Gradient without macrophytes | 0.0 |
| > 4% Gradient with macrophytes | 2.0 |
| **Proposed Cover Factor** | |
| **Cover Description** | **$C_S$ Factor** |
| ≤ 4% Gradient without macrophytes | 1.0 |
| ≤ 4% Gradient with macrophytes | 15 |
| > 4% Gradient without macrophytes | 0 |
| > 4% Gradient with macrophytes | 5 |
| Region 17 high density stranding area | 30 |

### *6.1.2.5. Macrophyte Periodicity for Stranding Analysis*

Macrophyte periodicity needs to be applied to determine the period of the year when the factor values associated with the three levels of macrophyte cover apply. Macrophyte periodicity relative to the fish stranding analysis was based on observations of aquatic macrophyte growth in

Boundary Reservoir portion of the Pend Oreille River in 2007 and 2008 and 12 years of aquatic macrophyte observation in Box Canyon Reservoir portion of the Pend Oreille River.

Macrophytes in the Pend Oreille River are not active or adding biomass from December 15 through March 14; the biomass that is present from the previous growth season is decaying with limited structural definition. Depending on the species, in winter aquatic plants exist in resting stages either as turions, root crowns, seeds, tubers, or polymorphic buds. None of these life cycle stages have any significant biomass to impact potential stranding of fish during reductions in reservoir water surface elevations. Depending on climatic and local weather conditions, aquatic macrophytes start to grow about March 15 through April 14, but during this germination period, plants generate limited biomass or plants are very low in stature and also do not have the biomass to block or interfere with fish movement during water drawdown. Plant growth starting about April 15 is controlled by light and is not rigorous until mid-July. For this late spring period, the plant biomass is low and hence interference with fish movement is low. There is little biomass to lie down and cover fish during dewatering relative to the volume of wetted area. Plant growth is vigorous from July 15 through mid-September and plant biomass produced during this period remains through October. Therefore, stranding potential related to macrophyte cover is high from July 15 through October 31. The plant biomass then declines and collapses to the bottom or disintegrates from approximately November 1 through December 14. During this period, there is less biomass in the water column, and thus, little contribution to increased risk of fry stranding.

Based on the above seasonal characteristics of macrophyte growth, the following periods were adopted to account for seasonal levels of macrophyte presence related to the stranding cover factor.

- December 16 through April 15—Macrophytes are not present or are in a decayed state and partially covered with sediment. Macrophytes do not contribute to stranding potential.
    - Cover factor = 1 for slopes ≤ 4 percent
    - Cover factor = 0 for slopes > 4 percent

- April 16 through July 15—Annual growth of macrophytes starts, though it is limited by light and does not become rigorous until July. All mapped macrophyte areas are considered to have low macrophyte cover.
    - Cover factor = 2 for slopes ≤ 4 percent
    - Cover factor = 0 for slopes > 4 percent

- July 16 through October 31—Macrophytes presence is high as they experience vigorous growth through mid September with a high level of biomass persisting though the end of October. All mapped macrophyte areas considered to have high macrophyte cover:
    - Cover factor = 15 for slopes ≤ 4 percent
    - Cover factor = 5 for slopes > 4 percent

- November 1 through December 15—Macrophyte biomass declines and collapses to the bottom; greatly reducing the potential influence on stranding. All mapped macrophyte areas are considered to have low macrophyte cover.
    - Cover factor = 2 for slopes ≤ 4 percent
    - Cover factor = 0 for slopes > 4 percent

#### *6.1.2.6. Summary of Final Stranding Factors*

The final cover factor values for all conditions including the high density stranding area in Region 17 are presented in Table 6.1-5. These factors consider a value for slopes greater than 4 percent with moderate/high macrophyte cover, and seasonal variation in macrophyte cover. All areas mapped as containing macrophytes, including both low density and high density based on the number of macrophyte stems are considered to contain macrophytes during the summer period of high macrophyte growth. The low macrophyte cover condition factors is applied to all areas mapped as containing macrophytes during the period of early growth and late fall senescence. The high density of fry observed beached in the area of Region 17 is modeled by using a stranding weighting factor of 30 for this specific area for the entire year. Macrophyte periodicity is incorporated by identifying the period of high macrophyte presence to be July 15 though October 31 and the period of low macrophyte presence to be April 15 to July 15 and November 1 though December 15.

**Table 6.1-5.** Summary of final stranding cover factor seasonal values for combinations of channel bed gradient and presence of macrophytes.

| **High Season of Macrophyte Growth (July 16 through October 31)** | | |
|---|---|---|
| | No macrophytes | Macrophytes |
| Less than 4% gradient | 1 | 15 |
| Greater than 4 % gradient | 0 | 5 |
| **Low Season of Macrophyte Growth (December 16 through April 15 and November 1 through December 15)** | | |
| | No macrophytes | Macrophytes |
| Less than 4% gradient | 1 | 2 |
| Greater than 4 % gradient | 0 | 0 |
| **Macrophyte Winter Resting Period (December 16 through April 15)** | | |
| | No macrophytes | Macrophytes |
| Less than 4% gradient | 1 | 1 |
| Greater than 4 % gradient | 0 | 0 |
| **Region 17 High Density Area (January 1 through December 31)** | | |
| Less than 4% gradient (Area ~ 1%) | 30 (cover is “no macrophytes” for entire area) | |

## 6.2. Development of Final Trapping Factors

This section presents the determination of the trapping factors utilizing the data collected in the summer of 2008 and summarized in Section 5.2.2. As indicated in the discussion of the overall data collection for 2008, the trapping survey results from the months of July and August form the

database to develop the trapping factors. For the other three months in which fish trapping data were collected, March, April, and May, only 11 trapped fish were observed while performing 50 trapping surveys on pools representing over 230,000 square feet.

### 6.2.1. Risk Factors

Three factors were initially proposed to describe the risk portion of the trapping index. These factors were $A_T$, $B_T$, and $C_T$. These factors were defined in Section 3.2 and represent the trapping pool area, contributing basin area ratio and cover factor, respectively.

#### *6.2.1.1. Area Factor $A_T$*

As with the development of the stranding factors previously presented and agreed upon by the Relicensing Participants, the development of the trapping risk factors utilizes comparison of trapping densities for various groupings of conditions potentially influencing trapping to develop the appropriate set of factors and their values to be used in the trapping analysis. The density of fish trapped in a pool is defined as the number of fish, both live and dead within the pool footprint, divided by the area of the pool. This includes fish that are beached within the pool footprint in the case where the pool continues to dewater after becoming isolated from the mainstem. The area of the trapping pool is defined as the surface area in square feet of the pool when it becomes disconnected from the mainstem.

The trapping density is the number of fish trapped in a pool per unit area of the pool. By dividing the number of trapped fish by the pool area, comparison of the potential trapping risk between pools of varying sizes can be made. It is a basic assumption of the trapping index procedure that the potential to trap fish is directly proportional to the surface area of the trapping pool when it becomes isolated from the mainstem flow.

#### *6.2.1.2. Cover Factor $C_T$*

The cover factor represents the influence of cover on the risk of fish being trapped in a pool. Based on the 2007 stranding and trapping surveys it was believed that the presence of submerged macrophytes (referred to as macrophytes) greatly influenced the risk of both stranding and trapping. Consequently, the provisional trapping factors reflected an increasing potential for trapping as the level of macrophyte cover increased.

Table 6.2-1 provides a summary of the trapping surveys and results based on the seven cover levels, including the six levels of macrophytes and grasses as well as the “No Macrophyte” category representing essentially bare substrate. The results in this table show the highest average trapping densities for the high and moderate submerged macrophyte categories, but also show high average densities for the No Macrophyte category. The total average density of 424 fish per 1,000 square feet for the No Macrophyte category is three or more times greater than for any of the grass categories or Low Macrophytes. Three of the four remaining cover conditions have similar total average density ranging from 69 to 139 fish per 1,000 square feet. The fourth, Moderate Grass, has only 2 samples and a total average density of 1 fish per 1,000 square feet.

**Table 6.2-1.** Summary of July and August 2008 trapping surveys categorized by seven cover conditions.

| Condition | No. of Drawdown Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| High Macrophyte | 6 | 155,738 | 5 | 3,937 | 919 | 608 |
| Moderate Macrophyte | 7 | 40,764 | 0 | 2,657 | 1,226 | 1,396 |
| Low Macrophyte | 66 | 252,791 | 0 | 1,126 | 99 | 109 |
| No Macrophyte | 32 | 117,240 | 0 | 3,606 | 350 | 424 |
| High Grass | 2 | 23,274 | 1 | 120 | 60 | 69 |
| Moderate Grass | 2 | 8,613 | 0 | 1 | 1 | 1 |
| Low Grass | 13 | 22,302 | 0 | 2,168 | 221 | 139 |

In reviewing the data it was noted that the No Macrophyte cover condition included most of the trapping surveys with gravel or cobble substrate and that all the gravel and cobble substrate pools either had No Macrophyte or Low Macrophyte cover. Therefore, the fish trapping information was analyzed based on the three substrate categories: Fines, Gravel, and Cobble. Table 6.2-2 presents a summary of the trapping information further partitioned by substrate categories. In reviewing this information it is evident that both cobble substrate pools and pools with fines had trapping risks an order of magnitude higher than gravel substrate. All trapping pools surveyed in 2008 with cobble substrate were located in Region 10. One trapping pool in Region 10 had an estimate of over 30,000 fish for one survey and several other pools in Region 10 had estimates of over 5,000 fish.

**Table 6.2-2.** Summary of July and August 2008 trapping surveys categorized for cover conditions based on three substrate categories.

| Condition | No. of Drawdown Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| Fines | 107 | 528,853 | 0 | 3,937 | 252 | 350 |
| Gravel | 13 | 8,745 | 0 | 1,693 | 239 | 54 |
| Cobble | 8 | 83,124 | 0 | 3,606 | 588 | 577 |

To further investigate the influence of macrophyte cover, the vegetative cover conditions were combined into two categories, High-Moderate Macrophyte and Low-No Macrophyte. The later category includes all the pools with grass cover as well as pools with no vegetative cover or Low Macrophyte cover. Table 6.2-3 presents the trapping results utilizing these two categories. With this set of categories, the High-Moderate macrophyte total average density is about four times higher than the Low-No Macrophyte cover condition. This again shows the strong influence of substantial macrophyte cover on the risk of trapping fish. However, the Low-No Macrophyte category still includes the cobble areas in Region 10 that had relatively high trapping densities.

Table 6.2-4 provides a look at the trapping densities based on partitioning the data by a combination of vegetative cover and substrate. The data are sorted by a combination of the simplified vegetation categories from Table 6.2-3 and the substrate conditions from Table 6.2-2 to develop four cover types. Four cover types are required rather than six, since the High-Moderate macrophyte category was not observed in trapping pools with gravel or cobble substrate. This table reveals that the highest trapping potential, based on the surveyed average total density, is highest for the High-Moderate Macrophyte category at nearly 800 fish per 1,000 square feet and is also high for the cobble substrate with Low-No Macrophyte cover at nearly 600 fish per 1,000 square feet. In contrast, the Fines with Low-No Macrophytes and the Gravels with Low-No Macrophyte cover had average total densities of approximately 100 and 50, respectively.

**Table 6.2-3.** Summary of July and August 2008 trapping surveys categorized by combining cover conditions to two categories.

| Condition | No. of Drawdown Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| High-Moderate Macrophytes | 13 | 196,502 | 0 | 3,937 | 1,085 | 771 |
| Low-No Macrophytes | 115 | 424,220 | 0 | 3,606 | 180 | 193 |

**Table 6.2-4.** Summary of July and August 2008 trapping surveys categorized by four cover conditions incorporating substrate.

| Condition | No. of Draw-down Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| Fines with High-Moderate Macrophytes | 13 | 196,502 | 0 | 3,937 | 1,085 | 771 |
| Fines with Low-No Macrophytes | 94 | 332,351 | 0 | 3,457 | 137 | 101 |
| Gravel | 13 | 8,745 | 0 | 1,693 | 239 | 54 |
| Cobble | 8 | 83,124 | 0 | 3,606 | 588 | 577 |

Considering that the gravel category covers less than 9,000 square feet and has densities on the same order as the Fines with Low-No Macrophytes, these two categories were combined. Table 6.2-5 presents the information from Table 6.2-4 after combining the two categories just identified. After combining these categories into the Fines and Gravel with Low-No Macrophytes category, the average total density is 100 fish per 1,000 square feet.

**Table 6.2-5.** Summary of July and August 2008 trapping surveys categorized by three cover conditions incorporating substrate.

| Condition | No. of Draw-down Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| Fines with High-Moderate Macrophytes | 13 | 196,502 | 0 | 3,937 | 1,085 | 771 |
| Fines & Gravel with Low-No Macro. | 107 | 341,096 | 0 | 3,457 | 150 | 100 |
| Cobble | 8 | 83,124 | 0 | 3,606 | 588 | 577 |

The values for the cover factors were calculated by taking the total average density for each of the three cover conditions and dividing by the total average density for the lowest total average density condition, Fines and Gravel with Low-No Macrophytes. The results, along with the provisional values, are shown in Table 6.2-6 and consist of the following:

- Fines and Gravel with Low-None Macrophytes = 100/100 = 1
- Fines with High-Moderate Macrophytes = 771/100 = 7.7 (round to 8)
- Cobbles = 577/100 = 5.7 (round to 6)

**Table 6.2-6.** Provisional and final values for the cover factor in the trapping analysis.

| Provisional Cover Factor | |
|---|---|
| **Cover Description** | **$C_T$ Factor** |
| No macrophytes | 1.0 |
| < = 25 % (sparse submerged macrophytes) | 1.5 |
| > 25 % (abundant submerged macrophytes) | 3.0 |
| **Final Cover Factor** | |
| **Cover Description** | **$C_T$ Factor** |
| Fines and gravel with low-no submerged macrophytes | 1.0 |
| Fines with high-moderate submerged macrophytes | 8.0 |
| Cobbles | 6.0 |

Since the cover factor incorporates submerged macrophytes, it is necessary to consider macrophyte periodicity when applying the cover factor. Macrophyte periodicity was agreed upon during the development of the final stranding factors. The same seasons are used for the trapping analysis. An additional aspect of the stranding analysis treatment of macrophytes that was agreed upon was to consider all areas of mapped macrophytes during the season of peak presence as having a high macrophyte condition, in the shoulder seasons as having low presence and in the winter season as none. In the stranding analysis, low macrophyte cover was found to increase the potential for stranding; however, a similar influence was not supported by the data

collected for the trapping analysis. The macrophytes seasons and the level of macrophyte presence assigned to areas with mapped macrophytes are provided below:

- December 16 through April 15—Macrophytes are not present or are in a decayed state.
- April 16 through July 15—Annual growth of macrophytes starts, though biomass does not sufficiently accumulate to affect fish trapping until July. ***All mapped macrophyte areas are considered to have low macrophyte cover.***
- July 16 through October 31—Macrophyte biomass is at its peak as they experience vigorous growth through mid September with a high level of biomass persisting though the end of October. ***All mapped macrophyte areas considered to have high macrophyte cover.***
- November 1 through December 15—Macrophyte biomass declines and collapses to the bottom; greatly reducing the potential influence on trapping. ***All mapped macrophyte areas are considered to have low macrophyte cover.***

Because the data collected did not indicate that low macrophyte cover increased the risk of trapping, the shoulder season (April 16 through July 15 and November 1 through December 15), are grouped with the period of no macrophyte presence (December 16 through April 15). The results in the trapping cover factor values for areas with mapped macrophytes being set to 1.0, corresponding to Fines and Gravel with Low-No Macrophytes, for the period of November 1 through July 15. For the period of high macrophyte presence, the cover factor will be set to 8. Applying macrophyte periodicity, the resulting final cover factors are presented in Table 6.2-7.

**Table 6.2-7.** Final cover factor values considering submerged macrophyte periodicity.

| **High Season of macrophyte biomass (July 16 though October 31)** | |
|---|---|
| **Condition** | **Cover Factor $C_T$** |
| Fines and Gravel (without mapped macrophytes) | 1 |
| Fines (with mapped macrophytes) | 8 |
| Cobbles | 6 |
| **Seasons of low macrophyte biomass and winter resting (November 1 through July 15)** | |
| **Condition** | **Cover Factor $C_T$** |
| Fines and Gravel (without mapped macrophytes) | 1 |
| Fines (with mapped macrophytes) | 1 |
| Cobbles | 6 |

### *6.2.1.3. Contributing Basin Factor BT*

The contributing basin ratio factor $B_T$ is defined as the ratio of the area of the contributing basin draining into the trapping pool and the trapping pool area. The provisional assumption was to limit the ratio to a maximum value of 3 and to only consider areas within four feet vertically of the basin outlet. In developing the contributing basins, it was determined that of the 128 basins with trapping surveys, only ten had a contributing basin ratio of three or less. Therefore, the data were analyzed by adjusting the ranges of basin ratios to be 3 or less, 3 to 10, 10 to 30, and greater

than 30. Table 6.2-8 presents the 2008 trapping survey results stratified by the contributing basin area ratio. The average total density results do not show a consistent trend of either increasing or decreasing trapping densities with the contributing basin area ratio. The density starts at over 400, decreases to about 300, increase to nearly 500 and then decreases to below 200 as the contributing basin area ratio increases from less than 3 to over 30.

**Table 6.2-8.** Summary of July and August 2008 trapping surveys categorized by contributing basin area ratio.

| Condition | No. of Drawdown Events | Area (sq. ft.) | Fish Density (fish per 1,000 sq. ft.) | | | |
|---|---|---|---|---|---|---|
| | | | Range | | Average | |
| | | | Min. | Max. | Pool | Total |
| Contributing Basin Area Ratio < 3 | 10 | 101,880 | 0 | 1,282 | 195 | 416 |
| Contributing Basin Area Ratio 3-10 | 60 | 365,579 | 0 | 3,606 | 249 | 325 |
| Contributing Basin Area Ratio 10-30 | 44 | 5,433 | 0 | 3,937 | 314 | 487 |
| Contributing Basin Area Ratio >30 | 14 | 147,830 | 0 | 1,693 | 293 | 166 |

The data collected for development of the trapping index do not show an apparent relationship between the risk of trapping fish in a pool and the contributing basin area ratio. Based on these results a reliable contributing basin ratio cannot be developed. Therefore, the contributing basin area ratio was eliminated from the trapping index equation for the current study. Eliminating contributing basin factor, the trapping index equation becomes:

$$TI = A_T * T_T(D) * C_T$$

Where:

$TI$ = trapping index
$A_T$ = trapping area (square feet)
$T_T(D)$ = duration of trapping factor
$C_T$ = cover factor representing the influence of macrophytes and other cover

Table 6.2-9 presents the provisional contributing basin factors along with the decision to not include it in the trapping analysis for the Project.

**Table 6.2-9.** Summary of contributing basin area factor provisional values versus decision to drop the contributing basin as a trapping factor.

| **Provisional Contributing Basin Area Factor** | |
|---|---|
| Ratio: Basin Area/$A_T$ | Contributing Basin Factor |
| 1.0 | 1.0 |
| 1.5 | 1.5 |
| 2.0 | 2.0 |
| 2.5 | 2.5 |
| 3.0 | 3.0 |
| >3.0 | 3.0 |
| **Final Contributing Basin Area Factor** | |
| Drop contributing basin as a trapping factor | |

It is possible that the area of the contributing basin does not influence the risk of trapping fish or it may be that most pools have sufficiently large contributing basins that the influence is not evident in the survey data. Most likely, the physical processes associated with the role of the contributing basin ratio in determining the trapping risk are more complex than a ratio of contributing basin the trapping pool area can reflect. Topographic characteristics that define the boundary of contributing basin may influence the contributing basin's potential to increase the risk of trapping. For example, a topographic condition that may cause high trapping risk is a contributing basin having distinct side slopes that funnel flow into the trapping basin. This topographic condition may result in the contributing basin having more influence on the density of fish trapped than a contributing basin of similar area with gradual slope radiating out from the pool. In the latter situation, as the water level recedes, a large portion of the water in the contributing basin may flow out of the area without actually passing through the trapping basin. The portion of the water in the contributing basin that does not flow through the trapping basin does not transport fish through the trapping basin and therefore, does not increase the risk of trapping.

### 6.2.2. Mortality Factor

Mortality in the trapping index is represented by the duration of trapping factor $T_T(D)$. The considerations for the duration of trapping factor were presented in Section 3.2.4 along with provisional factor values. The initial proposal incorporated factor values for three depth ranges: less than 1 foot, 1 to 2 feet, and greater than 2 feet. These values are presented below in Table 6.2-10. This section presents the development of recommended duration of trapping factors from the trapping data collected in 2008.

**Table 6.2-10.** Provisional values for duration of trapping factor $T_T(D)$ for summer conditions in the trapping analysis.

| Depth < 1 foot | | Depth 1 to 2 feet | | Depth > 2 feet | |
|---|---|---|---|---|---|
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 6 | 0.25 | 9 | 0.25 | 12 | 0.25 |
| 12 | 0.50 | 18 | 0.50 | 24 | 0.50 |
| 18 | 0.75 | 27 | 0.75 | 36 | 0.75 |
| 24 | 1.0 | 36 | 1.0 | 48 | 1.0 |

### *6.2.2.1. Duration of Trapping Factor Values for Summer Conditions*

Evaluation of original data collected from pools throughout the Project during July and August 2008 were used to generate relationships between estimated duration of disconnection of a pool from the mainstem reservoir and the mortality of fish (percent of total numbers). Multiple pools were visited at various stages of disconnection from the main reservoir (hours since disconnection) and pool setting characteristics measured in order to classify by pool type (e.g., maximum depth of pool, macrophyte/grass vegetation present, and substrate composition). These repeated observations from different pools (and occasionally from the same pool) were partitioned by pool setting characteristics (e.g., maximum depth of pool) into distinct categories for further evaluation of mortality effects resulting from this disconnection.

Data were grouped by maximum pool depths into three categories and analyzed by constructing cumulative distribution frequency curves for each category (Figure 6.2-1). Table 6.2-11 reports characteristics of data used for analyzing the relationship between duration of disconnection and fish mortality. Aggregating data by depth assumes that: 1) influence of disconnection of the pool from the mainstem reservoir results in similar mortality rates over time, regardless of the pool from which data was recorded, and 2) a direct relationship exists between the elapsed time from pool disconnection and the biological response that is manifested by mortality (percent of total number of fish). Partitioning variables like maximum pool depth should account for increasing temperatures, increased predation, and water availability in disconnected pools if interpretable relational curves can be developed. The advantage in using cumulative distribution frequency curves for describing these relationships is that observations from independent pools can be combined to describe a relationship between environmental stressors and a biological response.

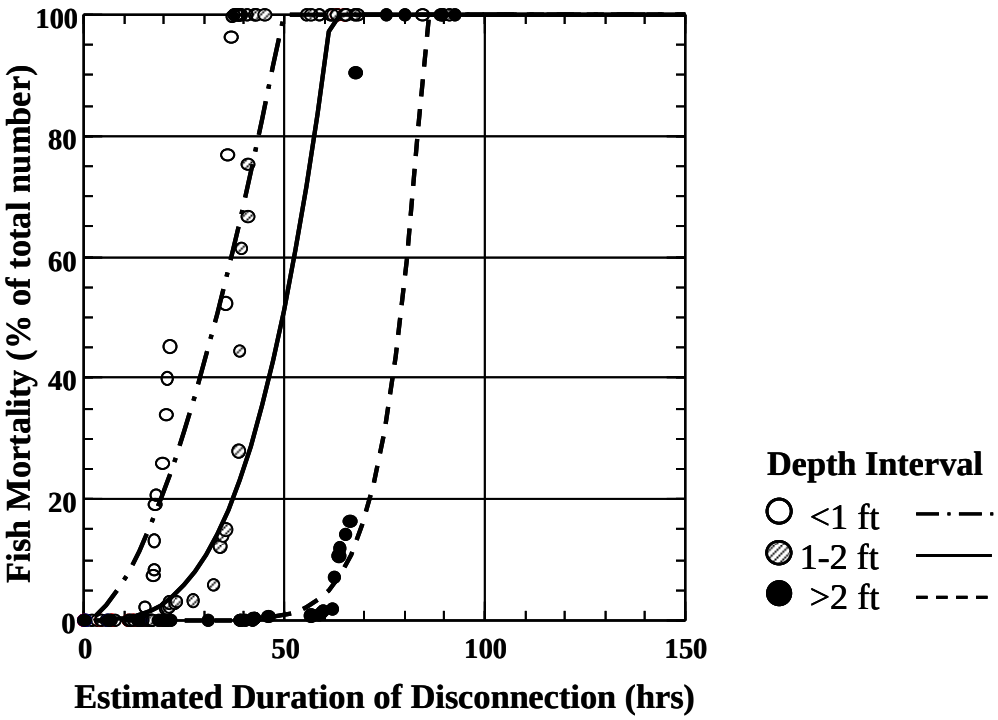


**Figure 6.2-1.** Distribution of time since disconnection from the main reservoir compared against the distribution of fish mortality resulting from lapsed time, summer conditions.

**Table 6.2-11.** Summary of fish mortalities by pool depth intervals from fish trapping surveys conducted in July and August 2008.

| Maximum Pool Depth Category | Number of Events Analyzed | Total Number of Pools | Total Number of Measurements | Total Number of Fish Mortalities |
|---|---|---|---|---|
| < 1 foot | 40 | 23 | 40 | 9,281 |
| 1-2 feet | 48 | 24 | 48 | 5,255 |
| > 2 feet | 40 | 19 | 40 | 3,440 |

Each of the curves represents response of the fish community (mortality rate) over time in each of the depth interval categories. The original data used to derive analytical curves represent percentiles (cumulative distribution frequency) of the duration of disconnection as they are fitted against percentiles of the response observations (percent fish mortality).

Derivation of the initial duration of disconnection (in hours) that corresponds with pre-determined duration of trapping factor ($T_T[D]$) values is shown in Figure 6.2-2. Duration of trapping factor intervals ($T_T[D]$) were predetermined and recorded in Figure 6.2-2 as hatched horizontal lines extending from the y-axis (fish mortality). The predicted duration of disconnection time (hours) results from extension of a vertical line from each intersection with

each representative curve. These intersections between $T_T(D)$ and the curves are reported in Table 6.2-12.

**Table 6.2-12.** Quantitatively derived values for duration of trapping factor $T_T(D)$ for summer conditions in the trapping analysis.

| Depth < 1 foot | | Depth 1 to 2 feet | | Depth > 2 foot | |
|---|---|---|---|---|---|
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 8 | 0.05 | 23 | 0.05 | 60 | 0.05 |
| 12 | 0.10 | 29 | 0.10 | 66 | 0.10 |
| 19 | 0.20 | 37 | 0.20 | 70 | 0.20 |
| 22 | 0.25 | 40 | 0.25 | 73 | 0.25 |
| 32 | 0.50 | 50 | 0.50 | 79 | 0.50 |
| 41 | 0.75 | 56 | 0.75 | 82 | 0.75 |
| 50 | 1.0 | 63 | 1.0 | 86 | 1.0 |

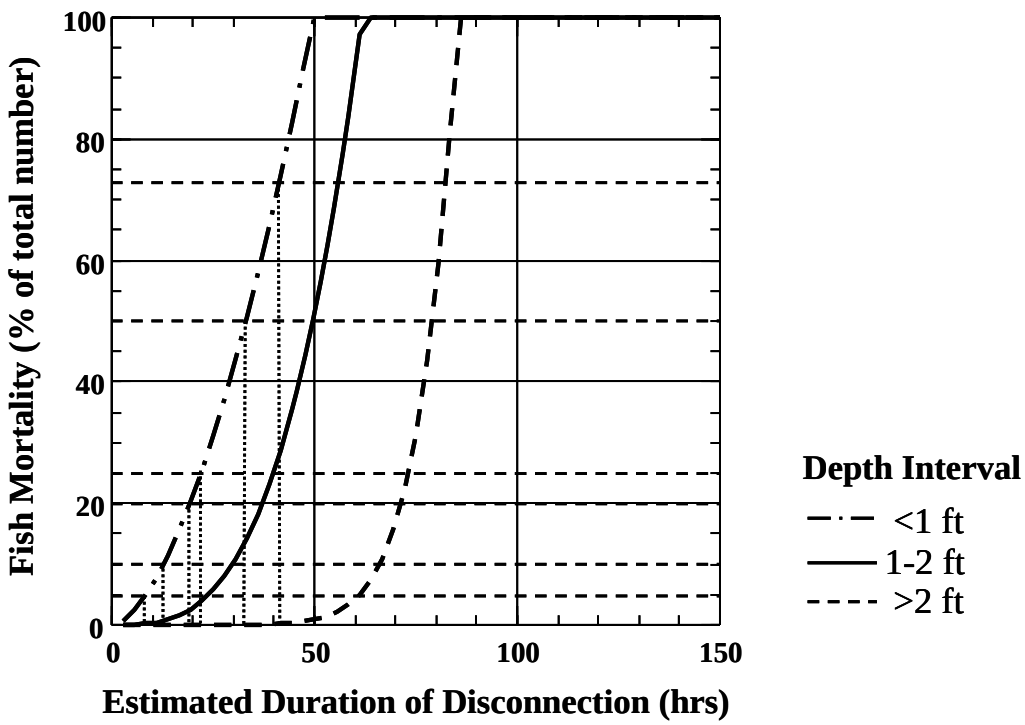


**Figure 6.2-2.** Determination of trapping durations that correspond to predetermined initial duration of trapping factor values as predicted from fish mortality percentiles, summer conditions.

Pools with maximum depths of less than one foot have the greatest measured mortality rate in existing fish communities. Predicted fish mortality progresses at a much slower rate in pools with maximum depths of greater than 2 feet than in pools with shallower maximum depths. The rate of mortality in shallower depths over time is a likely combination of the factors previously

stated: increased water temperature, decreased dissolved oxygen concentrations, increased predation, and quicker evacuation of water from the shallow pool. The more complex a pool environment, as reflected by maximum depth, the more likely the fish community is to find suitable refugia for extended survival.

The initial fish mortality response curves (Figure 6.2-2 and Table 6.2-12) were adjusted to account for the influence of predation and trapping will result in stress to fish that survive the event. The use of fish mortality based on counts of dead fish does not measure these detrimental aspects of a fish being trapped. To account for this, the duration of trapping factor curves were adjusted, based on professional judgment, to have an initial value of 0.1 after the first hour of trapping. The resulting recommended curves are graphed in Figure 6.2-3. Adjustment of the origin involved maintaining the shape of the original curve and re-scaling the origin of each curve to begin at one-hour of pool disconnection and with ten percent fish mortality. This point of origin was chosen to account for time since disconnection of the pool prior to census of fish mortality by the field team.

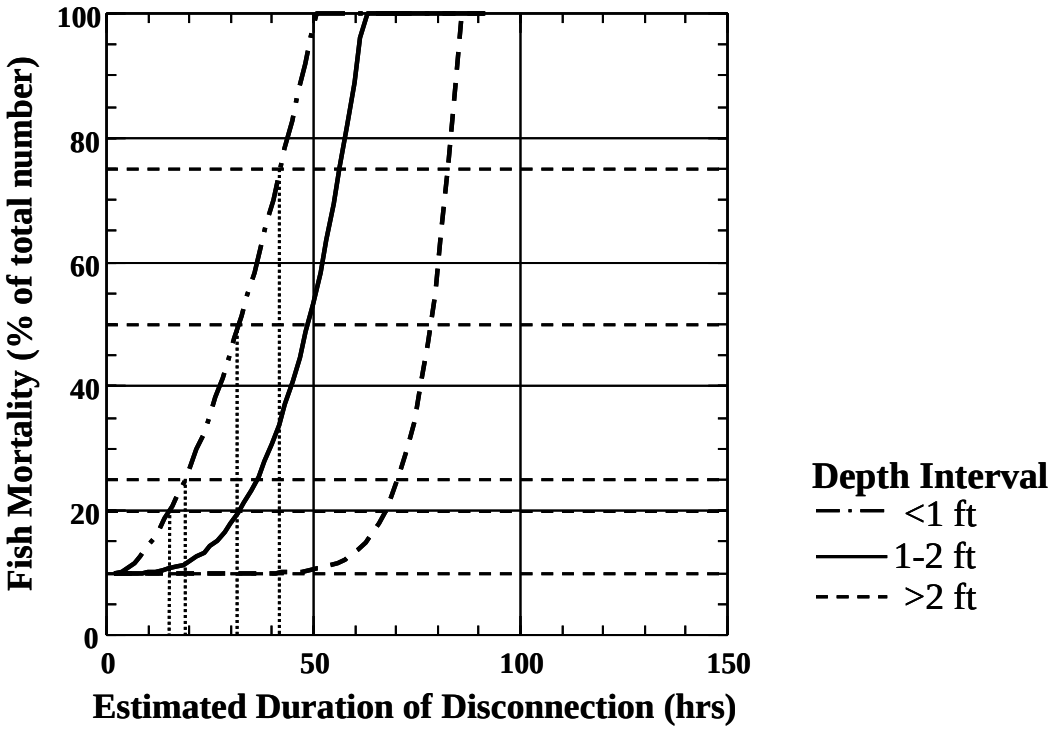


**Figure 6.2-3.** Adjusted fish mortality curves for duration of trapping factor based on depth intervals, summer conditions.

The inclusion of the 0.1 mortality factor for the first hour of pool disconnection from the mainstem resulted in an adjustment to the estimated duration of disconnection (in hours) times for fish mortality rates. These adjusted hourly values are reported in Table 6.2-13.

**Table 6.2-13.** Final values for duration of trapping factor $T_T(D)$ for summer conditions in the trapping analysis.

| Depth < 1 foot | | Depth 1 to 2 feet | | Depth > 2 foot | |
|---|---|---|---|---|---|
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 1 | 0.10 | 1 | 0.10 | 1 | 0.10 |
| 15 | 0.20 | 32 | 0.20 | 67 | 0.20 |
| 19 | 0.25 | 37 | 0.25 | 71 | 0.25 |
| 31 | 0.50 | 48 | 0.50 | 78 | 0.50 |
| 42 | 0.75 | 57 | 0.75 | 83 | 0.75 |
| 51 | 1.0 | 63 | 1.0 | 86 | 1.0 |

### *6.2.2.2. Duration of Trapping Factor for Winter Conditions*

The last aspect of the duration of trapping factor development is to identify adjustments for winter period. Curves for the duration trapping factor were originally proposed for the winter. This was proposed primarily based on temperature and oxygen having smaller influences on fish mortality during the winter. The originally proposed winter factors were provided in Table 3.1-3 and reflect a duration 3.5 times longer to reach mortality in the winter than in the summer. During the 2008 data collection effort, field conditions (snow and ice) prevented collection of trapping data in February or early March. Therefore, no data were available to adjust the mortality factor for winter conditions. Because of this, it is proposed and agreed upon by the relicensing participants during the October 1 WebEx that the summer factors be adopted as the initial basis for the winter factors. This was expected to produce conservatively high winter factors.

During discussion of the duration of trapping factor with relicensing participants in 2008, it was brought up that temperature could also contribute to mortality in the winter if low temperatures resulted in trapping pools freezing solid. To address this important point, an assessment of the duration necessary to completely freeze trapping pools within the depth intervals associated with the factor was conducted.

To assess the ice thickness anticipated due to climatic conditions experienced at the Project, the following equation was used:

$$h_j = \alpha\sqrt{U_j}$$

Where:

$h_j$ = calculated ice thickness on day j, in inches
$\alpha$ = coefficient, assumed 0.5
$U_j$ = Accumulated Freezing Degree-Days (AFDDs) recorded between the onset of freeze-up (day 1) and day j

The parameter $\alpha$ was based on recommendations presented by the U.S. Army Corps of Engineers for an average lake with snow (USACE 2002). This equation was applied to determine the number of accumulated freezing degree-days (AFDDs) required to develop ice thicknesses of 0.5, 1, and 2.5 feet. The first two ice thicknesses correspond to the mid-point of the first two depth intervals in the duration of trapping factor (0 to 1 foot and 1 to 2 feet). The last value, 2.5 feet, is the lower limit of the third interval (>2 feet) plus 0.5 foot. An estimated 140, 1,300, and 3,600 AFDDs are necessary to freeze a pool having a depth of 0.5, 1.5, and 2.5 feet, respectively.

Application of the ice formation equation using the average daily temperatures recorded from 1965 through 2007 at the Project forebay (COOP Station ID 450844; WRCC 2008) was conducted to determine the duration at which sufficient AFDDs occur to freeze a pool for a specific depth. Based on average temperatures recorded at the Project a pool with a depth of 0.5 foot would freeze solid within 32 days. Pools with depths of 1.5 feet and 2.5 feet would not freeze entirely based on review of the average daily temperatures. Using the average daily temperatures for the period of record, a maximum ice thickness of approximately 1.2 feet was calculated.

Review of extreme low temperatures recorded at the Project was also conducted to identify the shortest duration that would be required to form ice of the three specified thicknesses. During a period in December 1968 in January 1969 temperatures dropped significantly below 0°F for several extended periods. The lowest minimum temperature in 42 years of record of -28°F occurred for two consecutive days during this period beginning on December 30, 1980. This was preceded by a day at -24°F low. Using this extreme period of record starting on December 28, 1968, a day with a low of 0°F, a duration of 72 hours (3 days) is required to reach an ice thickness of 0.5 foot. The maximum ice thickness achieved in this 30 day period is estimated at 15 inches.

The time required to freeze the pools solid can be compared against the recommended factors to determine if the pools may actually freeze in a shorter duration than the factors indicate for 100 percent mortality. For the average temperature conditions 648 hours (27 days) are required to freeze the 0.5-foot deep pool solid. This period is over ten times the duration to reach 100 percent mortality using the proposed duration of trapping curve for a depth of < 1 foot, which reaches 100 percent mortality after 51 hours. The duration is also much longer than the 63 hours and 86 hours required for 100 percent mortality in the 1- to 2-foot pool depth and greater than 2-foot depth intervals, respectively. Therefore, under the average condition, freezing of the trapping pools does not influence fish mortality and the duration of trapping factor. Use of the extreme low temperature data also indicates it will take longer to freeze a 0.5-foot deep pool, 72 hours, than it does to reach 100 percent mortality. Consequently, the influence of pools freezing solid does not indicate the adjustment of the proposed winter factors is warranted.

#### *6.2.2.3. Summary of Final Duration of Trapping Factor Values*

Table 6.2-14 lists both the provisional and final values for the duration of trapping factor $T_T(D)$. The final factor values retain the three depth intervals from the provisional factor, but 100 percent mortality is not achieved as rapidly in the recommended values. An initial mortality value of 0.1 was set in the final factors to account for predation not being directly measured in

the field efforts and non-lethal stress that may occur when fish are trapped. In developing the final factors, the potential for pools freezing solid in the winter was investigated but determined to require a longer duration than already proposed for 100 percent mortality. Because freezing is not an issue and in the absence of sufficient data available from winter, spring, and fall trapping surveys, the duration of trapping factor values presented in Table 6.2-14 are proposed for the entire year.

**Table 6.2-14.** Provisional (summer period) and final duration of trapping factor $T_T(D)$ values (all seasons).

| **Provisional Values** | | | | | |
|---|---|---|---|---|---|
| **Depth < 1 foot** | | **Depth 1 to 2 feet** | | **Depth > 2 feet** | |
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 6 | 0.25 | 9 | 0.25 | 12 | 0.25 |
| 12 | 0.50 | 18 | 0.50 | 24 | 0.50 |
| 18 | 0.75 | 27 | 0.75 | 36 | 0.75 |
| 24 | 1.0 | 36 | 1.0 | 48 | 1.0 |
| **Final Values** | | | | | |
| **Depth < 1 foot** | | **Depth 1 to 2 feet** | | **Depth > 2 feet** | |
| **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** | **Hours** | **$T_T(D)$** |
| 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 1 | 0.10 | 1 | 0.10 | 1 | 0.10 |
| 15 | 0.20 | 32 | 0.20 | 67 | 0.20 |
| 19 | 0.25 | 37 | 0.25 | 71 | 0.25 |
| 31 | 0.50 | 48 | 0.50 | 78 | 0.50 |
| 42 | 0.75 | 57 | 0.75 | 83 | 0.75 |
| 51 | 1.0 | 63 | 1.0 | 86 | 1.0 |

# 7 STRANDING MODEL AND TRAPPING MODEL RESULTS

The detailed discussion of the results is presented in the main body Section 5.4 of the Study 7 Final Report (SCL 2009a). This section of the report provides the figures that display the results of the stranding and trapping modeling effort.

The results presented in this section address the historic Project effects. The potential term of a new license is 50 years, but Project effects on certain resources were evaluated only during three representative years. These years were selected as representative of wet, dry, and average conditions based on average annual flows (R2 Resource Consultants 2008). The wet year is based on 1997, the dry year on 2001, and the average year on 2002.

## 7.1. Stranding Model Results

This section presents the results from the stranding modeling effort. Stranding index (SI) values were calculated for each of the regions on an hourly basis for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. A summary of the annual total SI value and average daily weighted channel width of exposed stranding areas for each of the representative years is presented in Table 7.1-1. The exposed stranding areas values in Table 7.1-1 were developed by dividing the annual SI values by 365 (days per year) and the appropriate reach length. The width is considered weighted since the SI includes a cover factor that has a value ranging from 1 to 30. The stranding modeling results are presented graphically in the figures in Attachment D.

**Table 7.1-1.** Summary of annual total stranding index values and average daily weighted channel width of exposed stranding area that occurred during the wet (1997), dry (2001), and average year (2002).

| Reach | Reach Length (ft) | Potential Strand-ing Risk Area ($ft^2$) | Average Channel Width of Potential Strand-ing Risk Area (ft) | Wet Year (1997) | | Dry Year (2001) | | Average Year (2002) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Stranding Area (ft) | Annual Total Stranding Index (10,000 $ft^2$) | Average Daily Weighted Channel Width of Exposed Strand-ing Area (ft) |
| Forebay | 5,360 | 281,200 | 52 | 1,250 | 6.4 | 940 | 4.8 | 400 | 2.0 |
| Canyon | 44,156 | 538,200 | 12 | 7,075 | 4.4 | 3,668 | 2.3 | 2,700 | 1.7 |
| Upper Reservoir | 38,549 | 11,896,900 | 309 | 88,943 | 63.2 | 168,200 | 119.5 | 128,112 | 91.1 |
| Total Boundary Reservoir | 88,065 | 12,716,300 | 144 | 97,267 | 31 | 172,808 | 55 | 131,212 | 42 |
| Tailrace | 15,613 | 285,300 | 18 | 2,473 | 4.3 | 2,490 | 4.4 | 2,600 | 4.6 |
| **Total Project** | **103,678** | **13,001,600** | **125** | **99,740** | **26** | **175,297** | **46** | **133,813** | **35** |

The figures presented in Attachment D are organized by reach starting downstream at the Tailrace Reach and progressing upstream to the Upper Reservoir Reach. A figure presenting the monthly total SI values by reach for the three representative years is shown in Attachment D. Additionally daily total SI values for a given region within a reach are presented graphically for the three representative years. The location of the regions was presented in Figure 4.1-1. An example of the monthly total SI values for the Upper Reservoir Reach is presented in Figure 7.1-1. Daily total SI values for Region 10 and Region 11 are shown in Figure 7.1-2 and Figure 7.1-3, respectively. Region 10 represents an area predominantly of cobble substrate without the presence of macrophytes. Region 11 represents an area predominantly of fines substrate with the

presence of macrophytes. As illustrated in these example figures, the x-axis for each plot covers the calendar year from January 1 through December 31. The left y-axis is for SI.

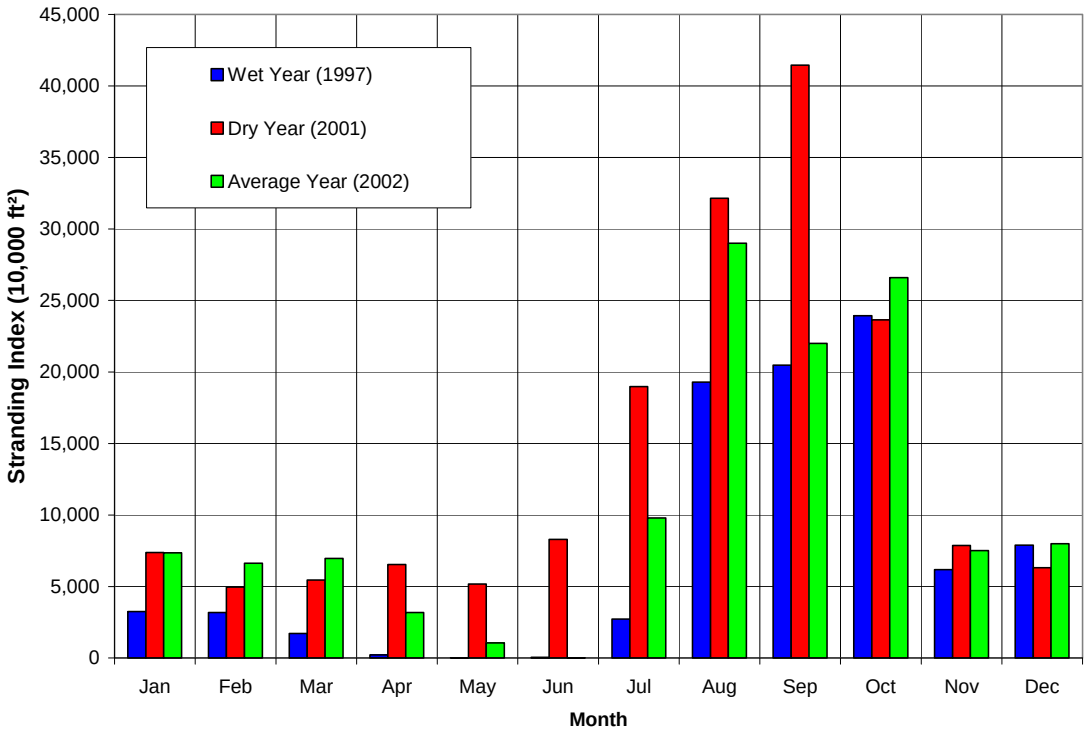


**Figure 7.1-1.** Example of monthly total stranding index values for the Upper Reservoir Reach that occurred during the wet (1997), dry (2001), and average year (2002).

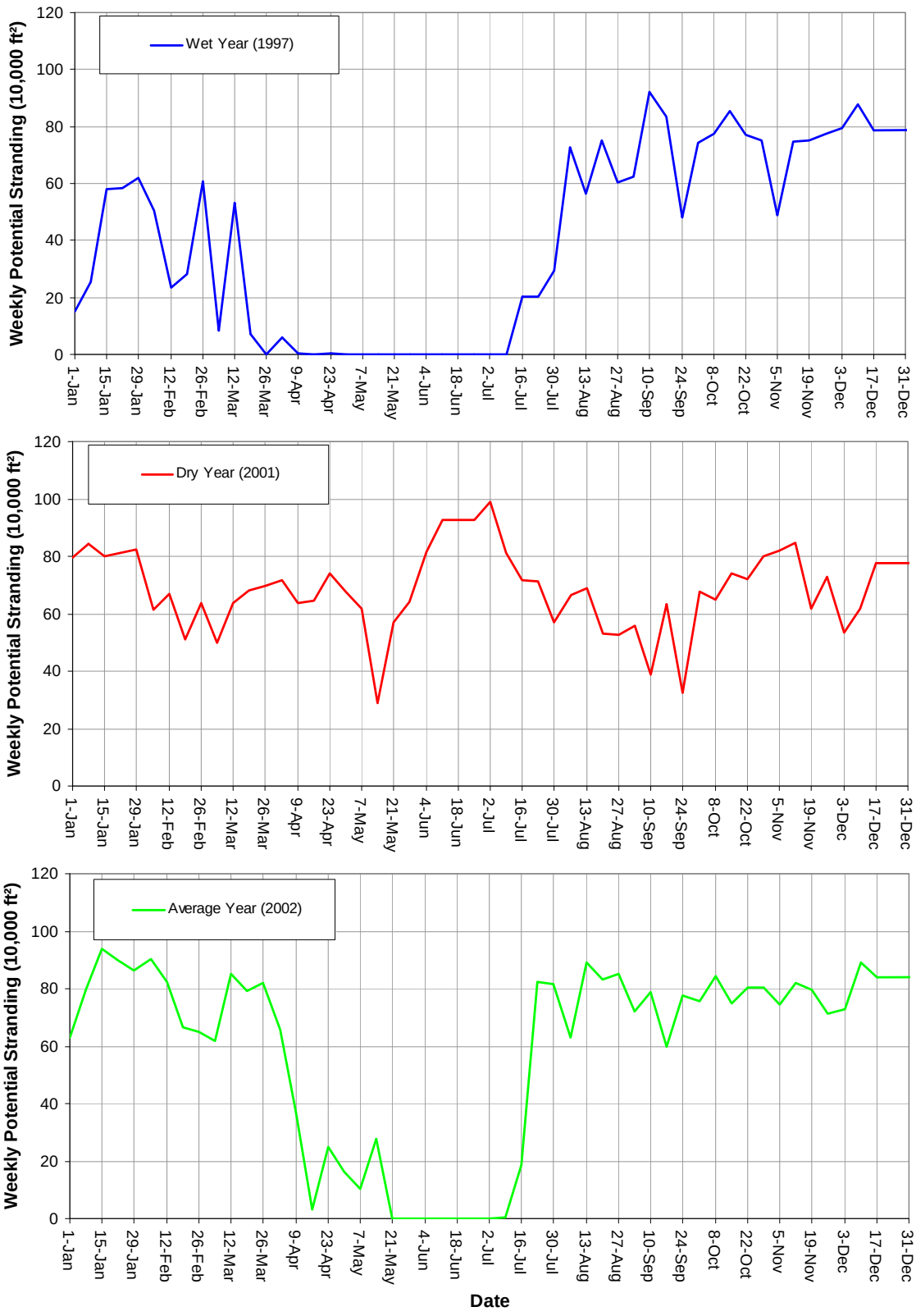


**Figure 7.1-2.** Example of the comparison of Region 10 daily total stranding index values that occurred during the wet (1997), dry (2001), and average year (2002).

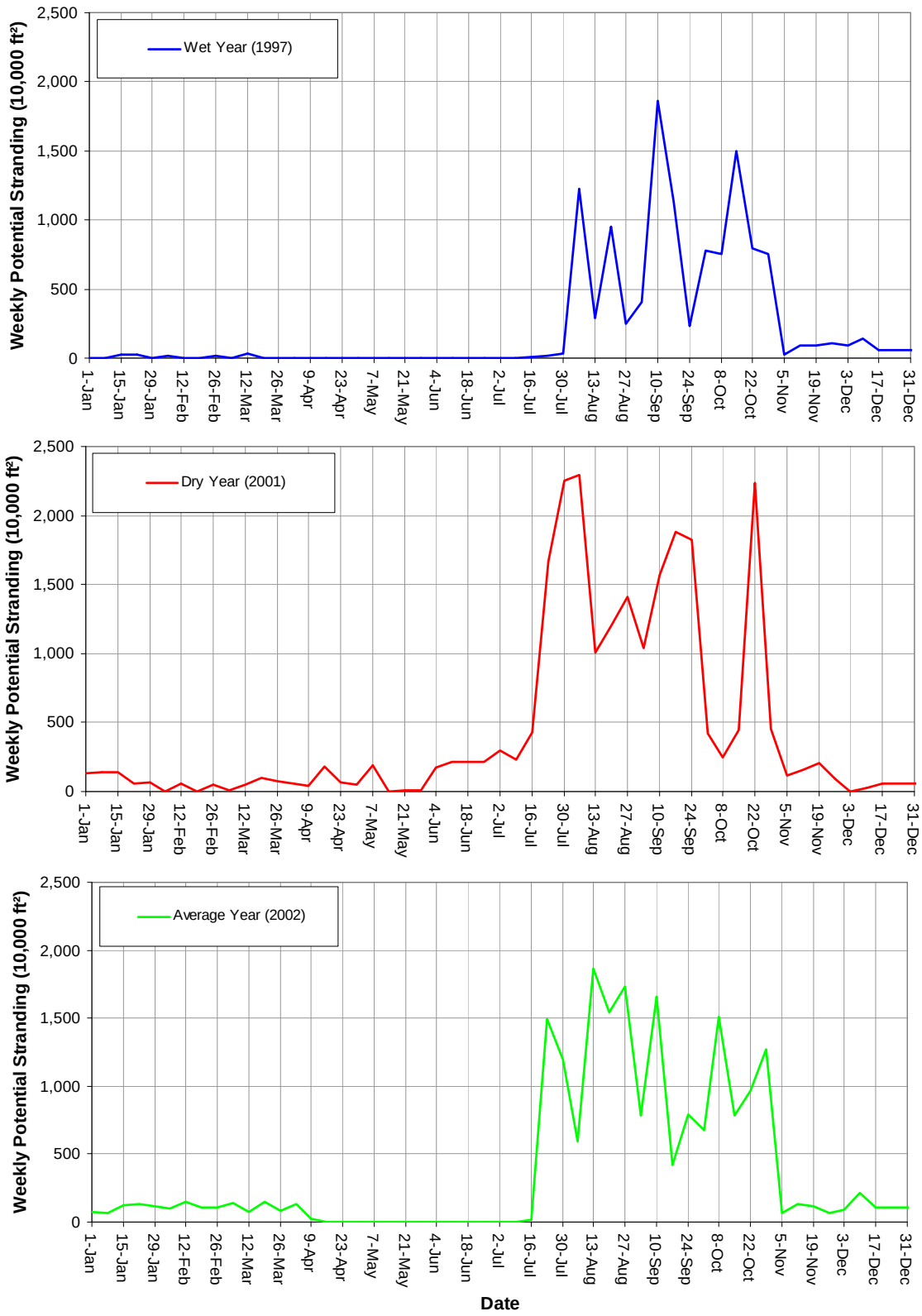


**Figure 7.1-3.** Example of the comparison of Region 11 daily total stranding index values that occurred during the wet (1997), dry (2001), and average year (2002).

## 7.2. Trapping Model Results

This section presents the results from the trapping modeling effort. Trapping index values were calculated for each of the regions on an hourly basis for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. A summary of the annual total trapping index (TI) value for each of the representative years is presented in Table 7.2-1. The trapping modeling results are presented graphically in the figures in Attachment E.

**Table 7.2-1.** Summary of annual total trapping index values that occurred during the wet (1997), dry (2001), and average year (2002).

| Reach | Total Area of Trapping Pool ($ft^2$) | Annual Total Trapping Index (10,000 $ft^2$) | | |
|---|---|---|---|---|
| | | Wet Year (1997) | Dry Year (2001) | Average Year (2002) |
| Forebay | 11,300 | 1.1 | 2.4 | 1.0 |
| Canyon | 99,800 | 163 | 160 | 93 |
| Upper Reservoir | 2,487,200 | 1,616 | 3,916 | 2,478 |
| Total Boundary Reservoir | 2,598,300 | 1,780 | 4,079 | 2,572 |
| Tailrace | 20,300 | 139 | 213 | 163 |
| **Annual Total** | **2,618,600** | **1,920** | **4,292** | **2,735** |

Figures presenting monthly total trapping index values for the three representative years are shown in Attachment E and are organized by reach starting at the Forebay Reach and progressing upstream to the Upper Reservoir Reach. The Tailrace Reach is presented lastly. Additionally weekly trapping index values for a given region within a reach are presented graphically for the three representative years in Attachment E. An example of the monthly total trapping index values for the Upper Reservoir Reach is presented in Figure 7.2-1. An example of weekly trapping index values for Region 10 and Region 11 are shown in Figure 7.2-2 and Figure 7.2-3, respectively. Region 10 represents an area predominantly of cobble substrate without the presence of macrophytes. Region 11 represents an area predominantly of fines substrate with the presence of macrophytes. As illustrated in these example figures, the x-axis for each plot covers the calendar year from January 1 through December 31. The left y-axis is for the TI.

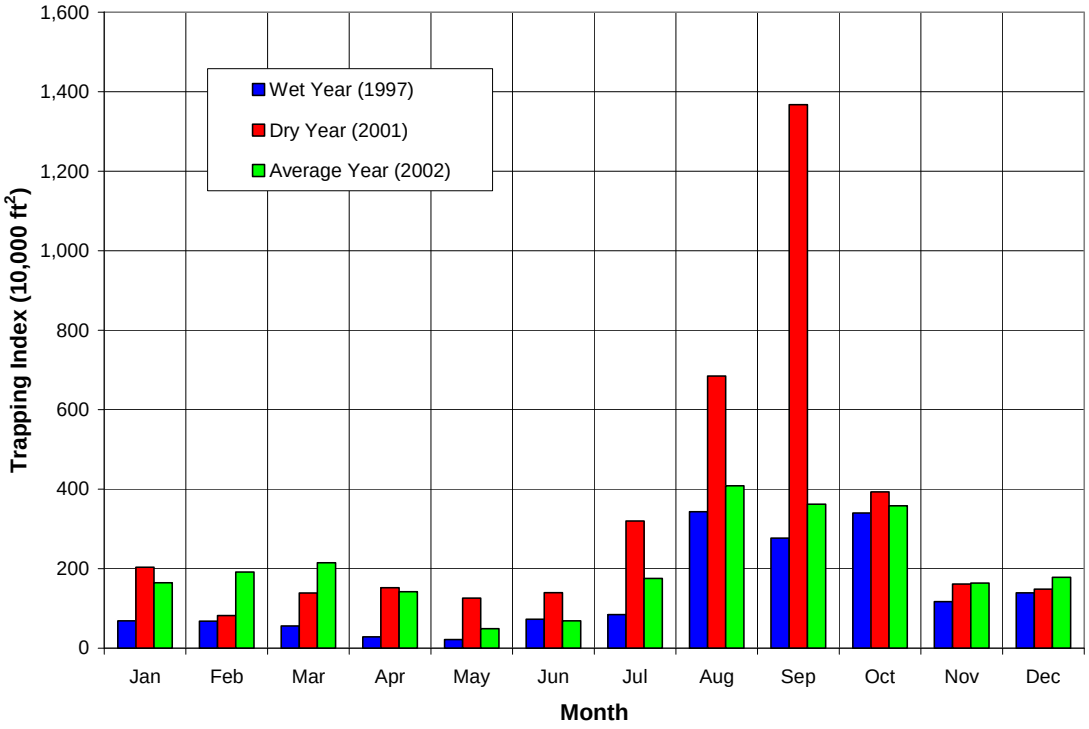


**Figure 7.2-1.** Example of monthly total trapping index values for the Upper Reservoir Reach that occurred during the wet (1997), dry (2001), and average year (2002).

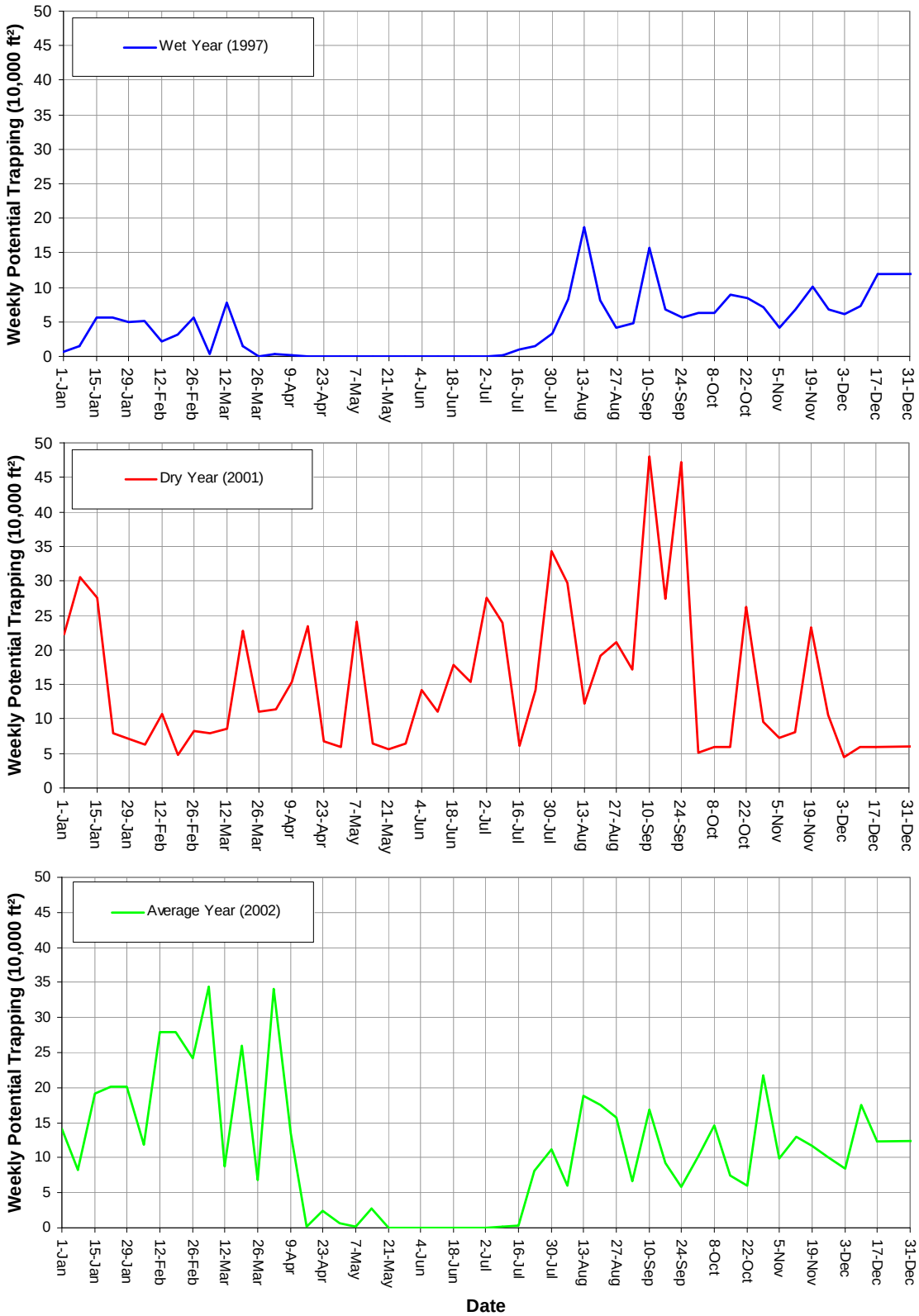


**Figure 7.2-2.** Example of the comparison of Region 10 daily total trapping index values that occurred during the wet (1997), dry (2001), and average year (2002).

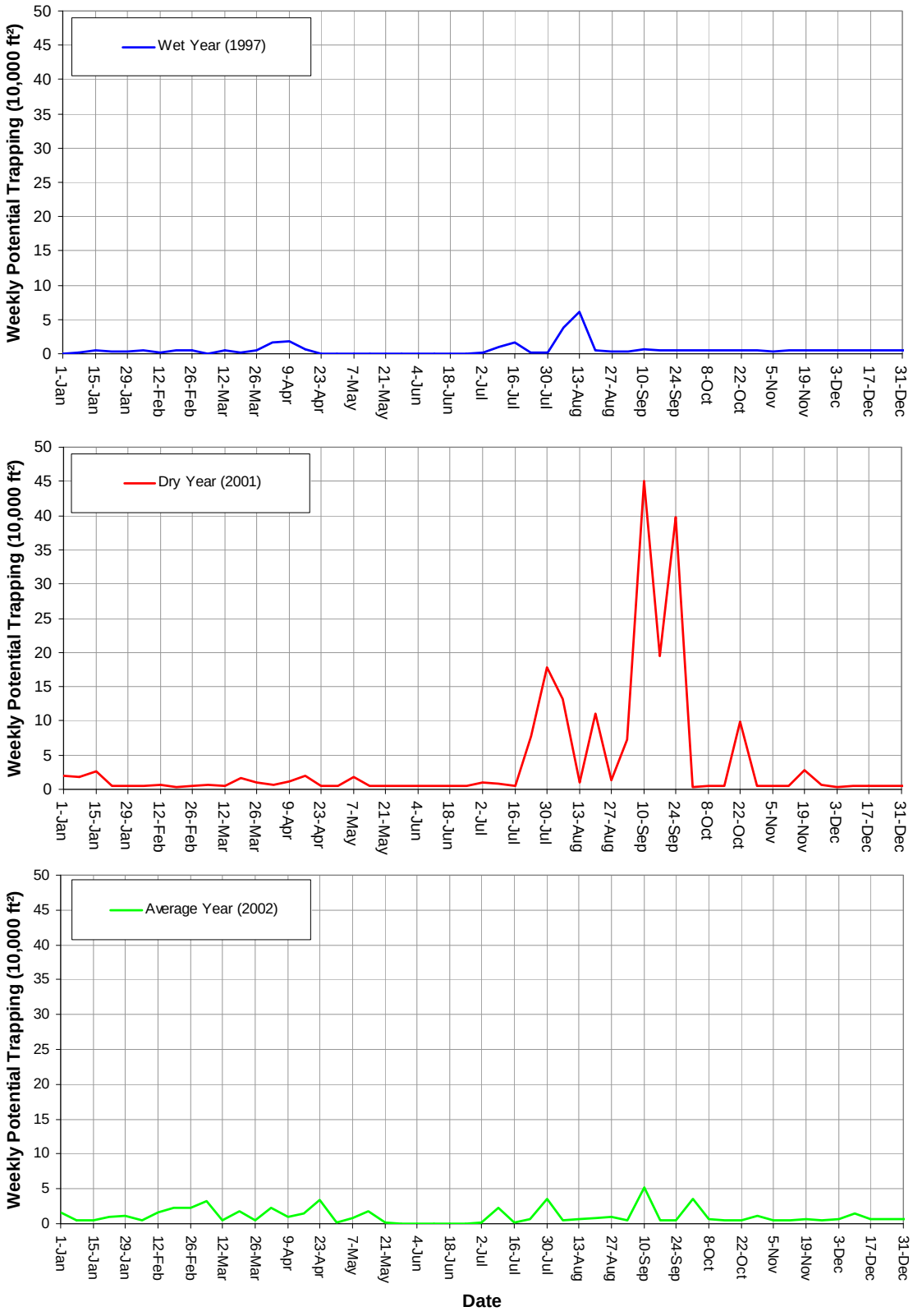


**Figure 7.2-3.** Example of the comparison of Region 11 daily total trapping index values that occurred during the wet (1997), dry (2001), and average year (2002).

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# Attachment A: General Descriptions of Stranding and Trapping Regions from 2007 Field Observations

Forebay Launch Region

The Forebay Launch Region consisted of a large area with a gradual slope. This area is dominated by fines and has high levels of aquatic macrophyte growth. Three pools had formed adjacent to the launch along the shoreline. These pools formed as a larger pool decreased in size and split as water surface elevations dropped. Stranded and trapped fish were not observed during the survey, but the potential for stranding and trapping to occur was documented. Deep mud made sampling at this region difficult; therefore, slopes and pool size, depth and temperature were not recorded.

Region 1

Region 1 was surveyed on September 7, 2007. This region was located on an island in the Forebay Reach of Boundary Dam. As water surface elevations recede, ridges dominated by gravel and cobble substrate become exposed. Between these ridges, dry pockets of fines with moderate concentrations of aquatic macrophytes and algae were recorded. Pools were not observed at this region, and only the potential for stranding was documented. Stranded or trapped fish were not observed during the survey.

Region 2

Region 2 consisted of side channel habitat on the near shore side of Everett Island. This was the largest region surveyed in the lower reservoir. As water surface elevations drop, a ridge divides the side channel into two separate areas. Upstream of the ridge, the site drains evenly into two large pools that are connected to the mainstem by a wetted channel approximately 2 to 4 inches deep. One of these pools had moderate concentrations of aquatic macrophytes, in which one trapped sucker was observed, while the other pool and the wetted channel had high concentrations of macrophytes. Due to deep mud at the region and the size of the pools, data on the area, depth and temperature measurements of the pools were not recorded. The exposed areas around the pools and channels were dominated by fines and had high concentrations of aquatic macrophyte growth.

Downstream of the ridge, the region drains evenly into two pools. These pools were at one time connected to the mainstem by a channel, but at the time of survey they were isolated, and the upstream pool had drained completely. At the outlet of the channel downstream of the ridge, a large stranding area with gradual gradients was observed. All areas downstream of the ridge had high concentrations of aquatic macrophytes. Downstream of the ridge, approximately 5,500 stranded and trapped fish were observed. Over 90 percent were young-of-the-year, and the remainder were primarily juveniles. Black crappie was the most abundant species observed followed by yellow perch. Other species observed include bullhead species, bass species, sucker species and pumpkinseed. Additional information on fish observations at this region is discussed in Section 5.1.2. Both stranding and trapping were observed at this region. Habitat information on this region is provided in.

Region 3

Region 3 was surveyed on September 7, 2007. This region was characterized by a basin with moderate gradients that drains evenly into two channels, which in turn drain into the mainstem. The substrate at this region is dominated by fines. High concentrations of exposed macrophytes were observed near both channels, but would still allow fish movement within the channels.

Pools were not observed during the survey at this region, and only stranding was documented. Stranded or trapped fish were not observed during the survey.

Region 4

Region 4 was surveyed on September 7, 2007. This region was characterized by a basin that drains evenly as water surface elevations recede. This region had steep gradients and was dominated by fines, gravel and cobble substrate. Pools were not observed at this region, and only the potential for stranding was documented. Stranded or trapped fish were not observed during the survey.

Region 5

Region 5 was surveyed on September 7, 2007. This region consisted of shoreline habitat that dewatered evenly. This region had mostly steep gradients and was dominated by fines, gravel, and cobble substrate. Pools were not observed at this region, and only the potential for stranding was documented. Stranded or trapped fish were not observed during the survey.

Region 6

Region 6 was surveyed on September 7, 2007. Areas of stranding and trapping in Region 6 at higher elevations have gradual slopes with substrate dominated by fines. As elevation decreases, the gradient becomes greater and the substrate changes to a combination of gravel, cobbles, and boulders. The region then drops off to the mainstem. As water surface elevations recede, three pools form at this region. The downstream pool drains directly into another pool which in turn drains into the mainstem. At the time of the survey, the two downstream pools were dry. The upstream pool was fed by groundwater and drained over the drop off into the mainstem at two locations. Stranded and trapped fish were not observed during the survey at this region, although the potential for stranding and trapping was documented.

Stump Farm Region

This stranding and trapping region was surveyed on September 7, 2007, and is located across the reservoir from Region 6. Areas with higher elevations at this region consisted of banks with moderate gradients that were dominated by fines. As elevations decrease, the substrate changes to a combination of cobble, boulder, and gravel. The region then drops off to the mainstem. Several root wads were observed at this region that could potentially trap fish. Pools were not observed at this region, and both stranding and trapping were documented. Stranded or trapped fish were not observed during the survey of this region.

Flume Creek Mouth Region

This stranding and trapping region was surveyed on September 7, 2007. Three depressions that drain evenly were observed near the creek mouth, with substrates dominated by gravels. Areas away from the creek mouth consisted of steep gradients that drained into a series of channels. All channels were fed by groundwater and were connected to the mainstem. Moderate concentrations of aquatic macrophytes were observed at the outlets of these channels in which four trapped black crappie young-of-the-year were documented. Information on fish observations at this region is discussed in Section 5.1.2. One pool was observed at the upstream end of the region in the bedrock, which was too deep to obtain a depth measurement. Both stranding and trapping were observed at this region.

Sullivan Creek Delta Region

A reconnaissance-level survey of the Sullivan Creek Delta was conducted on July 12, 2007. Approximately 50 trapped young-of-the-year largescale suckers were observed in a side channel, and both stranding and trapping were observed. Because of the dynamic nature of the delta, specific locations of stranding areas and trapping pools are likely to change from year to year as Sullivan Creek reworks existing delta deposits and lays down new deposits.

Region 7

This stranding and trapping region was surveyed August 22, 2007 and consisted of a side channel that forms downstream of the Metaline Falls boat launch. As water surface elevations drop, the side channel divides into two separate channels. Both channels were connected to the mainstem at the time of survey, and were dominated by fines and high concentrations of aquatic macrophytes. The high concentrations of aquatic macrophytes at the outlet of the downstream channel restricted but still allowed fish movement. Approximately 900 fish, all but one young-of-the-year mix of black crappie, pumpkinseed, and yellow perch, were observed trapped in the high concentrations of aquatic macrophytes at the outlet of the upstream channel, which did not allow fish movement out of the channel. The most abundant species observed at this region was black crappie. Other species observed included pumpkinseed, yellow perch and tench.

The upstream channel was also fed by groundwater and runoff from a nearby sewage outlet. One pool that was connected to the mainstem was observed at high water elevations during the reconnaissance survey (detailed habitat information was not collected). Deep mud at the region made sampling difficult, and therefore slopes were not recorded. Both stranding and trapping were observed at this region.

Region 8

This region was surveyed on August 22, 2007 and consisted of a large area mid-channel with two distinct habitat types. Upstream areas of this region were dominated by gradual gradients with fines and high concentrations of aquatic macrophyte growth. Deep mud at the upstream areas of the region made surveying difficult; therefore, detailed habitat information was not collected. The downstream areas of the region consisted of several ridges and depressions dominated by cobble substrate. Over 50 pools were observed and inspected visually in the downstream areas of the region, but due to time constraints, detailed habitat information was collected for only the pools with the highest probability of trapping fish. Approximately 640 trapped fish, all young-of-the-year, were observed at this region. Most of the fish observed were not identified, but 10 trapped bass were observed in isolated pools. One largemouth bass was also observed stranded on the substrate.

Region 9

This region was surveyed on August 22, 2007, and consisted of two separate habitat types. A side channel with high concentrations of macrophytes forms along the bank as water surface elevations drop. At the time of survey, the side channel had shrunk into four pools, each with high concentrations of macrophytes. Groundwater also kept a large portion of the largest pool wetted. Downstream areas of the region are dominated by areas with fines and high concentrations of aquatic macrophytes. Two small channels had formed in the macrophytes and

approximately 70 unidentified young-of-the-year fish were observed trapped in these channels. Large areas with gradual gradients and high concentrations of aquatic macrophytes had also become exposed. Deep mud at the side made sampling difficult and therefore slopes and habitat data for pools observed were not collected.

Region 10

This region was surveyed on August 3 and September 8, 2007, and was dominated by large areas with gradual gradients and cobble substrate. As water surface elevations recede, these areas drain into several pools, and large areas with cobble substrate become exposed. On August 3, three large and deep pools had formed, most of the cobble substrate was still inundated and stranded or trapped fish were not observed.

During the survey on September 8, the three previously documented pools were dry and five new pools had formed. Large areas with cobble substrate were also exposed. Approximately 140 young-of-the-year stranded and trapped fish were observed at this site during the survey in September, with bass species the most abundant. Black crappie were also observed at this region. Both stranding and trapping were observed at this region.

Region 11

Region 11 was surveyed on August 22, 2007, and was dominated by areas with gradual gradients, fines, and high concentrations of aquatic macrophytes. At the time of the survey, four pools had formed, one of which was too large to obtain area and depth measurements, and was connected to the mainstem. The large pool had high concentrations of aquatic macrophytes both in the pool itself as well as at the outlet to the mainstem, which restricted fish movement. A shallow stranding area (too large to obtain area) with high concentrations of macrophytes was connected to the mainstem by a channel that was 6.6 feet at the widest, and narrowed to 1.6 feet at the outlet to the mainstem. The depth at the outlet of the channel was 0.3 foot. Seven young-of-the-year fish were observed trapped during the survey of this region, including bullhead species, bass species, and sucker species. Both stranding and trapping were observed at this region.

Region 12

Region 12 was located at the Sweet Creek Mouth and was surveyed on August 3, 2007. This region was dominated by areas with gradual gradients and gravel substrates. At the time of the survey, four pools were observed: three were very small in size and dewatered as the crew was onsite. The largest pool was connected to the mainstem by a channel 1 inch (2 cm) deep, was fed by seepage from Sweet Creek, and was isolated shortly after arrival on site. Stranded or trapped fish were not observed at this region although the potential for stranding and trapping were documented.

Region 13

Region 13 was surveyed on August 3, 2007, and consisted of an inlet that drained evenly as water surface elevations receded. The banks of the inlet had gradual gradients and were dominated by fines. Terrestrial vegetation was present at the higher elevations. At the time of the survey, one small pool had formed near the inlet and a larger pool had formed along the mainstem bank. Several small depressions that formed very small pools were also recorded along the mainstem bank. In the upstream areas of the region, the substrate is dominated by

gravel and four small pools (~11 square feet each) had formed. Stranded or trapped fish were not observed at this region, although the potential for stranding and trapping were documented.

Region 14

This region was surveyed on August 3 and September 8, 2007, and consisted of two habitat types: a side channel dominated by fines along the east bank forms as water surface elevations recede, and an area with gradual gradients dominated by gravels becomes exposed along the mainstem bank of the region. On August 3, the side channel was deep and still connected to the mainstem, and stranded or trapped fish were not observed.

On September 8, the side channel was completely dry as were two pools. At the downstream outlet of the side channel, a large stranding area with gradual gradients and high concentrations of macrophyte growth was observed. Along the mainstem bank, three pools and one drained pool were observed. These four pools formed when a larger isolated pool divides as water surface elevations recede. During the survey in September, approximately 5,700 young-of-the-year stranded and trapped fish were observed. Bullhead species were the most abundant followed by yellow perch, pumpkinseed, and black crappie. Other species observed include sucker species and northern pikeminnow. Approximately 240 unidentified trapped fish were also documented. Both stranding and trapping were observed at this region.

Region 15

Region 15 was surveyed on August 22 and September 8, 2007, and consists of a large gravel bar near the west bank of the reservoir. At lower water elevations, a side channel forms between the gravel bar and the right upstream bank. Stranded or trapped fish were not observed at this region during the survey in August. No pools were present in August.

On September 8, the side channel had high concentrations of aquatic macrophytes, was dominated by fines and boulder substrate, and was connected to the mainstem at the downstream end. Two pools formed near the upstream end of the side channel, one of which was drained completely. During the survey of this region in September, approximately 1,050 young-of-the-year stranded and trapped fish were observed. Bass species were the most abundant followed by black crappie, yellow perch, and bullhead species. Deep mud near the side channel made sampling difficult and therefore slopes, depth, and temperature of the isolated pool were not measured. Both stranding and trapping were observed at this region.

Region 16

This region was surveyed on August 3 and September 8, 2007, and was characterized by side channel habitat that drains into the mainstem at the downstream end. As water surface elevations receded, the side channel divides into four large pools that connect to the mainstem via a channel, three of which had high concentrations of aquatic macrophytes. The upstream areas of the side channel are dominated by high concentrations of terrestrial vegetation, which are inundated at higher reservoir elevations. On August 3, the side channel was still connected to the mainstem and approximately 50 stranded suckers were observed.

On September 8, the side channel was isolated from the mainstem and had drained into three large pools with high aquatic macrophyte concentrations, two of which were fed by groundwater. During the survey in September, four young-of-the-year stranded yellow perch were observed. Deep mud near the side channel made sampling difficult and therefore the size and depth of the isolated pools in the side channel were not measured. Both stranding and trapping were observed at this region.

Region 17

Region 17 was surveyed on August 3 and September 8, 2007, and was characterized by side channel habitat. During the August 3 survey, the sidechannel was wetted and was connected to the mainstem at two locations. The side channel area was dominated by fines, and as water surface elevation receded, over 50 small dry depressions with no cover were observed. Two isolated pools near the wetted channel were also observed. On September 8, the side channel and all nearby areas were dry including the two pools observed in August. One stranded sucker was observed during the survey in August. An isolated pool was observed near the upstream outlet of the side channel, with high concentrations of aquatic macrophytes. The mainstem banks at this region consisted of two distinct areas. The downstream areas of the region had moderate gradient banks dominated by fines. The mainstem bank along the upstream area of the region had gradual slopes and was dominated by cobbles and gravels. Pools were not observed at the upstream end of the region. During the survey in September, one stranded black crappie was observed.

Region 18

Region 18 was surveyed on August 3, 2007. During the survey, the exposed shore of this region consisted of steep banks dominated by cobble and gravel substrate. Pools were not observed at this region. Due to time constraints and low potential for stranding observed at this region, habitat information was not collected. Fish were not observed at this region and only the potential for stranding was documented.

Tailrace of Boundary Dam

A reconnaissance level survey of the Boundary tailrace was conducted on July 12, 2007. A large area with gradual gradients and substrates dominated by cobble and boulders was exposed along the east bank. Two isolated pools, less than 1,000 square feet each, that recently formed were observed on an island near the east bank. Along the west bank, two more pools were observed, which had been isolated during a previous flow reduction. Stranded or trapped fish were not observed at this region, but both stranding and trapping mechanisms were documented. A detailed bathymetry map has not been developed at this time.

# Attachment B: 2008 Stranding Area Survey Data

**Table B-1.** 2008 stranding area survey data.

| Region | Date Time | Transect Number | Substrate | Macro-phyte | Transect Length (ft) | Transect Width (ft) | Transect Area (sq ft) | No. of Fish | Fish Density (No./ sq ft) |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 3/3/2008 11:22 | 1 | Gravel | None | 154 | 8 | 1232 | 0 | 0.00000 |
| 18 | 3/3/2008 20:31 | 5 | Cobbles | None | 200 | 12 | 2400 | 0 | 0.00000 |
| 18 | 3/3/2008 20:44 | 6 | Cobbles | None | 150 | 6 | 900 | 0 | 0.00000 |
| SC | 3/3/2008 22:02 | 11 | Gravel | None | 300 | 50 | 15000 | 0 | 0.00000 |
| 8 | 3/5/2008 0:03 | 14 | Gravel | None | 500 | 12 | 6000 | 0 | 0.00000 |
| 2 | 3/5/2008 20:00 | 13 | Fines | None | 1000 | 12 | 12000 | 0 | 0.00000 |
| 7 | 3/10/2008 11:22 | 18 | Fines | None | 270 | 12 | 3240 | 0 | 0.00000 |
| 7 | 3/10/2008 11:30 | 21 | Fines | None | 200 | 12 | 2400 | 0 | 0.00000 |
| 9 | 3/10/2008 12:12 | 26 | Fines | None | 700 | 6 | 4200 | 0 | 0.00000 |
| 9 | 3/10/2008 12:18 | 27 | Fines | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 9 | 3/10/2008 12:28 | 28 | Fines | None | 590 | 12 | 7080 | 1 | 0.00014 |
| 9 | 3/10/2008 12:37 | 29 | Fines | None | 650 | 6 | 3900 | 0 | 0.00000 |
| 10 | 3/10/2008 13:00 | 31 | Cobbles | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 10 | 3/10/2008 13:10 | 2 | Cobbles | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 14 | 3/10/2008 13:40 | 37 | Gravel | None | 250 | 6 | 1500 | 0 | 0.00000 |
| 14 | 3/10/2008 13:50 | 41 | Gravel | None | 450 | 6 | 2700 | 0 | 0.00000 |
| 8 | 3/10/2008 14:41 | 42 | Gravel | None | 700 | 12 | 8400 | 0 | 0.00000 |
| 9 | 3/10/2008 15:02 | 43 | Fines | None | 330 | 12 | 3960 | 0 | 0.00000 |
| 9 | 3/14/2008 0:00 | 16 | Fines | None | 300 | 12 | 3600 | 0 | 0.00000 |
| 10 | 3/14/2008 0:35 | 17 | Cobbles | None | 300 | 12 | 3600 | 0 | 0.00000 |
| 8 | 3/26/2008 11:30 | 1 | Gravel | None | 100 | 25 | 2500 | 0 | 0.00000 |
| 8 | 3/26/2008 11:30 | 79 | Gravel | None | 100 | 6 | 600 | 0 | 0.00000 |
| 16 | 3/27/2008 13:20 | 44 | Fines | None | 600 | 6 | 3600 | 0 | 0.00000 |
| 14 | 3/27/2008 14:30 | 51 | Gravel | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 9 | 3/27/2008 16:30 | 56 | Fines | None | 305 | 6 | 1830 | 0 | 0.00000 |
| TR | 4/4/2008 1:20 | 74 | Cobbles | None | 400 | 6 | 2400 | 0 | 0.00000 |
| TR | 4/4/2008 1:24 | 75 | Cobbles | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 14 | 4/5/2008 18:22 | 59 | Fines | None | 160 | 8 | 1280 | 0 | 0.00000 |
| 14 | 4/5/2008 18:30 | 62 | Fines | None | 70 | 10 | 700 | 0 | 0.00000 |
| 14 | 4/5/2008 18:30 | 63 | Fines | None | 110 | 10 | 1100 | 0 | 0.00000 |
| 14 | 4/5/2008 18:30 | 65 | Fines | None | 100 | 6 | 600 | 0 | 0.00000 |
| 14 | 4/5/2008 18:35 | 66 | Gravel | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 13 | 4/5/2008 20:11 | 67 | Fines | None | 100 | 6 | 600 | 0 | 0.00000 |
| 13 | 4/5/2008 20:13 | 68 | Fines | None | 100 | 6 | 600 | 0 | 0.00000 |
| 13 | 4/5/2008 20:25 | 70 | Fines | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 10 | 4/22/2008 18:59 | 77 | Cobbles | None | 350 | 6 | 2100 | 0 | 0.00000 |
| 11 | 4/22/2008 19:15 | 78 | Fines | None | 140 | 12 | 1680 | 0 | 0.00000 |
| 14 | 4/22/2008 19:33 | 80 | Fines | None | 990 | 12 | 11880 | 0 | 0.00000 |
| 14 | 4/22/2008 19:54 | 84 | Fines | Low | 570 | 6 | 3420 | 0 | 0.00000 |

**Table B-1, continued…**

| Region | Date Time | Transect Number | Substrate | Macro-phyte | Transect Length (ft) | Transect Width (ft) | Transect Area (sq ft) | No. of Fish | Fish Density (No./ sq ft) |
|---|---|---|---|---|---|---|---|---|---|
| 14 | 4/22/2008 19:58 | 85 | Fines | Low | 40 | 6 | 240 | 0 | 0.00000 |
| 16 | 4/22/2008 20:34 | 88 | Fines | Low | 200 | 12 | 2400 | 0 | 0.00000 |
| 17 | 4/22/2008 21:17 | 90 | Fines | Low | 95 | 6 | 570 | 0 | 0.00000 |
| 17 | 4/22/2008 21:27 | 91 | Fines | Low | 445 | 6 | 2670 | 0 | 0.00000 |
| 17 | 4/22/2008 21:30 | 92 | Fines | Low | 950 | 6 | 5700 | 0 | 0.00000 |
| 10 | 4/22/2008 22:30 | 95 | Cobbles | None | 120 | 6 | 720 | 0 | 0.00000 |
| 16 | 5/5/2008 21:14 | 100 | Fines | None | 400 | 6 | 2400 | 0 | 0.00000 |
| 13 | 5/5/2008 22:32 | 105 | Fines | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 12 | 5/5/2008 22:50 | 106 | Cobbles | None | 500 | 6 | 3000 | 0 | 0.00000 |
| 11 | 5/5/2008 23:40 | 110 | Fines | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 9 | 5/6/2008 1:45 | 113 | Fines | None | 850 | 6 | 5100 | 0 | 0.00000 |
| 7 | 7/13/2008 14:45 | 1 | Fines | L. Grass | 75 | 6 | 450 | 1 | 0.00222 |
| 7 | 7/13/2008 14:48 | 2 | Fines | L. Grass | 125 | 6 | 750 | 5 | 0.00667 |
| 7 | 7/13/2008 15:01 | 3 | Fines | L. Grass | 100 | 6 | 600 | 0 | 0.00000 |
| 7 | 7/13/2008 15:09 | 4 | Fines | L. Grass | 100 | 6 | 600 | 1 | 0.00167 |
| 7 | 7/13/2008 15:22 | 5 | Fines | none | 150 | 6 | 900 | 0 | 0.00000 |
| 7 | 7/13/2008 15:22 | 6 | Fines | none | 175 | 6 | 1050 | 3 | 0.00286 |
| 11 | 7/13/2008 16:58 | 1 | Fines | L. Grass | 250 | 6 | 1500 | 6 | 0.00400 |
| 11 | 7/13/2008 16:58 | 2 | Fines | L. Grass | 250 | 6 | 1500 | 0 | 0.00000 |
| 16 | 7/13/2008 17:02 | 1 | Fines | M. Grass | 175 | 6 | 1050 | 0 | 0.00000 |
| 17 | 7/13/2008 17:36 | 1 | Fines | M. Grass | 300 | 6 | 1800 | 3 | 0.00167 |
| 17 | 7/13/2008 17:58 | 2 | Fines | M. Grass | 250 | 6 | 1500 | 0 | 0.00000 |
| 14 | 7/13/2008 18:26 | 1 | Gravel | M. Grass | 150 | 6 | 900 | 0 | 0.00000 |
| 14 | 7/13/2008 18:26 | 2 | Gravel | M. Grass | 250 | 6 | 1500 | 0 | 0.00000 |
| 14 | 7/13/2008 18:26 | 3 | Fines | M. Grass | 225 | 6 | 1350 | 3 | 0.00222 |
| 12 | 7/13/2008 19:20 | 1 | Gravel | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 12 | 7/13/2008 19:20 | 1 | Cobbles | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 13 | 7/13/2008 19:40 | 1 | Fines | L. Grass | 150 | 6 | 900 | 2 | 0.00222 |
| 13 | 7/13/2008 19:40 | 2 | Fines | L. Grass | 250 | 6 | 1500 | 0 | 0.00000 |
| 13 | 7/13/2008 19:40 | 2 | Fines | L. Grass | 175 | 6 | 1050 | 5 | 0.00476 |
| 2 | 7/22/2008 9:09 | 1 | Cobbles | Mod. | 120 | 18 | 2160 | 61 | 0.02824 |
| 2 | 7/22/2008 9:23 | 0 | Gravel | Low | 70 | 18 | 1260 | 10 | 0.00794 |
| 2 | 7/22/2008 9:23 | 0 | Gravel | Low | 70 | 18 | 1260 | 22 | 0.01746 |
| 2 | 7/22/2008 9:23 | 2 | Gravel | Mod. | 85 | 15 | 1275 | 70 | 0.05490 |
| 2 | 7/22/2008 9:37 | 3 | Fines | Low | 100 | 6 | 600 | 0 | 0.00000 |
| 2 | 7/22/2008 9:54 | 4 | Fines | Mod. | 225 | 18 | 4050 | 23 | 0.00568 |
| 2 | 7/22/2008 9:54 | 1 | Fines | High | 70 | 6 | 420 | 36 | 0.08571 |
| 2 | 7/22/2008 9:54 | 10 | Fines | High | 3.3 | 3.3 | 10.8 | 2 | 0.18581 |
| 2 | 7/22/2008 9:54 | 11 | Fines | High | 3.3 | 3.3 | 10.8 | 5 | 0.46452 |
| 2 | 7/22/2008 9:54 | 12 | Fines | High | 3.3 | 3.3 | 10.8 | 0 | 0.00000 |

**Table B-1, continued…**

| Region | Date Time | Transect Number | Substrate | Macro-phyte | Transect Length (ft) | Transect Width (ft) | Transect Area (sq ft) | No. of Fish | Fish Density (No./ sq ft) |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 7/22/2008 9:54 | 13 | Fines | High | 3.3 | 3.3 | 10.8 | 7 | 0.65032 |
| 2 | 7/22/2008 9:54 | 14 | Fines | High | 3.3 | 3.3 | 10.8 | 0 | 0.00000 |
| 2 | 7/22/2008 9:54 | 15 | Fines | High | 3.3 | 3.3 | 10.8 | 4 | 0.37161 |
| 2 | 7/22/2008 9:54 | 16 | Fines | High | 3.3 | 3.3 | 10.8 | 2 | 0.18581 |
| 3 | 7/22/2008 10:44 | 1 | Gravel | Low | 75 | 12 | 900 | 0 | 0.00000 |
| 3 | 7/22/2008 10:51 | 2 | Gravel | None | 75 | 12 | 900 | 0 | 0.00000 |
| 3 | 7/22/2008 10:52 | 3 | Fines | Mod. | 150 | 12 | 1800 | 2 | 0.00111 |
| 6 | 7/22/2008 11:12 | 1 | Gravel | None | 100 | 12 | 1200 | 0 | 0.00000 |
| 6 | 7/22/2008 11:12 | 2 | Fines | None | 150 | 12 | 1800 | 3 | 0.00167 |
| Stump | 7/22/2008 11:25 | 1 | Gravel | Low | 100 | 12 | 1200 | 1 | 0.00083 |
| Stump | 7/22/2008 11:25 | 2 | Gravel | Low | 100 | 12 | 1200 | 0 | 0.00000 |
| 17 | 7/22/2008 14:56 | 1 | Fines | None | 60 | 18 | 1080 | 40 | 0.03704 |
| 17 | 7/22/2008 15:06 | 2 | Fines | M. Grass | 125 | 6 | 750 | 0 | 0.00000 |
| 17 | 7/22/2008 15:09 | 3 | Fines | M. Grass | 125 | 6 | 750 | 0 | 0.00000 |
| 17 | 7/22/2008 15:20 | 3 | Fines | L. Grass | 250 | 18 | 4500 | 20 | 0.00444 |
| 17 | 7/22/2008 15:29 | 4 | Fines | L. Grass | 150 | 18 | 2700 | 206 | 0.07630 |
| 17 | 7/22/2008 15:45 | 1 | Fines | Low | 200 | 12 | 2400 | 49 | 0.02042 |
| 17 | 7/22/2008 15:50 | 5 | Fines | L. Grass | 350 | 18 | 6300 | 1 | 0.00016 |
| 15 | 7/22/2008 16:50 | 1 | Gravel | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 15 | 7/22/2008 16:50 | 2 | Gravel | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 16 | 7/22/2008 17:07 | 1 | Fines | Low | 350 | 18 | 6300 | 0 | 0.00000 |
| 16 | 7/22/2008 17:49 | 2 | Fines | M. Grass | 150 | 18 | 2700 | 0 | 0.00000 |
| 16 | 7/22/2008 17:49 | 1 | Fines | Low | 300 | 6 | 1800 | 0 | 0.00000 |
| 16 | 7/22/2008 17:49 | 2 | Fines | Low | 150 | 12 | 1800 | 0 | 0.00000 |
| 16 | 7/22/2008 17:49 | 3 | Fines | Mod. | 150 | 12 | 1800 | 5 | 0.00278 |
| 14 | 7/22/2008 18:41 | 1 | Fines | Mod. | 80 | 12 | 960 | 0 | 0.00000 |
| 14 | 7/22/2008 18:52 | 2 | Fines | High | 125 | 18 | 2250 | 2 | 0.00089 |
| 14 | 7/22/2008 18:59 | 3 | Fines | Mod. | 60 | 18 | 1080 | 30 | 0.02778 |
| 8 | 7/22/2008 19:25 | 2 | Gravel | None | 150 | 12 | 1800 | 0 | 0.00000 |
| 8 | 7/22/2008 19:25 | 2 | Gravel | None | 75 | 18 | 1350 | 0 | 0.00000 |
| 13 | 7/22/2008 19:30 | 1 | Fines | Low | 70 | 18 | 1260 | 0 | 0.00000 |
| 12 | 7/22/2008 19:31 | 1 | Gravel | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 8 | 7/22/2008 19:35 | 2 | Cobbles | None | 100 | 12 | 1200 | 0 | 0.00000 |
| 13 | 7/22/2008 19:38 | 2 | Fines | Low | 125 | 12 | 1500 | 11 | 0.00733 |
| 9 | 7/22/2008 19:40 | 1 | Fines | Mod. | 175 | 18 | 3150 | 0 | 0.00000 |
| 9 | 7/22/2008 19:45 | 2 | Fines | Mod. | 200 | 18 | 3600 | 0 | 0.00000 |
| 13 | 7/22/2008 19:45 | 3 | Fines | Low | 250 | 12 | 3000 | 0 | 0.00000 |
| 2 | 7/22/2008 20:52 | 1 | Gravel | Low | 120 | 18 | 2160 | 5 | 0.00231 |
| 9 | 7/23/2008 9:45 | 1 | Fines | Low | 400 | 18 | 7200 | 10 | 0.00139 |
| 9 | 7/23/2008 10:00 | 2 | Fines | Low | 200 | 6 | 1200 | 0 | 0.00000 |

**Table B-1, continued…**

| Region | Date Time | Transect Number | Substrate | Macro-phyte | Transect Length (ft) | Transect Width (ft) | Transect Area (sq ft) | No. of Fish | Fish Density (No./ sq ft) |
|---|---|---|---|---|---|---|---|---|---|
| SC | 7/23/2008 11:24 | 1 | Cobbles | None | 200 | 24 | 4800 | 2 | 0.00042 |
| SC | 7/23/2008 11:31 | 1 | Cobbles | None | 200 | 24 | 4800 | 2 | 0.00042 |
| 17 | 7/23/2008 14:14 | 2 | Fines | Low | 200 | 24 | 4800 | 24 | 0.00500 |
| 7 | 7/23/2008 20:15 | 1 | Fines | Low | 300 | 12 | 3600 | 0 | 0.00000 |
| 7 | 7/23/2008 20:15 | 2 | Fines | Low | 250 | 12 | 3000 | 2 | 0.00067 |
| 17 | 7/24/2008 15:05 | 1 | Fines | Low | 50 | 12 | 600 | 0 | 0.00000 |
| 17 | 7/24/2008 15:05 | 2 | Fines | Low | 200 | 12 | 2400 | 7 | 0.00292 |
| 10 | 8/18/2008 12:45 | 1 | Cobbles | None | 150 | 18 | 2700 | 4 | 0.00148 |
| 10 | 8/18/2008 12:50 | 2 | Cobbles | None | 300 | 18 | 5400 | 4 | 0.00074 |
| 10 | 8/18/2008 13:00 | 1 | Cobbles | None | 180 | 6 | 1080 | 0 | 0.00000 |
| 14 | 8/18/2008 15:00 | 1 | Gravel | None | 300 | 6 | 1800 | 0 | 0.00000 |
| 14 | 8/18/2008 15:00 | 2 | Gravel | None | 150 | 6 | 900 | 0 | 0.00000 |
| 11 | 8/18/2008 15:09 | 1 | Fines | Low | 250 | 6 | 1500 | 0 | 0.00000 |
| 11 | 8/18/2008 15:09 | 2 | Fines | Low | 180 | 12 | 2160 | 0 | 0.00000 |
| 11 | 8/18/2008 15:09 | 4 | Fines | Low | 150 | 6 | 900 | 0 | 0.00000 |
| 11 | 8/18/2008 15:09 | 3 | Fines | Low | 150 | 12 | 1800 | 25 | 0.01389 |
| 14 | 8/18/2008 15:10 | 3 | Fines | H. Grass | 145 | 18 | 2610 | 2 | 0.00077 |
| 11 | 8/18/2008 15:14 | 6 | Fines | Mod. | 300 | 6 | 1800 | 21 | 0.01167 |
| 11 | 8/18/2008 15:14 | 5 | Fines | Mod. | 300 | 6 | 1800 | 176 | 0.09778 |
| 16 | 8/18/2008 15:40 | 1 | Fines | None | 300 | 12 | 3600 | 2 | 0.00056 |
| 16 | 8/18/2008 15:40 | 2 | Fines | Low | 300 | 6 | 1800 | 0 | 0.00000 |
| 16 | 8/18/2008 16:00 | 3 | Fines | Low | 300 | 6 | 1800 | 1 | 0.00056 |
| 16 | 8/18/2008 16:00 | 4 | Fines | Low | 150 | 6 | 900 | 3 | 0.00333 |
| 16 | 8/18/2008 16:00 | 6 | Fines | Low | 150 | 6 | 900 | 1 | 0.00111 |
| 12 | 8/18/2008 16:15 | 1 | Cobbles | None | 200 | 6 | 1200 | 0 | 0.00000 |
| 17 | 8/18/2008 17:25 | 1 | Fines | Low | 250 | 18 | 4500 | 0 | 0.00000 |
| 17 | 8/18/2008 17:30 | 2 | Fines | Low | 270 | 12 | 3240 | 0 | 0.00000 |
| 17 | 8/18/2008 17:30 | 1 | Fines | Low | 270 | 12 | 3240 | 2 | 0.00062 |
| 17 | 8/18/2008 17:30 | 4 | Fines | Low | 250 | 12 | 3000 | 3 | 0.00100 |
| 17 | 8/18/2008 17:50 | 1 | Fines | Low | 150 | 12 | 1800 | 2 | 0.00111 |
| 17 | 8/18/2008 17:50 | 3 | Fines | Low | 250 | 12 | 3000 | 4 | 0.00133 |
| 17 | 8/18/2008 17:50 | 2 | Fines | Low | 50 | 12 | 600 | 4 | 0.00667 |
| 13 | 8/18/2008 18:13 | 1 | Fines | Low | 220 | 12 | 2640 | 1 | 0.00038 |
| 13 | 8/18/2008 18:19 | 1 | Fines | Low | 250 | 12 | 3000 | 1 | 0.00033 |
| 13 | 8/18/2008 18:19 | 4 | Fines | Low | 250 | 12 | 3000 | 2 | 0.00067 |
| 13 | 8/18/2008 18:19 | 2 | Fines | High | 200 | 12 | 2400 | 144 | 0.06000 |
| 13 | 8/18/2008 19:07 | 5 | Fines | High | 200 | 12 | 2400 | 7 | 0.00292 |
| 9 | 8/18/2008 19:07 | 1 | Fines | High | 300 | 18 | 5400 | 21 | 0.00389 |
| 13 | 8/18/2008 19:07 | 3 | Gravel | None | 200 | 12 | 2400 | 0 | 0.00000 |
| 9 | 8/18/2008 19:20 | 1 | Fines | Low | 150 | 6 | 900 | 0 | 0.00000 |

**Table B-1, continued…**

| Region | Date Time | Transect Number | Substrate | Macro-phyte | Transect Length (ft) | Transect Width (ft) | Transect Area (sq ft) | No. of Fish | Fish Density (No./ sq ft) |
|---|---|---|---|---|---|---|---|---|---|
| 9 | 8/18/2008 19:20 | 2 | Fines | Low | 300 | 12 | 3600 | 0 | 0.00000 |
| 9 | 8/18/2008 19:20 | 3 | Fines | Low | 200 | 12 | 2400 | 0 | 0.00000 |
| 9 | 8/18/2008 19:20 | 4 | Fines | Low | 200 | 6 | 1200 | 5 | 0.00417 |
| 9 | 8/18/2008 19:45 | 1 | Fines | Mod. | 150 | 6 | 900 | 5 | 0.00556 |
| 15 | 8/19/2008 10:45 | 1 | Gravel | None | 300 | 18 | 5400 | 1 | 0.00019 |
| 15 | 8/19/2008 10:45 | 2 | Gravel | None | 100 | 18 | 1800 | 0 | 0.00000 |
| 15 | 8/19/2008 10:45 | 3 | Gravel | None | 100 | 18 | 1800 | 1 | 0.00056 |
| 8 | 8/19/2008 11:20 | 1 | Gravel | None | 125 | 18 | 2250 | 0 | 0.00000 |
| 8 | 8/19/2008 11:20 | 2 | Gravel | None | 150 | 18 | 2700 | 0 | 0.00000 |
| 8 | 8/19/2008 11:20 | 3 | Gravel | None | 200 | 18 | 3600 | 3 | 0.00083 |
| 9 | 8/19/2008 19:20 | 3 | Fines | High | 300 | 12 | 3600 | 10 | 0.00278 |
| 7 | 8/19/2008 19:45 | 1 | Fines | High | 300 | 12 | 3600 | 16 | 0.00444 |
| 7 | 8/19/2008 19:45 | 2 | Fines | Low | 250 | 12 | 3000 | 27 | 0.00900 |
| 7 | 8/19/2008 19:55 | 3 | Fines | Low | 300 | 12 | 3600 | 11 | 0.00306 |
| 7 | 8/19/2008 19:55 | 4 | Fines | Low | 200 | 6 | 1200 | 1 | 0.00083 |
| 7 | 8/19/2008 20:05 | 5 | Fines | None | 175 | 6 | 1050 | 0 | 0.00000 |

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# Attachment C: 2008 Trapping Pool Survey Data

**Table C-1.** 2008 trapping pool survey data.

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02-009 | 2 | 7/22/2008 9:07 | 432 | 0.4 | 108,608 | 300 | 0 | 300 | Fines | Mod. | 0.7 | 16.8 | 11.9 | 0.0 | 694.44 |
| 02-009 | 2 | 7/22/2008 17:53 | 432 | 0.4 | 108,608 | 300 | 0 | 300 | Fines | Mod. | 0.8 | 22 | 20.6 | 0.0 | 694.44 |
| 02-009 | 2 | 7/23/2008 11:30 | 432 | 0.4 | 108,608 | 0 | 300 | 300 | Fines | Mod. | 0.8 | 22.2 | 38.2 | 100.0 | 694.44 |
| 02-011 | 2 | 7/22/2008 9:09 | 8,550 | 1.7 | 93,058 | 1,073 | 34 | 1,107 | Fines | High | 1.4 | 21.6 | 12.2 | 3.1 | 129.49 |
| 02-011 | 2 | 7/22/2008 17:45 | 8,550 | 1.7 | 93,058 | 903 | 55 | 958 | Fines | High | 1.1 | 22.8 | 20.8 | 5.8 | 112.07 |
| 02-011 | 2 | 7/23/2008 11:40 | 8,550 | 1.7 | 93,058 | 620 | 240 | 860 | Fines | High | 0.05 | 22.8 | 38.7 | 27.9 | 100.58 |
| 02-014 | 2 | 7/22/2008 10:00 | 5,877 | 7.8 | 92,737 | 21,542 | 60 | 21,602 | Fines | High | 5 | 16.9 | 13.5 | 0.3 | 3,675.68 |
| 02-014 | 2 | 7/23/2008 11:40 | 5,877 | 7.8 | 92,737 | 22,935 | 203 | 23,139 | Fines | High | 5 | 21.9 | 39.2 | 0.9 | 3,937.16 |
| 02-018 | 2 | 7/22/2008 10:04 | 1,818 | 2.9 | 41,146 | 0 | 0 | 0 | Fines | Low | 0 | no data | 14.1 | | 0.00 |
| 02-019 | 2 | 7/22/2008 9:38 | 50,375 | 6.8 | 73,228 | 51,675 | 95 | 51,770 | Fines | High | 4 | 16.5 | 13.9 | 0.2 | 1,027.69 |
| 02-019 | 2 | 7/23/2008 11:58 | 50,375 | 6.8 | 73,228 | 63,750 | 825 | 64,575 | Fines | High | 4 | 16.7 | 40.2 | 1.3 | 1,281.89 |
| 07-012 | 7 | 8/19/2008 19:25 | 35,622 | 1.8 | 169,517 | 4,816 | 669 | 5,485 | Fines | High | 1.9 | 18 | 27.4 | 12.2 | 153.98 |
| 07-017 | 7 | 3/10/2008 11:27 | 153 | 0.2 | 2,604 | 0 | 0 | 0 | Fines | None | 0 | no data | 0.9 | | 0.00 |
| 07-018 | 7 | 3/10/2008 11:24 | 684 | 0.8 | 4,620 | 0 | 0 | 0 | Fines | None | 0.1 | 3 | 0.1 | | 0.00 |
| 07-022 | 7 | 7/13/2008 15:20 | 3,573 | 2.2 | 27,315 | 151 | 0 | 151 | Fines | Low | 1.4 | 24.4 | 56.8 | 0.0 | 42.26 |
| 07-022 | 7 | 7/13/2008 17:50 | 3,573 | 2.2 | 27,315 | 151 | 0 | 151 | Fines | Low | 1.2 | 27.8 | 59.3 | 0.0 | 42.26 |
| 07-022 | 7 | 7/14/2008 10:00 | 3,573 | 2.2 | 27,315 | 129 | 22 | 151 | Fines | Low | 0.9 | 29.5 | 75.5 | 14.6 | 42.26 |
| 07-023 | 7 | 7/13/2008 15:02 | 288 | 0.9 | 11,609 | 0 | 12 | 12 | Fines | Low | 0 | no data | 58.8 | 100.0 | 41.67 |
| 07-024 | 7 | 7/13/2008 14:48 | 7,686 | 2.9 | 63,367 | 68 | 0 | 68 | Fines | Low | 1.1 | 25.6 | 18.8 | 0.0 | 8.85 |
| 07-024 | 7 | 7/13/2008 17:50 | 7,686 | 2.9 | 63,367 | 68 | 0 | 68 | Fines | Low | 0.9 | 27.8 | 21.8 | 0.0 | 8.85 |
| 07-024 | 7 | 7/14/2008 10:00 | 7,686 | 2.9 | 63,367 | 68 | 0 | 68 | Fines | Low | 0.4 | 30 | 0.2 | 0.0 | 8.85 |
| 07-025 | 7 | 7/13/2008 15:09 | 423 | 1.0 | 7,756 | 0 | 0 | 0 | Fines | Low | 0 | no data | 59.9 | | 0.00 |
| 07-026 | 7 | 7/13/2008 14:48 | 117 | 0.4 | 2,236 | 0 | 0 | 0 | Fines | None | 0 | no data | 65.0 | | 0.00 |
| 07-028 | 7 | 7/13/2008 14:45 | 468 | 1.7 | 4,551 | 0 | 65 | 65 | Fines | Low | 0 | no data | 63.3 | 100.0 | 138.89 |
| 07-029 | 7 | 7/13/2008 15:01 | 162 | 0.2 | 1,770 | 0 | 0 | 0 | Fines | Low | 0 | no data | 60.8 | | 0.00 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-030 | 7 | 7/13/2008 14:57 | 3,942 | 2.6 | 12,222 | 256 | 0 | 256 | Fines | None | 0.1 | 16.5 | 62.4 | 0.0 | 64.94 |
| 07-030 | 7 | 7/13/2008 17:50 | 3,942 | 2.6 | 12,222 | 0 | 256 | 256 | Fines | None | 0 | no data | 65.3 | 100.0 | 64.94 |
| 08-a | 8 | 3/26/2008 11:30 | 1,800 | 1.3 | 3,171 | 0 | 0 | 0 | Cobble | None | 0.3 | 6 | 3.0 | | 0.00 |
| 08-a | 8 | 7/23/2008 12:30 | 1,800 | 1.3 | 3,171 | 7 | 0 | 7 | Gravel | None | 0.8 | 23.2 | 7.3 | 0.0 | 3.89 |
| 08-b | 8 | 3/26/2008 11:30 | 1,200 | 1.1 | 2,932 | 0 | 0 | 0 | Gravel | None | 0.3 | 6.1 | 2.5 | | 0.00 |
| 08-b | 8 | 7/23/2008 12:30 | 1,200 | 1.1 | 2,932 | 0 | 0 | 0 | Gravel | None | 0.6 | 23 | 5.5 | | 0.00 |
| 10-011 | 10 | 7/22/2008 20:25 | 297 | 0.8 | 4,284 | 0 | 0 | 0 | Cobble | None | 1.1 | 21 | 16.9 | | 0.00 |
| 09-056 | 9 | 8/19/2008 12:45 | 657 | 0.3 | 10,988 | 0 | 6 | 6 | Fines | Low | 0.2 | 22.9 | 35.5 | 100.0 | 9.13 |
| 09-053 | 9 | 8/19/2008 12:45 | 25,362 | 1.0 | 163,173 | 8 | 24 | 32 | Fines | Low | 0.1 | 22.5 | 32.5 | 75.3 | 1.27 |
| 09-055 | 9 | 8/19/2008 12:35 | 30,987 | 1.7 | 87,113 | 123 | 22 | 144 | Fines | High | 0.2 | 23.1 | 35.3 | 15.0 | 4.65 |
| 09-059 | 9 | 8/19/2008 12:45 | 2,115 | 0.2 | 73,973 | 0 | 2 | 2 | Fines | Low | 0.2 | 23.1 | 37.0 | 100.0 | 0.95 |
| 09-066 | 9 | 3/26/2008 12:00 | 9,387 | 0.9 | 121,085 | 0 | 0 | 0 | Fines | None | 0.3 | 5.5 | 4.7 | | 0.00 |
| 09-066 | 9 | 8/18/2008 20:00 | 9,387 | 0.9 | 121,085 | 90 | 10 | 100 | Fines | None | 0.4 | 27 | 21.5 | 10.0 | 10.65 |
| 09-066 | 9 | 8/19/2008 12:00 | 9,387 | 0.9 | 121,085 | 0 | 100 | 100 | Fines | None | 0 | no data | 37.5 | 100.0 | 10.65 |
| 09-070 | 9 | 8/18/2008 19:20 | 24,327 | 1.8 | 187,079 | 100 | 80 | 180 | Fines | High | 1.4 | 25 | 17.1 | 44.4 | 7.40 |
| 09-070 | 9 | 8/19/2008 12:20 | 24,327 | 1.8 | 187,079 | 60 | 120 | 180 | Fines | High | 0.4 | 27 | 34.1 | 66.7 | 7.40 |
| 09-074 | 9 | 7/23/2008 10:07 | 2,763 | 0.9 | 22,018 | 50 | 0 | 50 | Fines | Low | 0.3 | 21 | 7.9 | 0.0 | 18.10 |
| 09-074 | 9 | 7/24/2008 11:13 | 2,763 | 0.9 | 22,018 | 20 | 0 | 20 | Fines | Low | 0.1 | 24.8 | 0.2 | 0.0 | 7.24 |
| 09-078 | 9 | 3/10/2008 12:08 | 1,080 | 0.4 | 9,553 | 0 | 0 | 0 | Fines | None | 0.6 | 3.5 | 0.1 | | 0.00 |
| 09-079 | 9 | 7/23/2008 10:20 | 171 | 0.3 | 8,040 | 12 | 7 | 19 | Fines | Low | 0.1 | 24 | 35.8 | 36.8 | 111.11 |
| 09-080 | 9 | 7/23/2008 10:30 | 108 | 0.3 | 8,121 | 0 | 19 | 19 | Gravel | Low | 0 | no data | 38.5 | 100.0 | 175.93 |
| 09-083 | 9 | 7/17/2008 23:55 | 4,374 | 1.0 | 21,134 | 26 | 0 | 26 | Fines | None | 0.3 | 16.8 | 0.7 | 0.0 | 5.94 |
| 09-083 | 9 | 8/18/2008 19:45 | 4,374 | 1.0 | 21,134 | 0 | 4 | 4 | Fines | Low | 0 | no data | 23.2 | 100.0 | 0.91 |
| 09-087 | 9 | 7/24/2008 12:00 | 972 | 0.6 | 8,558 | 0 | 0 | 0 | Fines | Low | 0 | no data | 75.2 | | 0.00 |
| 09-091 | 9 | 3/10/2008 12:04 | 504 | 0.4 | 3,052 | 0 | 0 | 0 | Fines | None | 0.2 | no data | 0.6 | | 0.00 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-095 | 9 | 7/17/2008 23:10 | 1,260 | 1.2 | 13,724 | 0 | 0 | 0 | Fines | None | 0 | no data | 4.2 | | 0.00 |
| 09-095 | 9 | 7/24/2008 11:50 | 1,260 | 1.2 | 13,724 | 0 | 0 | 0 | Fines | Low | 0 | no data | 83.8 | | 0.00 |
| 09-096 | 9 | 7/17/2008 23:10 | 1,377 | 1.1 | 15,057 | 0 | 4 | 4 | Fines | None | 0 | no data | 2.2 | 100.0 | 2.90 |
| 09-100 | 9 | 5/6/2008 1:24 | 6,939 | 1.3 | 53,868 | 0 | 0 | 0 | Fines | None | 0.25 | 8.4 | 7.4 | | 0.00 |
| 09-100 | 9 | 7/17/2008 23:00 | 6,939 | 1.3 | 53,868 | 25 | 0 | 25 | Fines | Low | 1.1 | 16.5 | 3.5 | 0.0 | 3.60 |
| 09-100 | 9 | 7/23/2008 9:17 | 6,939 | 1.3 | 53,868 | 0 | 6 | 6 | Fines | Low | 0 | no data | 56.8 | 100.0 | 0.86 |
| 09-100 | 9 | 8/14/2008 19:00 | 6,939 | 1.3 | 53,868 | 0 | 0 | 0 | Fines | Low | 0 | no data | 6.5 | | 0.00 |
| 09-103 | 9 | 7/23/2008 9:30 | 324 | 0.3 | 9,965 | 0 | 0 | 0 | Fines | Low | 0 | no data | 57.8 | | 0.00 |
| 09-104 | 9 | 7/17/2008 23:25 | 774 | 0.7 | 12,496 | 0 | 7 | 7 | Fines | None | 0 | no data | 5.7 | 100.0 | 9.04 |
| 09-104 | 9 | 7/24/2008 11:30 | 774 | 0.7 | 12,496 | 0 | 30 | 30 | Fines | Low | 0 | no data | 84.5 | 100.0 | 38.76 |
| 09-106 | 9 | 7/23/2008 9:35 | 153 | 0.3 | 3,352 | 0 | 0 | 0 | Fines | Low | 0 | no data | 58.8 | | 0.00 |
| 09-107 | 9 | 5/6/2008 1:10 | 3,357 | 1.8 | 14,759 | 0 | 0 | 0 | Fines | Low | 0 | no data | 12.4 | | 0.00 |
| 09-110 | 9 | 7/13/2008 16:19 | 1,287 | 0.9 | 9,082 | 0 | 0 | 0 | Fines | Low | 0 | no data | 58.6 | | 0.00 |
| 09-114 | 9 | 7/13/2008 15:51 | 6,381 | 4.2 | 12,948 | 2538 | 0 | 2538 | Fines | Low | 0.9 | 24 | 58.9 | 0.0 | 397.74 |
| 09-114 | 9 | 7/13/2008 20:51 | 6,381 | 4.2 | 12,948 | 2529 | 9 | 2538 | Fines | Low | 0.7 | 28 | 63.9 | 0.4 | 397.74 |
| 09-115 | 9 | 7/13/2008 16:22 | 189 | 4.2 | 1,458 | 0 | 0 | 0 | Fines | Low | 0 | no data | 82.9 | | 0.00 |
| 09-117 | 9 | 7/23/2008 10:57 | 315 | 0.3 | 2,837 | 0 | 260 | 260 | Fines | Low | 0 | no data | 301.7 | 100.0 | 825.40 |
| 10-007 | 10 | 8/18/2008 12:40 | 144 | 0.2 | 20,554 | 0 | 0 | 0 | Cobble | None | 0 | no data | 6.9 | | 0.00 |
| 10-008 | 10 | 3/26/2008 12:50 | 48,447 | 8.7 | 106,080 | 0 | 0 | 0 | Cobble | None | 5 | 5.6 | 2.8 | | 0.00 |
| 10-008 | 10 | 8/18/2008 12:40 | 48,447 | 8.7 | 106,080 | 5,911 | 0 | 5,911 | Cobble | None | 7 | 24.3 | 12.4 | 0.0 | 122.01 |
| 10-009 | 10 | 3/26/2008 12:40 | 9,702 | 2.4 | 59,994 | 0 | 0 | 0 | Cobble | None | 1.2 | 5.6 | 4.9 | | 0.00 |
| 10-009 | 10 | 3/27/2008 15:06 | 9,702 | 2.4 | 59,994 | 0 | 0 | 0 | Cobble | None | 2.4 | 5.5 | 0.8 | | 0.00 |
| 10-009 | 10 | 8/14/2008 19:30 | 9,702 | 2.4 | 59,994 | 0 | 0 | 0 | Cobble | None | 2.3 | 23.4 | 0.7 | | 0.00 |
| 10-009 | 10 | 8/18/2008 13:35 | 9,702 | 2.4 | 59,994 | 32,888 | 580 | 33,468 | Cobble | None | 2.3 | 25 | 14.3 | 1.7 | 3,449.56 |
| 10-009 | 10 | 8/19/2008 14:30 | 9,702 | 2.4 | 59,994 | 34,374 | 615 | 34,989 | Cobble | None | 1.8 | no data | 39.2 | 1.8 | 3,606.38 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10-011 | 10 | 3/27/2008 14:53 | 297 | 0.8 | 4,284 | 0 | 0 | 0 | Cobble | None | 0.9 | 5.5 | 3.9 | | 0.00 |
| 10-013 | 10 | 3/10/2008 13:00 | 1,881 | 0.3 | 13,775 | 0 | 0 | 0 | Cobble | None | 0 | no data | 1.0 | | 0.00 |
| 10-013 | 10 | 3/27/2008 15:35 | 1,881 | 0.3 | 13,775 | 0 | 1 | 1 | Gravel | None | 0 | no data | 76.3 | 100.0 | 0.53 |
| 10-013 | 10 | 7/22/2008 20:05 | 1,881 | 0.3 | 13,775 | 0 | 0 | 0 | Gravel | None | 0 | no data | 22.3 | | 0.00 |
| 10-015 | 10 | 7/22/2008 20:10 | 252 | 0.1 | 1,828 | 0 | 0 | 0 | Cobble | None | 0 | no data | 35.4 | | 0.00 |
| 10-016 | 10 | 3/10/2008 13:05 | 7,290 | 0.8 | 53,965 | 0 | 0 | 0 | Cobble | None | 0.7 | 4.8 | 2.6 | | 0.00 |
| 10-016 | 10 | 4/22/2008 18:53 | 7,290 | 0.8 | 53,965 | 0 | 0 | 0 | Cobble | None | 0.5 | 6.7 | 3.4 | | 0.00 |
| 10-016 | 10 | 4/22/2008 22:34 | 7,290 | 0.8 | 53,965 | 0 | 0 | 0 | Cobble | None | 0.6 | 6.1 | 7.1 | | 0.00 |
| 10-016 | 10 | 8/14/2008 14:00 | 7,290 | 0.8 | 53,965 | 1055 | 795 | 1850 | Cobble | None | 0.5 | 28.6 | 0.5 | 43.0 | 253.77 |
| 10-016 | 10 | 8/14/2008 19:30 | 7,290 | 0.8 | 53,965 | 150 | 1700 | 1850 | Cobble | None | 0.5 | 28.1 | 6.0 | 91.9 | 253.77 |
| 10-016 | 10 | 8/18/2008 13:00 | 7,290 | 0.8 | 53,965 | 0 | 5,249 | 5,249 | Cobble | None | 0 | no data | 17.3 | 100.0 | 720.00 |
| 10-a | 10 | 3/10/2008 12:52 | 150 | 1.0 | 4,575 | 0 | 0 | 0 | Gravel | None | 0.3 | 3 | 1.1 | | 0.00 |
| 10-a | 10 | 3/10/2008 13:15 | 150 | 1.0 | 4,575 | 0 | 0 | 0 | Gravel | None | 1 | 5.1 | 1.5 | | 0.00 |
| 10-a | 10 | 3/27/2008 16:07 | 150 | 1.0 | 4,575 | 0 | 1 | 1 | Gravel | None | 0.4 | 5.5 | 8.4 | 100.0 | 6.67 |
| 10-a | 10 | 4/22/2008 22:27 | 150 | 1.0 | 4,575 | 1 | 0 | 1 | Gravel | None | 0.6 | 6.1 | 5.7 | 0.0 | 6.67 |
| 10-a | 10 | 7/22/2008 20:05 | 150 | 1.0 | 4,575 | 50 | 0 | 50 | Gravel | None | 0.2 | 21 | 22.6 | 0.0 | 333.33 |
| 10-a | 10 | 7/23/2008 16:30 | 150 | 1.0 | 4,575 | 0 | 50 | 50 | Gravel | None | 0 | no data | 43.0 | 100.0 | 333.33 |
| 10-a | 10 | 8/18/2008 13:40 | 150 | 1.0 | 4,575 | 0 | 254 | 254 | Gravel | None | 0 | no data | 16.7 | 100.0 | 1,693.33 |
| 11-007 | 11 | 8/18/2008 13:45 | 33,534 | 0.9 | 117,837 | 78 | 0 | 78 | Fines | Low | 0.7 | 29 | 11.2 | 0.0 | 2.32 |
| 11-008 | 11 | 5/5/2008 23:32 | 180 | 0.5 | 24,885 | 0 | 0 | 0 | Fines | None | 0 | no data | 2.5 | | 0.00 |
| 11-010 | 11 | 4/22/2008 19:17 | 1,116 | 1.3 | 16,020 | 0 | 0 | 0 | Fines | None | 0.3 | 10 | 4.5 | | 0.00 |
| 11-010 | 11 | 5/5/2008 23:14 | 1,116 | 1.3 | 16,020 | 0 | 0 | 0 | Fines | None | 0 | no data | 2.7 | | 0.00 |
| 11-010 | 11 | 7/17/2008 19:41 | 1,116 | 1.0 | 16,020 | 0 | 4 | 4 | Fines | None | 0 | no data | 0.2 | 100.0 | 3.58 |
| 11-011 | 11 | 5/5/2008 23:24 | 1,116 | 1.1 | 8,088 | 0 | 0 | 0 | Fines | None | 0 | no data | 4.9 | | 0.00 |
| 11-011 | 11 | 7/17/2008 19:41 | 1,116 | 1.1 | 8,088 | 0 | 0 | 0 | Fines | None | 0 | no data | 0.2 | | 0.00 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-012 | 11 | 7/13/2008 16:51 | 2,403 | 2.2 | 11,064 | 0 | 32 | 32 | Fines | Low G. | 0 | no data | 62.1 | 100.0 | 13.32 |
| 11-013 | 11 | 7/13/2008 16:58 | 558 | 1.3 | 2,634 | 0 | 0 | 0 | Fines | Low | 0 | no data | 63.2 | | 0.00 |
| 11-014 | 11 | 7/13/2008 16:58 | 13,347 | 5.2 | 25,887 | 1600 | 0 | 1600 | Fines | High G. | 2.8 | 16.6 | 59.8 | 0.0 | 119.88 |
| 11-014 | 11 | 7/14/2008 13:15 | 13,347 | 5.2 | 25,887 | 1600 | 0 | 1600 | Fines | High G. | 3.6 | 16.8 | 80.0 | 0.0 | 119.88 |
| 12-005 | 12 | 7/11/2008 20:14 | 1,026 | 2.0 | 2,998 | 16 | 0 | 16 | Gravel | None | 0.8 | 16.4 | 11.2 | 0.0 | 15.59 |
| 12-009 | 12 | 7/11/2008 19:45 | 207 | 1.3 | 935 | 0 | 0 | 0 | Fines | Low G. | 0.4 | 16 | 27.2 | | 0.00 |
| 12-011 | 12 | 7/22/2008 19:31 | 117 | 3.5 | 479 | 5 | 1 | 6 | Gravel | None | 0.2 | 20.8 | 346.3 | 16.7 | 51.28 |
| 13-007 | 13 | 8/18/2008 18:13 | 9,828 | 0.8 | 37,701 | 3 | 0 | 3 | Fines | Low | 0.7 | 28.9 | 11.5 | 0.0 | 0.31 |
| 13-009 | 13 | 8/18/2008 19:07 | 216 | 0.2 | 5,125 | 0 | 0 | 0 | Fines | Low | 0 | no data | 19.1 | | 0.00 |
| 13-010 | 13 | 8/18/2008 19:07 | 117 | 0.3 | 2,875 | 0 | 0 | 0 | Gravel | None | 0 | no data | 19.9 | | 0.00 |
| 13-011 | 13 | 4/5/2008 20:18 | 2,250 | 0.6 | 30,316 | 0 | 0 | 0 | Fines | None | 0 | no data | 33.8 | | 0.00 |
| 13-011 | 13 | 8/18/2008 18:19 | 2,250 | 0.6 | 30,316 | 0 | 0 | 0 | Fines | Low | 0 | no data | 21.8 | | 0.00 |
| 13-014 | 13 | 7/13/2008 19:01 | 306 | 1.1 | 2,497 | 0 | 0 | 0 | Fines | Low | 0.3 | 27.8 | 19.5 | | 0.00 |
| 13-015 | 13 | 7/13/2008 18:56 | 792 | 1.2 | 8,078 | 48 | 0 | 48 | Fines | Low | 1 | no data | 19.7 | 0.0 | 60.61 |
| 13-019 | 13 | 7/13/2008 18:51 | 207 | 3.5 | 9,779 | 0 | 0 | 0 | Fines | Low | 0 | no data | 63.6 | | 0.00 |
| 13-020 | 13 | 7/13/2008 19:07 | 9,243 | 3.1 | 42,702 | 0 | 6 | 6 | Fines | Low | 0.6 | 28 | 31.1 | 100.0 | 0.65 |
| 13-022 | 13 | 7/13/2008 19:11 | 3,654 | 2.5 | 11,628 | 0 | 34 | 34 | Fines | Low | 0 | no data | 66.4 | 100.0 | 9.30 |
| 14-008 | 14 | 4/5/2008 18:20 | 16,353 | 1.8 | 37,685 | 0 | 0 | 0 | Fines | None | 0.6 | 6.4 | 4.3 | | 0.00 |
| 14-008 | 14 | 8/18/2008 15:14 | 16,353 | 1.8 | 37,685 | 100 | 2 | 100 | Fines | Low | 1 | 24 | 14.7 | 2.0 | 6.12 |
| 14-008 | 14 | 8/19/2008 15:25 | 16,353 | 1.8 | 37,685 | 100 | 2 | 100 | Fines | Low | 1 | 26.8 | 38.9 | 2.0 | 6.12 |
| 14-009 | 14 | 4/5/2008 18:26 | 4,140 | 1.3 | 20,120 | 0 | 1 | 1 | Fines | Low | 0.4 | 6 | 8.7 | 100.0 | 0.24 |
| 14-009 | 14 | 7/24/2008 14:00 | 4,140 | 1.3 | 20,120 | 60 | 0 | 60 | Fines | Low | 1.2 | 27 | 41.0 | 0.0 | 14.49 |
| 14-009 | 14 | 8/14/2008 20:25 | 4,140 | 1.3 | 20,120 | 0 | 0 | 0 | Fines | Low | 1.2 | 20.7 | 3.2 | | 0.00 |
| 14-009 | 14 | 8/18/2008 15:14 | 4,140 | 1.3 | 20,120 | 45 | 1 | 46 | Fines | Low | 0.9 | 27.8 | 17.0 | 2.2 | 11.11 |
| 14-010 | 14 | 4/22/2008 19:51 | 180 | 0.2 | 14,598 | 0 | 0 | 0 | Fines | Low | 0.1 | 7.2 | 2.6 | | 0.00 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-010 | 14 | 7/23/2008 10:57 | 180 | 0.2 | 14,598 | 0 | 0 | 0 | Fines | Mod. G. | 0 | no data | 35.7 | | 0.00 |
| 14-011 | 14 | 7/24/2008 13:58 | 783 | 0.8 | 6,908 | 8 | 2 | 10 | Fines | Low | 0.2 | 34.3 | 67.7 | 20.0 | 12.77 |
| 14-011 | 14 | 4/5/2008 18:30 | 783 | 0.8 | 6,908 | 0 | 0 | 0 | Fines | None | 0.3 | 6.2 | 11.3 | | 0.00 |
| 14-011 | 14 | 4/22/2008 19:52 | 783 | 0.8 | 6,908 | 1 | 0 | 1 | Fines | None | 0.6 | 7.2 | 2.1 | 0.0 | 1.28 |
| 14-011 | 14 | 7/22/2008 18:48 | 783 | 0.8 | 6,908 | 10 | 0 | 10 | Fines | Low | 0.75 | 25.8 | 19.8 | 0.0 | 12.77 |
| 14-011 | 14 | 7/23/2008 15:47 | 783 | 0.8 | 6,908 | 10 | 0 | 10 | Fines | Low | 0.6 | 25.3 | 40.8 | 0.0 | 12.77 |
| 14-011 | 14 | 8/14/2008 20:20 | 783 | 0.8 | 6,908 | 0 | 0 | 0 | Fines | Low | 0.6 | 23.7 | 4.8 | | 0.00 |
| 14-011 | 14 | 8/18/2008 15:20 | 783 | 0.8 | 6,908 | 0 | 8 | 8 | Fines | Low | 0 | no data | 18.1 | 100.0 | 10.22 |
| 14-012 | 14 | 3/10/2008 13:48 | 144 | 0.8 | 3,142 | 0 | 0 | 0 | Gravel | None | 1 | 3.2 | 1.3 | | 0.00 |
| 14-012 | 14 | 7/22/2008 19:06 | 144 | 0.8 | 3,142 | 0 | 0 | 0 | Gravel | None | 0.4 | 20.6 | 19.1 | | 0.00 |
| 14-012 | 14 | 8/18/2008 15:20 | 144 | 0.8 | 3,142 | 0 | 120 | 120 | Gravel | None | 0 | no data | 17.8 | 100.0 | 833.33 |
| 14-013 | 14 | 3/10/2008 13:44 | 4,095 | 1.3 | 18,831 | 0 | 0 | 0 | Fines | None | 0.9 | 4.2 | 3.2 | | 0.00 |
| 14-013 | 14 | 4/5/2008 18:30 | 4,095 | 1.3 | 18,831 | 0 | 0 | 0 | Fines | None | 0.5 | 6 | 34.7 | | 0.00 |
| 14-013 | 14 | 4/22/2008 20:05 | 4,095 | 1.3 | 18,831 | 0 | 0 | 0 | Fines | Low G. | 0.9 | 20.6 | 5.6 | | 0.00 |
| 14-013 | 14 | 7/22/2008 18:55 | 4,095 | 1.3 | 18,831 | 35 | 1 | 35 | Fines | Low G. | 0.6 | 19.9 | 34.7 | 2.9 | 8.55 |
| 14-013 | 14 | 7/23/2008 15:50 | 4,095 | 1.3 | 18,831 | 35 | 1 | 35 | Fines | Low G. | 1.2 | no data | 55.6 | 2.9 | 8.55 |
| 14-013 | 14 | 8/18/2008 15:20 | 4,095 | 1.3 | 18,831 | 0 | 29 | 29 | Fines | Low G. | 0 | no data | 20.3 | 100.0 | 7.08 |
| 14-014 | 14 | 7/22/2008 18:41 | 720 | 0.8 | 9,603 | 0 | 0 | 0 | Fines | Low | 0.2 | 10.3 | 33.9 | | 0.00 |
| 14-017 | 14 | 3/10/2008 13:36 | 3,105 | 2.1 | 9,379 | 0 | 0 | 0 | Fines | None | na | no data | 4.1 | | 0.00 |
| 14-024 | 14 | 7/13/2008 18:14 | 1,242 | 2.2 | 5,188 | 0 | 0 | 0 | Fines | None | 0.2 | 28 | 20.5 | | 0.00 |
| 14-026 | 14 | 7/13/2008 18:28 | 14,661 | 3.4 | 45,749 | 0 | 56 | 56 | Fines | Low | 0 | no data | 63.7 | 100.0 | 3.82 |
| 16-003a | 16 | 3/27/2008 13:28 | 10,815 | 3.5 | 156,720 | 0 | 0 | 0 | Fines | None | 1.5 | 6.3 | 6.5 | | 0.00 |
| 16-003a | 16 | 4/22/2008 20:34 | 10,815 | 3.5 | 156,720 | 0 | 0 | 0 | Fines | None | 1.4 | 6.7 | 4.1 | | 0.00 |
| 16-003a | 16 | 7/22/2008 17:05 | 10,815 | 3.5 | 156,720 | 7500 | 0 | 7500 | Fines | Low | 1.5 | 20 | 20.6 | 0.0 | 693.48 |
| 16-003a | 16 | 7/24/2008 16:20 | 10,815 | 3.5 | 156,720 | 7480 | 20 | 7500 | Fines | Low | 1.4 | 21 | 67.8 | 0.3 | 693.48 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16-003a | 16 | 8/14/2008 21:00 | 10,815 | 3.5 | 156,720 | 6,000 | 1 | 6,001 | Fines | Low | 1.5 | 22.2 | 6.7 | 0.0 | 554.88 |
| 16-003a | 16 | 8/18/2008 15:54 | 10,815 | 3.5 | 156720 | 8,412 | 4 | 8,416 | Fines | Low | 1.6 | 23.4 | 19.6 | 0.0 | 778.18 |
| 16-003a | 16 | 8/18/2008 16:45 | 10,815 | 3.5 | 156,720 | 7,666 | 750 | 8,416 | Fines | Low | 1.6 | no data | 20.5 | 8.9 | 778.18 |
| 16-003a | 16 | 8/18/2008 16:55 | 10,815 | 3.5 | 156,720 | 7,486 | 930 | 8,416 | Fines | Low | 1.6 | no data | 20.7 | 11.1 | 778.18 |
| 16-003a | 16 | 8/19/2008 14:45 | 10,815 | 3.5 | 156,720 | 7,397 | 1,019 | 8,416 | Fines | Low | 1.5 | 23.8 | 42.5 | 12.1 | 778.18 |
| 16-003b | 16 | 3/27/2008 13:24 | 9,731 | 3.5 | 94,435 | 0 | 0 | 0 | Fines | None | 1.1 | 6.3 | 5.6 | | 0.00 |
| 16-003b | 16 | 4/22/2008 20:45 | 9,731 | 3.5 | 94,435 | 0 | 0 | 0 | Fines | None | 1.1 | 6.7 | 4.0 | | 0.00 |
| 16-003b | 16 | 8/14/2008 21:00 | 9,731 | 3.5 | 94,435 | 8,080 | 0 | 8,080 | Fines | Mod. | 1.4 | 23.4 | 6.5 | 0.0 | 830.34 |
| 16-003b | 16 | 8/18/2008 16:30 | 9,731 | 3.5 | 94,435 | 18,489 | 0 | 18,489 | Fines | Mod. | 1.4 | 26.2 | 20.0 | 0.0 | 1,900.00 |
| 16-003b | 16 | 8/19/2008 14:45 | 9,731 | 3.5 | 94,435 | 15,570 | 163 | 15,732 | Fines | Mod. | 1.4 | 26.8 | 42.2 | 1.0 | 1,616.71 |
| 16-003c | 16 | 8/18/2008 16:50 | 11,791 | 3.5 | 69,267 | 29,477 | 0 | 29,477 | Fines | Mod. | 1.7 | 26 | 20.6 | 0.0 | 2,499.96 |
| 16-003c | 16 | 8/19/2008 14:45 | 11,791 | 3.5 | 69,267 | 24,740 | 178 | 24,918 | Fines | Mod. | 1.7 | 26.4 | 42.5 | 0.7 | 2,113.31 |
| 16-003d | 16 | 4/22/2008 21:00 | 4,436 | 1.8 | 35,983 | 0 | 0 | 0 | Fines | None | 0.6 | 6.7 | 4.7 | | 0.00 |
| 16-003d | 16 | 7/22/2008 17:22 | 4,436 | 1.8 | 35,983 | 440 | 0 | 440 | Fines | Low | 0.3 | 25.2 | 21.4 | 0.0 | 99.19 |
| 16-003d | 16 | 7/24/2008 16:14 | 4,436 | 1.8 | 35,983 | 170 | 270 | 440 | Fines | Low | 0.2 | 33.5 | 68.2 | 61.4 | 99.19 |
| 16-003d | 16 | 8/14/2008 21:00 | 4,436 | 1.8 | 35,983 | 0 | 10 | 10 | Fines | Mod. | 0.4 | 22 | 7.2 | 100.0 | 2.25 |
| 16-003d | 16 | 8/18/2008 16:50 | 4,436 | 1.8 | 35,983 | 0 | 0 | 0 | Fines | Mod. | 0.3 | 27.5 | 20.8 | | 0.00 |
| 16-007 | 16 | 5/5/2008 21:50 | 7,245 | 3.9 | 38,500 | 0 | 0 | 0 | Fines | Low | 1.2 | 8.6 | 5.8 | | 0.00 |
| 16-007 | 16 | 7/22/2008 17:59 | 7,245 | 3.9 | 38,500 | 9 | 0 | 9 | Fines | Mod. G. | 1.8 | 18.6 | 42.7 | 0.0 | 1.24 |
| 16-007 | 16 | 7/24/2008 16:30 | 7,245 | 3.9 | 38,500 | 9 | 0 | 9 | Fines | Mod. G. | 1.2 | 24 | 89.2 | 0.0 | 1.24 |
| 16-011 | 16 | 7/22/2008 18:01 | 1,368 | 1.4 | 26,699 | 0 | 0 | 0 | Fines | Mod. G. | 0 | no data | 125.3 | | 0.00 |
| 16-013 | 16 | 7/22/2008 18:03 | 9,927 | 4.4 | 17,251 | 5 | 0 | 5 | Fines | High G. | 2.4 | 22.1 | 46.1 | 0.0 | 0.50 |
| 16-013 | 16 | 7/24/2008 16:40 | 9,927 | 4.4 | 17,251 | 5 | 0 | 5 | Fines | High G. | 2 | 26.2 | 92.7 | 0.0 | 0.50 |
| 17-005 | 17 | 7/22/2008 16:13 | 234 | 0.2 | 5,648 | 7 | 802 | 809 | Fines | None | 0.1 | 25 | 15.2 | 99.1 | 3,457.26 |
| 17-007 | 17 | 4/22/2008 21:55 | 6,021 | 1.0 | 62,447 | 3 | 0 | 3 | Fines | None | 0.8 | 6.7 | 5.2 | 0.0 | 0.50 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17-007 | 17 | 5/5/2008 20:50 | 6,021 | 1.0 | 62,447 | 3 | 0 | 3 | Fines | Low | 0.6 | 8.4 | 0.0 | 0.0 | 0.50 |
| 17-007 | 17 | 7/23/2008 12:56 | 6,021 | 1.0 | 62,447 | 300 | 0 | 300 | Fines | Low | 0.7 | 27 | 39.4 | 0.0 | 49.83 |
| 17-007 | 17 | 7/24/2008 15:00 | 6,021 | 1.0 | 62,447 | 290 | 10 | 300 | Fines | Low | 0.7 | 29.3 | 65.5 | 3.3 | 49.83 |
| 17-007 | 17 | 8/18/2008 17:25 | 6,021 | 1.0 | 62,447 | 12 | 0 | 12 | Fines | Low | 0.3 | 29.2 | 21.2 | 0.0 | 1.99 |
| 17-007 | 17 | 8/19/2008 17:25 | 6,021 | 1.0 | 62,447 | 12 | 0 | 12 | Fines | Low | 0.2 | 27 | 45.2 | 0.0 | 1.99 |
| 17-013 | 17 | 3/3/2008 21:45 | 4,248 | 0.5 | 92,399 | 0 | 0 | 0 | Fines | None | 0.5 | 1 | 8.5 | | 0.00 |
| 17-013 | 17 | 5/5/2008 20:43 | 4,248 | 0.5 | 92,399 | 0 | 0 | 0 | Fines | None | 0.3 | 8.1 | 0.0 | | 0.00 |
| 17-013 | 17 | 7/22/2008 15:45 | 4,248 | 0.5 | 92,399 | 25 | 2 | 27 | Fines | Low | 0.5 | 24.6 | 17.5 | 7.4 | 6.36 |
| 17-013 | 17 | 7/23/2008 13:32 | 4,248 | 0.5 | 92,399 | 25 | 2 | 27 | Fines | Low | 0.3 | 25.7 | 39.3 | 7.4 | 6.36 |
| 17-013 | 17 | 7/24/2008 15:25 | 4,248 | 0.5 | 92,399 | 22 | 5 | 27 | Fines | Low | 0.1 | 34.3 | 65.2 | 18.5 | 6.36 |
| 17-013 | 17 | 8/18/2008 17:23 | 4,248 | 0.5 | 92,399 | 2 | 0 | 2 | Fines | Low | 0.1 | 29.2 | 20.9 | 0.0 | 0.47 |
| 17-014 | 17 | 7/22/2008 15:34 | 351 | 0.2 | 46,927 | 11 | 5 | 16 | Fines | Low | 0.25 | 24.2 | 14.8 | 31.3 | 45.58 |
| 17-014 | 17 | 7/23/2008 13:40 | 351 | 0.2 | 46,927 | 7 | 9 | 16 | Fines | Low | 0.2 | 28 | 36.9 | 56.3 | 45.58 |
| 17-014 | 17 | 7/24/2008 16:00 | 351 | 0.2 | 46,927 | 0 | 0 | 0 | Fines | Low | 0 | no data | 63.2 | | 0.00 |
| 17-014 | 17 | 8/18/2008 17:30 | 351 | 0.2 | 46,927 | 0 | 0 | 0 | Fines | Low | 0.1 | 30.1 | 20.3 | | 0.00 |
| 17-017 | 17 | 3/3/2008 21:33 | 540 | 0.2 | 32,018 | 0 | 0 | 0 | Fines | None | 0.3 | 1 | 10.3 | | 0.00 |
| 17-017 | 17 | 8/18/2008 17:23 | 540 | 0.2 | 32,018 | 0 | 0 | 0 | Fines | None | 0.1 | 29 | 21.4 | | 0.00 |
| 17-018 | 17 | 7/22/2008 15:55 | 252 | 0.2 | 16,607 | 200 | 55 | 255 | Fines | Low | 0.1 | 24.8 | 14.4 | 21.6 | 1,011.90 |
| 17-020 | 17 | 7/22/2008 15:58 | 522 | 0.2 | 6,791 | 35 | 0 | 35 | Fines | Low | 0.2 | 20.7 | 17.7 | 0.0 | 67.05 |
| 17-020 | 17 | 7/23/2008 13:15 | 522 | 0.2 | 6,791 | 35 | 0 | 35 | Fines | Low | 0.1 | 25.9 | 39.0 | 0.0 | 67.05 |
| 17-020 | 17 | 7/24/2008 15:20 | 522 | 0.2 | 6,791 | 0 | 35 | 35 | Fines | Low | 0 | no data | 65.1 | 100.0 | 67.05 |
| 17-020 | 17 | 8/18/2008 17:25 | 522 | 0.2 | 6,791 | 0 | 0 | 0 | Fines | Low | 0.1 | 30 | 20.9 | | 0.00 |
| 17-024 | 17 | 7/13/2008 18:18 | 117 | 1.3 | 2,511 | 0 | 0 | 0 | Fines | Low | 0 | no data | 19.8 | | 0.00 |
| 17-026 | 17 | 7/17/2008 21:03 | 648 | 0.4 | 8,338 | 0 | 0 | 0 | Fines | Low G. | 0 | no data | 2.5 | | 0.00 |
| 17-027 | 17 | 7/22/2008 15:25 | 189 | 0.5 | 4,069 | 30 | 0 | 30 | Fines | Low G. | 0.3 | 24.2 | 38.9 | 0.0 | 158.73 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17-028 | 17 | 7/22/2008 14:51 | 207 | 0.8 | 3,208 | 290 | 260 | 550 | Fines | Mod. | 0.4 | 24 | 38.6 | 47.3 | 2,657.00 |
| 17-028 | 17 | 7/23/2008 14:14 | 207 | 0.8 | 3,208 | 0 | 550 | 550 | Fines | Mod. | 0 | no data | 62.0 | 100.0 | 2,657.00 |
| 17-030 | 17 | 7/13/2008 17:46 | 666 | 2.0 | 3,622 | 0 | 0 | 0 | Fines | Low | 0.2 | 30 | 0.0 | | 0.00 |
| 17-030 | 17 | 7/21/2008 12:41 | 666 | 2.0 | 3,622 | 750 | 0 | 750 | Fines | Low | 0.8 | 21 | 12.4 | 0.0 | 1,126.13 |
| 17-030 | 17 | 7/23/2008 13:55 | 666 | 2.0 | 3,622 | 645 | 105 | 750 | Fines | Low | 0.1 | 20.2 | 61.7 | 14.0 | 1,126.13 |
| 17-030 | 17 | 7/23/2008 17:20 | 666 | 2.0 | 3,622 | 0 | 750 | 750 | Fines | Low | 0 | no data | 65.1 | 100.0 | 1,126.13 |
| 17-033 | 17 | 7/17/2008 20:35 | 4,023 | 1.1 | 23,320 | 0 | 6 | 6 | Fines | Low G. | 0 | no data | 4.3 | 100.0 | 1.49 |
| 17-034 | 17 | 7/17/2008 20:45 | 1,863 | 0.9 | 13,052 | 0 | 3 | 3 | Fines | Low G. | 0 | no data | 6.0 | 100.0 | 1.61 |
| 17-038 | 17 | 7/21/2008 12:41 | 216 | 0.4 | 1,178 | 0 | 0 | 0 | Fines | Low | 0.8 | 21 | 14.7 | | 0.00 |
| 17-041 | 17 | 7/13/2008 17:56 | 1,107 | 2.0 | 4,075 | 150 | 0 | 150 | Fines | Low | 2 | 28.2 | 0.1 | 0.0 | 135.50 |
| 17-041 | 17 | 7/17/2008 21:15 | 1,107 | 2.0 | 4,075 | 180 | 0 | 180 | Fines | Low G. | 1.9 | 17 | 7.0 | 0.0 | 162.60 |
| 17-041 | 17 | 7/21/2008 12:31 | 1,107 | 2.0 | 4,075 | 2400 | 0 | 2400 | Fines | Low G. | 1.8 | 22.4 | 15.8 | 0.0 | 2,168.02 |
| 17-041 | 17 | 7/22/2008 15:15 | 1,107 | 2.0 | 4,075 | 2400 | 0 | 2400 | Fines | Low G. | 1.4 | 32.7 | 42.5 | 0.0 | 2,168.02 |
| 17-041 | 17 | 7/24/2008 16:00 | 1,107 | 2.0 | 4,075 | 0 | 2400 | 2400 | Fines | Low G. | 0 | no data | 91.2 | 100.0 | 2,168.02 |
| 17-042 | 17 | 7/17/2008 21:15 | 1,053 | 1.5 | 25,158 | 60 | 0 | 60 | Fines | Low G. | 1.4 | 17 | 4.5 | 0.0 | 56.98 |
| 17-042 | 17 | 7/22/2008 15:21 | 1,053 | 1.5 | 25,158 | 314 | 0 | 314 | Fines | Low G. | 0.9 | 19.3 | 40.9 | 0.0 | 298.43 |
| 17-042 | 17 | 7/23/2008 13:47 | 1,053 | 1.5 | 25,158 | 314 | 0 | 314 | Fines | Low G. | 0.3 | 24.4 | 63.3 | 0.0 | 298.20 |
| 17-042 | 17 | 7/24/2008 16:00 | 1,053 | 1.5 | 25,158 | 0 | 314 | 314 | Fines | Low G. | 0 | no data | 89.5 | 100.0 | 298.20 |
| 17-048 | 17 | 7/13/2008 17:43 | 405 | 4.4 | 1,510 | 0 | 0 | 0 | Fines | Low | 0.2 | 30 | 63.7 | | 0.00 |
| 17-048 | 17 | 7/21/2008 13:00 | 405 | 4.4 | 1,510 | 0 | 0 | 0 | Fines | Low | 2.1 | 20.5 | 251.0 | | 0.00 |
| 17-048 | 17 | 7/22/2008 15:08 | 405 | 4.4 | 1,510 | 0 | 0 | 0 | Fines | Low | 0 | no data | 277.1 | | 0.00 |
| 17-050 | 17 | 7/13/2008 17:29 | 459 | 0.7 | 4,648 | 0 | 0 | 0 | Fines | Low G. | 0 | no data | 72.2 | | 0.00 |
| 17-051 | 17 | 7/13/2008 17:28 | 261 | 0.7 | 6,576 | 0 | 0 | 0 | Fines | Low | 0 | no data | 71.0 | | 0.00 |
| SC-017 | SC | 7/18/2008 0:35 | 954 | 0.7 | 24,994 | 0 | 0 | 0 | Gravel | None | 0.1 | 16.5 | 4.6 | | 0.00 |
| SC-017 | SC | 7/23/2008 11:34 | 954 | 0.7 | 24,994 | 0 | 0 | 0 | Gravel | None | 0.3 | 18 | 51.8 | | 0.00 |

**Table C-1, continued…**

| Mapped Pool ID | Re gion | Date Time | Mapped Area | Mapped Max Depth (ft) | Contrib. basin area (sq ft) | No. Est. Live Fish | No. Est. Dead Fish | No. Est. Total Fish | Substrate | Field Ob. Veg. | Depth at time of survey (ft) | Trap pool temp at time of survey (°C) | Est. Dur. of Trapping at Time of Survey (hours) | Est. % Mort. | Density of Trapped fish (#/ 1,000 sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SC-021 | SC | 3/3/2008 21:50 | 504 | 0.7 | 2,890 | 0 | 0 | 0 | Gravel | None | 0.4 | 1 | 8.3 | | 0.00 |
| TR-033 | TR | 4/4/2008 1:05 | 765 | 0.4 | 7,360 | 0 | 0 | 0 | Cobble | None | 0 | no data | 1.3 | | 0.00 |
| TR-035 | TR | 4/4/2008 1:10 | 1,998 | 1.5 | 10,589 | 0 | 0 | 0 | Cobble | None | 0 | no data | 2.2 | | 0.00 |
| TR-038 | TR | 4/4/2008 1:05 | 459 | 0.3 | 10,994 | 0 | 0 | 0 | Cobble | None | 0 | no data | 2.1 | | 0.00 |

# Attachment D: Stranding Index Model Results

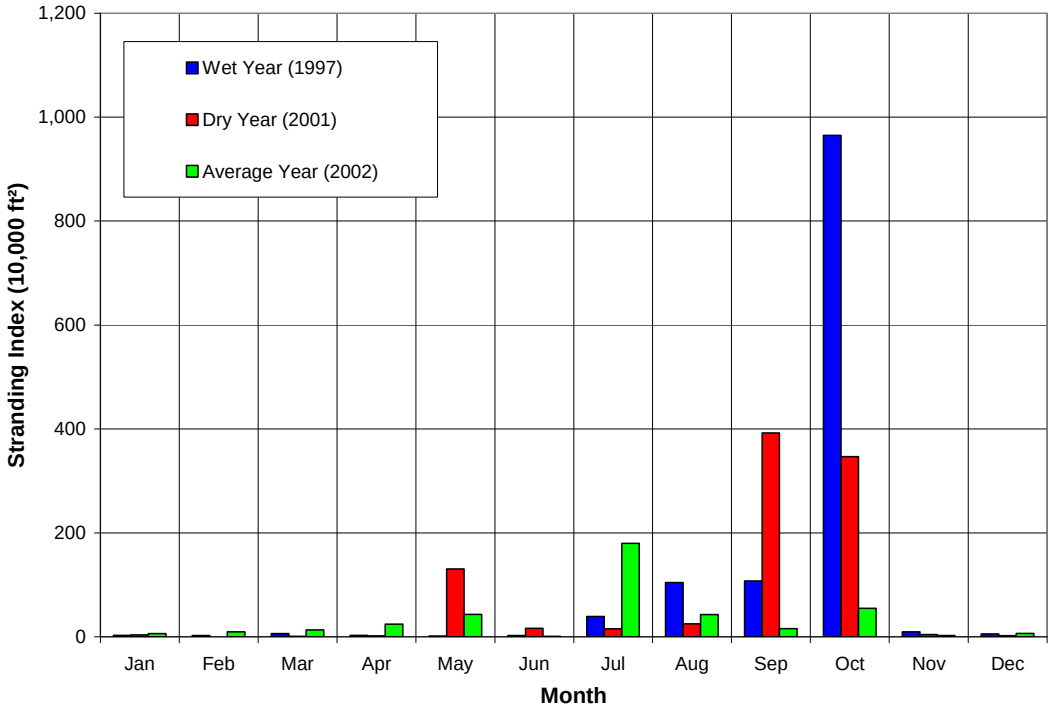



**Figure D-1.** Monthly total stranding index values for the Forebay Reach for the wet (1997), dry (2001), and average year (2002).

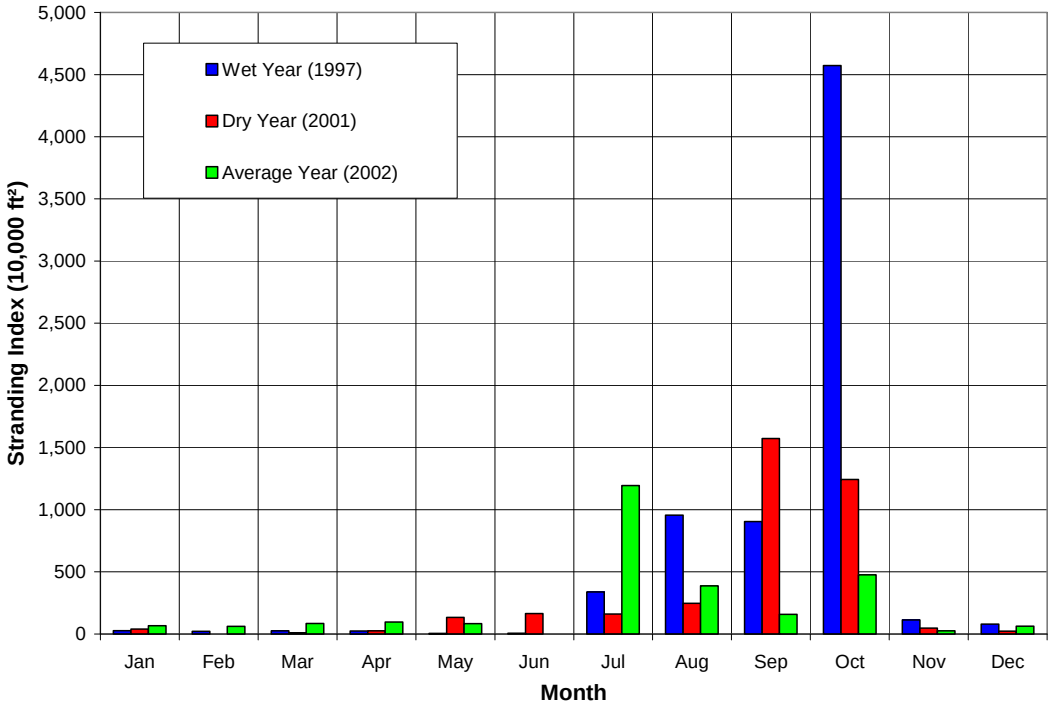



**Figure D-2.** Monthly total stranding index values for the Canyon Reach for the wet (1997), dry (2001), and average year (2002).

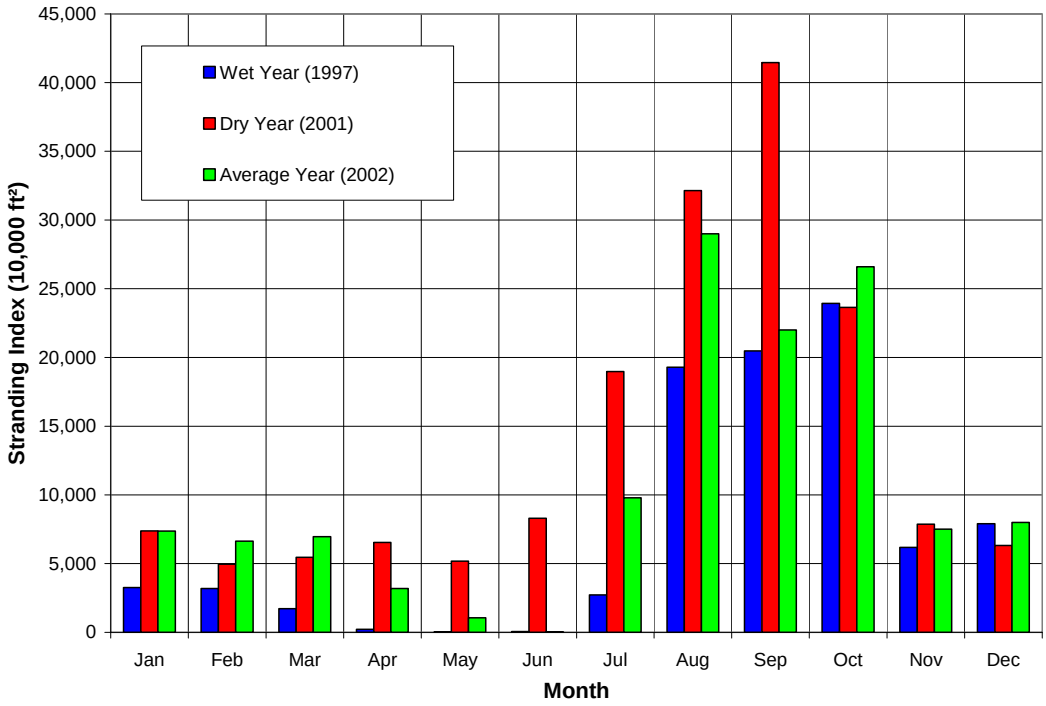



**Figure D-3.** Monthly total stranding index values for the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

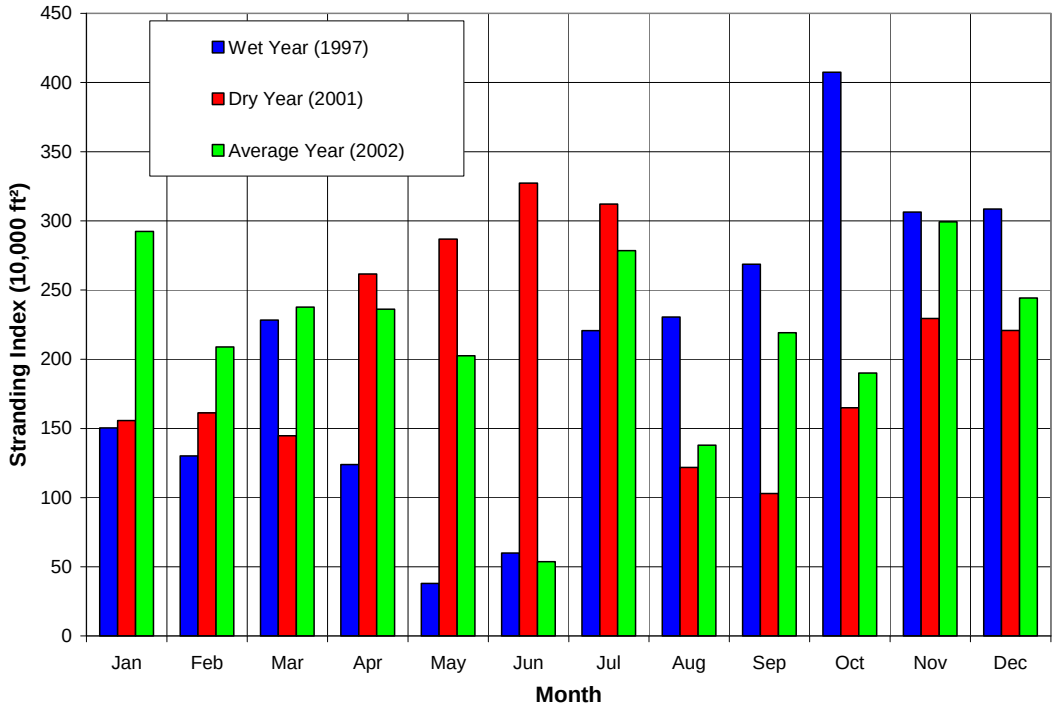



**Figure D-4.** Monthly total stranding index values for the Tailrace Reach for the wet (1997), dry (2001), and average year (2002).

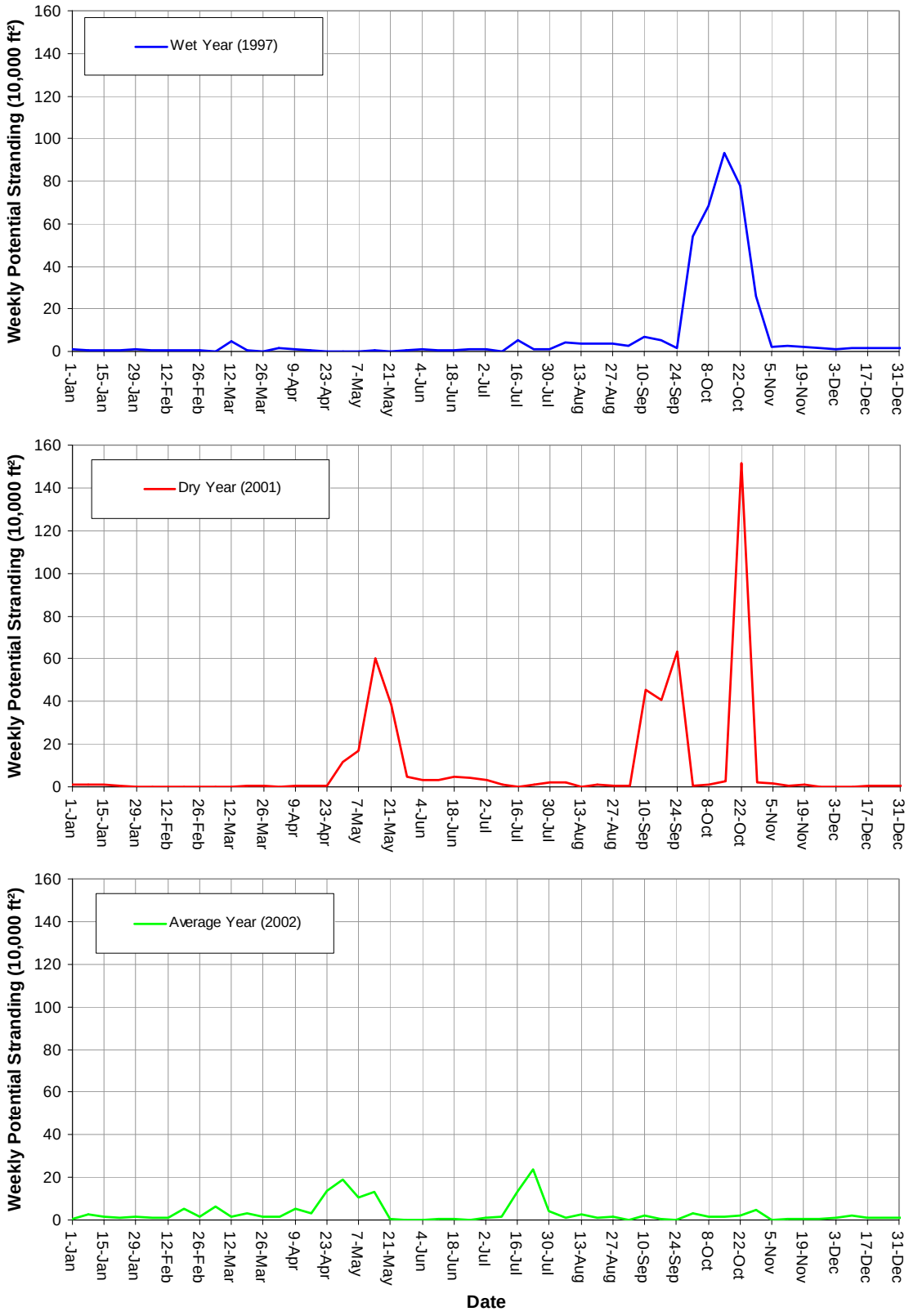



**Figure D-5.** Comparison of Forebay Launch Region weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

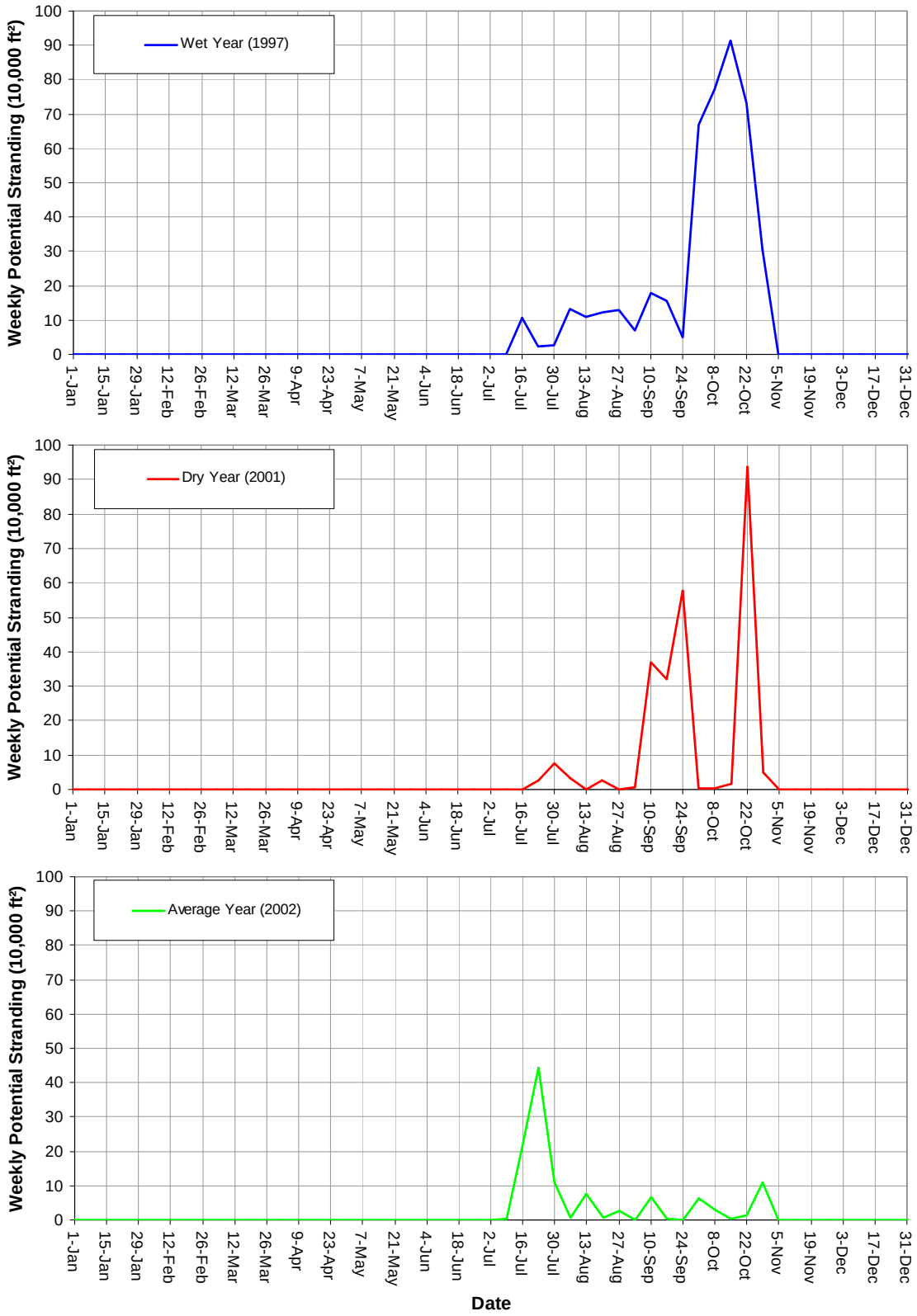



**Figure D-6.** Comparison of Region 1 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

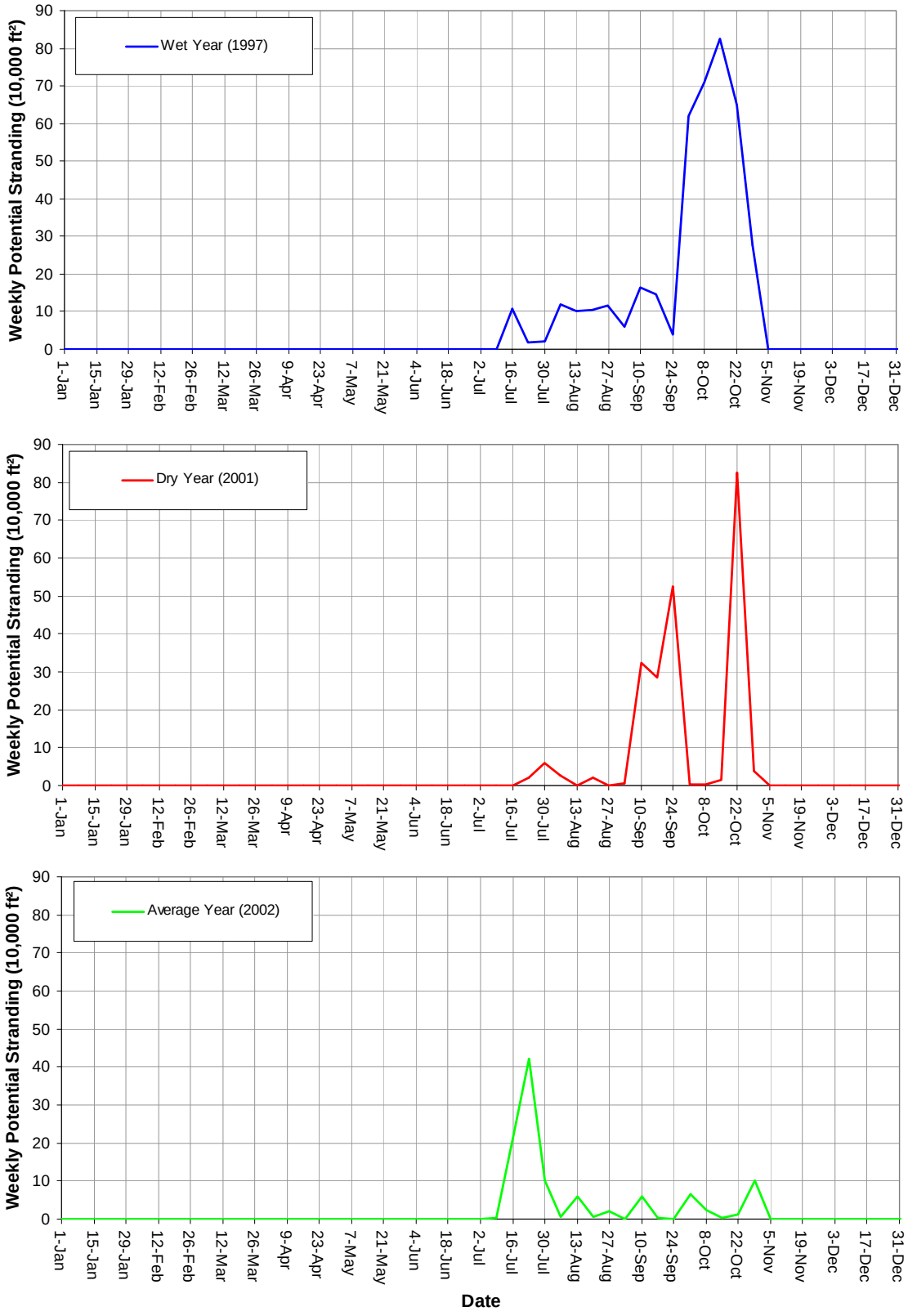



**Figure D-7.** Comparison of the weekly stranding index values for the additional stranding area in the Forebay Reach for the wet (1997), dry (2001), and average year (2002).

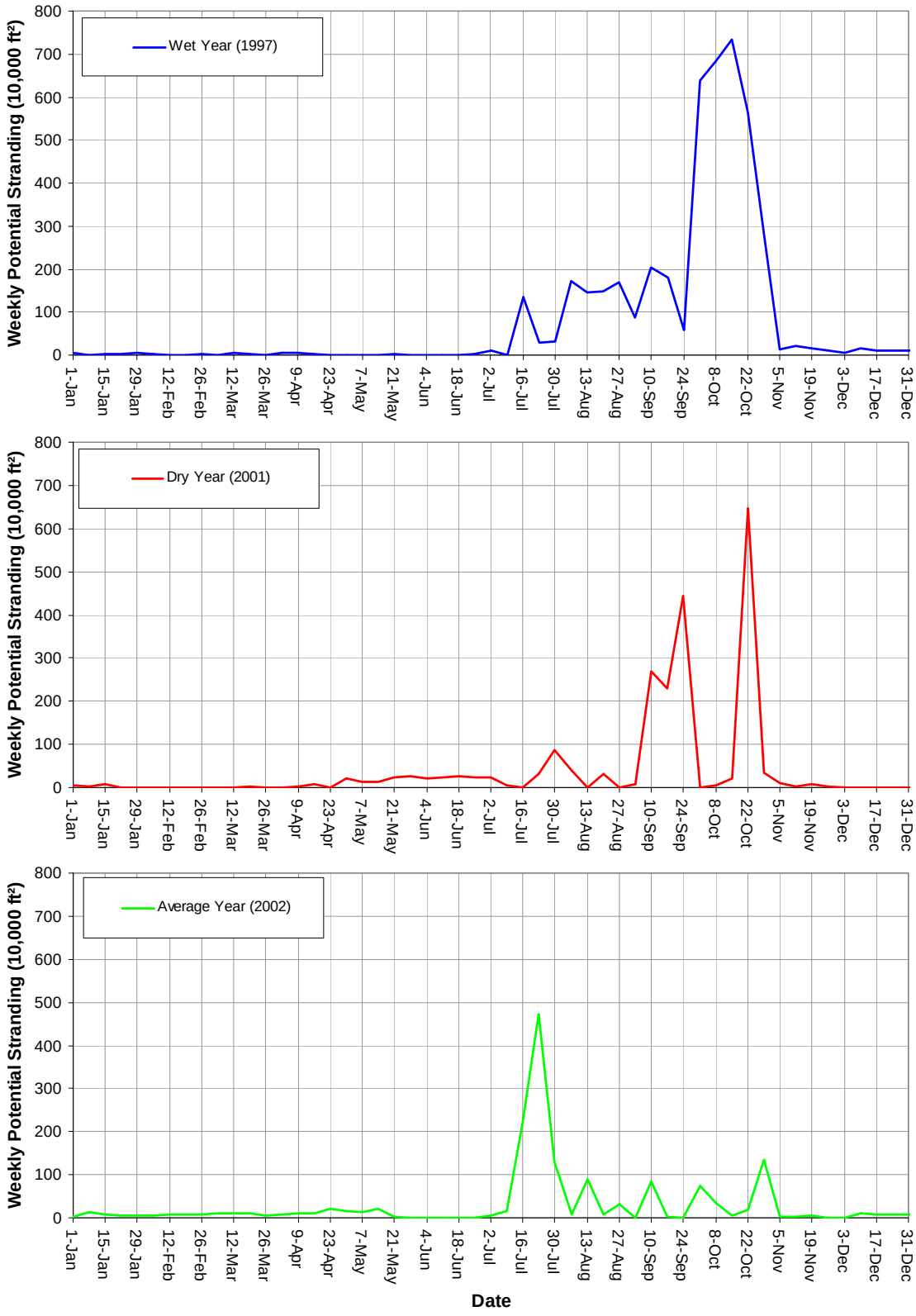



**Figure D-8.** Comparison of Region 2 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

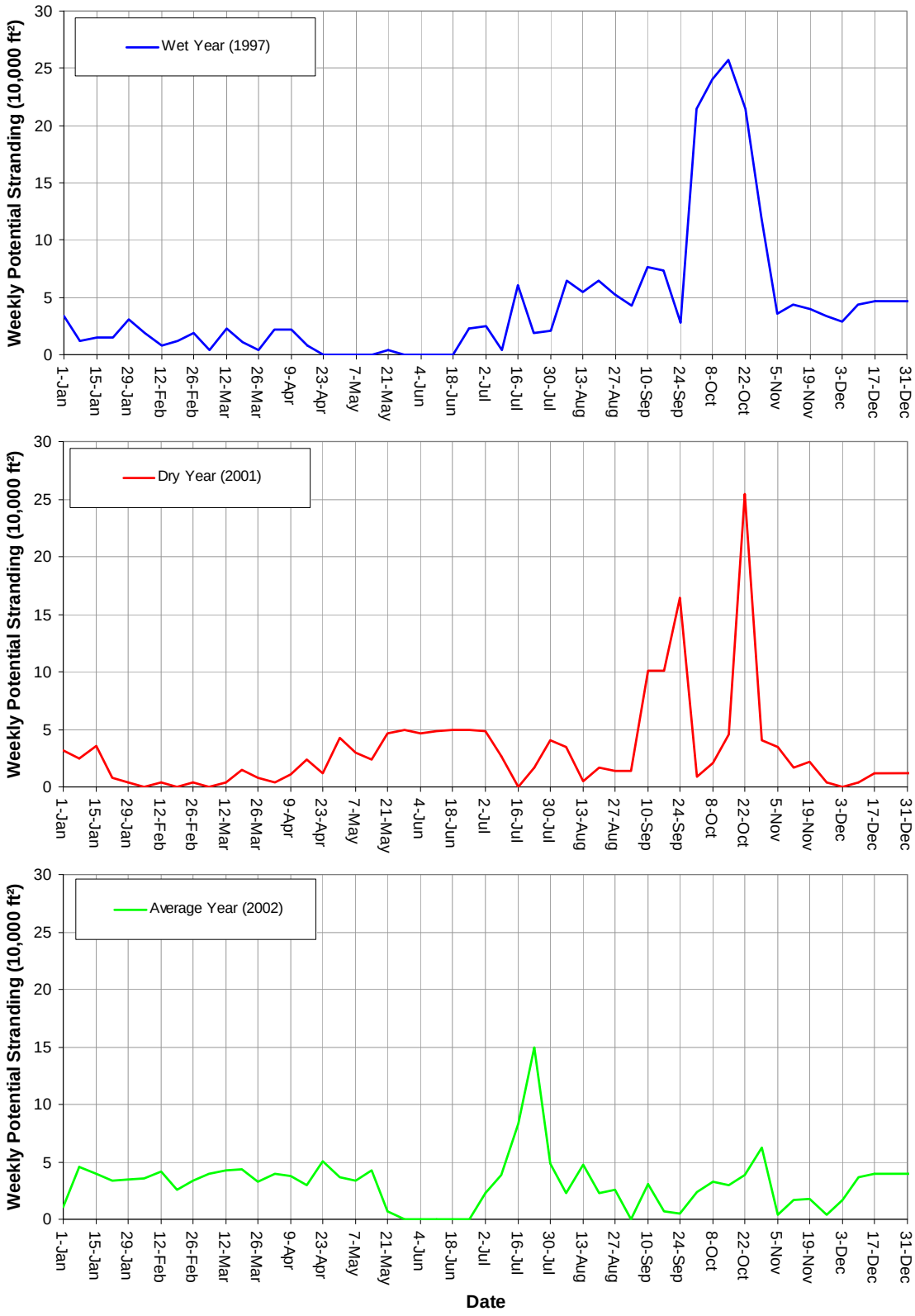



**Figure D-9.** Comparison of Region 3 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

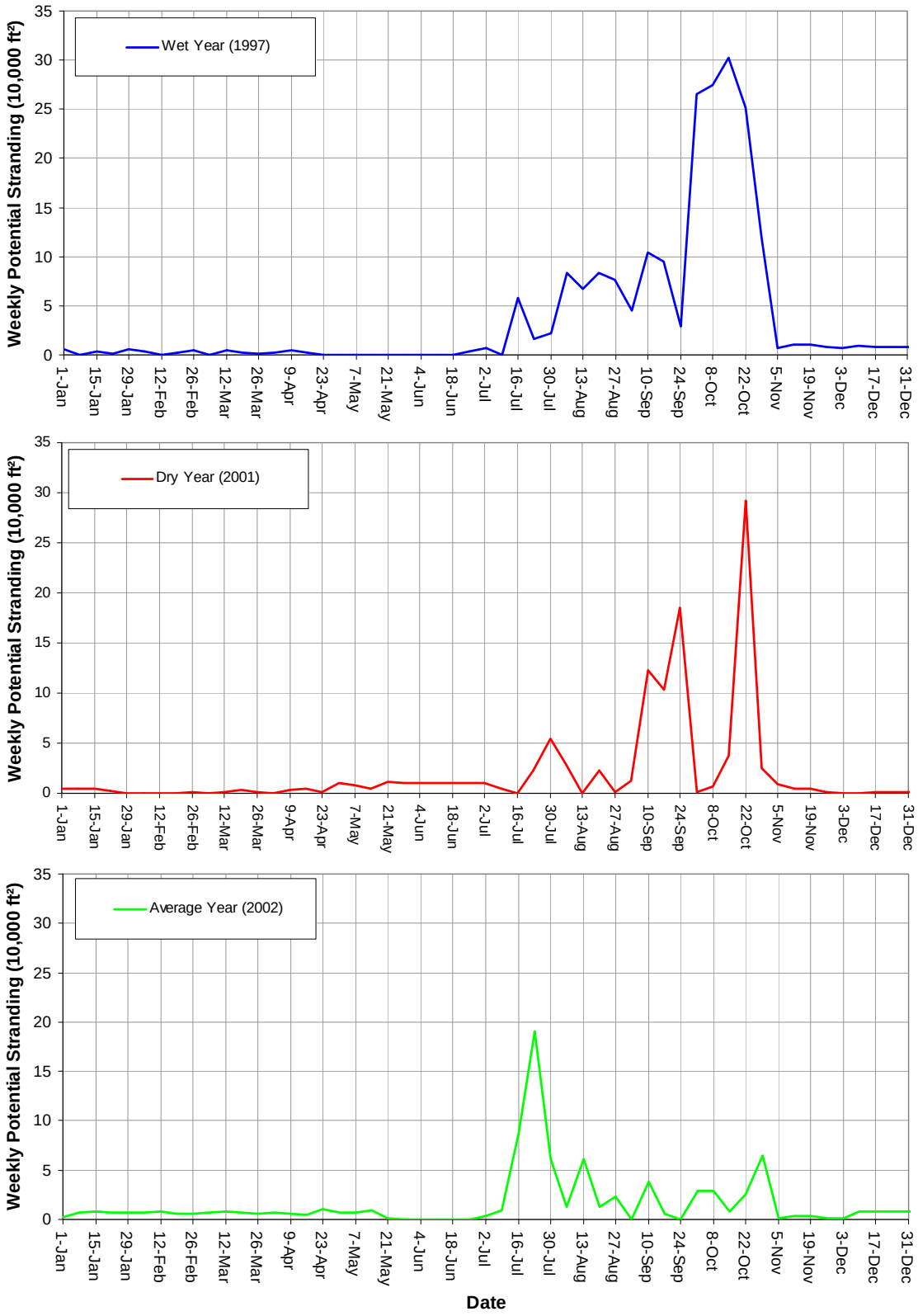



**Figure D-10.** Comparison of Region 4 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

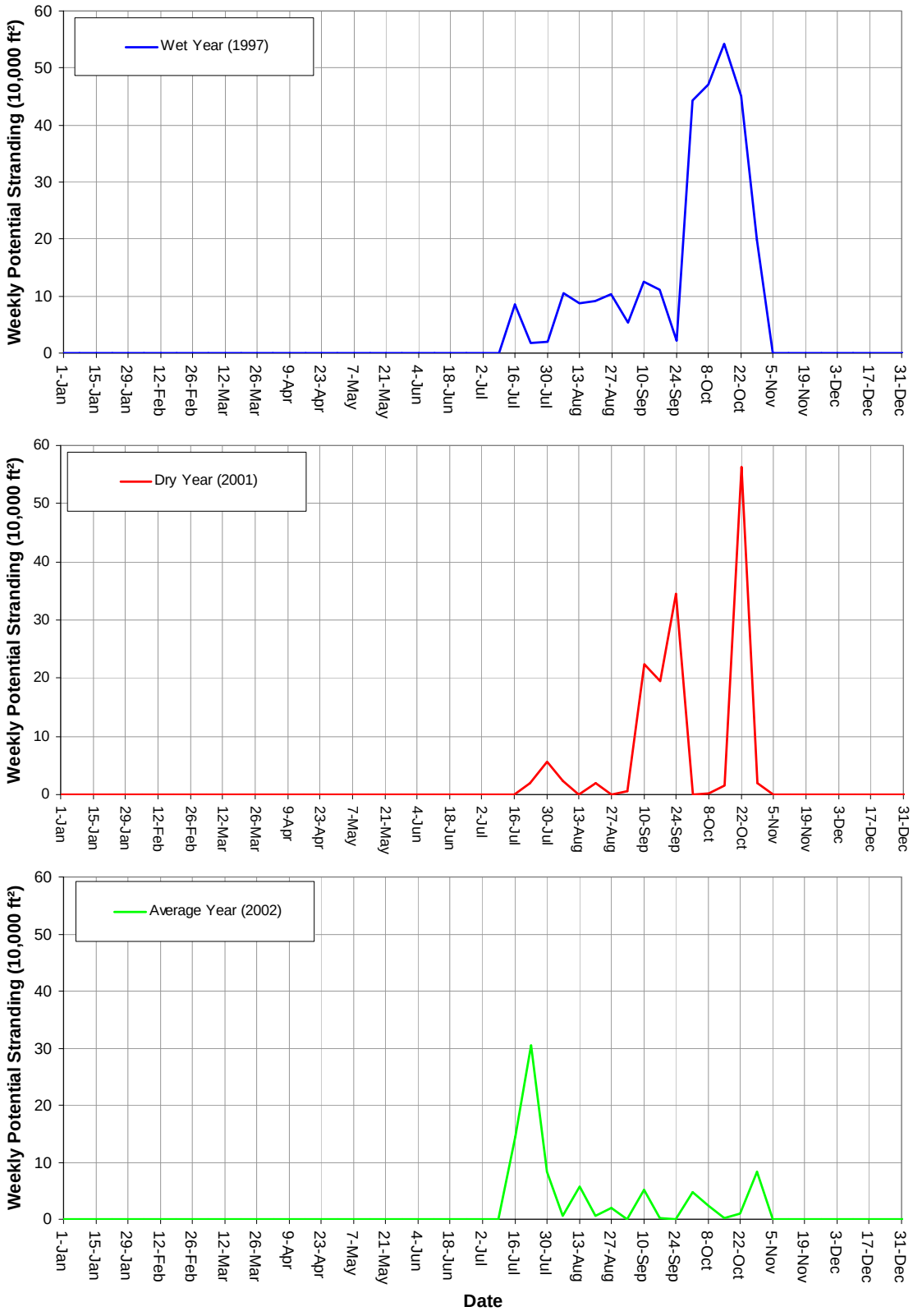



**Figure D-11.** Comparison of Region 5 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

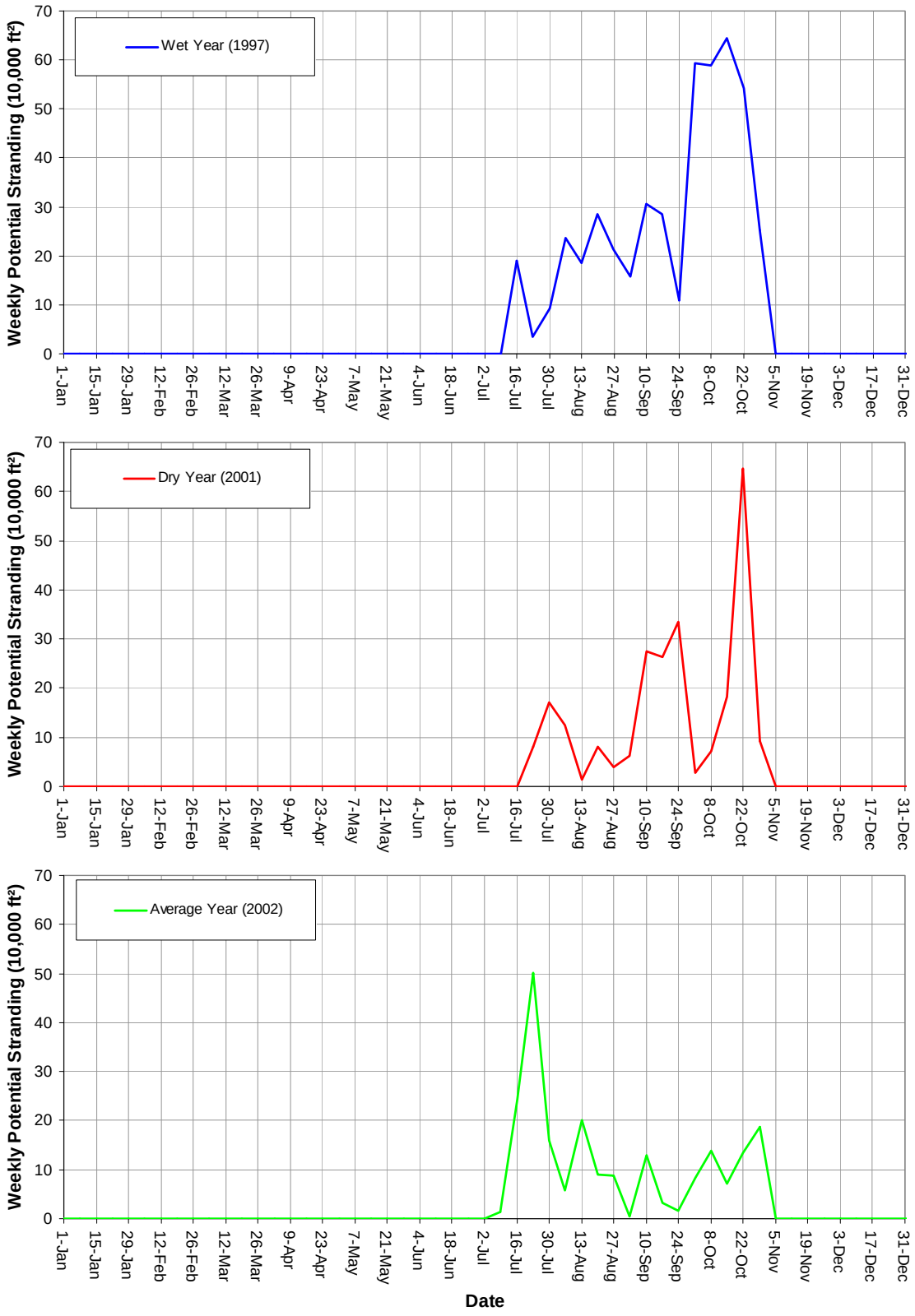



**Figure D-12.** Comparison of Stump Farm Region weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

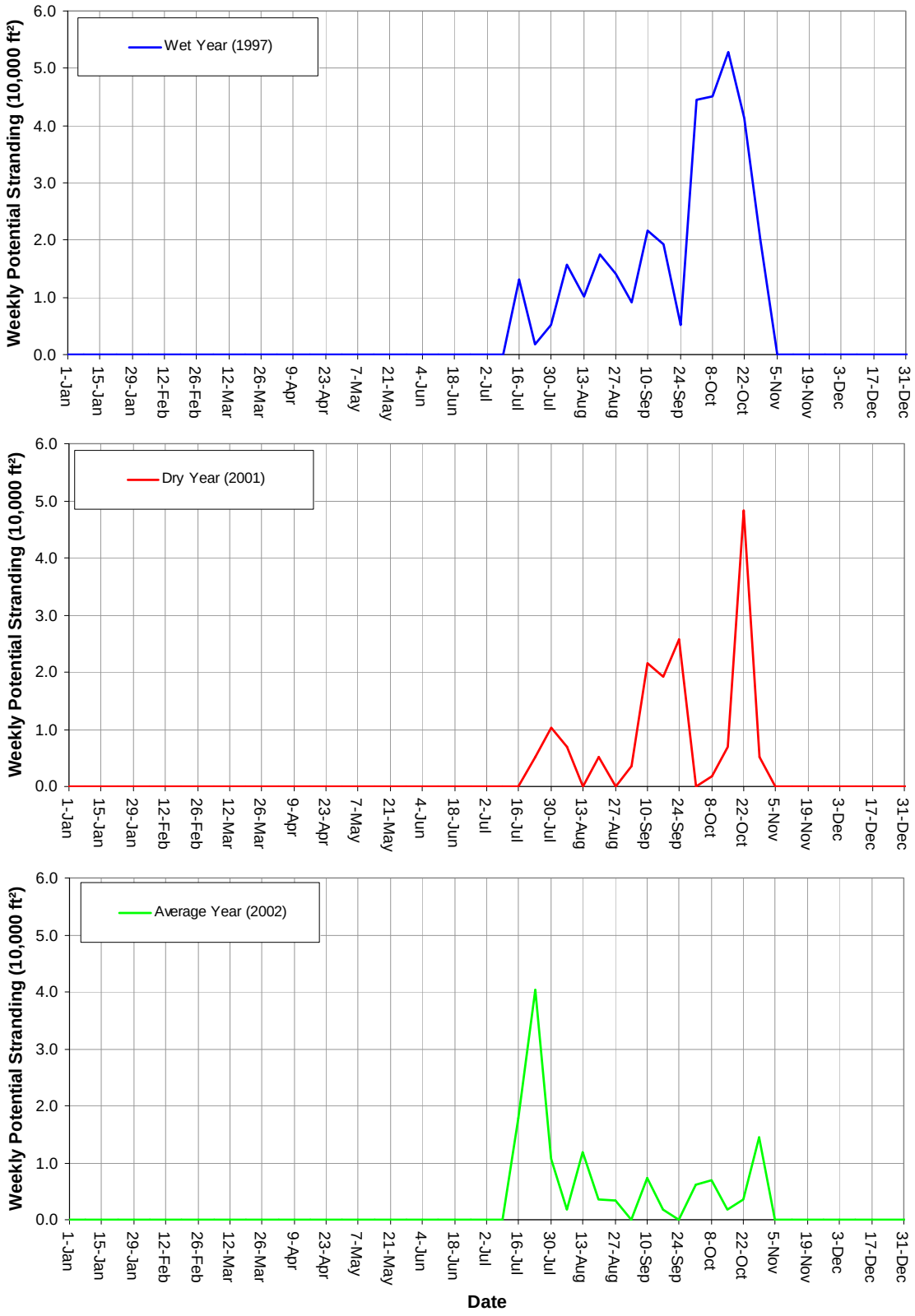



**Figure D-13.** Comparison of Region 6 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

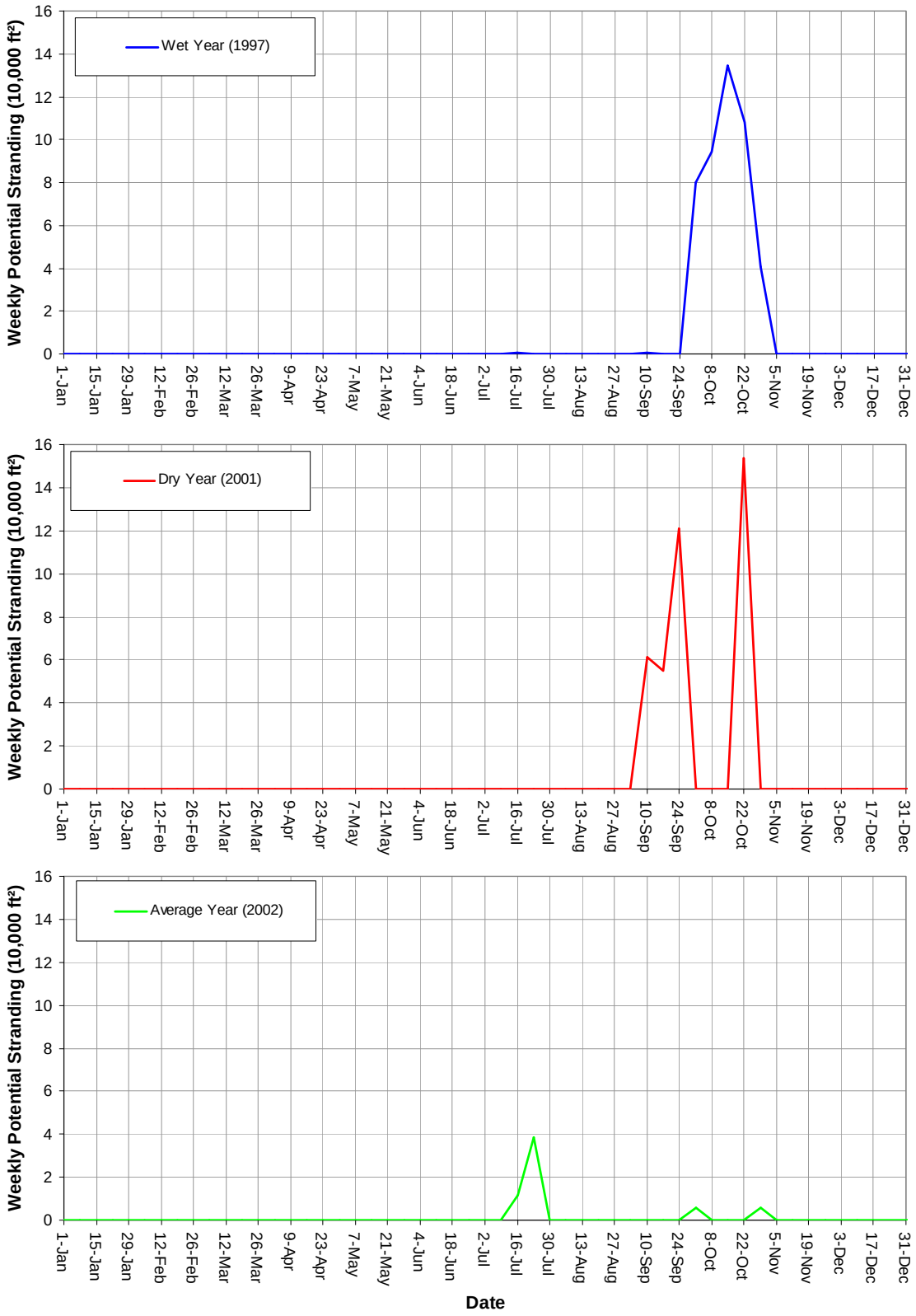



**Figure D-14.** Comparison of Flume Creek Region weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

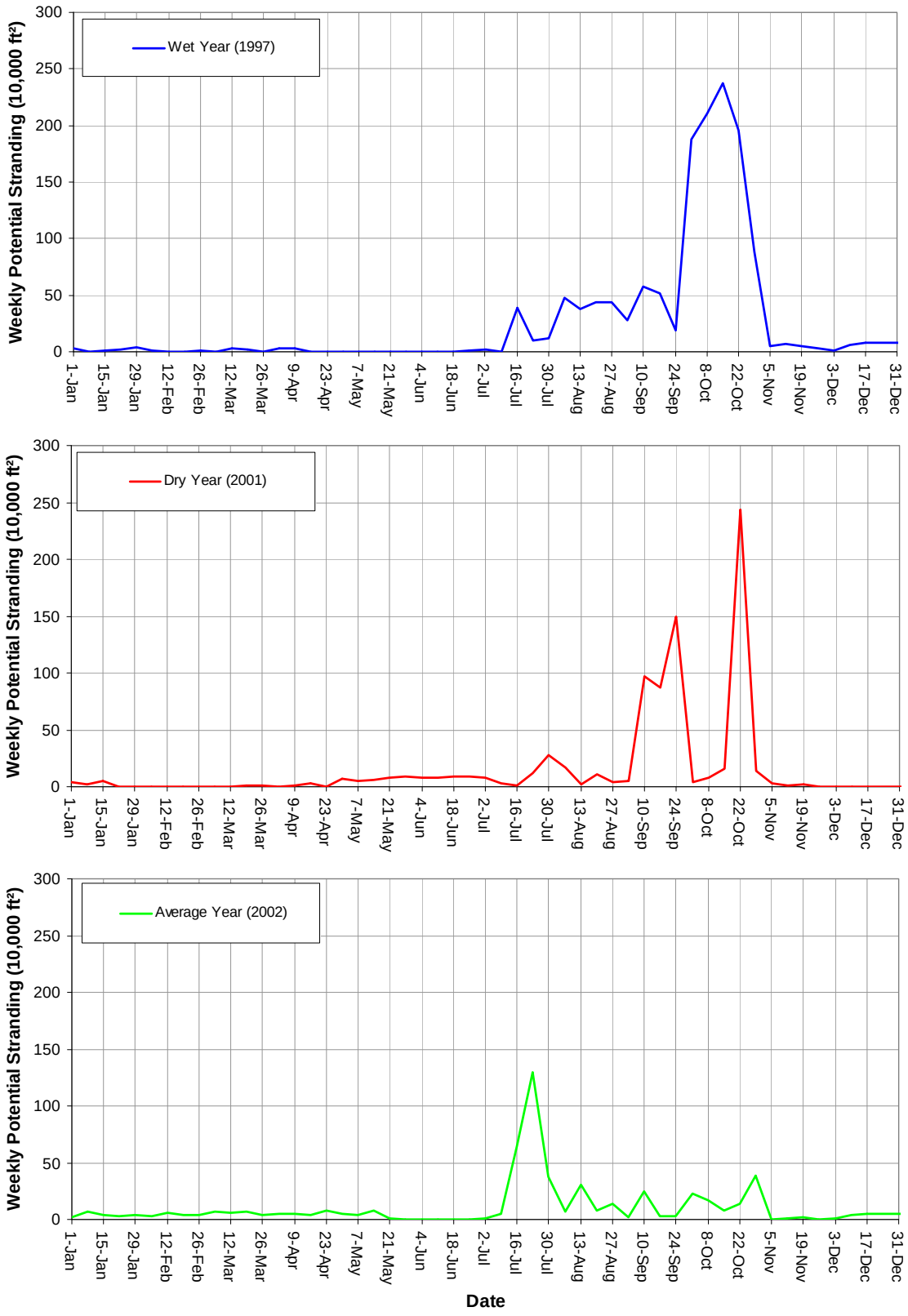



**Figure D-15.** Comparison of the weekly stranding index values for the additional stranding area in the Canyon Reach for the wet (1997), dry (2001), and average year (2002).

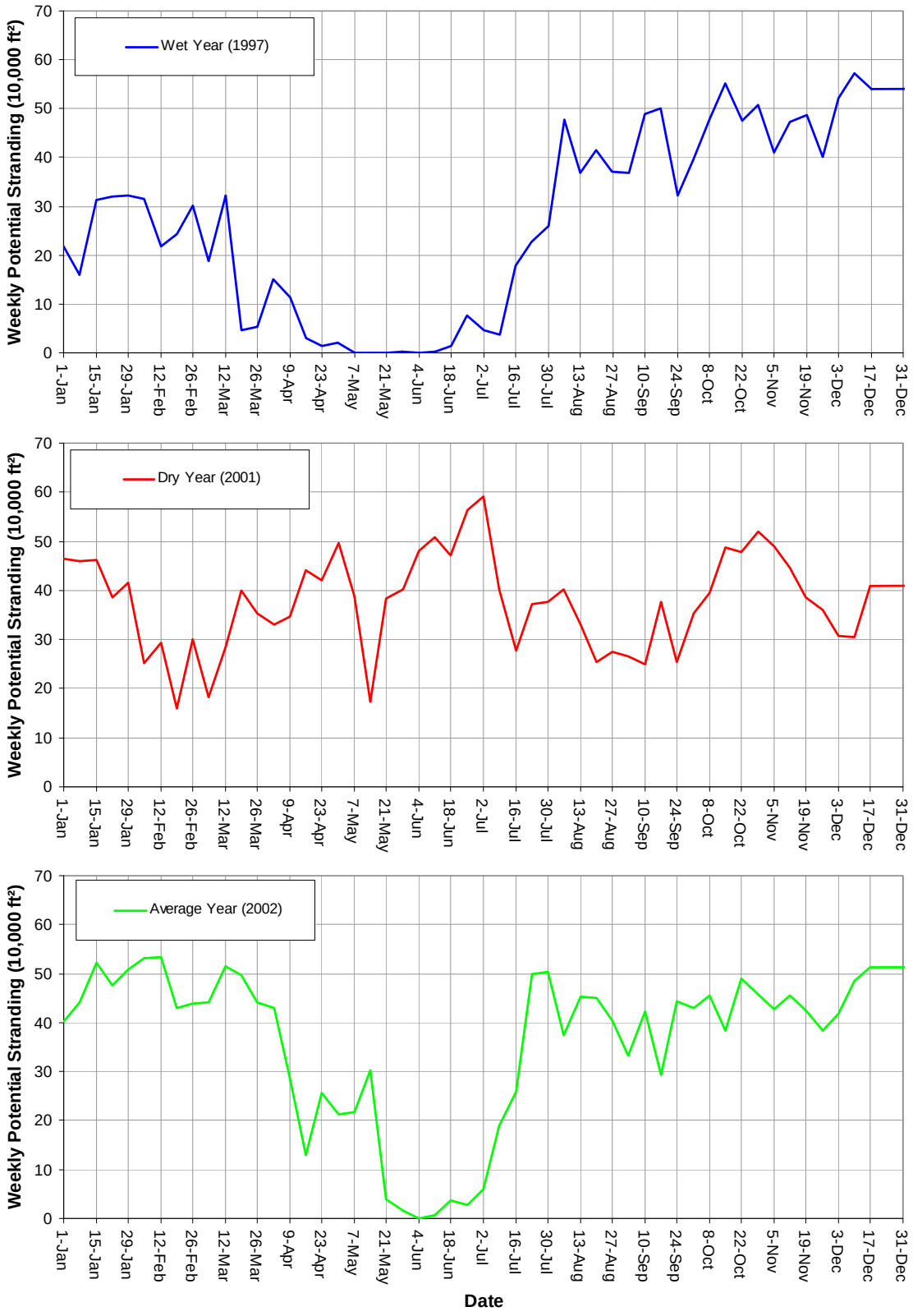



**Figure D-16.** Comparison of Sullivan Creek Region weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

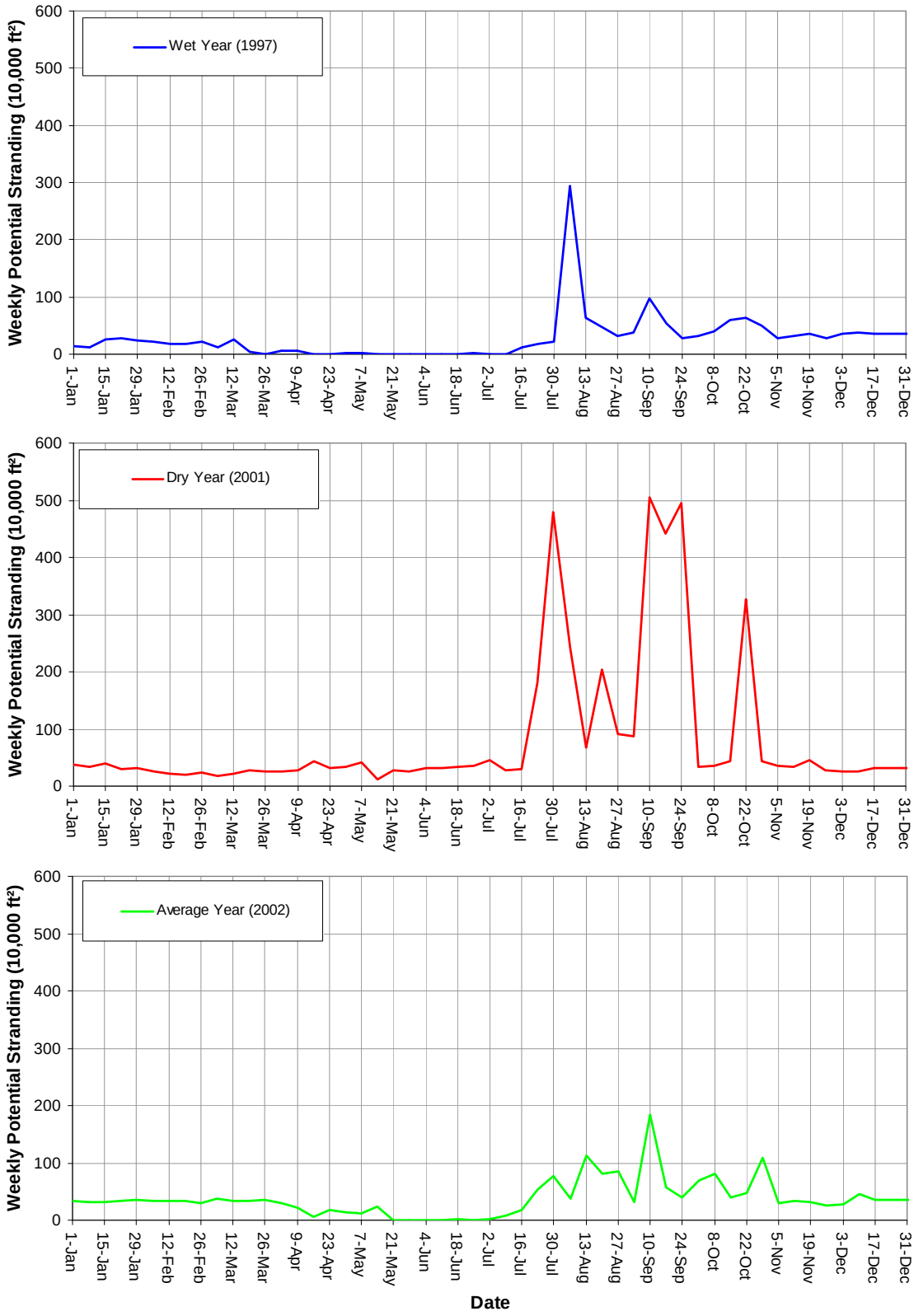



**Figure D-17.** Comparison of Region 7 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

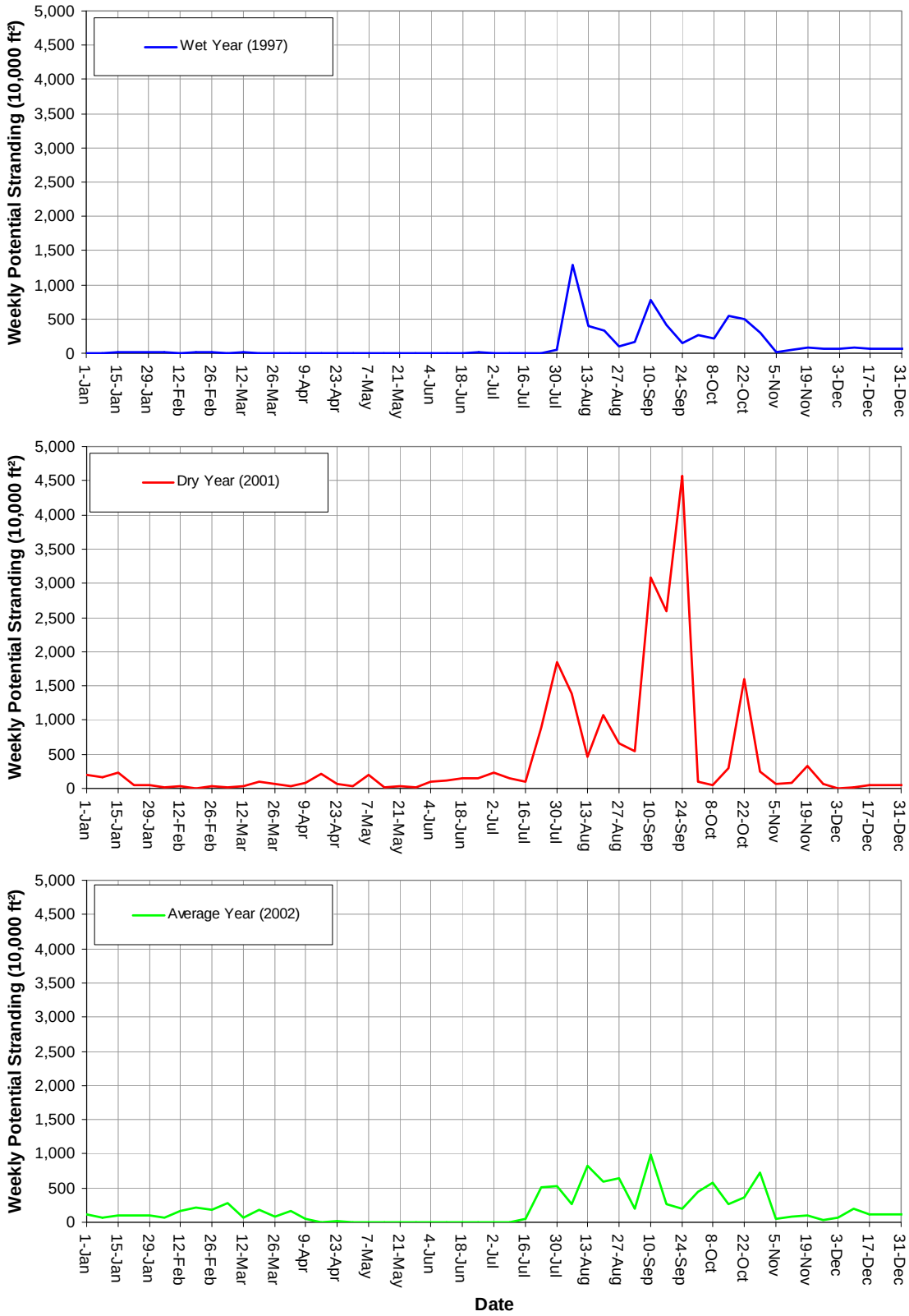



**Figure D-18.** Comparison of Region 8 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

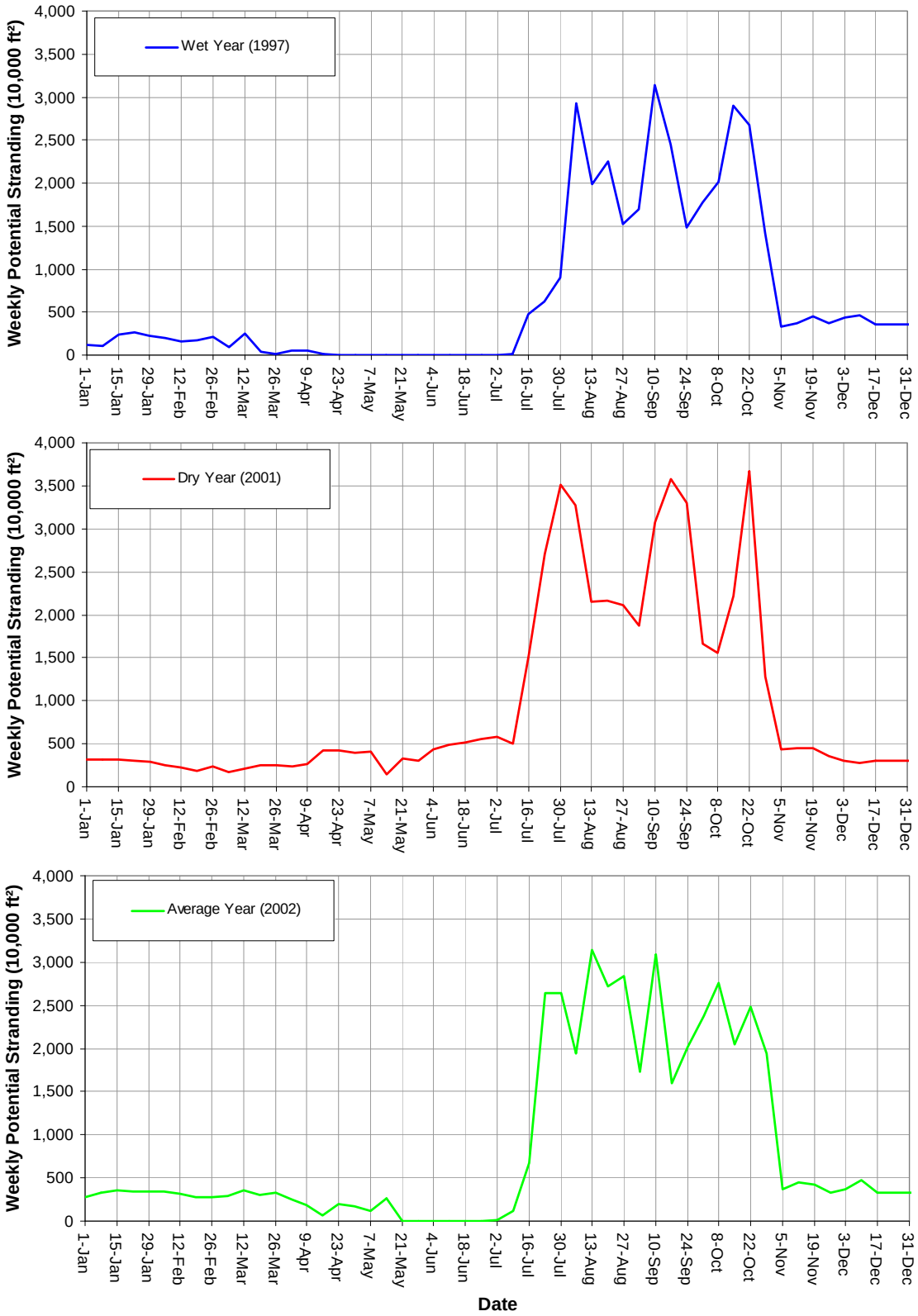



**Figure D-19.** Comparison of Region 9 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

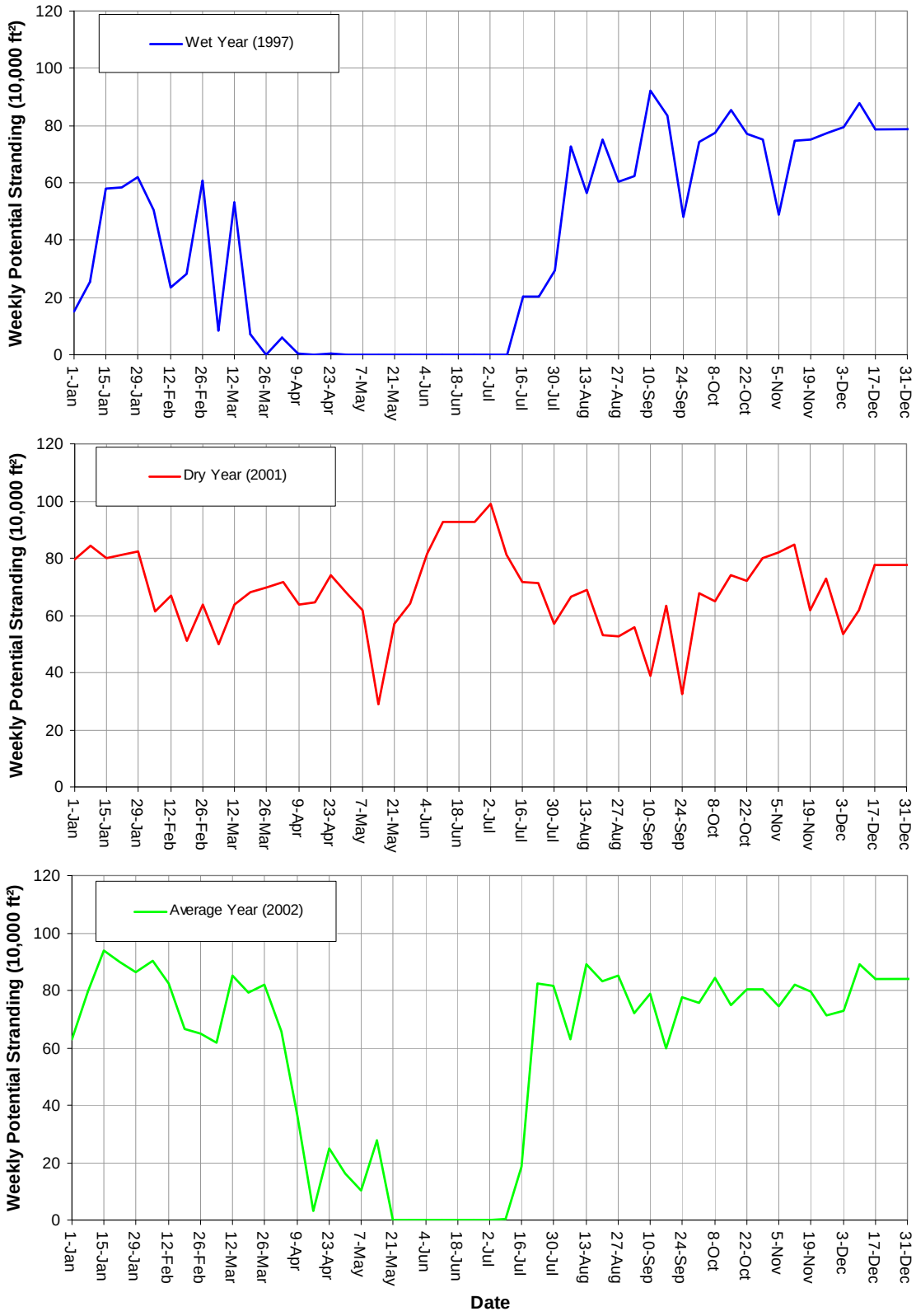



**Figure D-20.** Comparison of Region 10 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

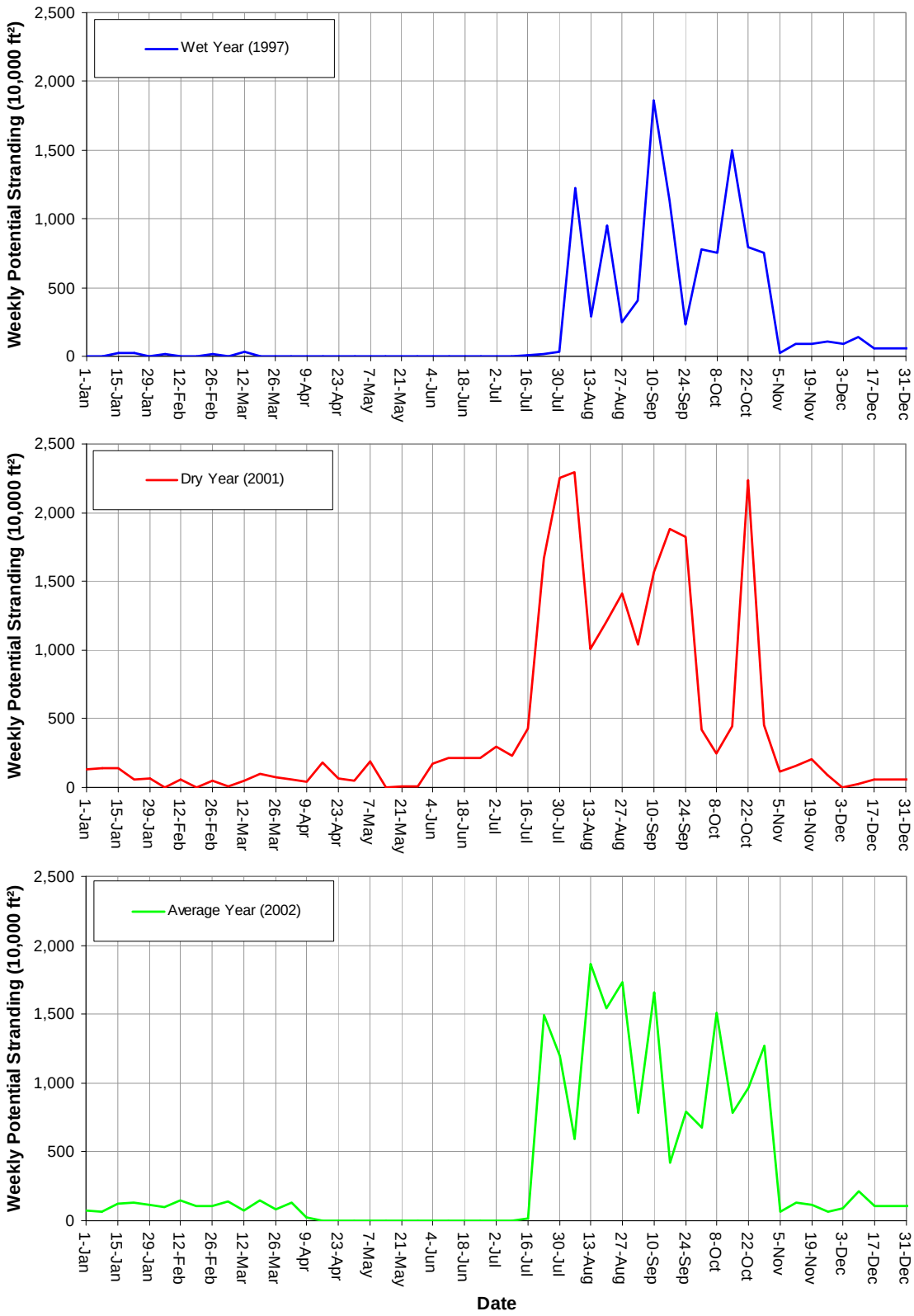



**Figure D-21.** Comparison of Region 11 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

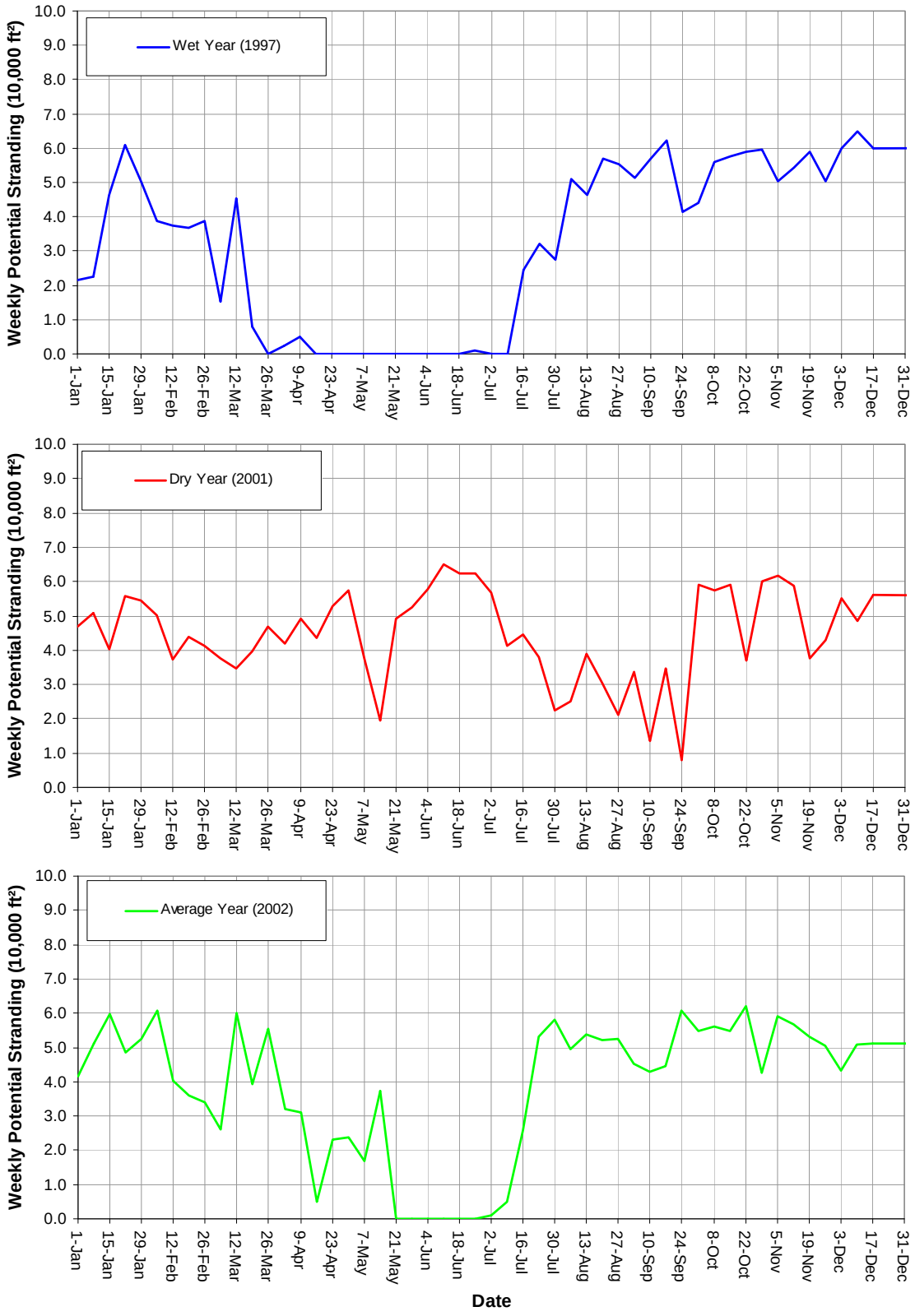



**Figure D-22.** Comparison of Region 12 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

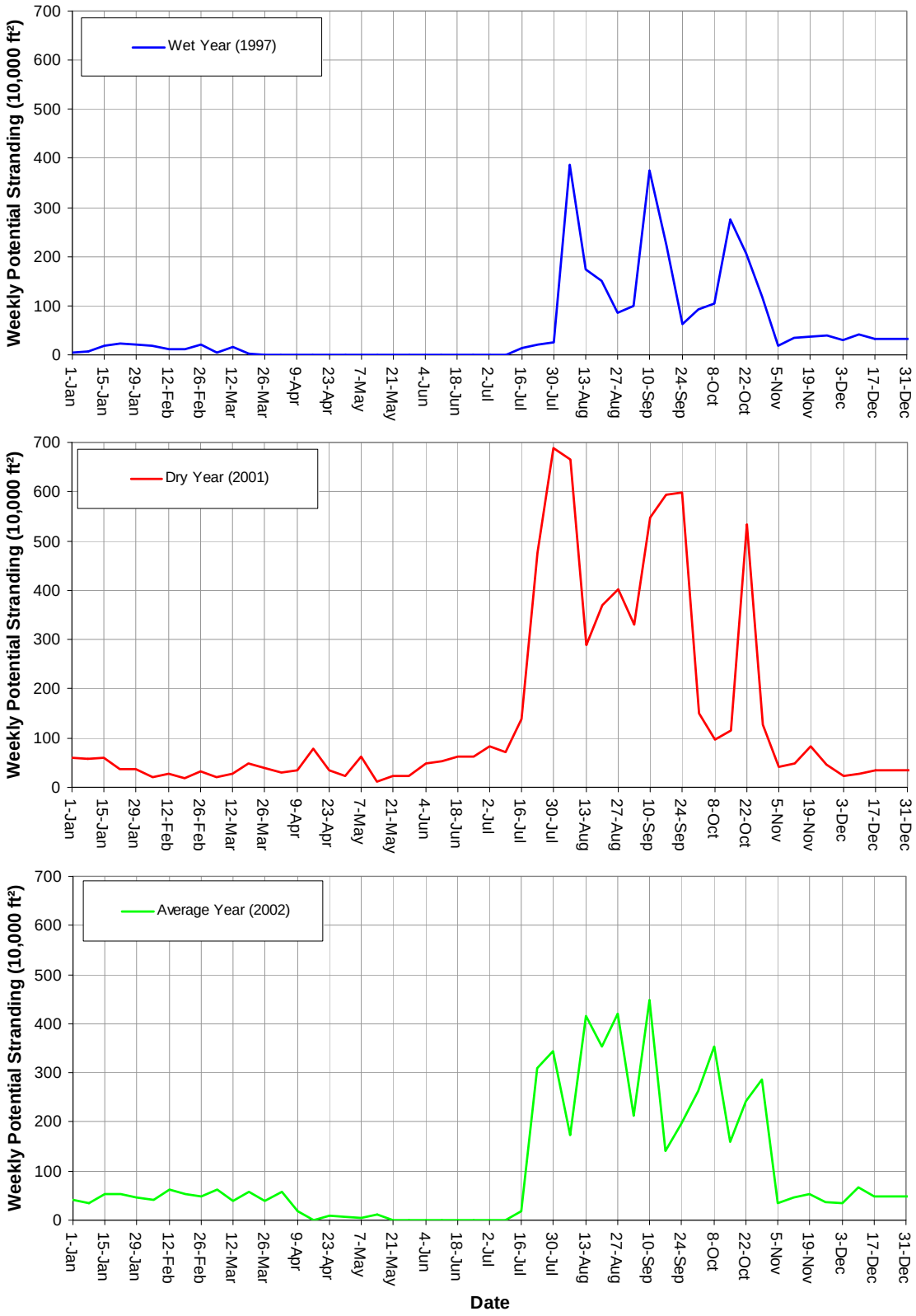



**Figure D-23.** Comparison of Region 13 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

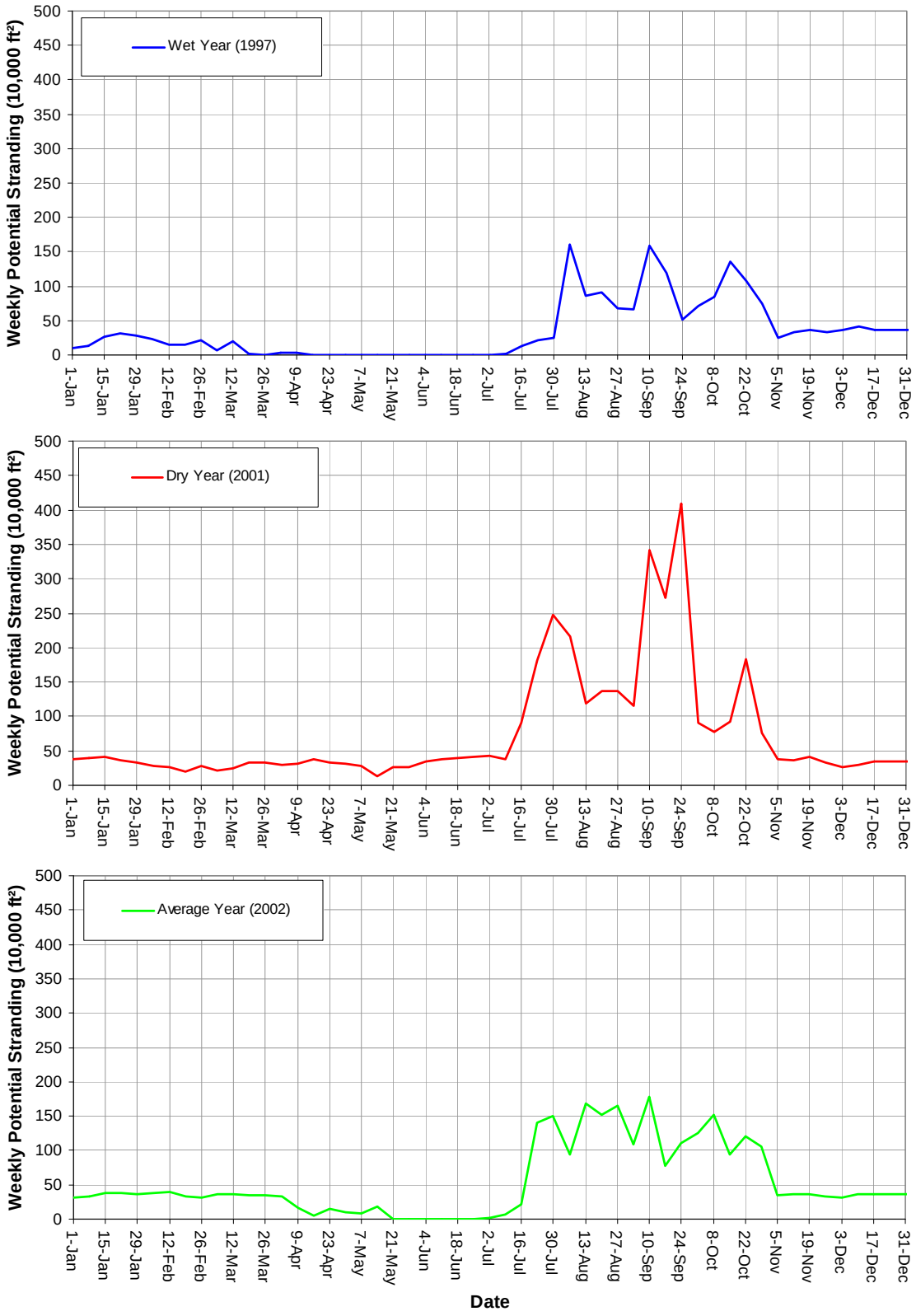



**Figure D-24.** Comparison of Region 14 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

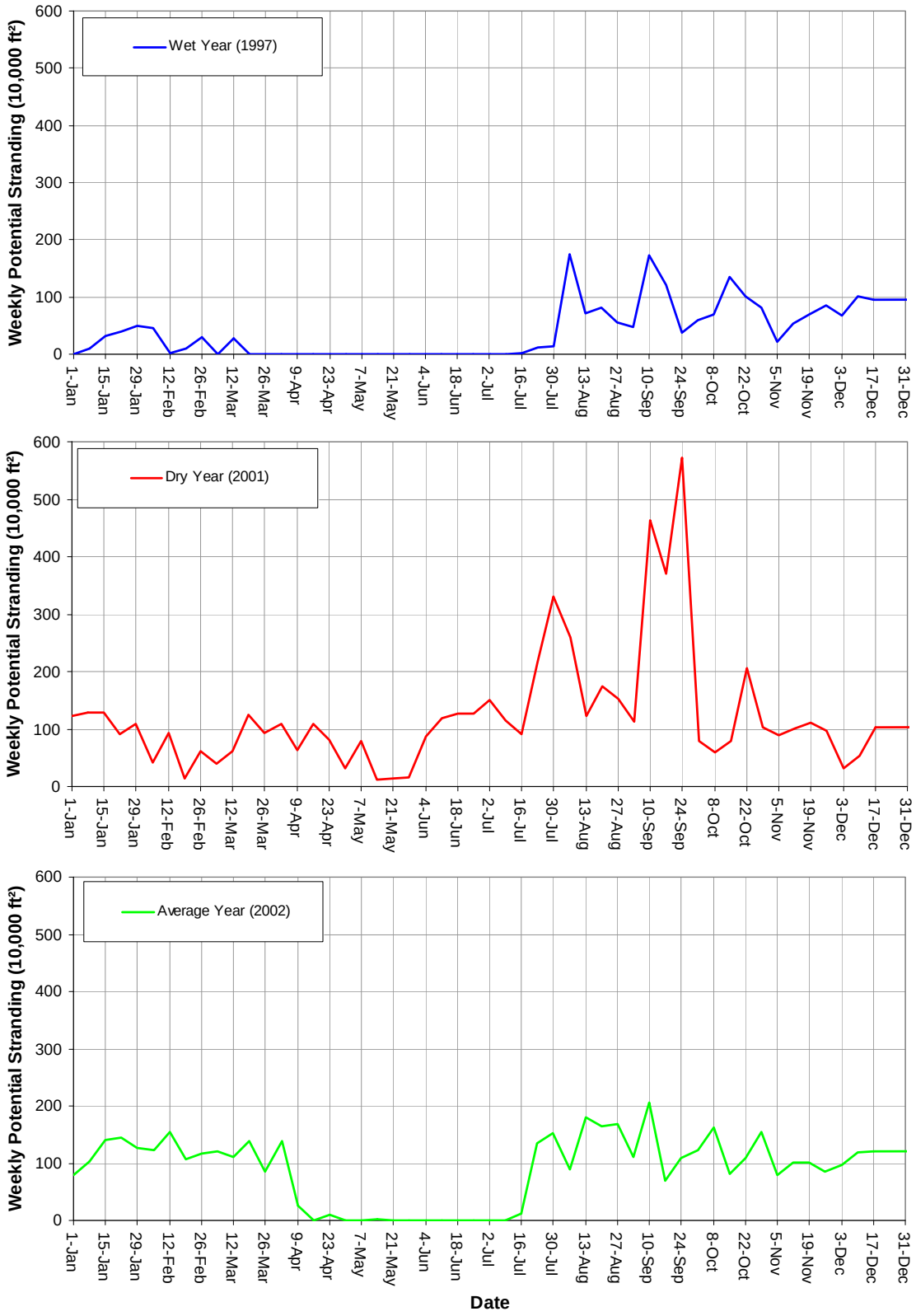



**Figure D-25.** Comparison of Region 15 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

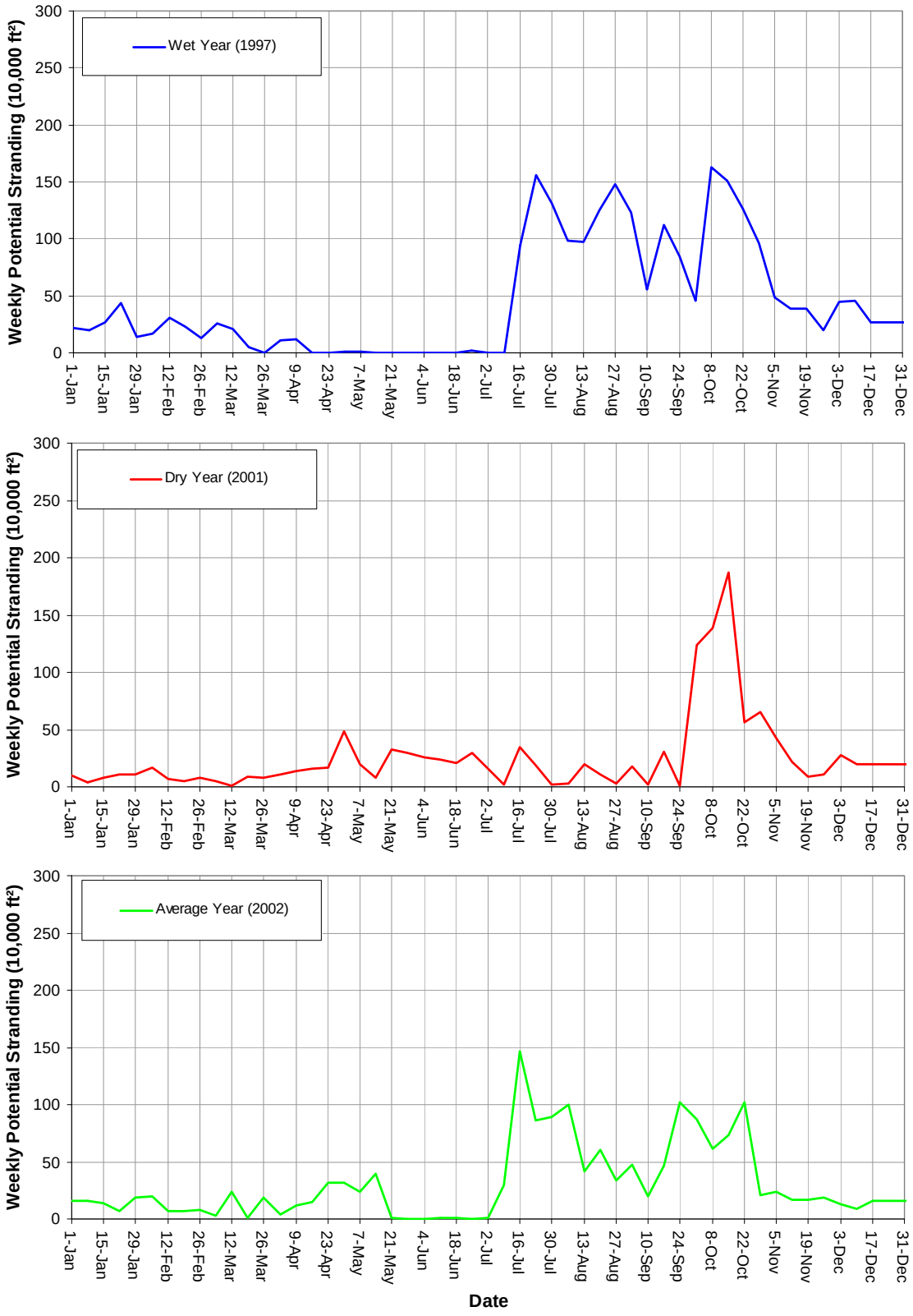



**Figure D-26.** Comparison of Region 16 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

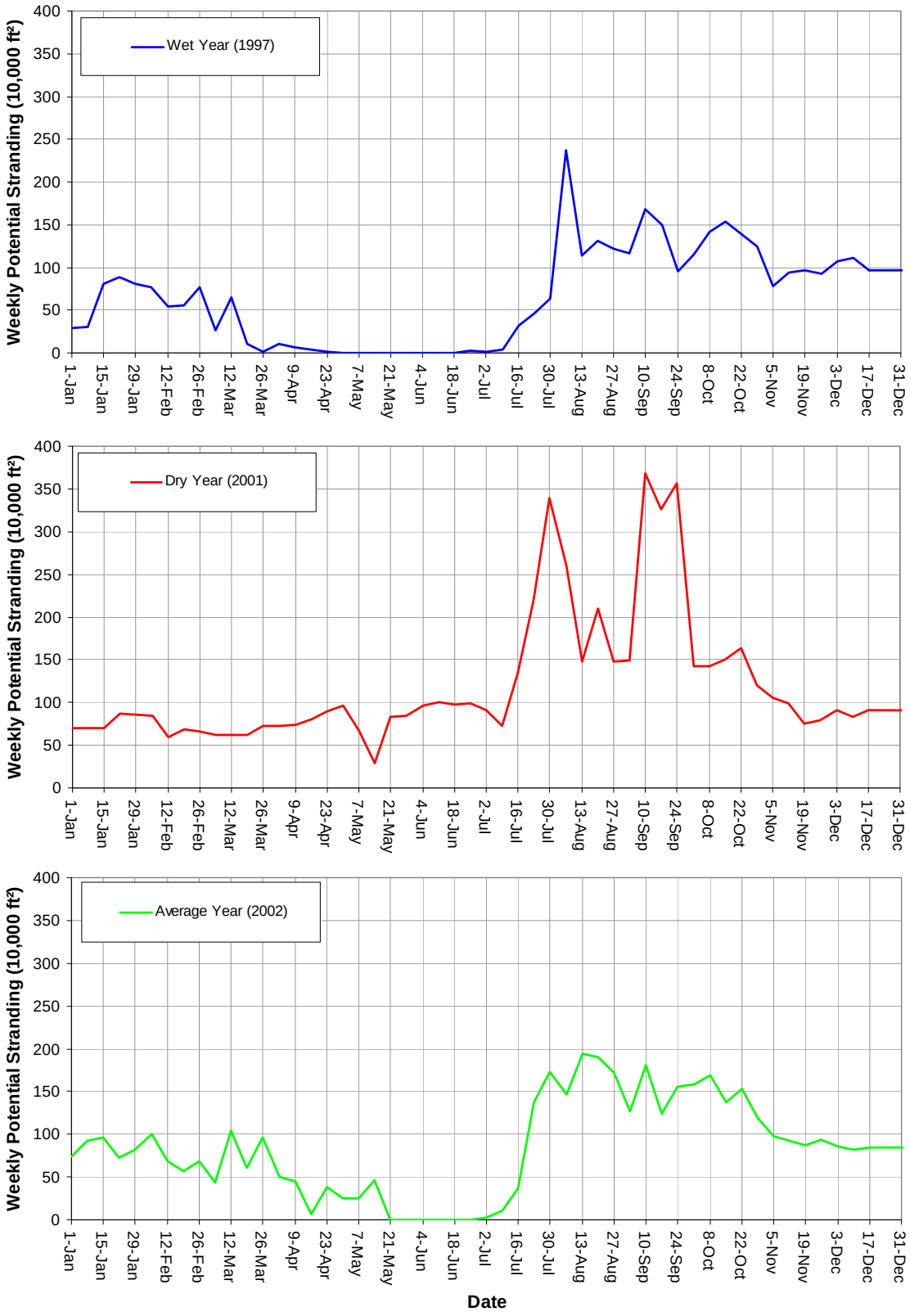



**Figure D-27.** Comparison of Region 17 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

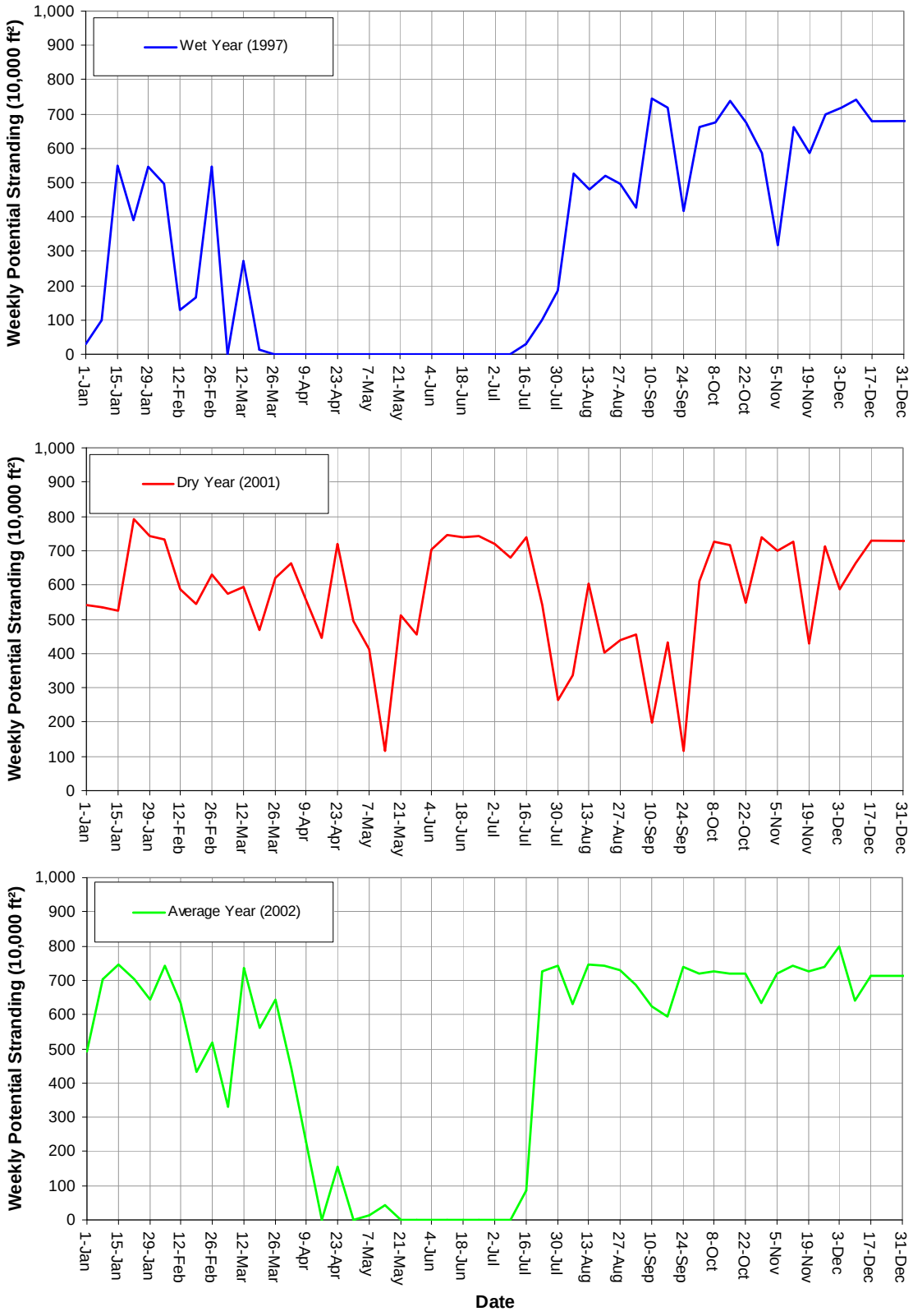



**Figure D-28.** Comparison of high density stranding area within Region 17 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

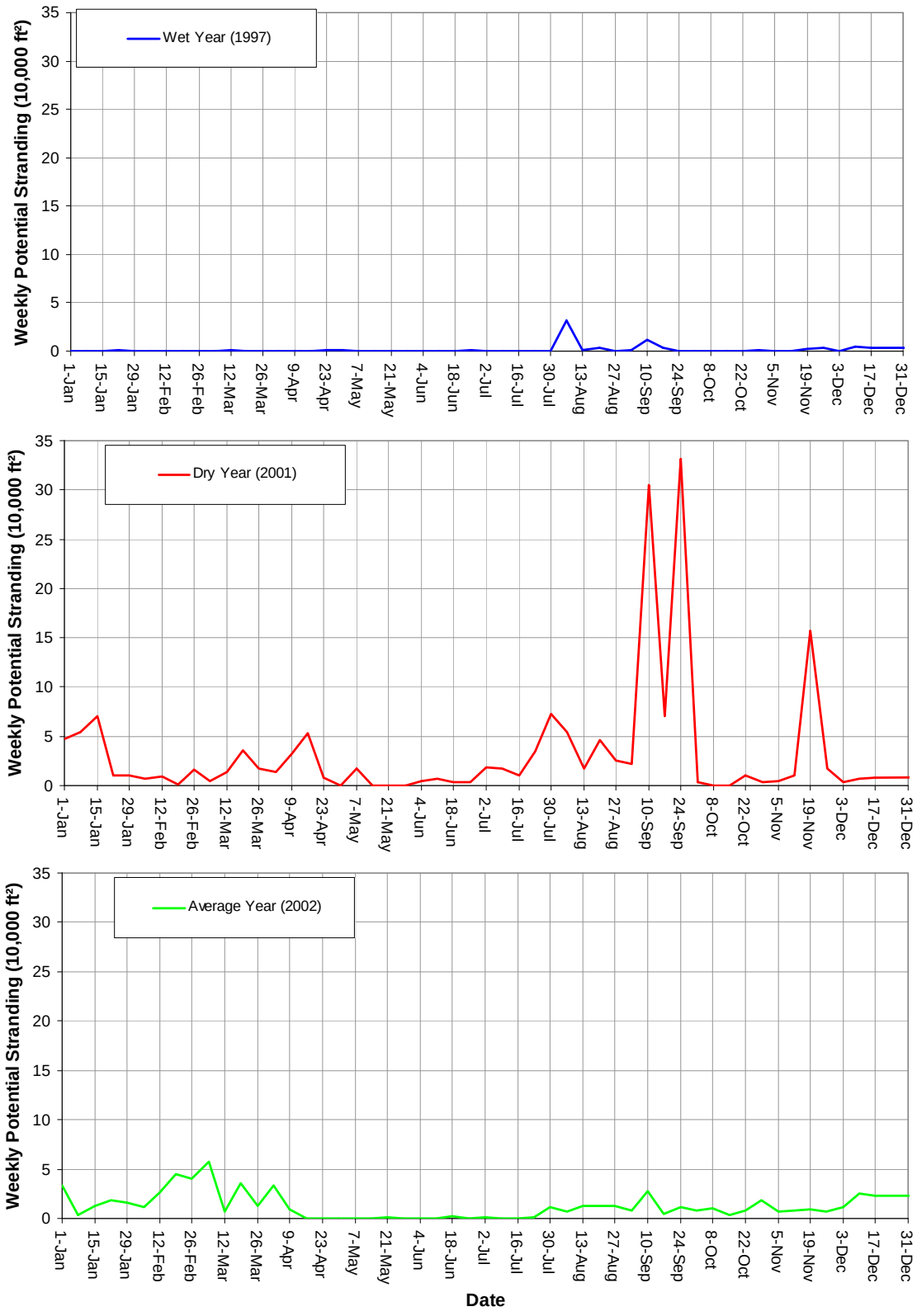



**Figure D-29.** Comparison of Region 18 weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

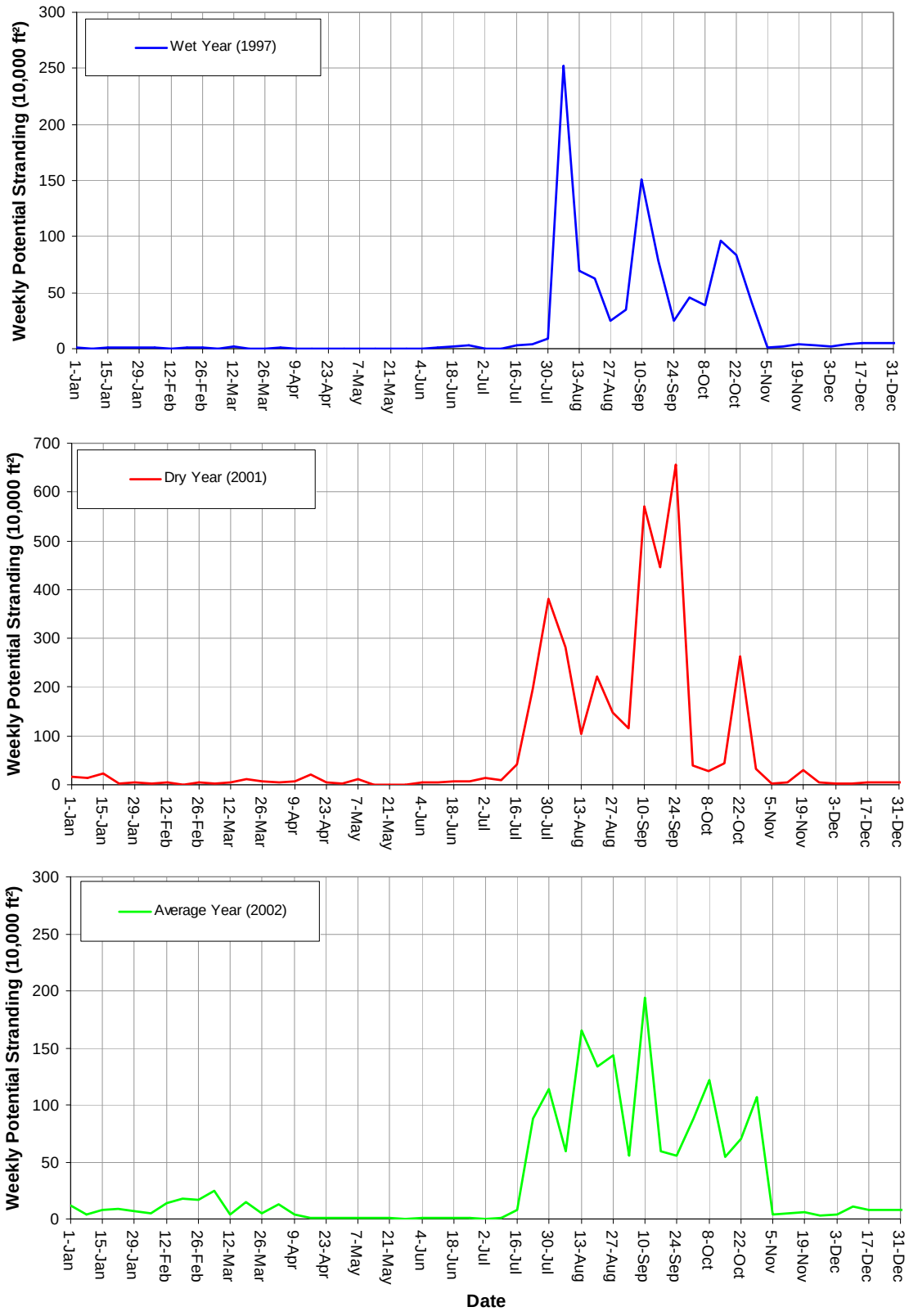



**Figure D-30.** Comparison of the weekly stranding index values for the additional stranding area in the Upper Reservoir Reach for the wet (1997), dry (2001), and average year (2002).

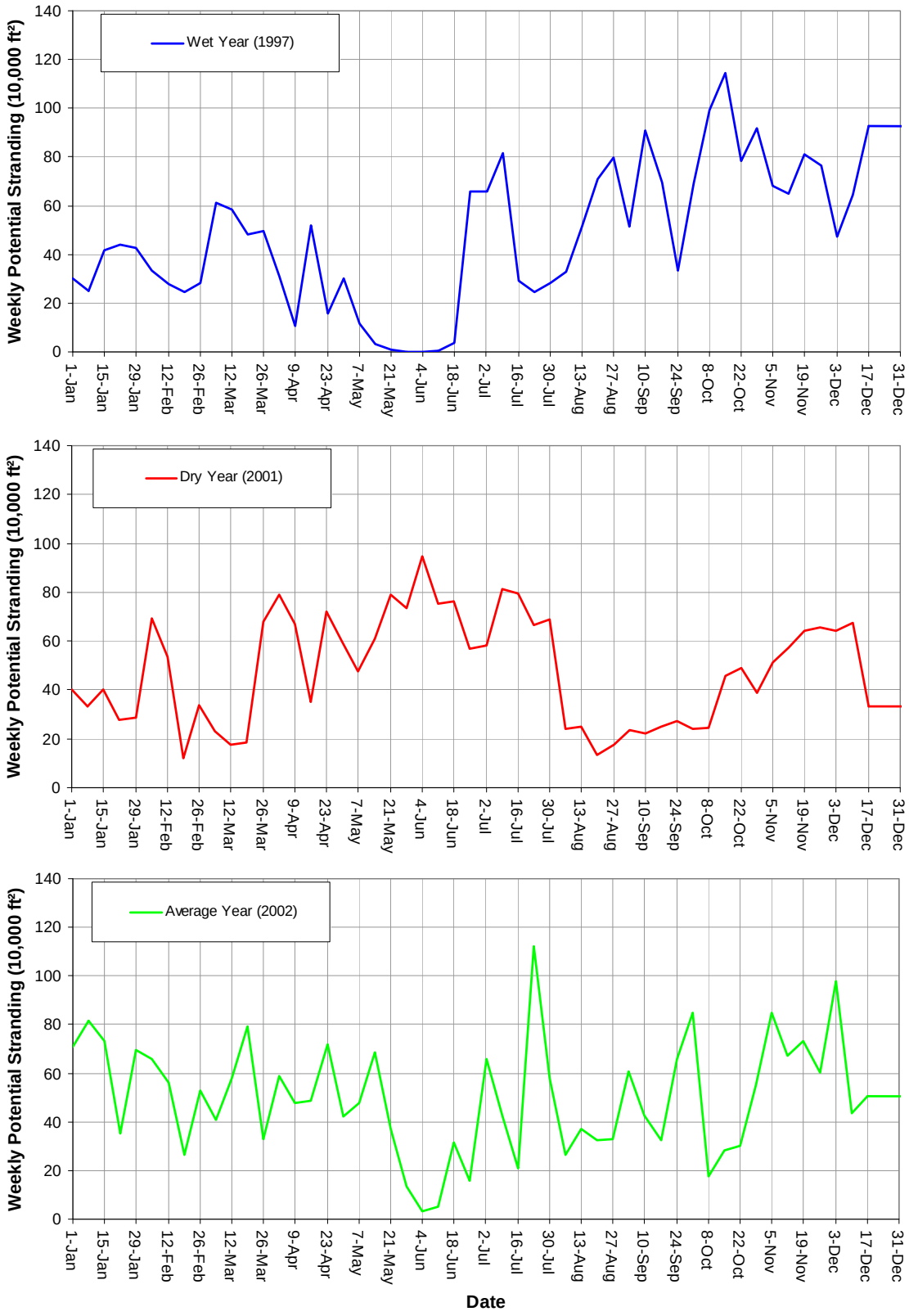



**Figure D-31.** Comparison of Tailrace Reach weekly stranding index values for the wet (1997), dry (2001), and average year (2002).

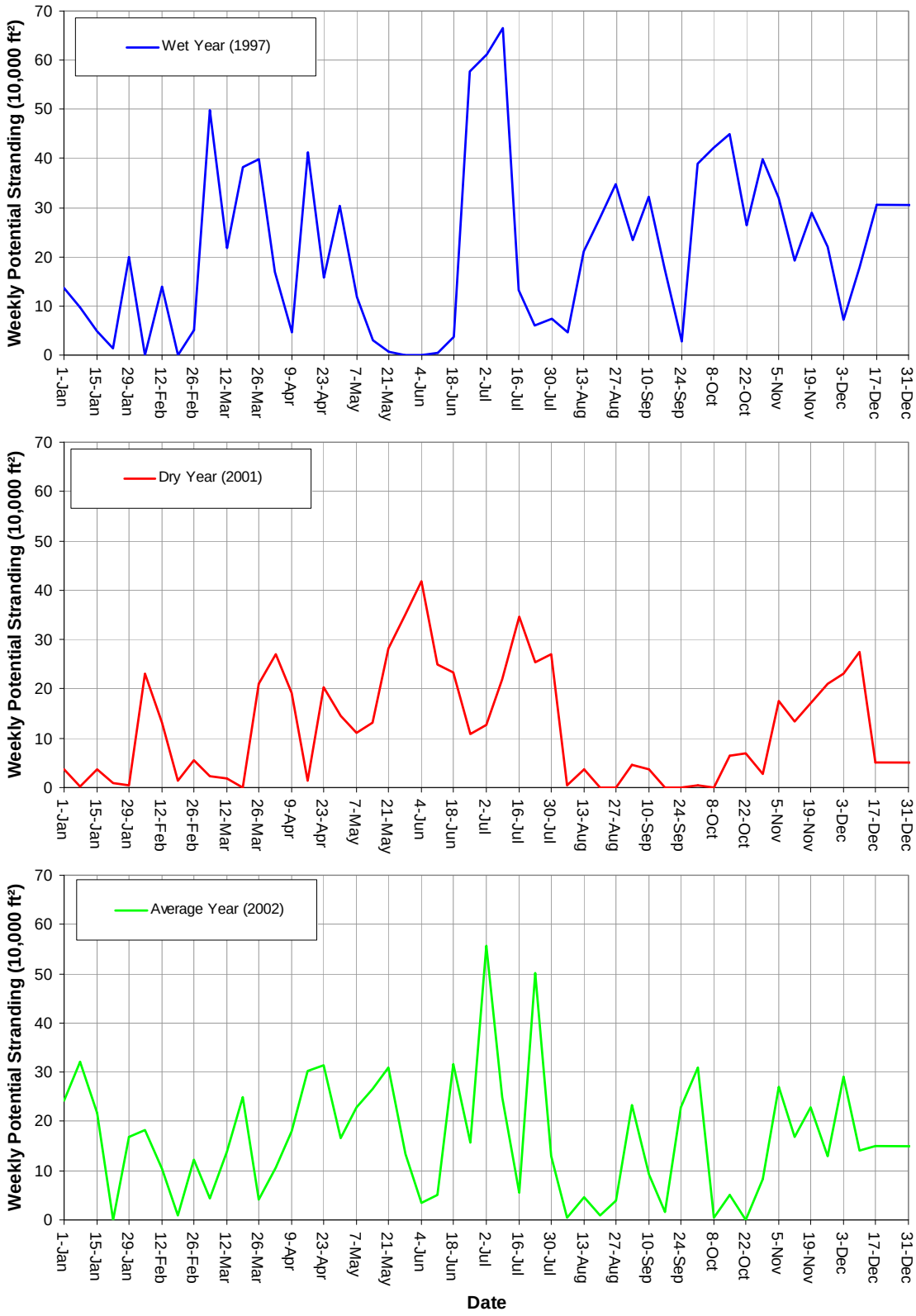



**Figure D-32.** Comparison of the weekly stranding index values for the additional stranding area in the Tailrace Reach for the wet (1997), dry (2001), and average year (2002).

# Attachment E: Trapping Index Model Results

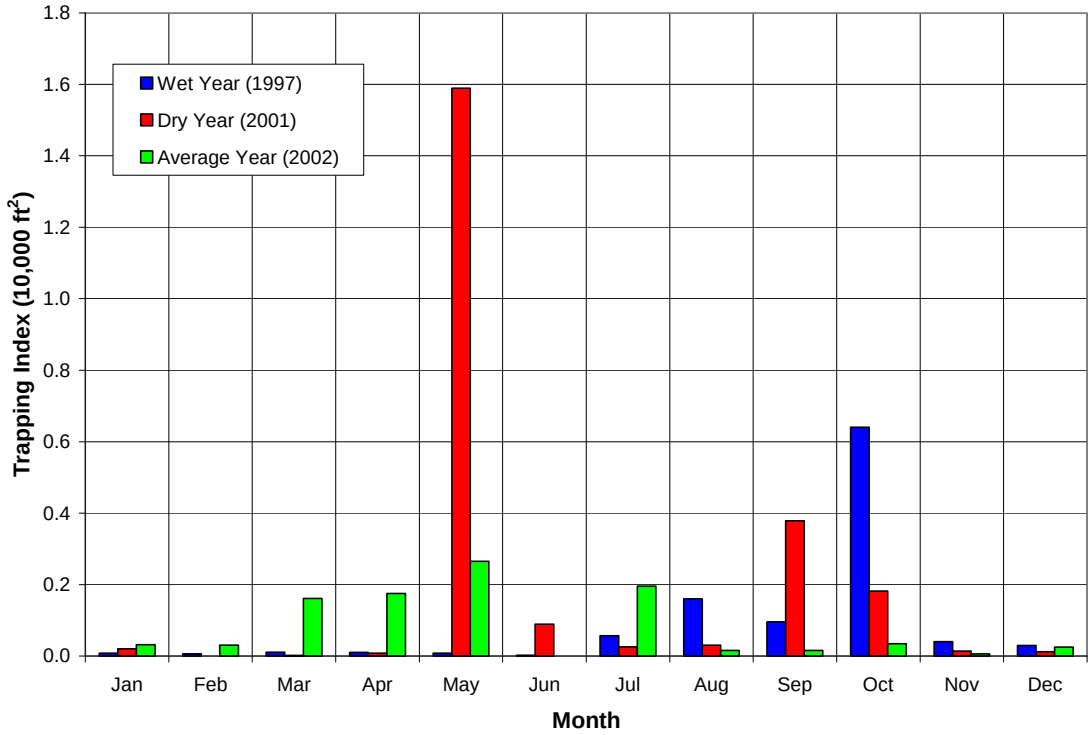



**Figure E-1.** Monthly total trapping index values for the Forebay Reach for the wet (1997), dry (2001), and average year (2002).

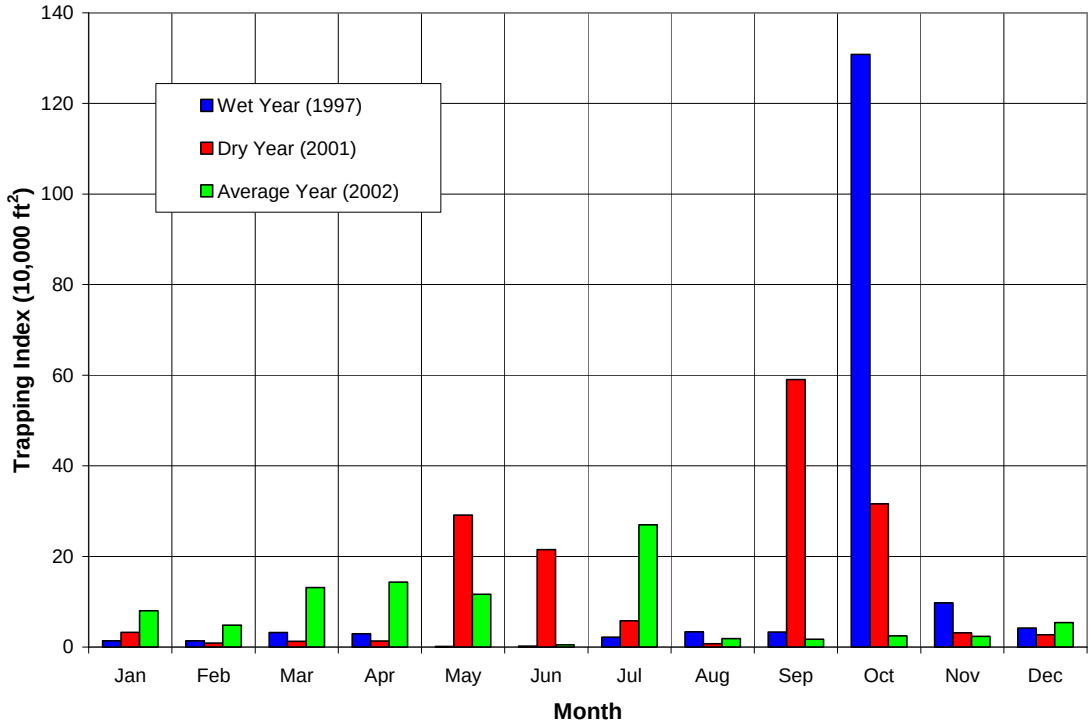
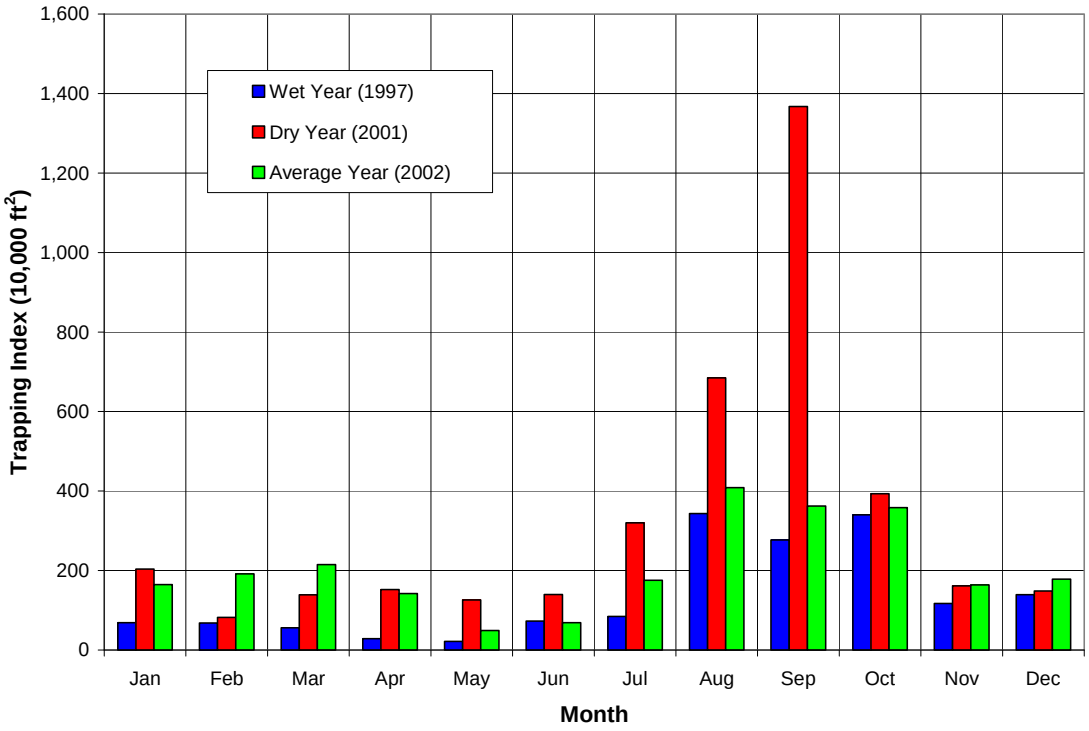



**Figure E-2.** Monthly total trapping index values for the Canyon Reach for the wet (1997), dry (2001), and average year (2002).

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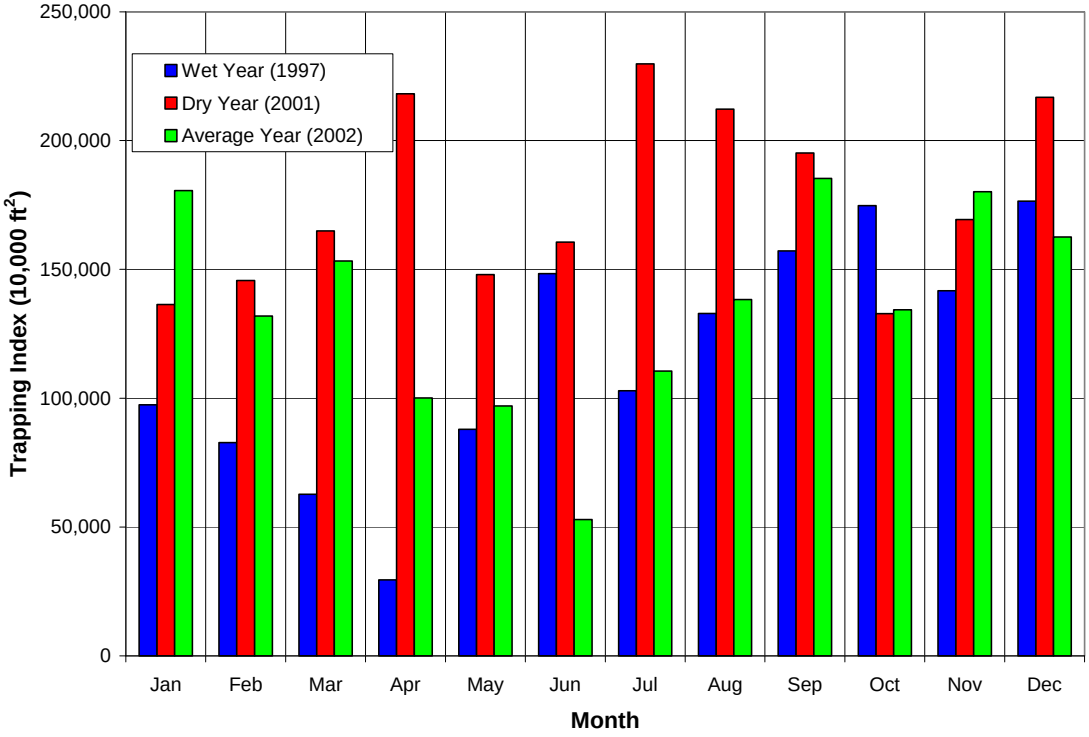


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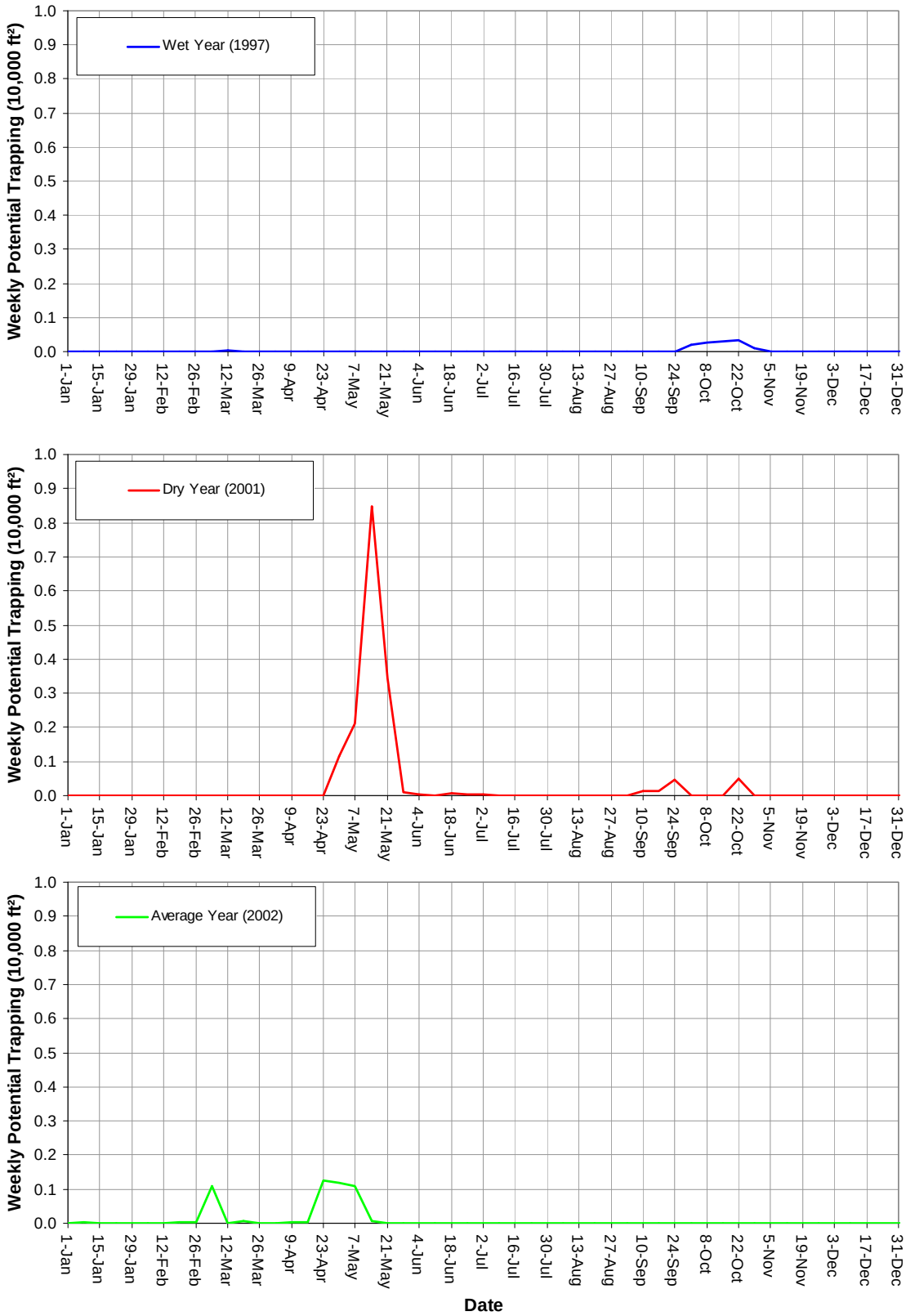


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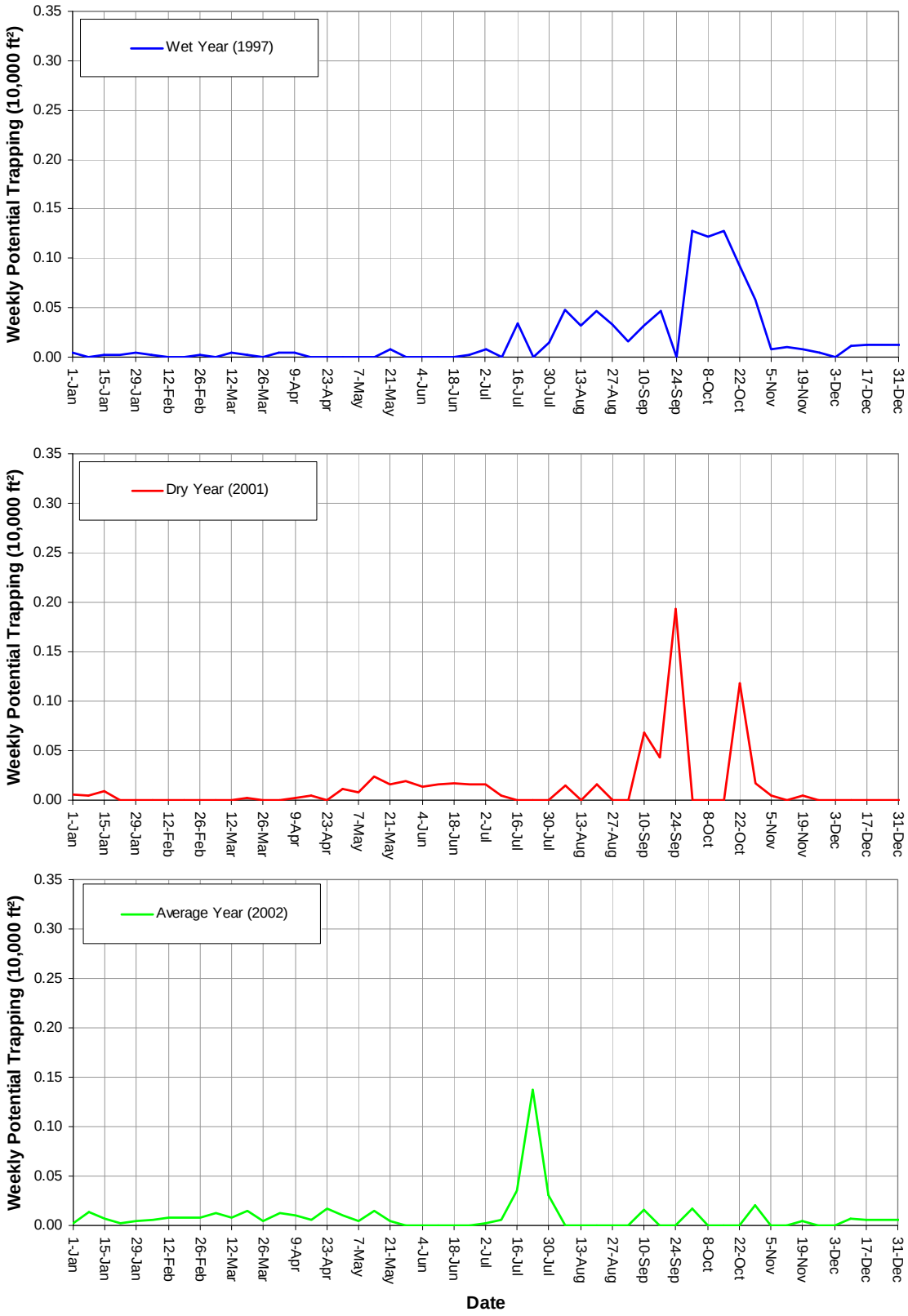


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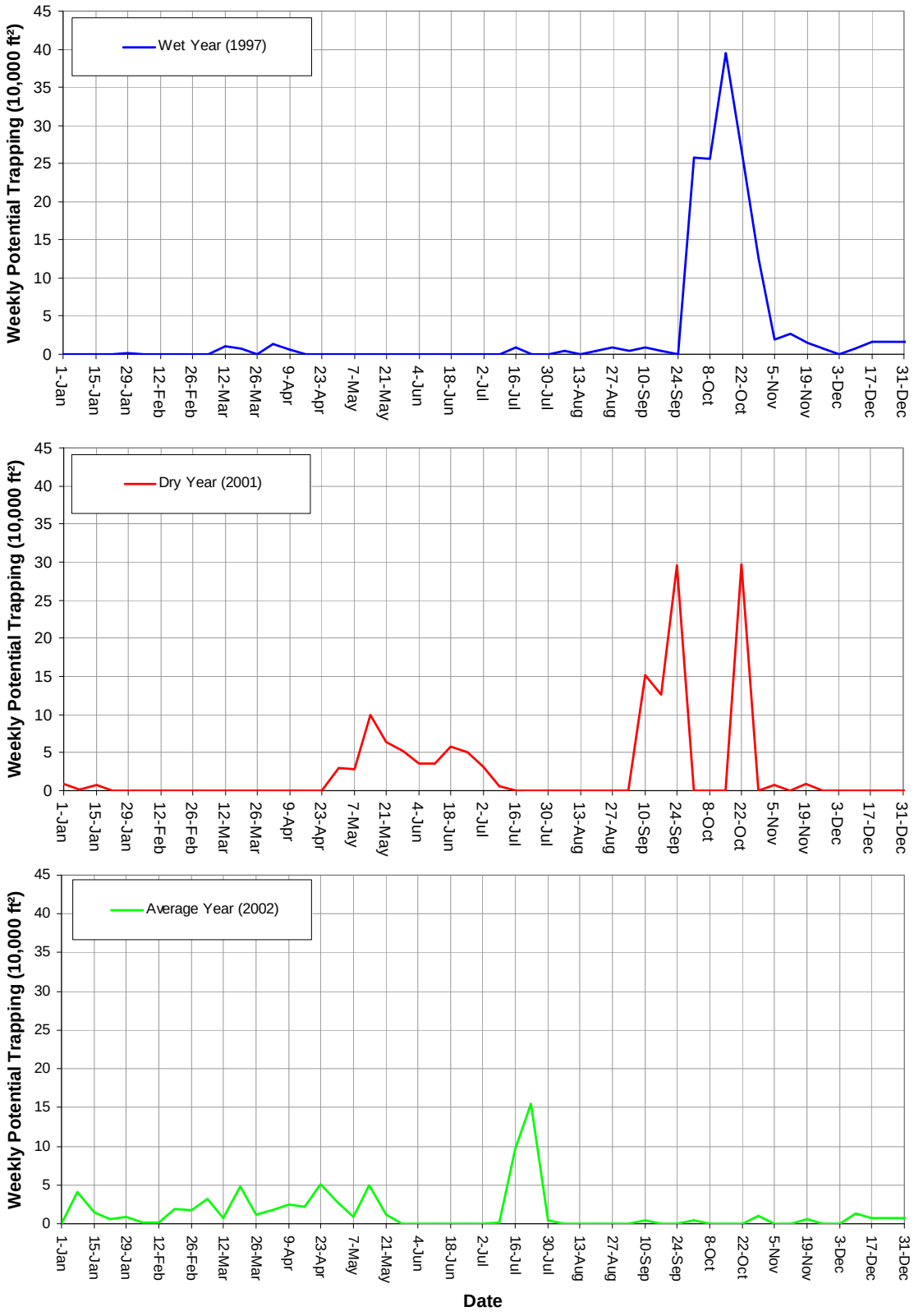


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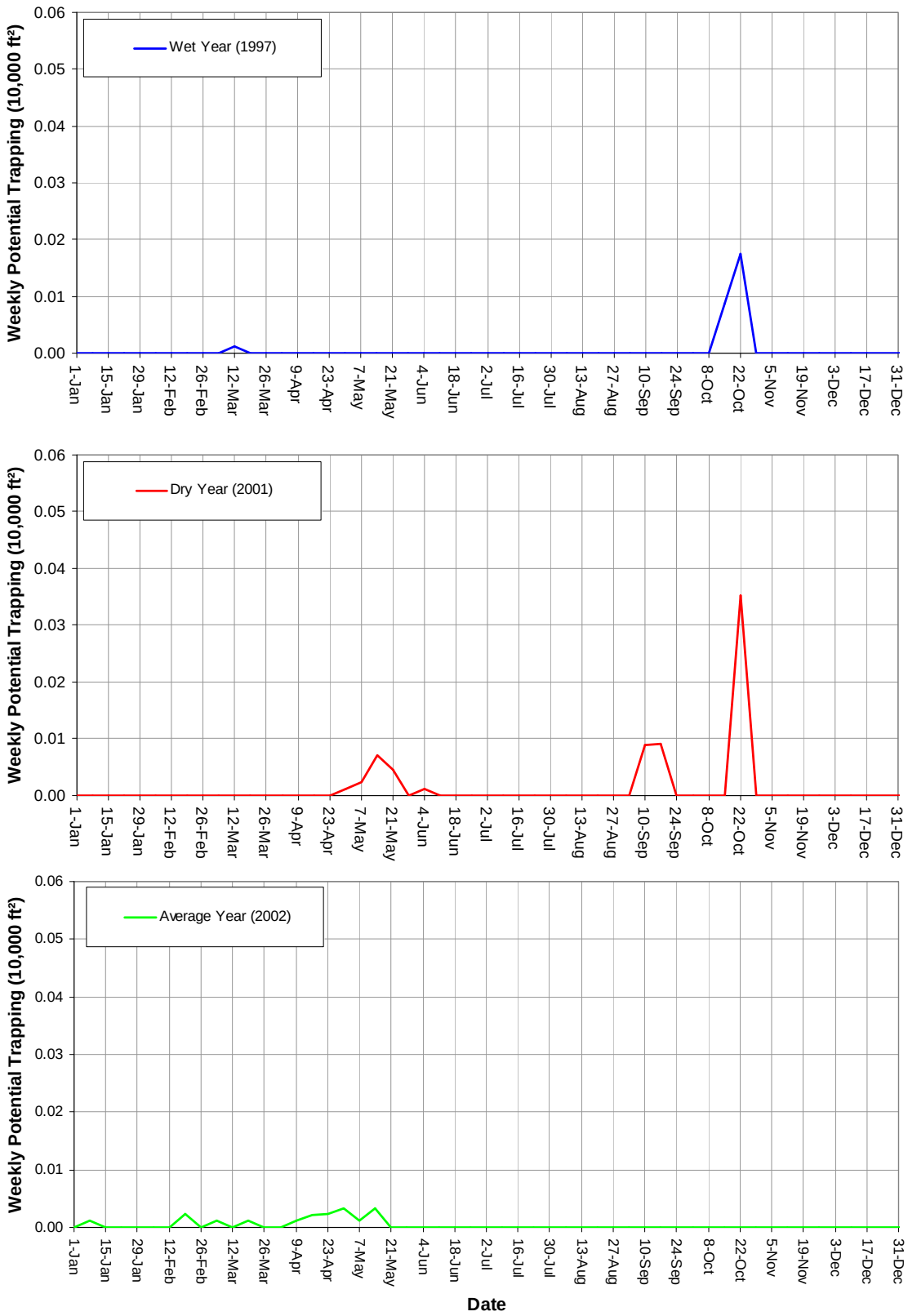
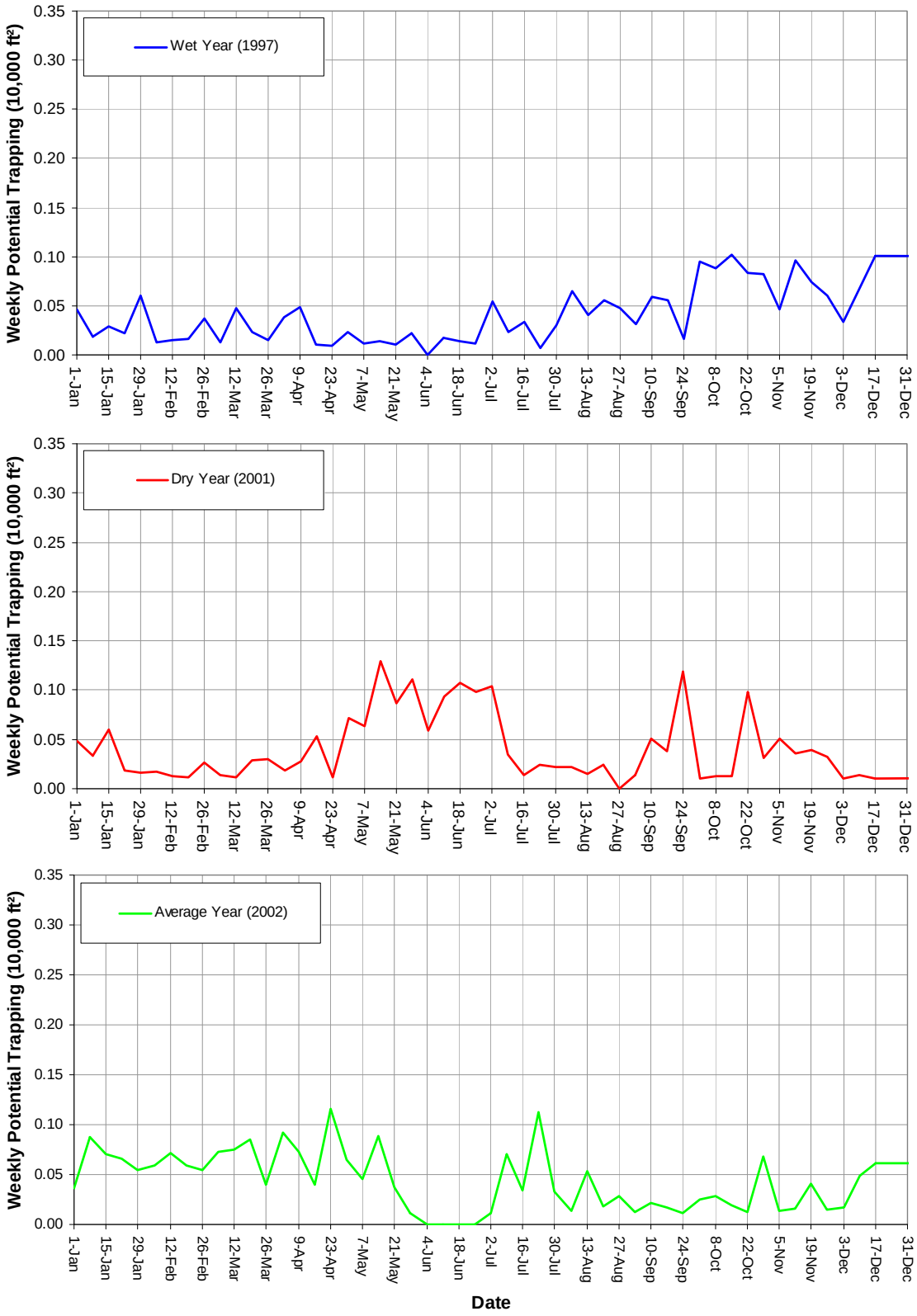



**Figure E-8.** Comparison of Region 3 weekly trapping index values for the wet (1997), dry (2001), and average year (2002).

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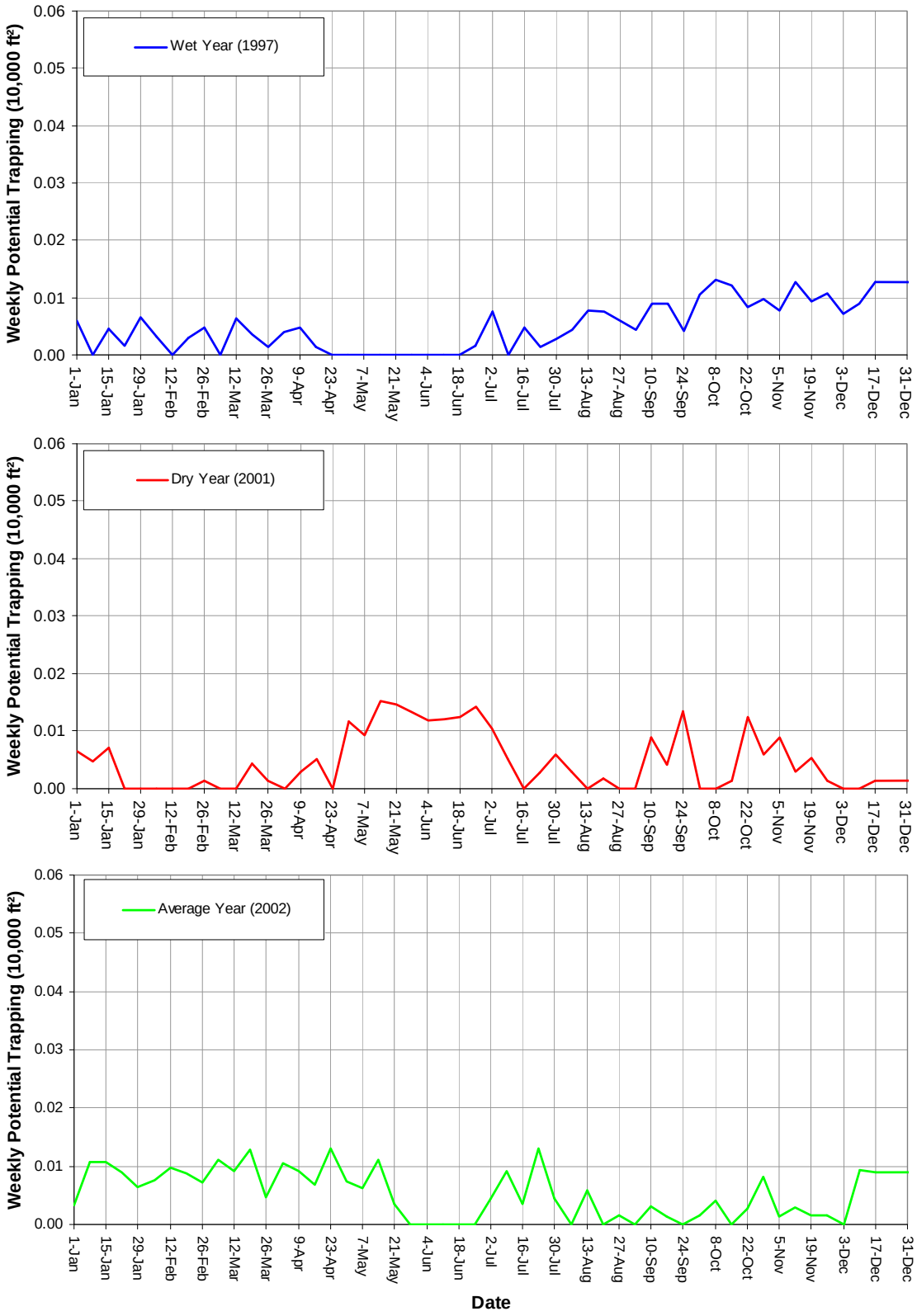


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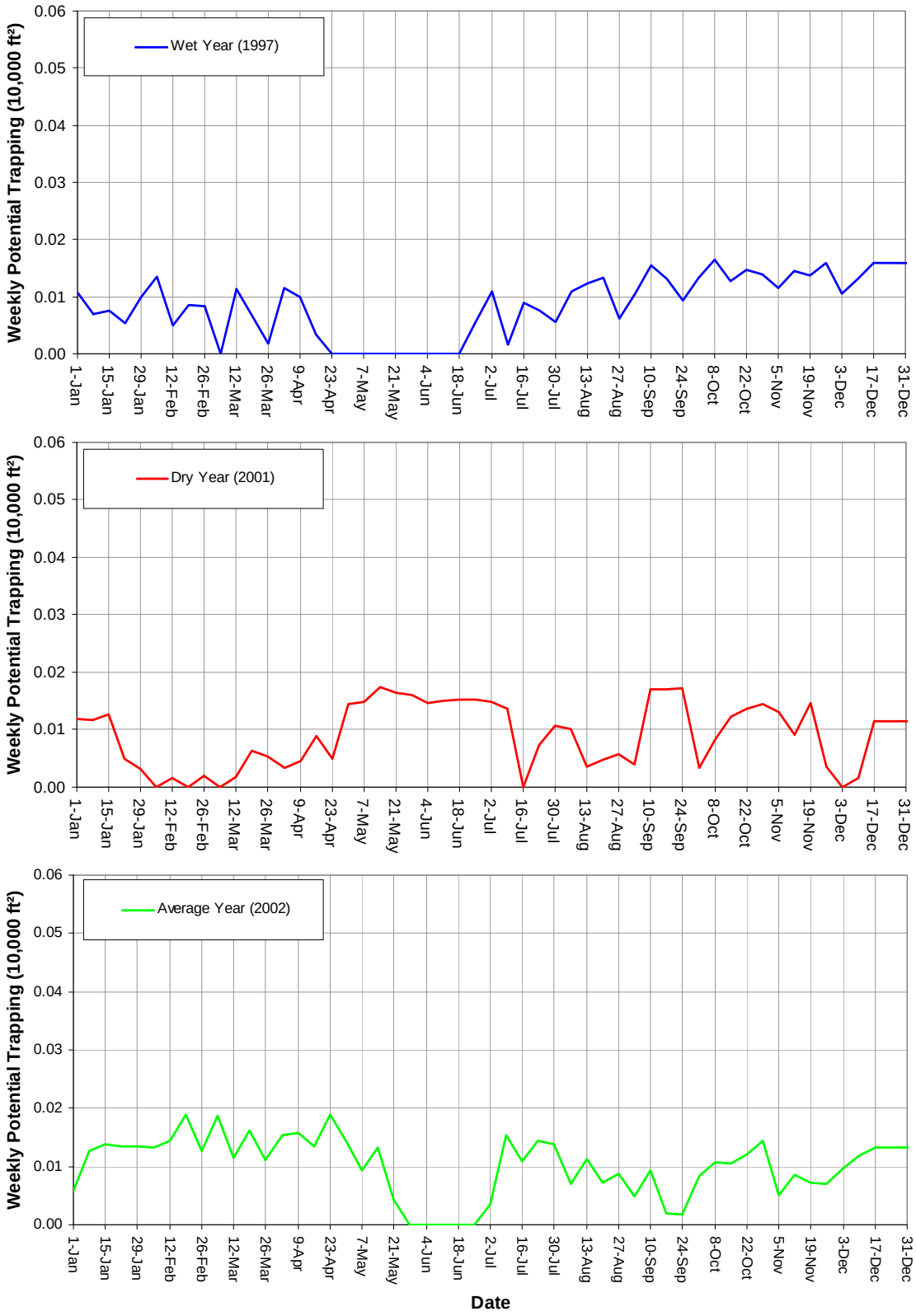


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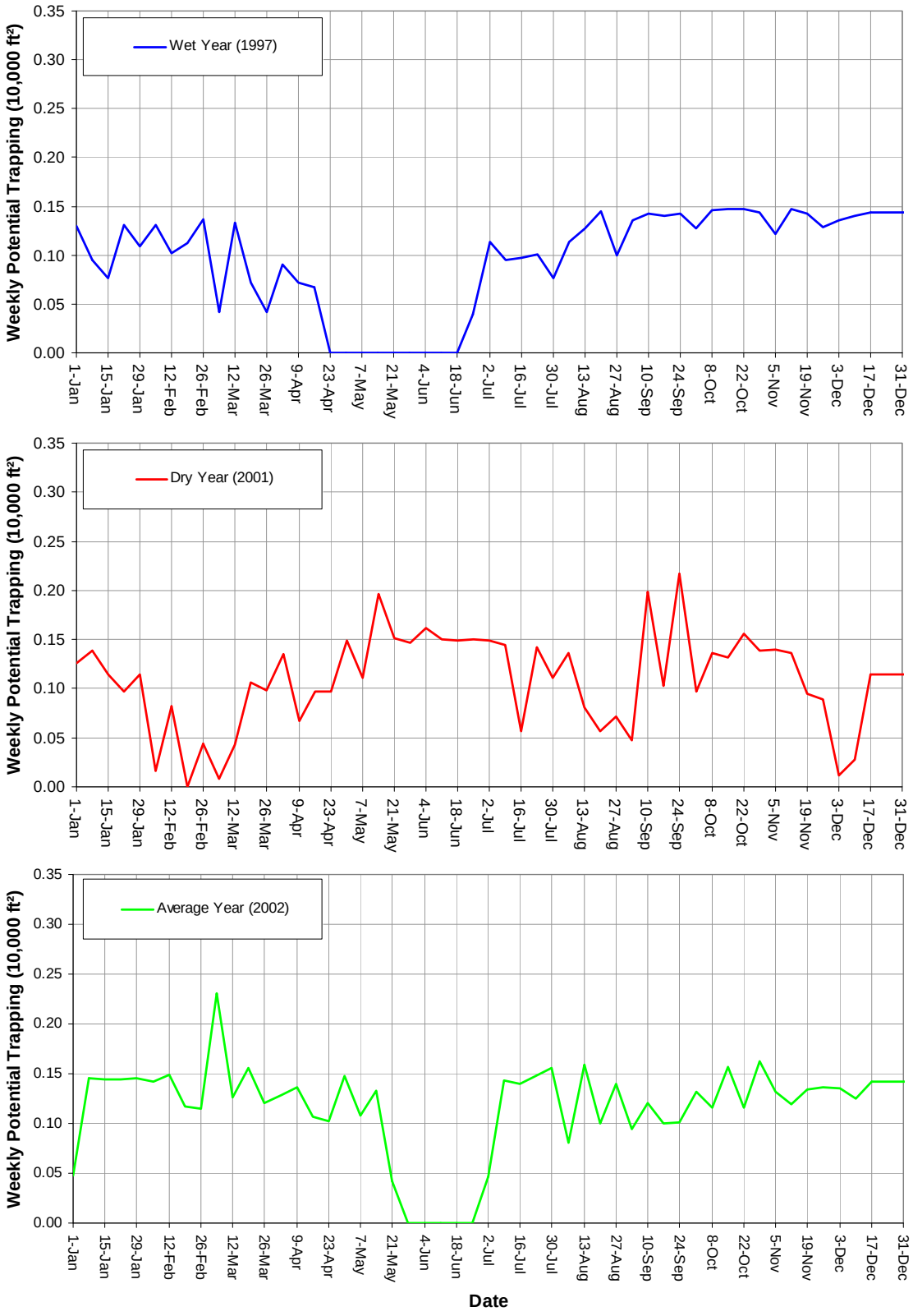


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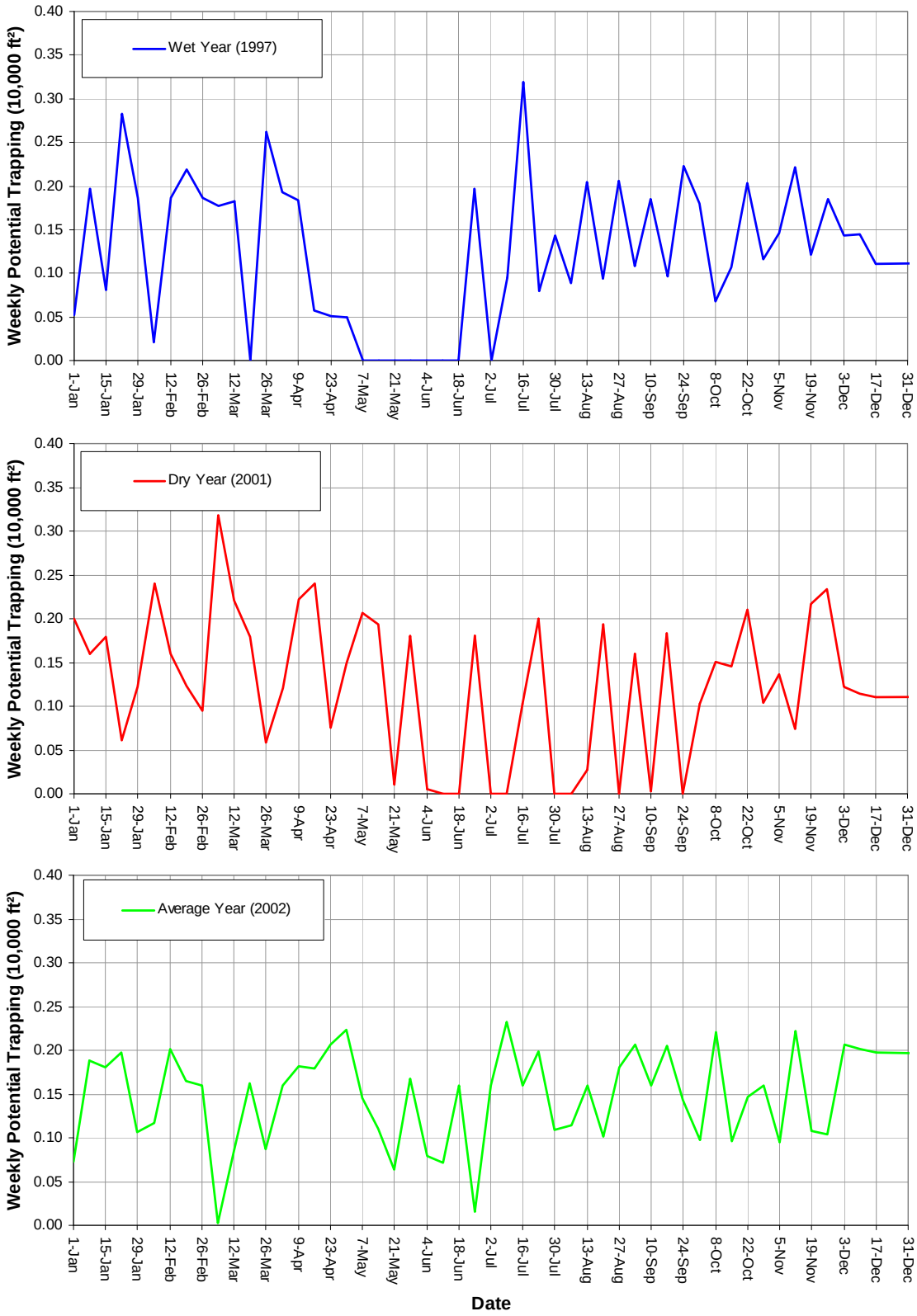


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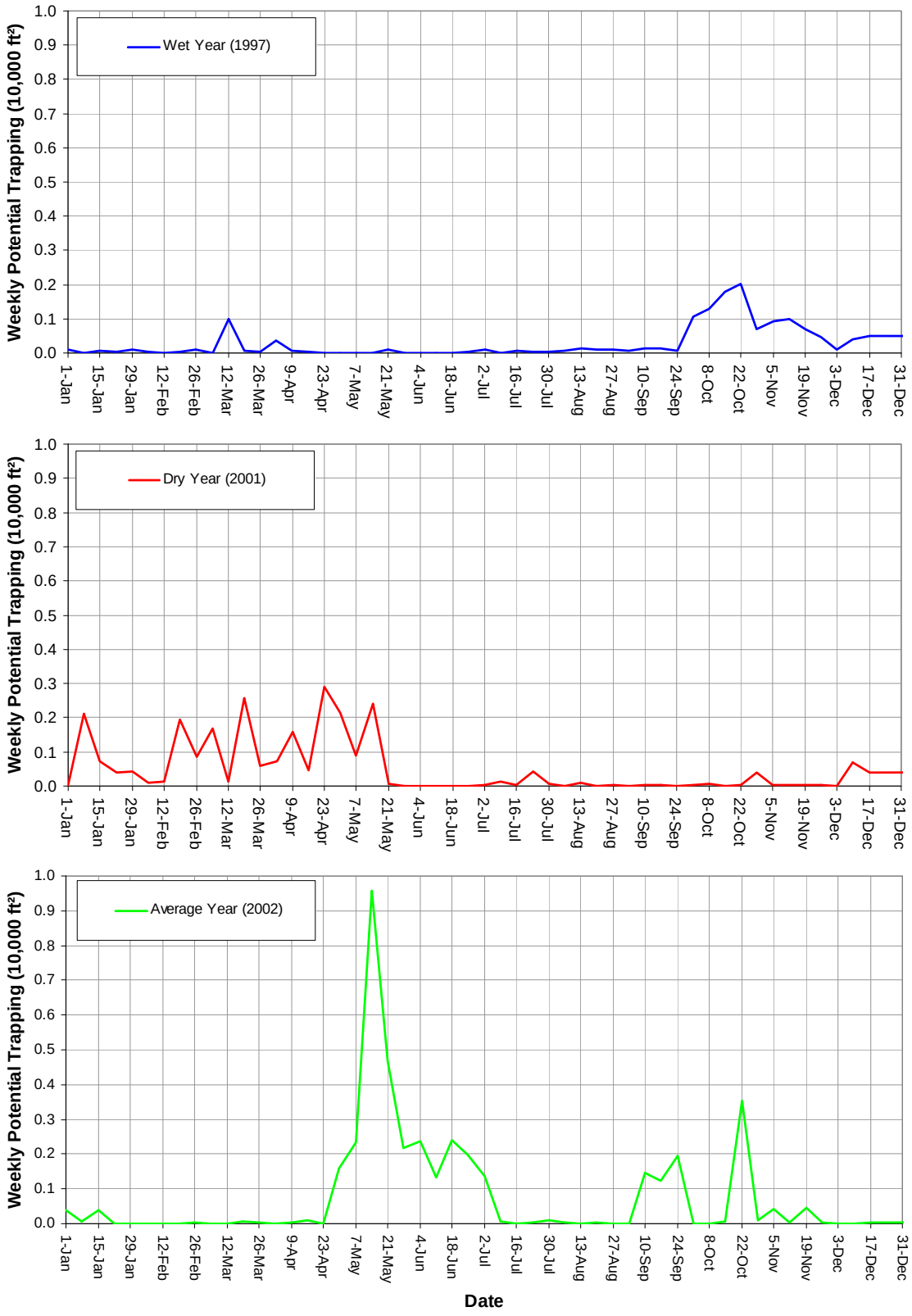


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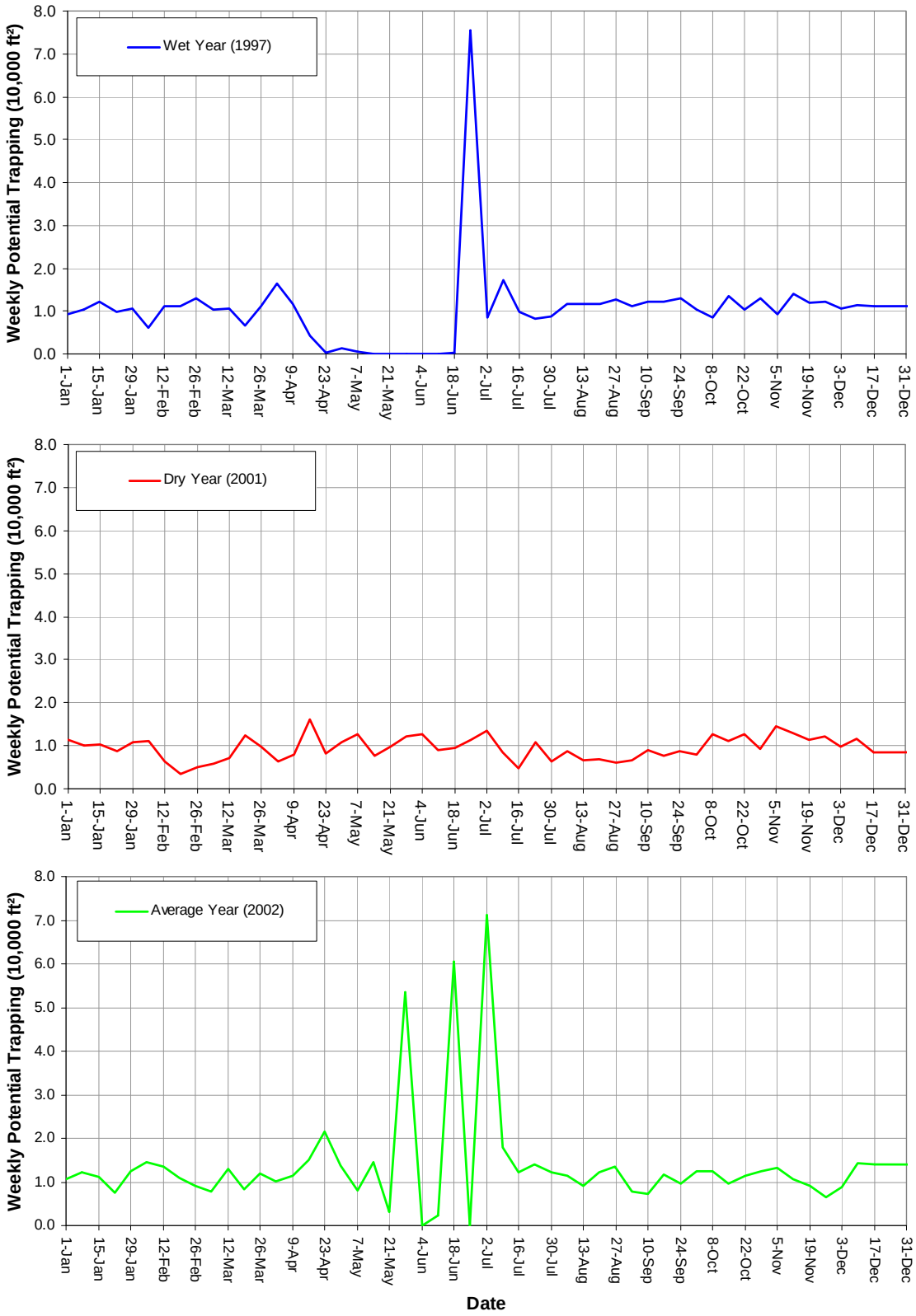


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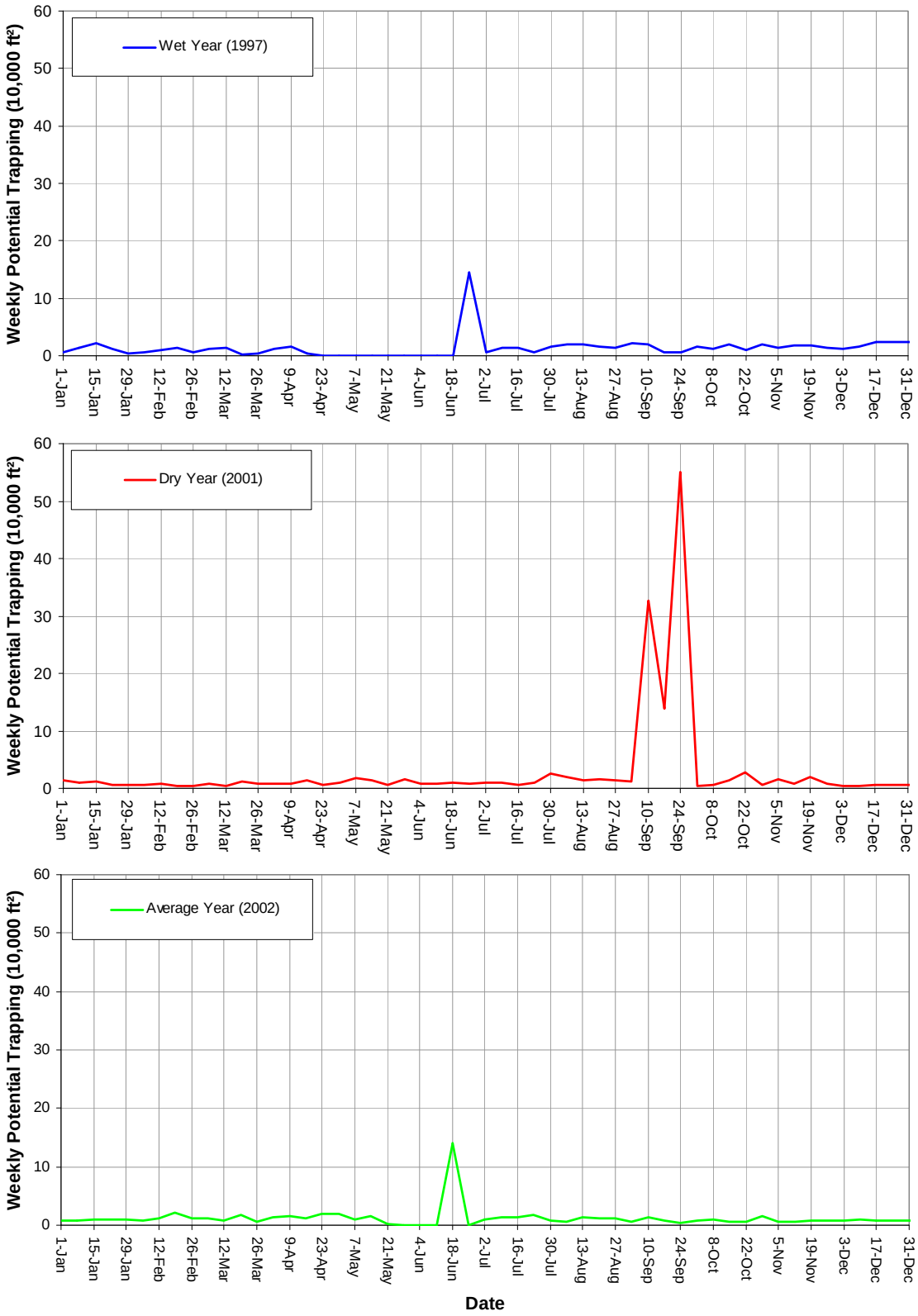


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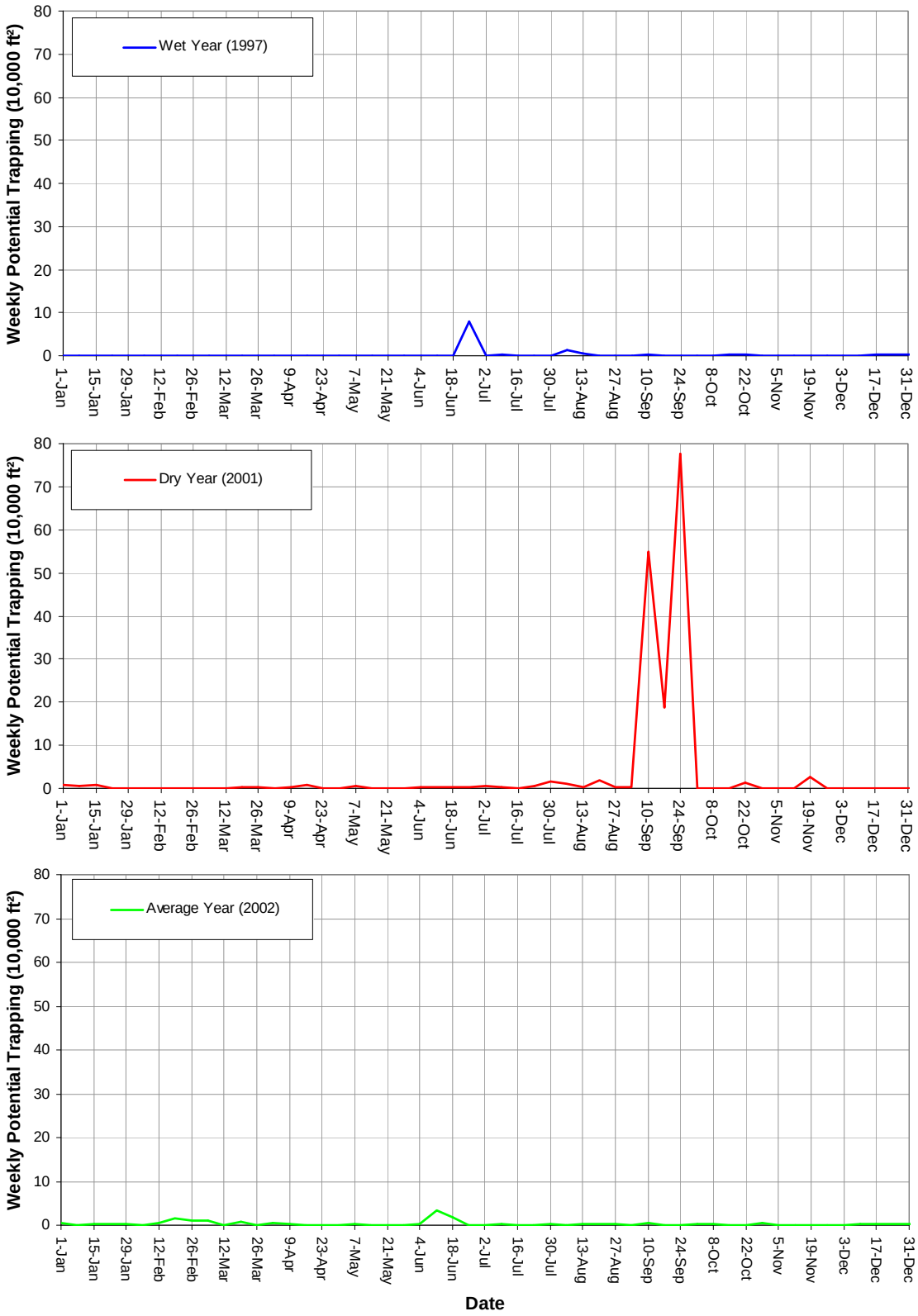


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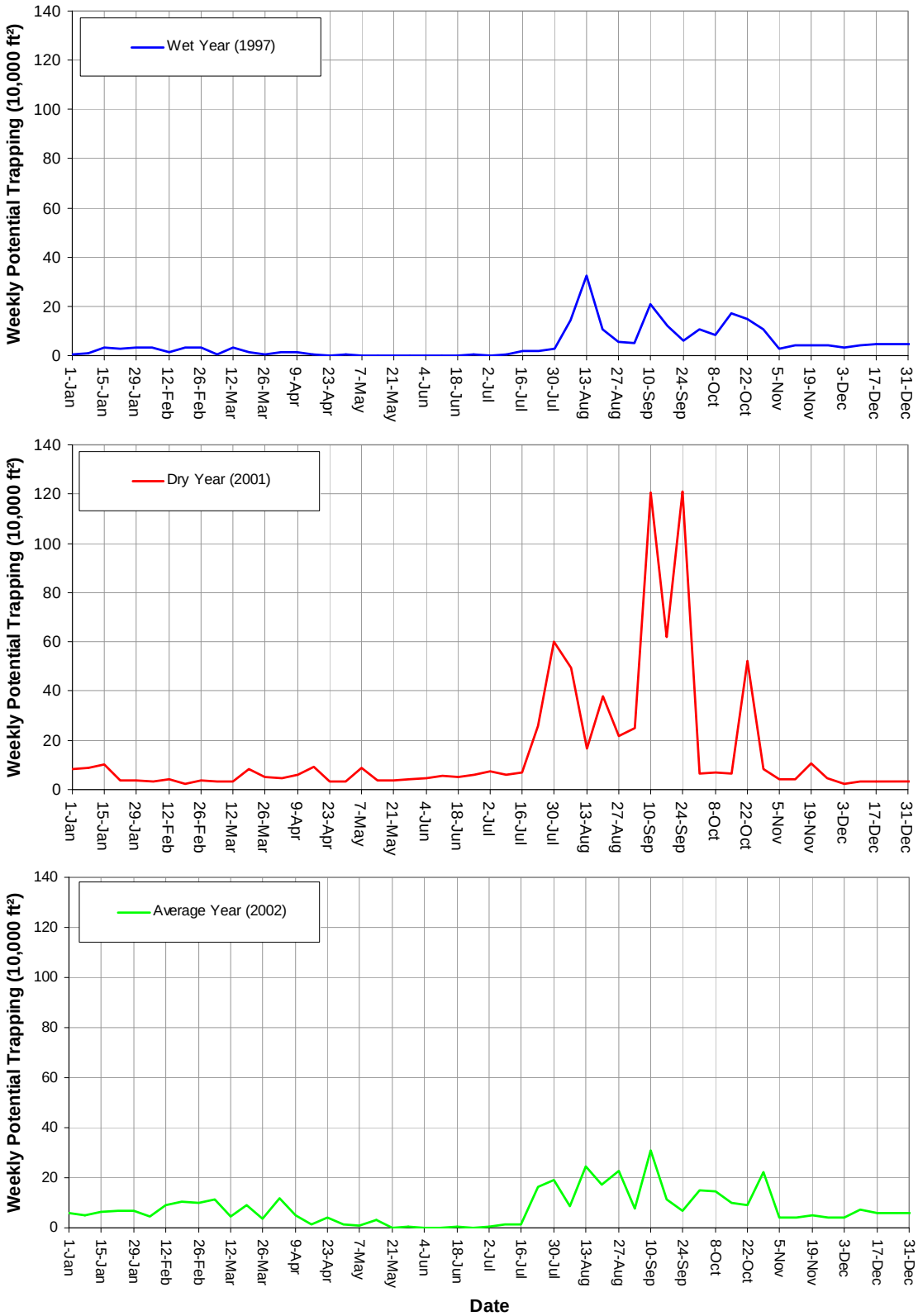


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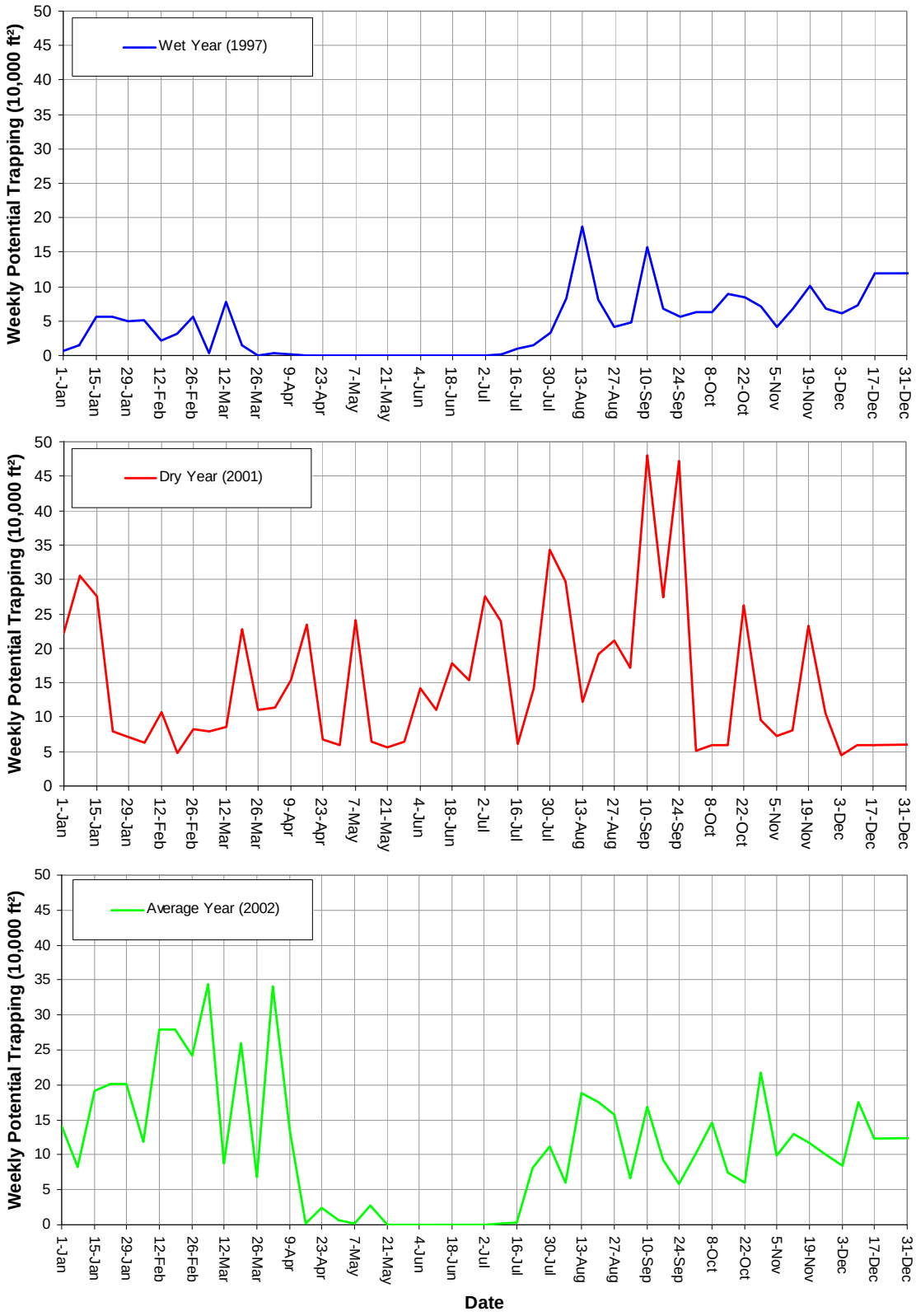


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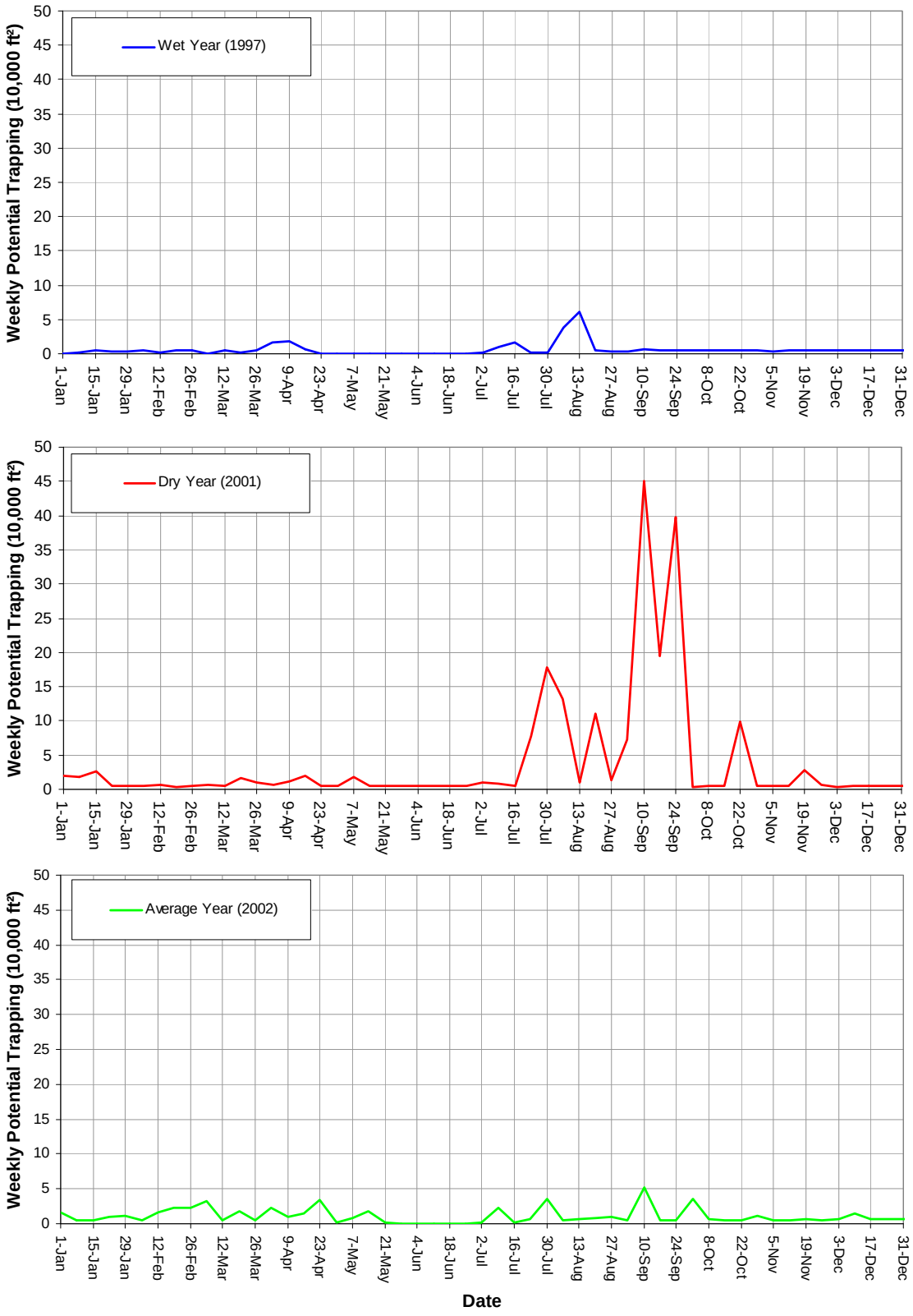


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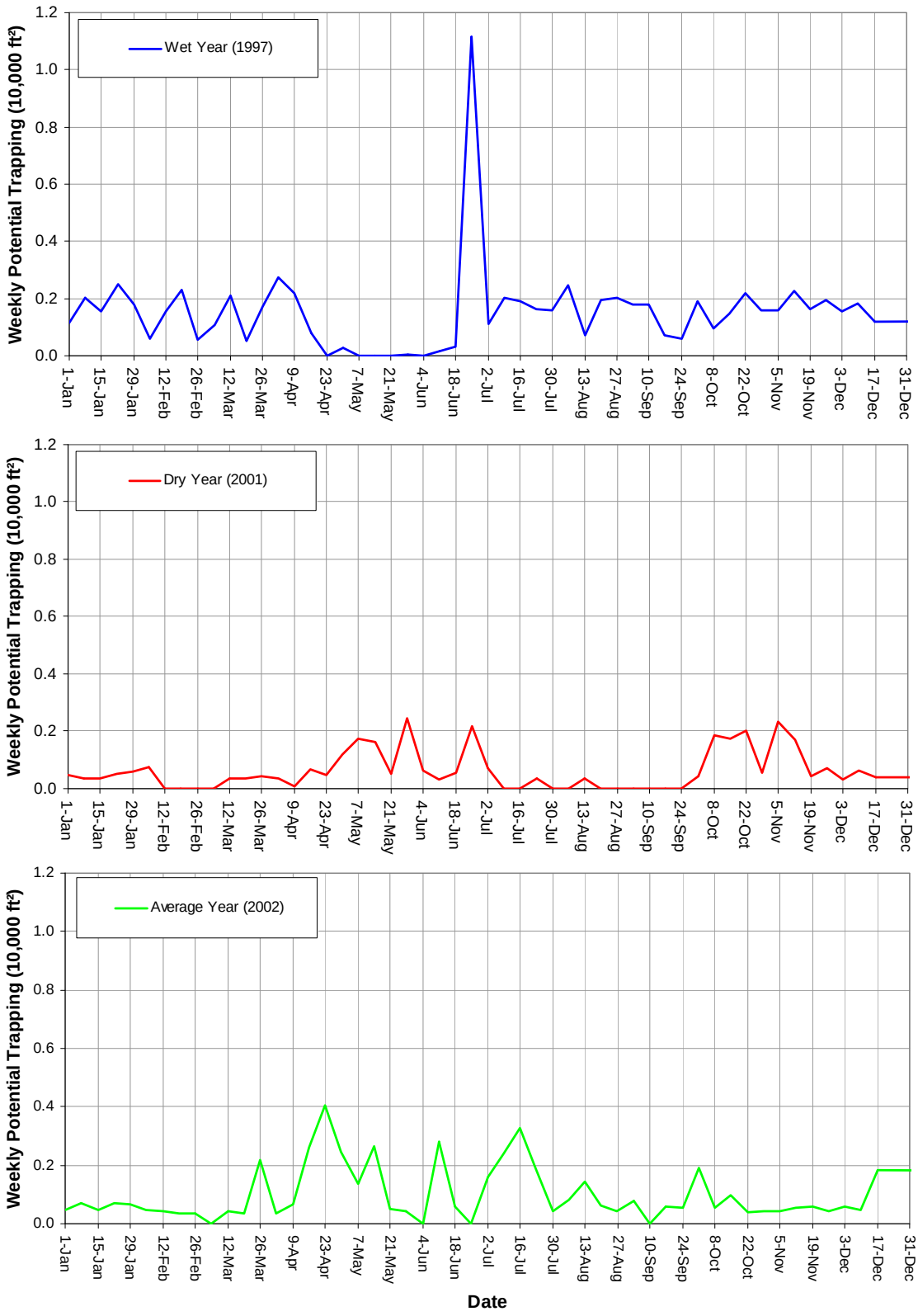


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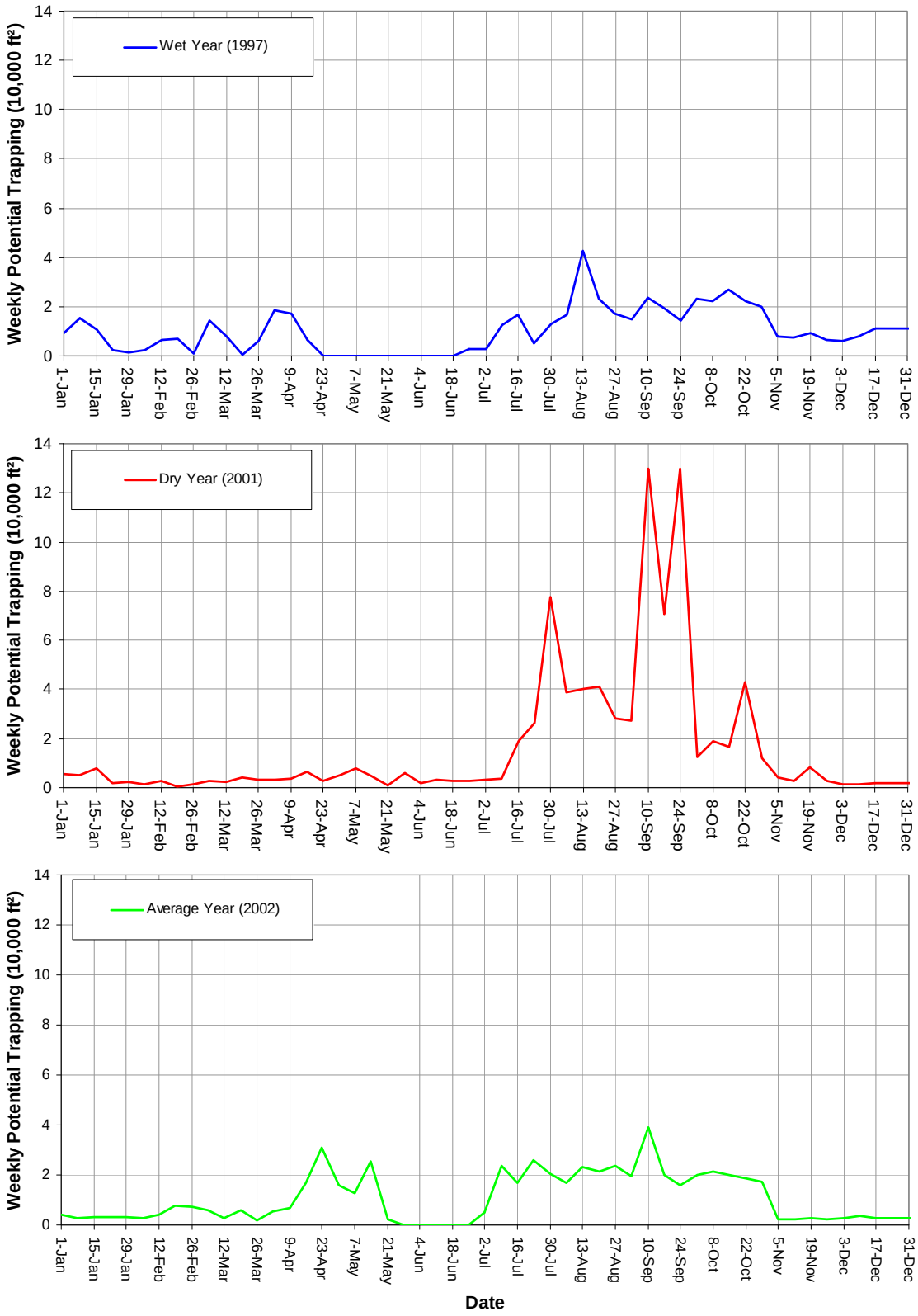


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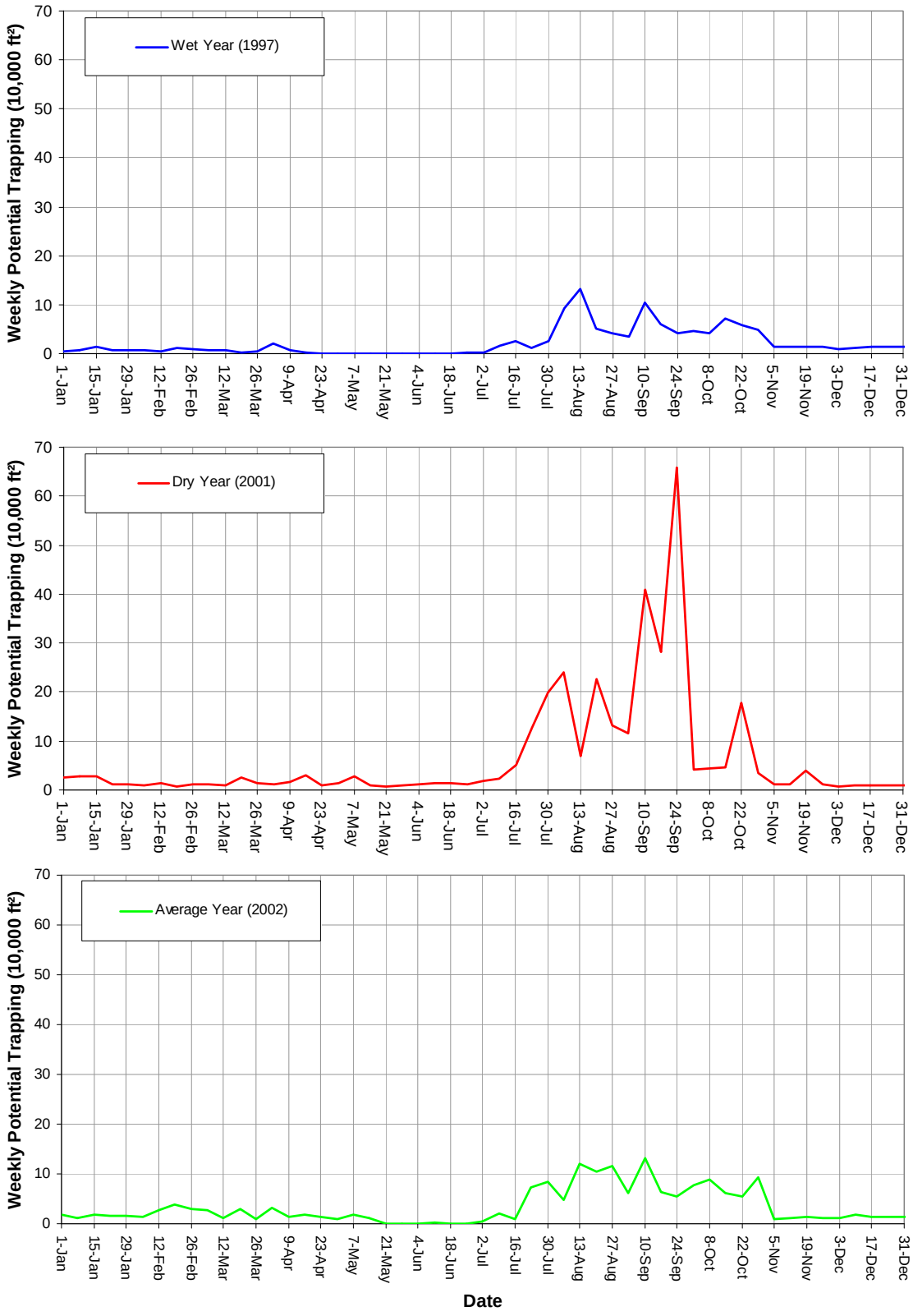


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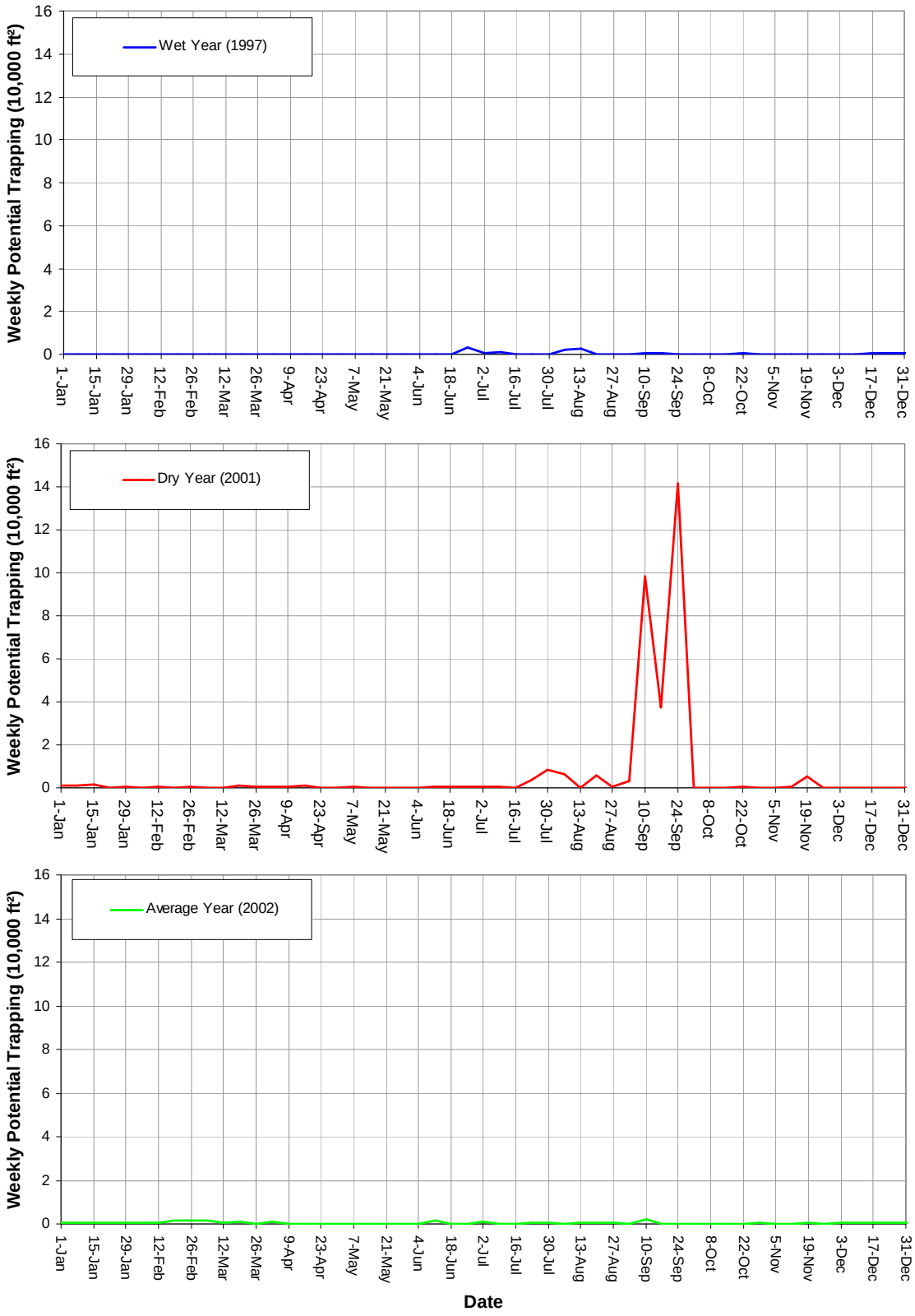


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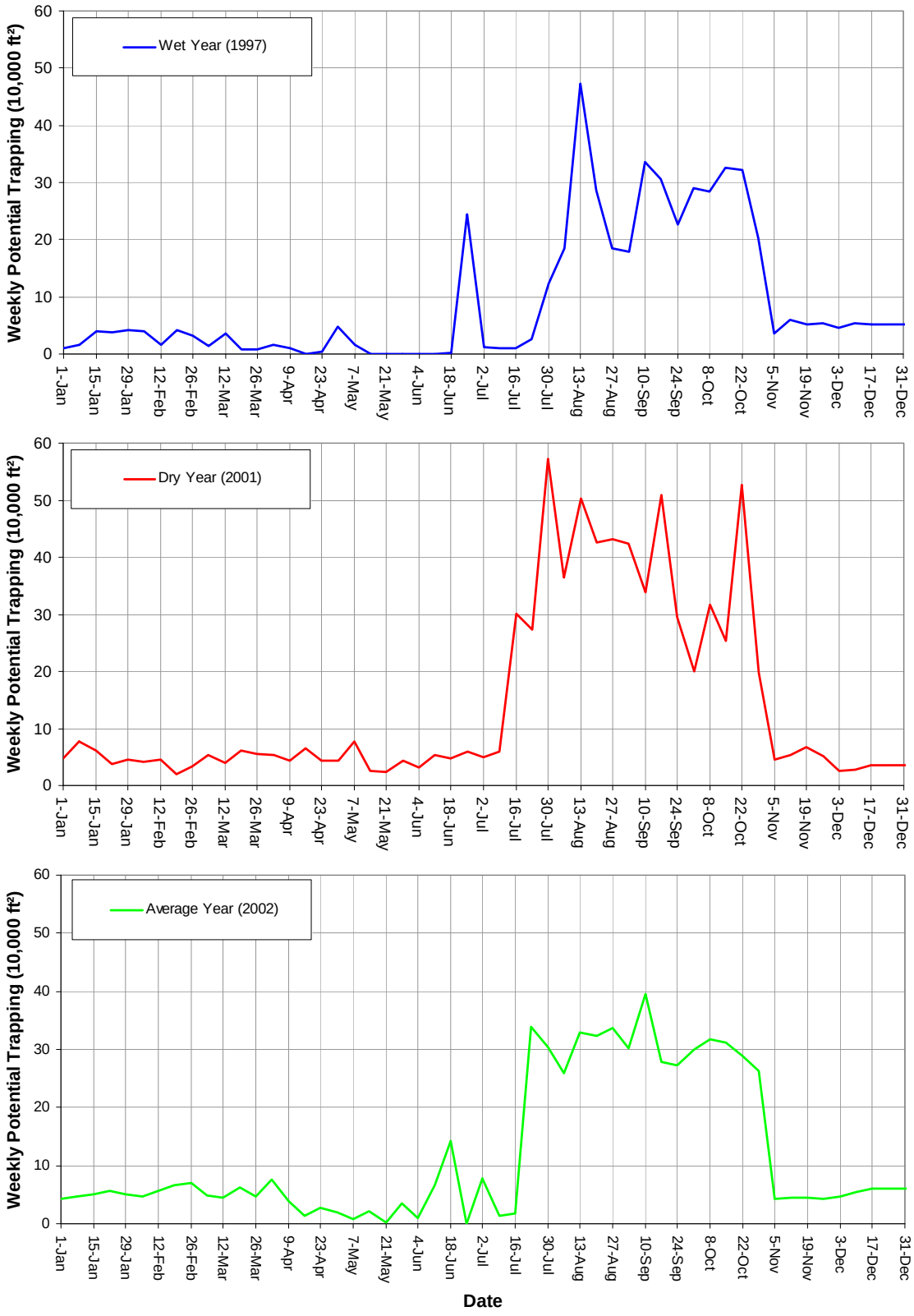


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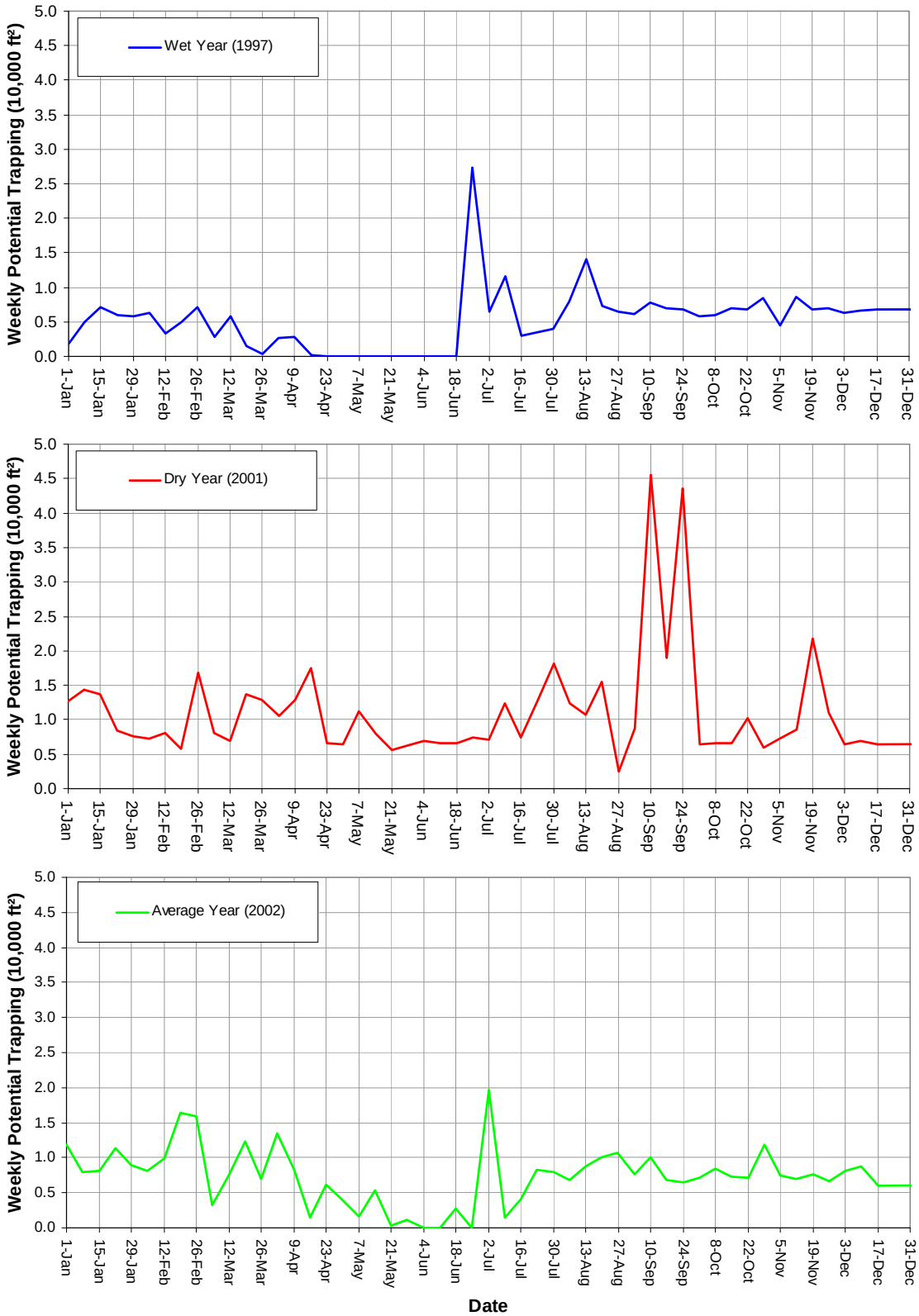


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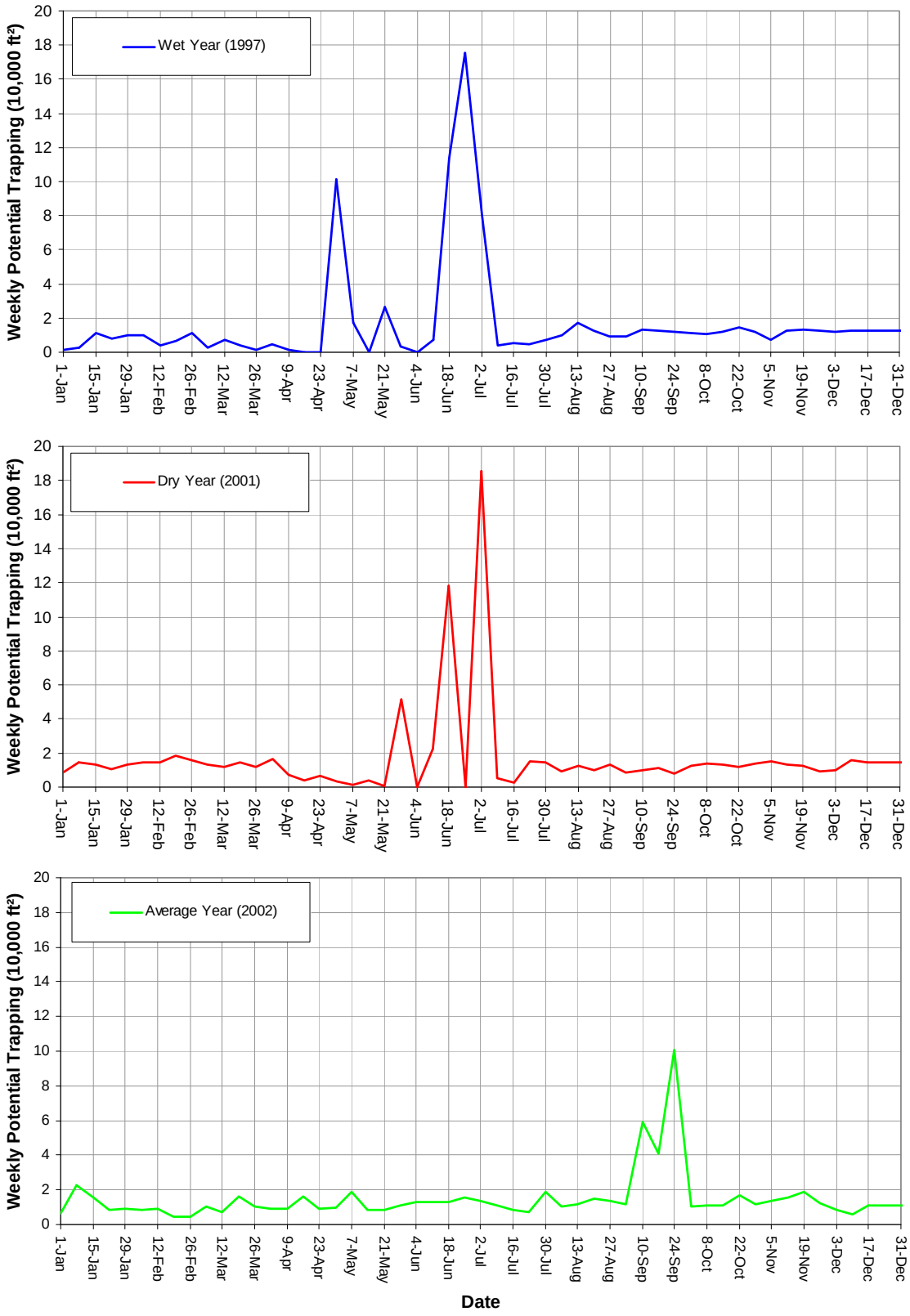


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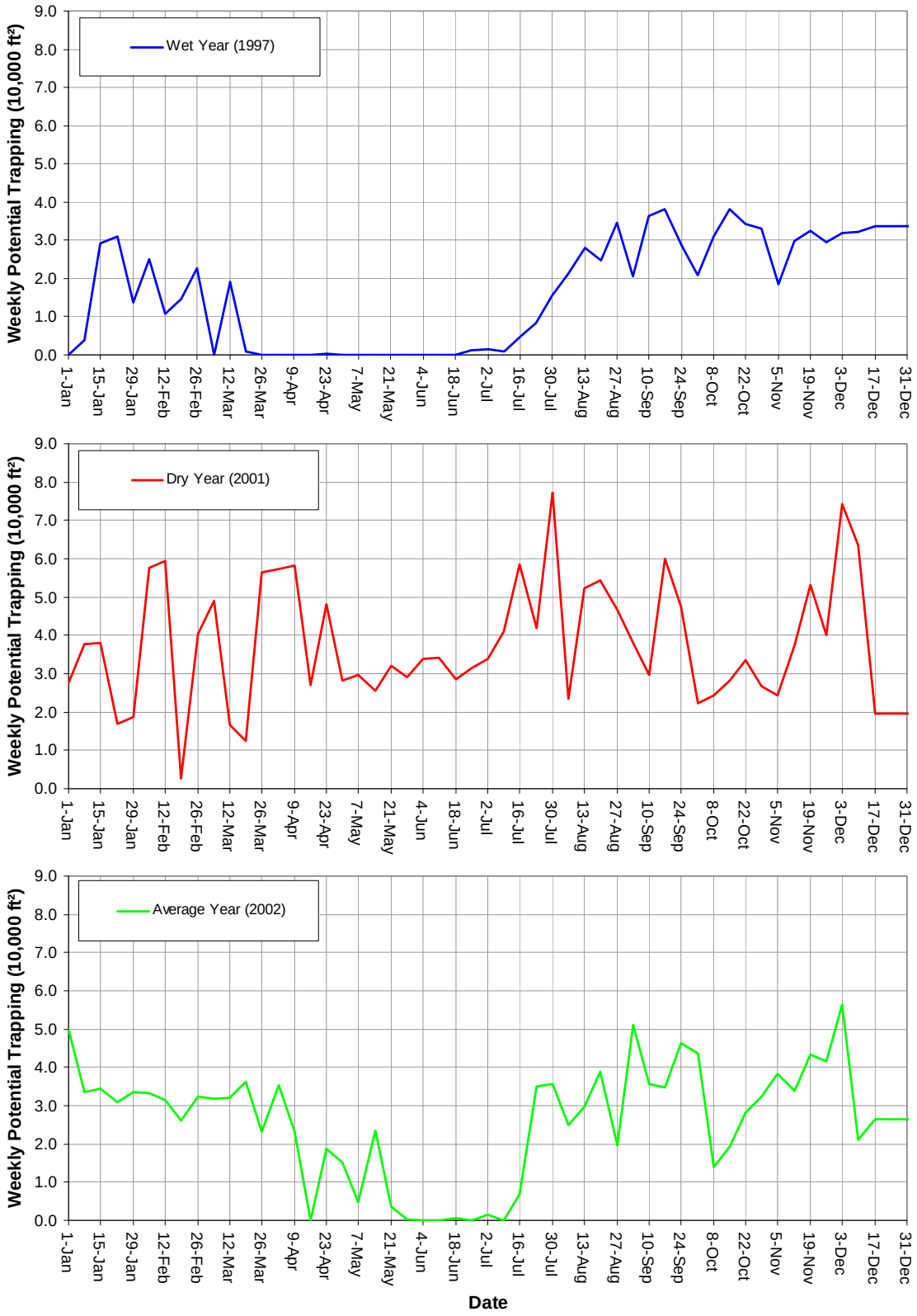


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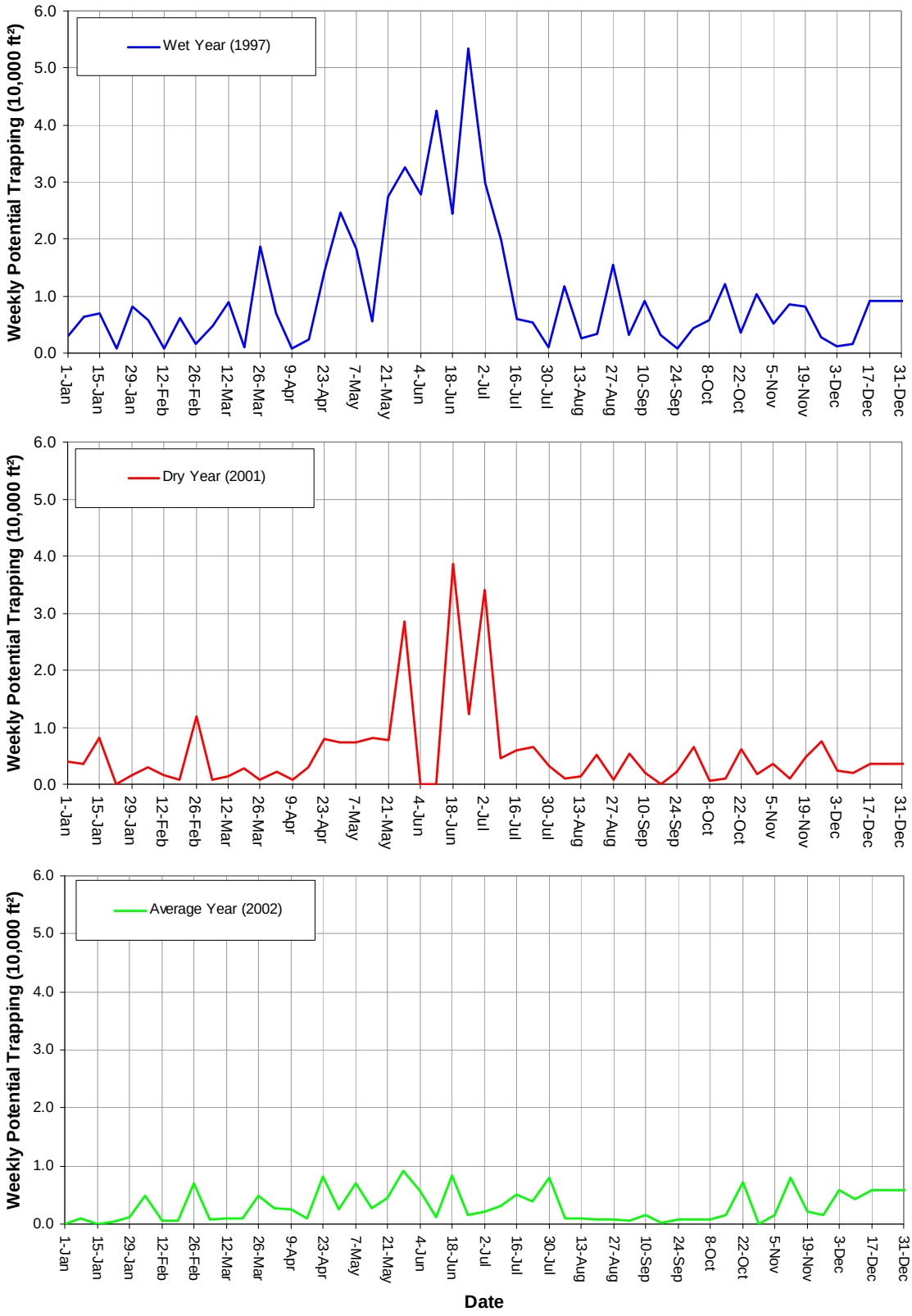


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# Appendix 5: Downramping Analysis Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Study 7: Mainstem Aquatic Habitat Modeling Study*

## *Appendix 5*

## *Downramping Analysis*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Bill Fullerton and Jay Smith**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 5
# Downramping Analysis Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

The downramping analysis was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This report summarizes the 2008 study efforts in regards to the downramping analysis and is being submitted as part of the Study 7 Final Report.

The downramping analysis is one of several tools that will be used to evaluate potential influences of operations scenarios on aquatic habitat in the mainstem of the Pend Oreille River from Box Canyon Dam downstream to Red Bird Creek. In the Final Report, the downramping analysis was applied to three representative hydrologic years from the historic condition.

### 1.1. Study Background

The Project is operated in a load-following mode, generating power during peak-load hours and curtailing generation during off-peak hours. This operating regime allows SCL to meet continued service area load growth and provide regional system reliability. The Project capacity of the six turbines is about 55,000 cubic feet per second (cfs), which is more than double the average annual flow of the Pend Oreille River (SCL 2007). The reservoir's relatively small storage capacity in relation to inflow, combined with the large turbine capacity, means that Project operations can, at times, cause the water surface elevation in the Forebay and Tailrace reaches[1] to fluctuate more than 10 feet in one day.

Water surface elevation fluctuations in the Project forebay occur primarily in response to daily Project operations and in response to changing flow conditions into the Boundary Reservoir. During peak-load hours, when the Project is generating power, the water surface elevation in the forebay will drop, but only when the discharge from the Project is greater than the flow entering the reservoir. When the Project curtails generation, the water surface elevation in the forebay increases as the reservoir refills.

[1] The reaches are defined as follows:

- Upper Reservoir Reach—Box Canyon Dam to Metaline Falls (Project river mile [PRM] 34.5–26.8)
- Canyon Reach—Metaline Falls to downstream end of Z Canyon (PRM 26.8–18.0)
- Forebay Reach—Downstream end of Z Canyon to Boundary Dam (PRM 18.0–17.0)
- Tailrace Reach—Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0–13.9)

Water surface elevation fluctuations in the Project tailrace occur in response to daily changes in Project discharge but also in response to fluctuations in the forebay water surface at BC Hydro's Seven Mile Dam, located 11 miles downstream of Boundary Dam. At full pool, the Seven Mile Dam is capable of backing water up to the tailrace of Boundary Dam.

When the water surface elevation at a specific location in the Pend Oreille River is dropping, it is considered to be downramping. The magnitude of the reduction in water surface elevation within a one-hour time period is referred to as the hourly downramping rate, or just simply the downramping rate.

The downramping analysis was conducted for both the 17.5-mile stretch of the mainstem Pend Oreille River between Box Canyon Dam and Boundary Dam as well as the 3.1-mile stretch of the mainstem Pend Oreille River between Boundary Dam and Red Bird Creek. The results of the downramping analysis were used to make qualitative conclusions regarding the potential effects of Project operations on aquatic organisms in terms of water surface elevation reduction.

## 1.2. Study Description

The downramping analysis is a comparative analysis conducted to quantify the effects of Project operations and of operations scenarios on aquatic organisms. The analysis included determination of the hourly reductions in water surface elevation at specific locations in the Project area for each of the three hydrologic years. Washington State Instream Flow Guidelines assume that faster rates of water surface elevation reduction are correlated to an increased risk of stranding of aquatic organisms (WDFW and Ecology 2004; Hunter 1992). In this regard, the downramping analysis was closely related to the stranding and trapping analysis (Appendix 4) and the varial zone analysis (Appendices 6, 7, and 8). All three of these efforts were directed toward evaluating the potential effect of mainstem water surface elevation fluctuations on aquatic habitat. For the stranding and trapping and varial zone analyses, the potential effect was evaluated by determining the change in wetted area associated with fluctuations in the water surface elevation. For the downramping analysis, the parameter of interest was the rate of the water surface elevation reduction over time and the frequency at which specific rates of downramping are exceeded.

The downramping analysis comprised several steps. The first step was to quantify the hourly downramping rates at each of the habitat transect locations for each of the three hydrologic years using output from the Boundary Reservoir Hydraulic Routing Model (HRM) and the Boundary Tailrace HRM. The output from these models was an hourly time series of water surface elevations at each habitat transect location. This output was then post-processed to determine the time periods when water surface elevations are dropping, and then to quantify the magnitude of the hourly reduction. A frequency analysis was conducted to determine the number of hours of downramping within specific numeric categories.

The number of hours when the downramping rates were within each of the numeric categories were then transect-weighted and reach-averaged. This process resulted in a transect-weighted, reach-averaged frequency distribution of downramping rates within the four study reaches (Forebay, Canyon, Upper Reservoir, and Tailrace). The transect weighting factors that were used in computing the transect-weighted, reach-averaged totals are presented in Appendix 1a.

The final step was then to report the transect-weighted, reach-averaged hourly rates in the form of cumulative exceedance curves.

The information generated from the downramping analysis will be used to evaluate the effects of historic Project operations on aquatic organisms and the effects of operations scenarios on aquatic organisms. Rapid rates of downramping have the greater potential to affect aquatic organisms due primarily to stranding on shallow gradient portions of the channel.

The methods used to conduct the downramping analysis are summarized in Section 3. Output from the analysis is presented in Section 4. Attachment A contains detailed output of the downramping analysis, exclusively in tabular format. Attachments B and C include supplemental graphical presentation of the downramping analysis output.

## 2 STUDY OBJECTIVES

The goal of the downramping analysis was to quantify historical downramping rates for the mainstem Pend Oreille River throughout the Project Area. The objectives of the study are to:

1. Determine hourly downramping rates at each of the habitat transect locations throughout each of the three hydrologic years (1997, 2001, and 2002).
2. Develop transect-weighted, reach-averaged downramping rate exceedance curves for each of the four reaches in the study area for each of the three hydrologic years.
3. Provide information to allow for the evaluation of the effects of existing Project operations and operations scenarios on aquatic organisms.

This report addresses each of the first two objectives and a portion of the third objective. In terms of the third objective, this report provides downramping rates for historic conditions and the methodologies that will be used in evaluating operations scenarios. Development of the baseline condition along with other operation scenarios will be conducted during the Integrated Resource Analysis (IRA) process. The IRA process has been discussed with relicensing participants throughout the relicensing proceeding and was a main topic of the December 3, 2008, relicensing workshop. Additional meetings were held in January and February 2009 and coordination with relicensing participants will continue through spring and early summer 2009. The results of the IRA effort will be documented in the License Application (LA) to be filed in September 2009.

## 3 METHODS

Because the entire study area can be influenced by backwater from Project operations (both Boundary Dam and Seven Mile Dam), the methodology used to conduct the downramping analysis varied somewhat from the typical riverine-based downramping analysis.

Downramping rates were determined using the unsteady model output at hourly time increments from the Boundary Reservoir HRM and the Boundary Tailrace HRM. Specifically, the output included hourly time series of water surface elevations at each habitat transect location. This output was then post-processed to determine hourly downramping rates at each transect location.

This information was statistically analyzed to determine the number of hours of downramping within specific numeric categories by annual totals and also by month. The results of the habitat transect specific frequency analyses were transect-weighted and reach-averaged to obtain reach average downramping rates for historic Project operations. The results were then expressed as the cumulative number of hours when downramping rates were in excess of 0, 2, 4, 8, and 12 inches per hour. The results are presented here in tabular format and also in a graphical format as downramping rate exceedance curves.

## 3.1. Hourly Downramping Rates

Hourly water surface elevation time series at each habitat transect were generated by the Boundary Reservoir HRM and the Boundary Tailrace HRM for each representative hydrologic year—1997 (wet year), 2001 (dry year), and 2002 (average year). For each habitat transect, a post-processing routine was used to first identify those specific hourly time periods in each year when the water surface elevation was decreasing (i.e., downramping). For those time periods, the hourly reduction in water surface elevation was then computed and expressed in units of inches per hour. To maintain consistency with the mainstem aquatic habitat modeling analysis, downramping rates were only determined when the Pend Oreille River flow rate (as measured at the USGS gage 12396500) was greater than 80,000 cfs. This is an appropriate threshold flow rate for the downramping analysis as well, because for flow rates greater than about 55,000 cfs, Boundary Project typically curtails the load following mode of operation. Extending the analysis to 80, 000 cfs, more than encompasses the range of flows where Project related downramping occurs. An additional reason why this threshold flow rate is appropriate is because on the receding limb of the annual hydrograph, downramping rates in the Boundary Reservoir are typically dominated by the natural recession of the flow rate, not Project operations.

## 3.2. Downramping Rate Exceedance Curves

A frequency analysis was then conducted on the hourly downramping rates at each of the reservoir and tailrace habitat transects. At each habitat transect, the frequency analysis determined the number of hours when the downramping rate was within the bounds of each of the following five numeric categories:

- Greater than 0 but less than 2 inches per hour
- Greater than 2 but less than 4 inches per hour
- Greater than 4 but less than 8 inches per hour
- Greater than 8 but less than 12 inches per hour
- Greater than 12 inches per hour

The number of hours of downramping within each of these categories was calculated by month and by annual total for each of the three representative hydrologic years. Finally, the number of hours of downramping within each category was calculated as a transect-weighted, reach-averaged total for the four mainstem Pend Oreille reaches (Upper Reservoir, Canyon, Forebay, and Tailrace). Again, the results were calculated by month and by annual total for each of the years. The transect weighting factors that were used in computing the transect-weighted, reach-averaged totals are presented in Appendix 1a. The final step was then to report the transect-weighted, reach-averaged hourly rates in the form of cumulative exceedance curves.

# 4 RESULTS

This section summarizes the results of the downramping analysis. Of the three objectives presented in Section 2, the first two are addressed in Section 4.1 of this report. The information presented in this section was used to evaluate the effects of historic Project operations on aquatic organisms and will ultimately be used in analyzing the effects of operations scenarios on aquatic organisms (fourth objective).

## 4.1. Hourly Downramping Rates

Hourly downramping rates were determined at each of the 49 habitat transect locations in the Boundary Reservoir and at each of the 14 habitat transect locations in the Boundary tailrace for each of the three hydrologic years. At each of the transect locations, the number of hours of downramping within each of the five numeric categories were quantified. These location-specific frequency distributions were then transect-weighted and reach-averaged to produce transect weighted reach averaged frequency distributions for downramping for each of the four reaches in the Project area for each of the three representative hydrologic years (1997, 2001, and 2002). The frequency distributions were then converted to cumulative distributions so that downramping rate exceedance curves could be developed.

This section documents the results of the downramping analysis in the form of these transect-weighted, reach-averaged cumulative distributions and downramping rate exceedance curves. The results are first presented in a tabular format. However, supplemental graphics are used to support the subsequent discussion regarding the interpretation of the results. The discussion in this section focuses on the following topics:

- Variability of hourly downramping rates within each of the four reaches in the Project Area for a given year. Specifically, the results are presented graphically so as to illustrate that downramping rates in the Forebay and Canyon Reaches within any given year are fairly similar. However, in the Upper Reservoir Reach, downramping rates are influenced by the hydraulic control of Metaline Falls. This results in downramping rates in the Upper Reservoir Reach that are much lower than those in the Canyon and Forebay reaches when comparing the results within a given year.
- Variability in downramping rates amongst the three hydrologic years. The three years that were included in the analysis were inclusive of a wet year (1997), a dry year (2001), and an average year (2002) based upon an analysis of average annual flows (R2 Resource Consultants 2008). Within each of these three years, Project operations were reflective of real-time and forecasted hydrologic conditions and regional power demands. As such, the resulting downramping rates and the distribution of downramping rates were noticeably different between each of these three years.
- Variability in downramping rates by month or by season. As Project operations responded to monthly and seasonal changes in hydrologic inflow conditions and regional power demands, downramping rates reflected these monthly and seasonal changes. For example, in the wet year (1997) the number of hours of downramping was very low in May and June when compared to these same months in the dry year (2001) and the average year (2002).

Table 4.1-1 summarizes the results of the downramping analysis by hydrologic year and by Project reach. This table includes the cumulative number of hours when downramping rates were in excess of 0, 2, 4, 8, and 12 inches per hour. This table can be used to compare the distribution of downramping rates for all four reaches within a given hydrologic year. Alternatively, this table can be used to compare the distribution of downramping rates for a given reach during each of the three hydrologic years.

At a glance, it is seen in Table 4.1-1 that within each year there are significantly fewer hours of downramping in the Upper Reservoir Reach with downramping rates that exceed 8 inches per hour compared to the Forebay and Canyon reaches. For example, in the wet year (1997), the transect-weighted, reach-averaged hours of downramping with rates exceeding 8 inches per hour was 1,036 for the Forebay Reach. However, in the Upper Reservoir Reach there were approximately 3 hours of downramping with rates in excess of 8 inches per hour. As described in detail in Section 5.2 of the Study 7 Final Report, Metaline Falls behaves as a hydraulic control on the system. When the water surface elevation in the forebay is reduced as a result of Project operations, there is not necessarily a commensurate reduction in water surface elevation upstream of Metaline Falls. Metaline Falls functions as a localized restriction that controls the rate of flow from the Upper Reservoir Reach into the Canyon Reach, much like a hydraulic weir. For conditions when the water surface elevation in the Boundary forebay is dropping, the flow rate through Metaline Falls represents the rate at which the Upper Reservoir Reach is draining, and can often be less than the outflow from the Project. As such, the rate at which the water surface elevation in the Upper Reservoir Reach drops is less than the rate at which the water surface elevation drops in the Canyon and Forebay reaches. Therefore, downramping rates in the Upper Reservoir Reach are less than those in the Forebay and Canyon reaches.

**Table 4.1-1.** Transect-weighted, reach-averaged cumulative distribution of hours of downramping by rate, by hydrologic year, and by reach.

| Downramping Rate | Number of Downramping Hours | | | |
|---|---|---|---|---|
| | Forebay Reach | Canyon Reach | Upper Reservoir Reach | Tailrace Reach |
| **1997 – Wet Hydrologic Year** | | | | |
| > 0 in/hr | 4,566 | 4,581 | 4,626 | 3,416 |
| > 2 in/hr | 3,672 | 3,654 | 2,759 | 2,558 |
| > 4 in/hr | 2,756 | 2,703 | 991 | 1,963 |
| > 8 in/hr | 1,036 | 977 | 3 | 1,234 |
| > 12 in/hr | 194 | 169 | 0 | 780 |
| **2001 – Dry Hydrologic Year** | | | | |
| > 0 in/hr | 5,192 | 5,198 | 5,324 | 3,790 |
| > 2 in/hr | 4,219 | 4,224 | 3,876 | 2,706 |
| > 4 in/hr | 2,816 | 2,796 | 1,558 | 2,014 |
| > 8 in/hr | 1,106 | 1,058 | 33 | 1,059 |
| > 12 in/hr | 376 | 331 | 0 | 586 |
| **2002 – Average Hydrologic Year** | | | | |
| > 0 in/hr | 5,034 | 5,042 | 5,173 | 3,655 |
| > 2 in/hr | 4,286 | 4,274 | 3,602 | 2,646 |
| > 4 in/hr | 3,151 | 3,103 | 1,444 | 2,005 |
| > 8 in/hr | 1,132 | 1,074 | 13 | 1,154 |
| > 12 in/hr | 283 | 249 | 0 | 647 |

Note:
1 Values in the table have been rounded to the nearest integer value.

## 4.2. Downramping Rate Exceedance Curves

Figures were developed to facilitate discussion and interpretation of the results in Table 4.1-1. Figures 4.2-1 through 4.2-3 present the tabular results from Table 4.1-1 illustrating the differences in downramping rates amongst each of the four reaches. These figures are referred to as downramping rate exceedance curves. A separate figure is used to summarize the results for each year. Figure 4.2-1 includes the results from the wet year (1997); Figures 4.2-2 and 4.2-3 include the results from the dry year (2001) and the average year (2002), respectively. Each figure shows the number of hours per year when the transect-weighted, reach-averaged downramping rate was in excess of specific threshold values.

Using these three figures and the information presented in Table 4.1-1, several general observations can be made. First, by comparing the Forebay Reach downramping results between all three figures it is seen that the wet year had the least amount of time associated with downramping (4,566 hours) as compared with the other two years. This is explained by the fact that, for the 2½-month period from mid-April 1997 through the end of June 1997, inflow to the

reservoir was greater than the turbine capacity of 55,000 cfs. For much of this 2½-month period, Project discharge (turbine plus spill) approximately equaled inflow thereby resulting in fewer hours of downramping. This is illustrated more clearly in figures later in this section that show downramping results by month. At the other extreme, the dry year had the most number of hours of downramping in the Boundary forebay (5,192 hours). The number of hours of downramping in the Boundary forebay during the average year (5,034 hours) was less than the dry year and more than the wet year. Also, based on the results for these three years alone, it is seen that on an annual basis, the Canyon and Forebay reaches of the reservoir are draining (downramping) more often than they are filling.

A second observation from Figures 4.2-1 through 4.2-3 concerns the effect of Metaline Falls on downramping rates. Each of the three figures clearly shows downramping rates in the Forebay and Canyon reaches in excess of 8 inches per hour. However, in the Upper Reservoir Reach, there are only a few instances of downramping rates between 8 and 12 inches per hour and there are no instances of downramping rates in excess of 12 inches per hour for any of the years. As mentioned previously, this is due to the hydraulic control that Metaline Falls has on the flow rate out of the Upper Reservoir Reach as it is "draining" in response to reduced water surface elevations in the Boundary forebay.

A third observation from Figures 4.2-1 through 4.2-3 concerns the downramping rates in the Tailrace Reach. The number of hours of downramping in the Tailrace Reach does not vary significantly from year to year. However, as was the case for the upstream reaches, the wet year had the fewest number of hours of downramping (3,416 hours) as compared with both the dry year (3,790 hours) and the average year (3,655 hours). These three figures show that the distribution of Tailrace Reach downramping rates within each of the years is more uniformly distributed than is the case for any of the other three reaches

As previously mentioned, downramping conditions in the Tailrace Reach are partly the result of daily fluctuations in Project outflow that cause daily fluctuations in the water surface elevation in the Tailrace Reach. As outflows from the Project are decreased, the water surface elevation in the Tailrace Reach decreases. The rate at which the water surface elevation decreases in the Tailrace Reach is controlled by the natural hydraulic controls downstream of Boundary Dam. Much in the same fashion as Metaline Falls controls the flow out of the Upper Reservoir Reach, the natural hydraulic controls in the Tailrace Reach control the flow out of the Tailrace Reach and therefore control the rate at which the water surface elevation decreases in the Tailrace Reach. Other factors that influence downramping rates in the Tailrace Reach include 1) the rate at which Boundary outflow is decreased and 2) the forebay elevation in Seven Mile Dam.

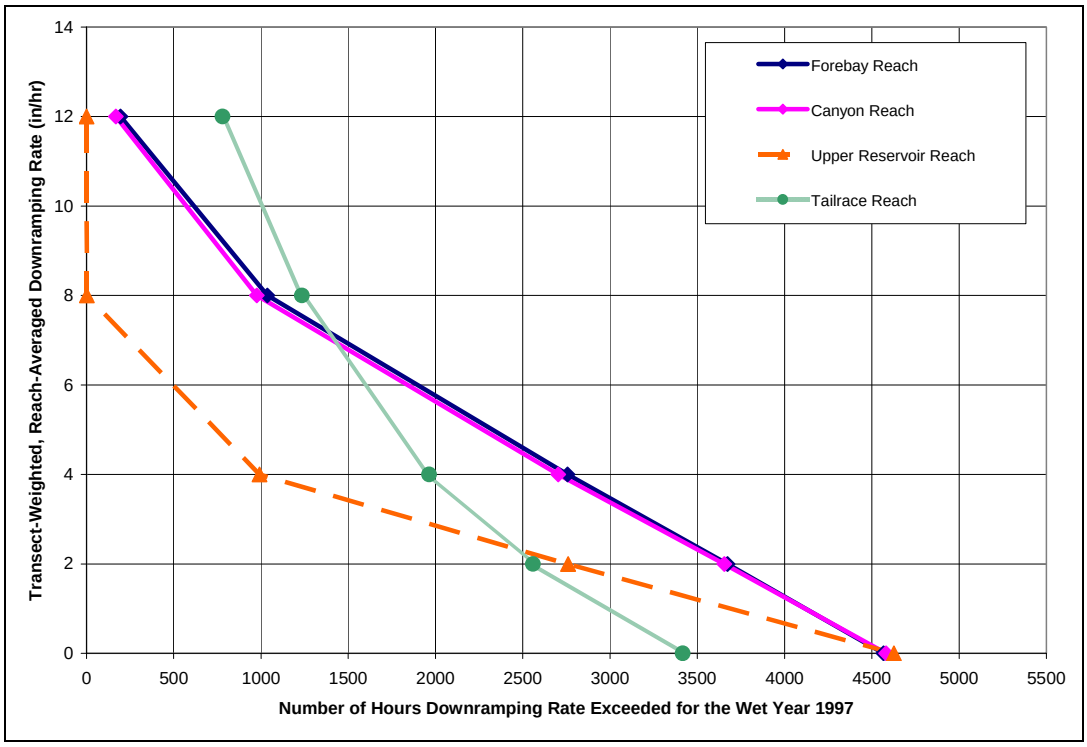


**Figure 4.2-1.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative wet year 1997.

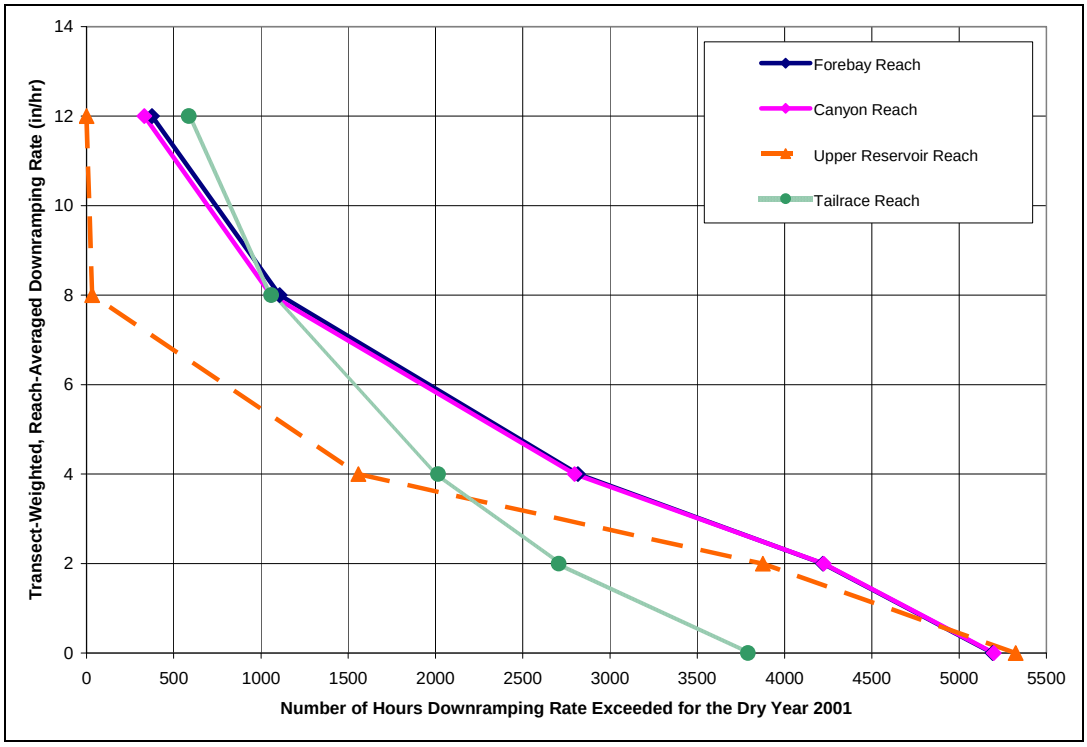


**Figure 4.2-2.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative dry year 2001.

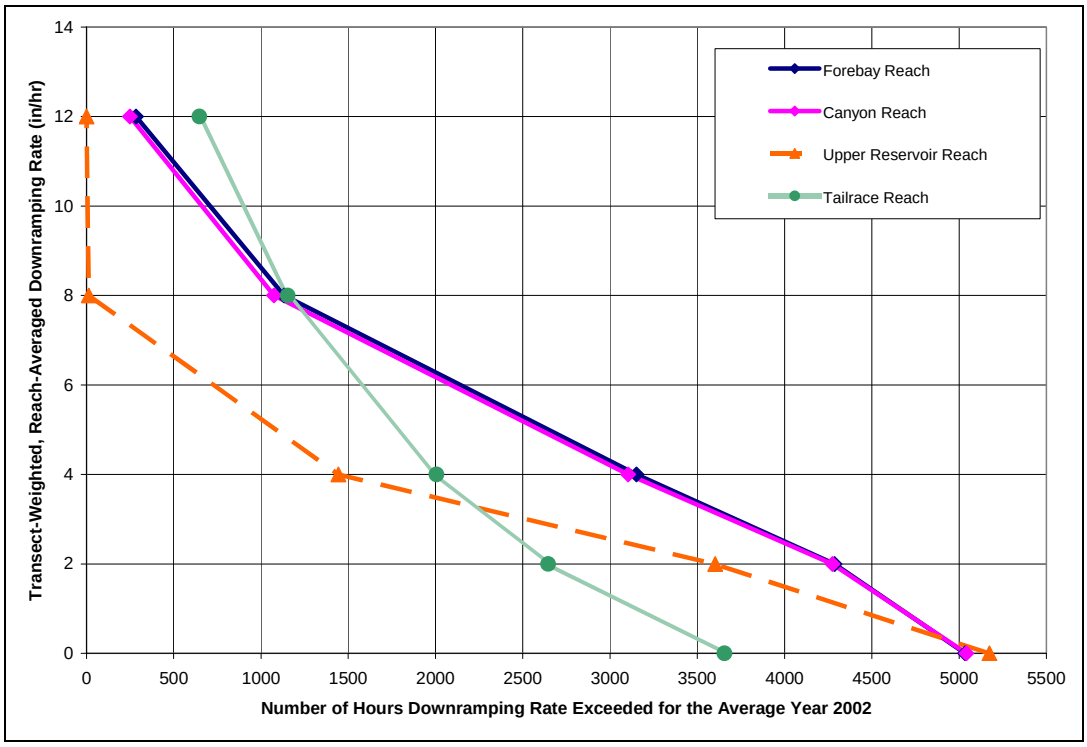


**Figure 4.2-3.** Annual transect-weighted, reach-averaged downramping rate exceedance curves by Project reach for the representative average year 2002.

The number of hours of downramping and the distribution of downramping rates also vary monthly and seasonally. For example, during the spring runoff period of wetter years there can be relatively fewer hours of downramping as compared to the spring runoff period during drier years. This is because Project operations during years with high spring runoff are more constant and do not load-follow as much as during drier years.

To illustrate the point, Figures 4.2-4 and 4.2-5 show the annual time series of hourly downramping rates in Boundary forebay (at habitat transect F-1) for the wet year (1997) and the dry year (2001). During the wet year of 1997, inflow to Boundary Reservoir exceeded the 55,000 cfs turbine capacity of the Project starting approximately April 21 and continuing through July 8. However, throughout the duration of the entire dry year of 2001, the peak inflow to Boundary Reservoir was only 30,200 cfs, well below the 55,000 cfs turbine capacity. Therefore, during the spring runoff period, the number of hours of downramping, and the magnitude of downramping were noticeably less in April through July of the wet year (1997) than they were during the dry year (2001). The approximately one-month period in Figure 4.2-4 with no instances of downramping corresponds with the time period when inflows to Boundary Reservoir were greater than the 80,000 cfs limit to compute downramping rates. This does not mean that downramping did not occur during this period, just that the downramping analysis was not conducted.

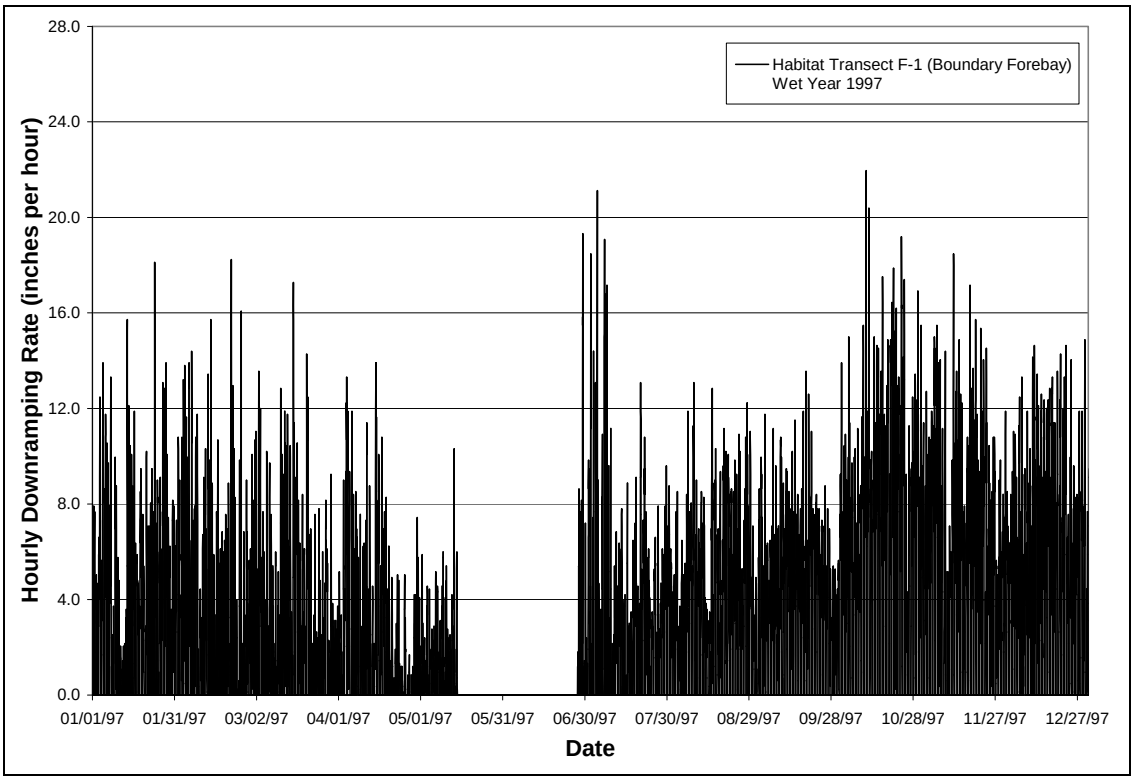


**Figure 4.2-4.** Hourly time series of downramping rates in Boundary Dam forebay for 1997 (wet year).

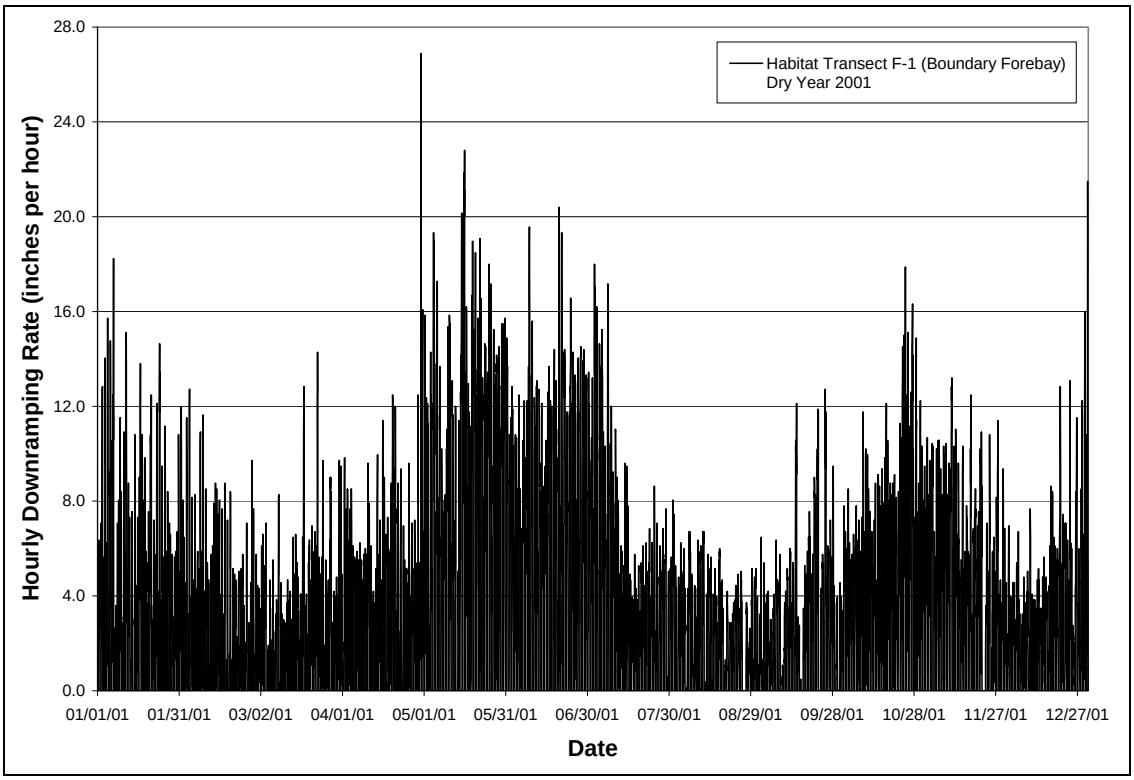


**Figure 4.2-5.** Hourly time series of downramping rates in Boundary Dam forebay for 2001 (dry year).

Attachment B includes a complete set of similar hourly downramping rate time series figures for four habitat transect locations in the Boundary Reservoir. The locations include Boundary Dam forebay (Transect F-1), downstream of Metaline Falls (Transect C-24), upstream of Metaline Falls (Transect U-1), and the Box Canyon tailrace (Transect U-24). At each location, a figure is included for each of the three years. Attachment B includes similar figures for two habitat transect locations in the Boundary tailrace. The locations include the U.S.-Canada border (Transect TR-11) and in the Boundary Dam tailrace (Transect TR-17). At each location, a figure is included for each of the three years.

To illustrate seasonal and monthly variability in downramping, transect-weighted reach-averaged downramping rates were determined by month. The methodology used was similar to that used to determine the transect-weighted, reach-averaged downramping rates for the entire year. For each month, the monthly frequency distributions of downramping rates at each transect location were transect-weighted and then reach-averaged. The frequency distributions were then converted to cumulative distributions and downramping rate exceedance duration curves were developed.

Figures 4.2-6 through 4.2-8 illustrate the downramping rate exceedance curves for the month of May for each of the three years. Attachment C includes similar figures for all of the months within each of the three hydrologic years. Each of these figures shows the transect-weighted, reach averaged downramping rate exceedance curves for each of the four reaches in the Project area for the indicated month and year.

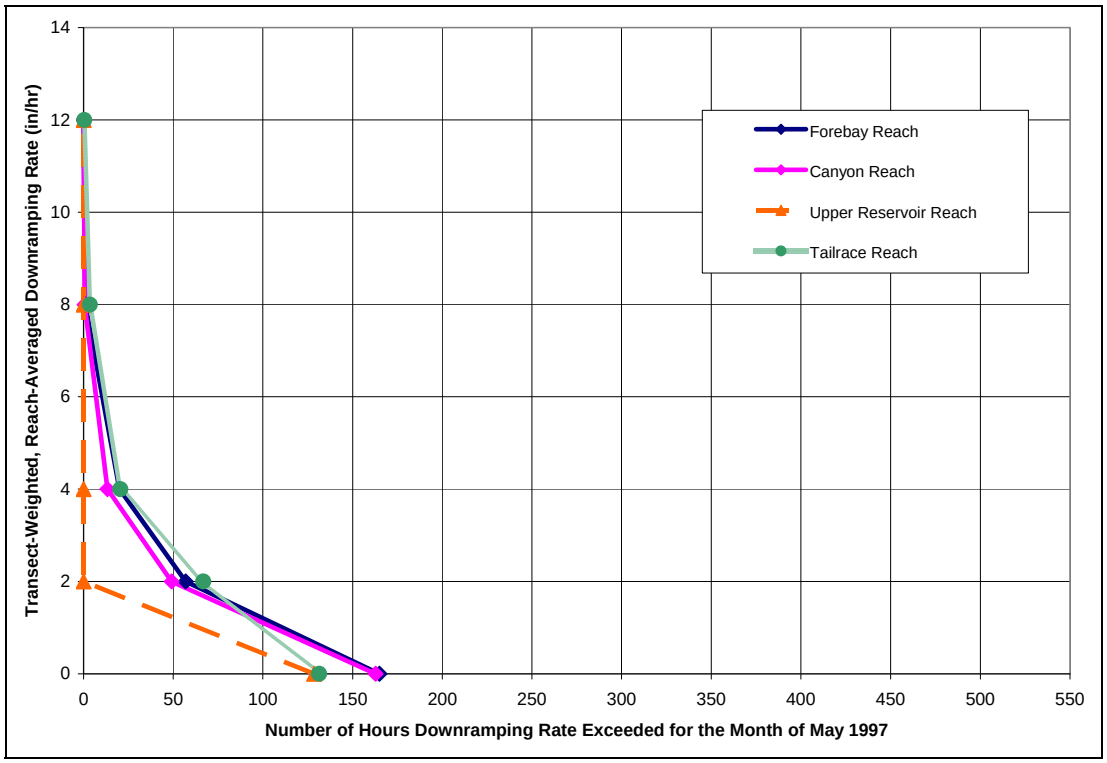


**Figure 4.2-6.** May of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

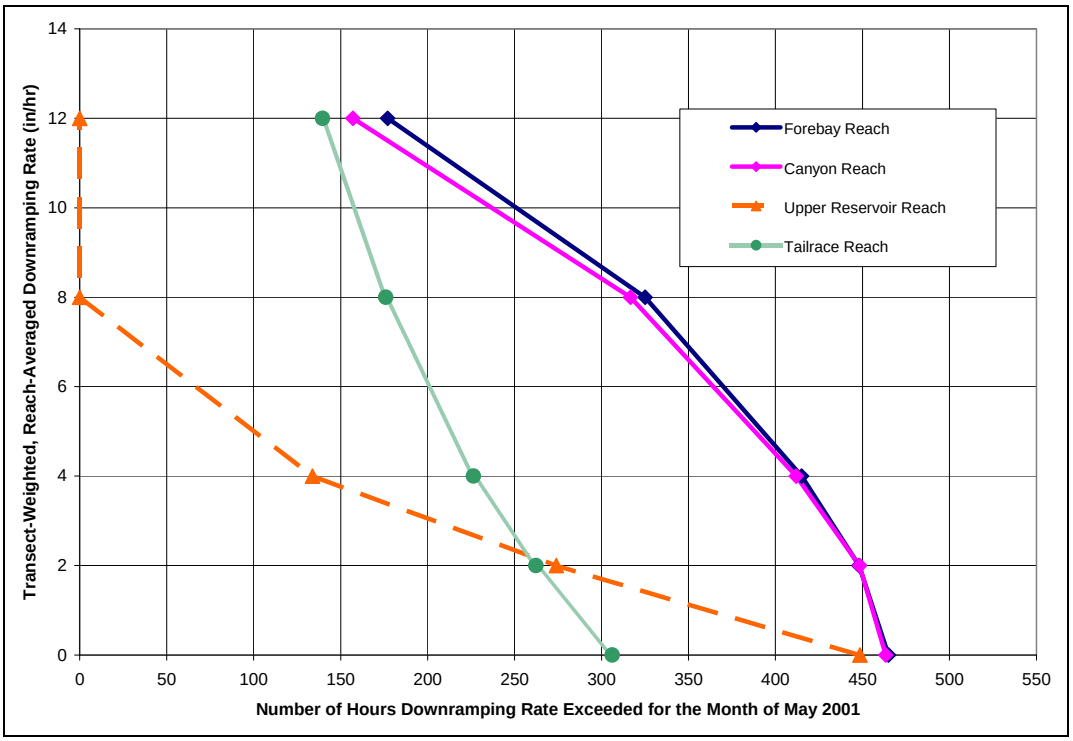


**Figure 4.2-7.** May of dry year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

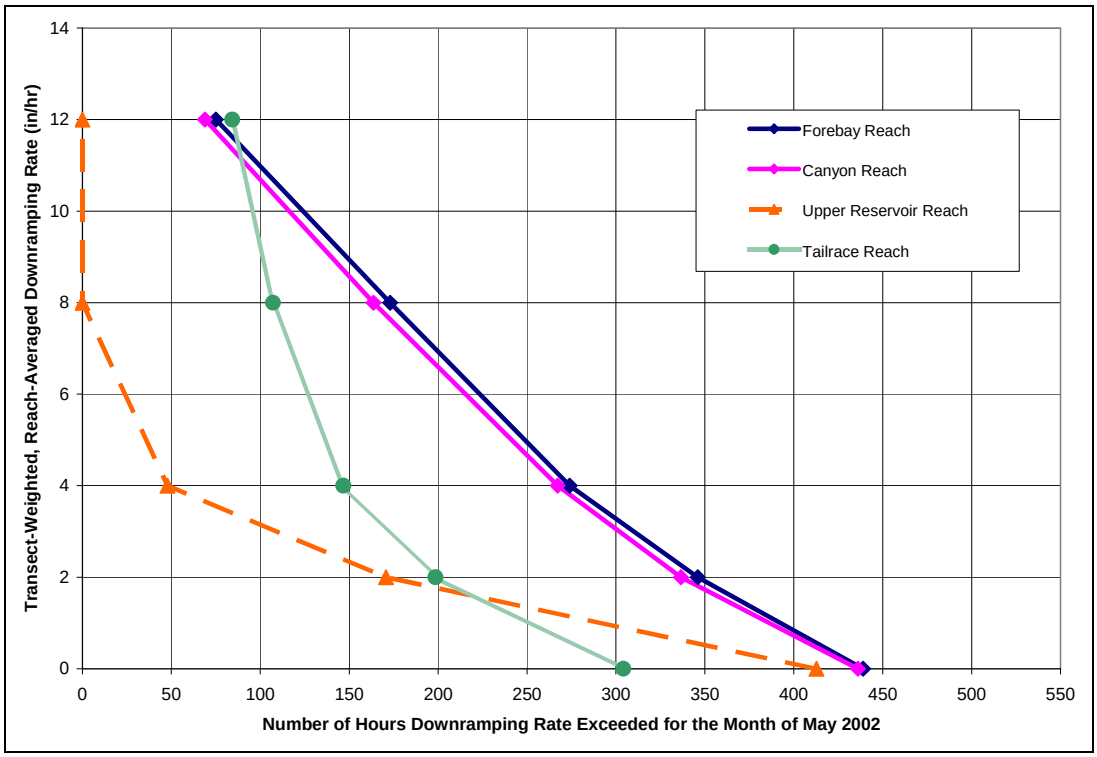


**Figure 4.2-8.** May of average year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

Based on Figures 4.2-6 through 4.2-8, and the figures included in Attachment C, some general observations can be made regarding the variability of downramping conditions by month.

The total number of hours of downramping can vary significantly by month. This is due to seasonal/monthly changes in regional power demands combined with seasonal/monthly changes in the annual runoff hydrograph. Project operations respond to higher peak power demands in the winter and summer and with more power generation therefore resulting in larger magnitudes of fluctuations as the Project is load following during these periods. The characteristic of the daily drawdown (the rate and the amount of drawdown) that occurs at the Project is affected by the inflow volume during a particular month. During months with lower inflow rates to the reservoir, Project operations would reflect the operational decision to limit the magnitude of the daily reservoir fluctuation to only that which will allow the reservoir to be subsequently refilled.

Secondly, monthly number of hours of downramping (and the associated downramping rates) in Boundary Reservoir was found to be lower during months when flow rates into the Boundary Reservoir were approaching or greater than the turbine capacity. Additionally, comparison of the monthly downramping exceedance curves for the months of April, May, June, and July (Attachment C) across the three years shows that during the wet and average years there was a significant reduction in the number of downramping hours. In the wet year (1997), the number of downramping hours was significantly less in May and June as compared to other months of the year, as inflows to the reservoir were in excess of the turbine capacity throughout the duration of these two months. Conversely, as seen in May and June of the dry year (2001), these months had the highest number of downramping hours and some of the highest rates of downramping of the year. During the average year (2002) releases from Box Canyon did not exceed the turbine capacity of the Project until near the end of May and for all of June. The reduction in the number of hours of downramping in May and June 2002 is reflective of this hydrologic condition.

## 5 REFERENCES

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R2 Resource Consultants, Inc. 2008. Compilation of Project Hydrologic Data - Preparation of Hydrologic Database and Hydrologic Statistics in Support of Relicensing Studies for the Boundary Hydroelectric Project (FERC No. 2144). Redmond, Washington. March 2008

SCL (Seattle City Light). 2007. Revised Study Plan for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. February 2007. Available online at: http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

WDFW and Ecology (Washington Department of Fish & Wildlife and Washington Department of Ecology). 2004. Instream Flow Study Guidelines: Technical and Habitat Suitability Issues. Updated April 5, 2004.

# Attachment A: Output Files for Downramping Analysis

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Tailrace - Wet Year 1997

TIME/DATE OF STUDY: 11:58 01/22/2009

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

Reach # 1 - Forebay

| Starting Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 53.0 | 42.0 | 50.0 | 46.0 | 48.0 | 47.0 | 27.0 | 39.0 | 22.0 | 13.0 | 13.0 | 6.0 | 14.0 | 1.0 | 0.0 |
| Feb | 44.0 | 45.0 | 49.0 | 39.0 | 32.0 | 36.0 | 29.0 | 21.0 | 17.0 | 11.0 | 14.0 | 7.0 | 12.0 | 1.0 | 0.0 |
| Mar | 62.0 | 75.0 | 75.0 | 48.0 | 24.0 | 36.0 | 28.0 | 22.0 | 13.0 | 15.0 | 9.0 | 8.0 | 10.0 | 0.0 | 0.0 |
| Apr | 109.0 | 75.0 | 43.0 | 28.0 | 37.0 | 25.0 | 21.0 | 8.0 | 22.0 | 4.0 | 6.0 | 7.0 | 5.0 | 0.0 | 0.0 |
| May | 48.0 | 60.0 | 23.0 | 14.0 | 11.0 | 8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jun | 3.0 | 16.0 | 3.0 | 0.0 | 3.0 | 6.0 | 2.0 | 3.0 | 3.0 | 0.0 | 0.0 | 1.0 | 3.0 | 1.0 | 0.0 |
| Jul | 48.0 | 35.0 | 82.0 | 53.0 | 57.0 | 48.0 | 27.0 | 15.0 | 13.0 | 11.0 | 4.0 | 6.0 | 10.0 | 3.0 | 0.0 |
| Aug | 24.0 | 46.0 | 50.0 | 45.0 | 66.0 | 61.0 | 57.0 | 35.0 | 44.0 | 15.0 | 10.0 | 6.0 | 3.0 | 0.0 | 0.0 |
| Sep | 17.0 | 15.0 | 48.0 | 60.0 | 74.0 | 80.0 | 58.0 | 62.0 | 22.0 | 12.0 | 5.0 | 5.0 | 2.0 | 0.0 | 0.0 |
| Oct | 6.0 | 8.0 | 11.0 | 19.0 | 21.0 | 40.0 | 34.0 | 64.0 | 79.0 | 66.0 | 40.0 | 28.0 | 61.0 | 3.0 | 0.0 |
| Nov | 11.0 | 21.0 | 24.0 | 24.0 | 45.0 | 55.0 | 48.0 | 62.0 | 44.0 | 41.0 | 34.0 | 23.0 | 36.0 | 1.0 | 0.0 |
| Dec | 11.0 | 20.0 | 30.0 | 52.0 | 37.0 | 52.0 | 56.0 | 53.0 | 44.0 | 43.0 | 29.0 | 26.0 | 28.0 | 0.0 | 0.0 |
| Annual | 436.0 | 458.0 | 488.0 | 428.0 | 455.0 | 494.0 | 387.0 | 384.0 | 323.0 | 231.0 | 165.0 | 123.0 | 184.0 | 10.0 | 0.0 |

Reach # 2 - Canyon

| Starting Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 55.6 | 45.2 | 47.6 | 48.9 | 51.3 | 49.3 | 32.9 | 30.3 | 21.6 | 13.8 | 9.8 | 7.4 | 11.5 | 0.1 | 0.0 |
| Feb | 44.6 | 45.4 | 52.2 | 43.6 | 30.1 | 42.6 | 26.5 | 19.4 | 15.3 | 14.5 | 10.3 | 5.0 | 11.1 | 0.4 | 0.0 |
| Mar | 71.6 | 76.2 | 73.6 | 41.9 | 28.9 | 39.4 | 25.3 | 18.7 | 14.7 | 15.1 | 8.1 | 5.5 | 8.5 | 0.0 | 0.0 |
| Apr | 115.2 | 68.9 | 45.0 | 32.3 | 32.6 | 24.4 | 20.2 | 10.5 | 16.3 | 6.2 | 6.2 | 3.9 | 4.4 | 0.0 | 0.0 |
| May | 51.5 | 62.2 | 21.3 | 14.5 | 7.7 | 4.2 | 0.6 | 0.2 | 0.2 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jun | 6.6 | 11.8 | 5.8 | 1.6 | 5.0 | 4.8 | 3.2 | 2.4 | 0.9 | 0.1 | 0.2 | 0.6 | 3.4 | 0.5 | 0.0 |
| Jul | 55.6 | 39.2 | 79.2 | 58.3 | 58.4 | 47.6 | 26.5 | 12.1 | 14.6 | 7.6 | 3.6 | 4.9 | 9.9 | 1.2 | 0.0 |
| Aug | 26.1 | 43.5 | 54.1 | 45.8 | 64.3 | 67.8 | 54.2 | 38.3 | 38.4 | 16.2 | 8.9 | 4.0 | 1.9 | 0.0 | 0.0 |
| Sep | 13.9 | 19.6 | 46.3 | 72.0 | 67.9 | 81.7 | 61.9 | 51.2 | 22.2 | 11.1 | 6.5 | 3.5 | 1.5 | 0.0 | 0.0 |
| Oct | 5.3 | 5.3 | 14.9 | 20.1 | 23.0 | 40.4 | 35.1 | 68.3 | 80.3 | 61.6 | 42.0 | 24.5 | 56.2 | 3.0 | 0.0 |
| Nov | 10.2 | 20.2 | 27.8 | 24.7 | 45.8 | 54.8 | 52.2 | 60.6 | 46.4 | 44.7 | 28.4 | 20.7 | 32.1 | 0.4 | 0.0 |
| Dec | 11.0 | 22.3 | 27.3 | 52.1 | 40.8 | 54.5 | 57.3 | 51.5 | 48.5 | 38.8 | 29.0 | 25.2 | 22.6 | 0.0 | 0.0 |
| Annual | 467.2 | 459.7 | 495.1 | 455.8 | 455.7 | 511.3 | 395.9 | 363.6 | 319.5 | 230.1 | 153.2 | 105.1 | 163.1 | 5.6 | 0.0 |

Reach # 3 - Upper_Reservoir

| Starting Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 97.8 | 99.1 | 102.2 | 79.8 | 39.8 | 19.1 | 7.0 | 5.1 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 69.1 | 102.3 | 98.4 | 70.6 | 30.5 | 9.7 | 1.5 | 1.4 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 178.1 | 108.4 | 70.8 | 29.1 | 26.3 | 6.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Apr | 194.6 | 87.7 | 45.3 | 12.9 | 5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| May | 126.0 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jun | 22.1 | 33.0 | 15.1 | 0.6 | 0.4 | 0.2 | 0.2 | 0.3 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jul | 158.6 | 134.5 | 93.8 | 41.4 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Aug | 54.7 | 74.9 | 102.8 | 97.5 | 81.8 | 48.2 | 7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sep | 30.4 | 57.2 | 138.1 | 121.4 | 86.2 | 24.2 | 3.5 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oct | 29.0 | 62.2 | 106.1 | 109.2 | 104.4 | 65.9 | 15.1 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nov | 28.5 | 62.3 | 102.1 | 132.5 | 111.4 | 37.3 | 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dec | 21.5 | 32.9 | 85.8 | 112.2 | 120.1 | 89.9 | 22.3 | 6.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Annual | 1010.4 | 857.0 | 960.5 | 807.3 | 611.8 | 301.2 | 60.9 | 14.8 | 2.3 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Tailrace - Wet Year 1997

TIME/DATE OF STUDY: 08:55 10/23/2008

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 44.0 | 37.9 | 35.1 | 31.0 | 30.9 | 22.5 | 17.1 | 21.3 | 18.9 | 13.1 | 10.1 | 12.6 | 35.7 | 7.1 | 3.9 |
| | Feb | 53.1 | 50.4 | 42.2 | 27.6 | 22.2 | 21.8 | 17.1 | 16.5 | 17.2 | 13.9 | 14.0 | 9.6 | 33.6 | 3.7 | 1.2 |
| | Mar | 66.1 | 41.8 | 39.9 | 37.3 | 32.0 | 25.3 | 20.3 | 12.5 | 9.4 | 8.2 | 7.5 | 6.9 | 28.0 | 9.9 | 4.7 |
| | Apr | 85.8 | 49.1 | 47.9 | 34.0 | 26.8 | 21.2 | 12.2 | 9.0 | 10.9 | 5.8 | 4.3 | 4.3 | 11.3 | 3.3 | 2.5 |
| | May | 36.3 | 28.3 | 30.2 | 16.0 | 7.1 | 5.7 | 2.1 | 2.1 | 1.8 | 0.7 | 0.3 | 0.3 | 0.4 | 0.0 | 0.0 |
| | Jun | 8.7 | 8.0 | 6.3 | 3.1 | 2.8 | 2.6 | 2.6 | 2.0 | 1.1 | 0.7 | 0.9 | 0.7 | 6.8 | 2.0 | 0.1 |
| | Jul | 58.5 | 44.3 | 37.5 | 28.8 | 22.0 | 22.5 | 19.1 | 18.0 | 14.2 | 14.2 | 9.8 | 9.1 | 25.7 | 7.7 | 4.3 |
| | Aug | 38.1 | 32.8 | 25.6 | 23.3 | 17.9 | 19.9 | 17.0 | 19.3 | 17.2 | 11.3 | 6.1 | 11.4 | 43.9 | 20.8 | 14.6 |
| | Sep | 31.8 | 20.6 | 19.7 | 14.3 | 13.8 | 16.6 | 19.1 | 15.7 | 17.0 | 13.0 | 12.9 | 13.1 | 55.7 | 20.7 | 19.4 |
| | Oct | 12.5 | 11.3 | 9.8 | 8.4 | 7.4 | 6.8 | 6.7 | 8.2 | 7.1 | 7.5 | 6.4 | 7.8 | 90.9 | 61.7 | 46.2 |
| | Nov | 24.9 | 20.2 | 18.2 | 13.6 | 17.0 | 14.2 | 12.5 | 17.5 | 13.3 | 11.8 | 7.7 | 13.8 | 60.0 | 39.2 | 24.1 |
| | Dec | 29.8 | 23.6 | 23.7 | 21.4 | 17.0 | 17.5 | 15.1 | 12.2 | 16.0 | 15.8 | 13.4 | 11.6 | 46.4 | 17.5 | 26.4 |
| | Annual | 489.7 | 368.2 | 336.2 | 258.6 | 216.9 | 196.6 | 160.9 | 154.3 | 144.1 | 116.0 | 93.5 | 101.1 | 438.5 | 193.7 | 147.5 |

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Reservoir - Dry Year 2001

TIME/DATE OF STUDY: 06:40 10/23/2008

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

Reach # 1 - Forebay

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 31.0 | 41.0 | 72.0 | 44.0 | 43.0 | 53.0 | 29.0 | 22.0 | 27.0 | 17.0 | 13.0 | 10.0 | 20.0 | 1.0 | 0.0 |
| | Feb | 74.0 | 84.0 | 54.0 | 36.0 | 37.0 | 29.0 | 11.0 | 14.0 | 13.0 | 1.0 | 3.0 | 4.0 | 1.0 | 0.0 | 0.0 |
| | Mar | 70.0 | 76.0 | 79.0 | 68.0 | 52.0 | 27.0 | 19.0 | 5.0 | 14.0 | 4.0 | 1.0 | 0.0 | 4.0 | 0.0 | 0.0 |
| | Apr | 50.0 | 46.0 | 60.0 | 46.0 | 55.0 | 63.0 | 32.0 | 25.0 | 8.0 | 15.0 | 3.0 | 3.0 | 6.0 | 0.0 | 1.0 |
| | May | 11.0 | 6.0 | 12.0 | 21.0 | 15.0 | 22.0 | 28.0 | 25.0 | 31.0 | 23.0 | 33.0 | 61.0 | 161.0 | 16.0 | 0.0 |
| | Jun | 8.0 | 9.0 | 16.0 | 13.0 | 23.0 | 31.0 | 36.0 | 32.0 | 60.0 | 33.0 | 49.0 | 52.0 | 94.0 | 6.0 | 0.0 |
| | Jul | 21.0 | 35.0 | 76.0 | 56.0 | 50.0 | 66.0 | 42.0 | 23.0 | 19.0 | 14.0 | 10.0 | 8.0 | 24.0 | 0.0 | 0.0 |
| | Aug | 46.0 | 63.0 | 79.0 | 96.0 | 65.0 | 40.0 | 17.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sep | 37.0 | 52.0 | 80.0 | 76.0 | 56.0 | 35.0 | 19.0 | 4.0 | 12.0 | 7.0 | 12.0 | 5.0 | 2.0 | 0.0 | 0.0 |
| | Oct | 20.0 | 32.0 | 51.0 | 64.0 | 64.0 | 69.0 | 50.0 | 39.0 | 35.0 | 12.0 | 16.0 | 10.0 | 25.0 | 0.0 | 0.0 |
| | Nov | 22.0 | 25.0 | 50.0 | 60.0 | 52.0 | 68.0 | 54.0 | 34.0 | 35.0 | 19.0 | 17.0 | 3.0 | 4.0 | 0.0 | 0.0 |
| | Dec | 48.0 | 66.0 | 111.0 | 83.0 | 64.0 | 43.0 | 17.0 | 11.0 | 8.0 | 2.0 | 5.0 | 3.0 | 8.0 | 3.0 | 0.0 |
| | Annual | 438.0 | 535.0 | 740.0 | 663.0 | 576.0 | 546.0 | 354.0 | 234.0 | 262.0 | 147.0 | 162.0 | 159.0 | 349.0 | 26.0 | 1.0 |

Reach # 2 - Canyon

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 32.2 | 46.9 | 67.5 | 44.9 | 45.8 | 52.4 | 33.2 | 20.2 | 24.9 | 15.1 | 15.0 | 11.6 | 17.0 | 0.2 | 0.0 |
| | Feb | 71.6 | 86.2 | 52.7 | 38.4 | 39.3 | 27.7 | 10.9 | 17.7 | 8.3 | 1.7 | 3.7 | 2.7 | 0.9 | 0.0 | 0.0 |
| | Mar | 72.5 | 72.4 | 81.2 | 72.4 | 50.1 | 30.3 | 15.5 | 3.7 | 14.8 | 3.2 | 0.9 | 0.8 | 3.2 | 0.0 | 0.0 |
| | Apr | 49.8 | 47.9 | 62.5 | 47.9 | 52.4 | 67.0 | 28.5 | 20.5 | 13.8 | 11.5 | 3.3 | 3.9 | 4.8 | 0.1 | 0.9 |
| | May | 8.1 | 7.0 | 13.8 | 22.6 | 16.8 | 24.9 | 26.6 | 27.0 | 30.1 | 25.8 | 37.9 | 65.8 | 144.2 | 12.8 | 0.0 |
| | Jun | 8.2 | 11.9 | 17.6 | 14.2 | 19.4 | 33.6 | 38.6 | 35.9 | 54.0 | 37.0 | 48.9 | 54.6 | 83.1 | 5.9 | 0.0 |
| | Jul | 21.0 | 33.8 | 76.5 | 57.1 | 53.0 | 66.0 | 40.0 | 26.6 | 17.1 | 11.2 | 11.5 | 6.9 | 23.1 | 0.0 | 0.0 |
| | Aug | 46.9 | 62.8 | 79.8 | 97.2 | 66.0 | 39.6 | 15.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sep | 36.4 | 51.4 | 82.7 | 77.9 | 53.5 | 36.0 | 17.7 | 4.1 | 11.4 | 7.8 | 11.3 | 5.4 | 1.6 | 0.0 | 0.0 |
| | Oct | 13.8 | 32.0 | 50.5 | 65.7 | 68.9 | 68.9 | 51.8 | 42.0 | 30.5 | 13.4 | 13.9 | 11.0 | 19.9 | 0.0 | 0.0 |
| | Nov | 22.8 | 23.3 | 50.2 | 56.9 | 58.8 | 70.8 | 53.1 | 35.5 | 35.6 | 17.4 | 12.7 | 2.2 | 3.6 | 0.0 | 0.0 |
| | Dec | 43.8 | 71.4 | 113.3 | 84.5 | 62.1 | 41.2 | 21.2 | 7.8 | 6.0 | 5.0 | 3.5 | 3.6 | 6.7 | 2.9 | 0.0 |
| | Annual | 426.9 | 546.9 | 748.5 | 679.6 | 586.2 | 558.1 | 352.5 | 241.0 | 246.6 | 149.0 | 162.6 | 168.5 | 308.2 | 22.1 | 0.9 |

Reach # 3 - Upper_Reservoir

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 42.2 | 59.3 | 86.6 | 75.2 | 75.6 | 43.9 | 24.0 | 24.0 | 11.1 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Feb | 76.5 | 87.0 | 68.3 | 53.2 | 38.8 | 28.9 | 14.2 | 7.3 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Mar | 68.2 | 89.7 | 103.8 | 86.0 | 42.1 | 23.1 | 10.7 | 6.1 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Apr | 58.9 | 68.8 | 89.5 | 65.1 | 77.0 | 42.8 | 20.1 | 4.8 | 3.8 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | May | 99.0 | 75.5 | 74.5 | 65.7 | 67.3 | 51.0 | 13.3 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jun | 43.4 | 68.6 | 91.3 | 93.4 | 76.0 | 72.8 | 27.9 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jul | 26.2 | 56.3 | 117.6 | 81.8 | 98.6 | 50.6 | 13.9 | 6.8 | 4.2 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Aug | 52.9 | 56.3 | 114.4 | 113.6 | 44.9 | 29.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sep | 57.0 | 65.2 | 121.8 | 72.9 | 46.4 | 20.6 | 9.9 | 6.0 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oct | 30.3 | 58.3 | 129.0 | 134.3 | 103.6 | 32.8 | 7.9 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Nov | 21.0 | 45.1 | 95.0 | 114.4 | 103.4 | 62.3 | 10.8 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Dec | 48.4 | 93.8 | 167.2 | 103.3 | 42.4 | 27.5 | 7.0 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Annual | 624.1 | 823.9 | 1258.9 | 1058.8 | 816.1 | 485.8 | 159.6 | 63.7 | 27.5 | 5.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Tailrace - Dry Year 2001

TIME/DATE OF STUDY: 08:50 10/23/2008

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

Reach # 1 - Tailrace

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 48.7 | 34.8 | 39.7 | 26.6 | 20.4 | 25.7 | 30.2 | 31.1 | 14.3 | 8.5 | 6.5 | 7.5 | 17.5 | 4.7 | 3.5 |
| | Feb | 60.2 | 39.6 | 32.9 | 19.4 | 18.8 | 17.7 | 17.2 | 18.9 | 22.1 | 8.5 | 4.0 | 3.8 | 12.5 | 4.0 | 2.9 |
| | Mar | 68.9 | 51.0 | 44.2 | 37.2 | 31.6 | 26.4 | 16.1 | 13.7 | 14.1 | 11.6 | 5.9 | 2.2 | 9.9 | 2.1 | 3.0 |
| | Apr | 47.8 | 26.0 | 32.3 | 25.6 | 25.1 | 25.9 | 21.3 | 14.2 | 16.4 | 8.7 | 7.5 | 6.4 | 25.7 | 5.5 | 10.1 |
| | May | 22.5 | 21.3 | 21.9 | 14.0 | 12.2 | 15.9 | 11.3 | 11.0 | 9.4 | 8.9 | 7.6 | 10.5 | 57.9 | 44.1 | 37.6 |
| | Jun | 21.3 | 15.6 | 13.1 | 9.4 | 6.6 | 9.6 | 13.5 | 17.6 | 16.9 | 8.9 | 7.7 | 6.8 | 100.0 | 35.8 | 18.2 |
| | Jul | 48.8 | 36.8 | 31.5 | 20.4 | 16.6 | 22.4 | 23.4 | 44.8 | 43.0 | 12.1 | 6.7 | 6.0 | 19.9 | 6.0 | 12.2 |
| | Aug | 70.8 | 48.5 | 22.2 | 23.1 | 20.2 | 23.9 | 18.7 | 25.1 | 15.7 | 6.0 | 4.1 | 1.8 | 7.3 | 1.9 | 3.7 |
| | Sep | 84.0 | 49.4 | 29.9 | 32.4 | 19.5 | 13.2 | 13.5 | 12.7 | 7.7 | 12.0 | 3.5 | 2.5 | 4.5 | 1.5 | 1.8 |
| | Oct | 63.2 | 46.3 | 49.7 | 29.4 | 23.8 | 18.9 | 14.2 | 15.0 | 21.0 | 9.1 | 5.7 | 4.7 | 26.8 | 15.2 | 6.8 |
| | Nov | 52.8 | 45.6 | 48.0 | 26.7 | 16.8 | 17.3 | 16.5 | 19.4 | 13.0 | 6.1 | 5.7 | 4.8 | 36.8 | 9.0 | 8.3 |
| | Dec | 46.4 | 33.6 | 31.3 | 31.0 | 28.2 | 28.7 | 28.0 | 22.4 | 28.6 | 9.8 | 10.1 | 8.3 | 18.1 | 4.0 | 7.1 |
| | Annual | 635.4 | 448.6 | 396.7 | 295.1 | 239.9 | 245.7 | 223.9 | 246.0 | 222.3 | 110.0 | 75.1 | 65.4 | 337.0 | 133.8 | 115.2 |

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Tailrace - Average Year 2002

TIME/DATE OF STUDY: 12:30 01/22/2009

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

Reach # 1 - Forebay

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 15.0 | 26.0 | 43.0 | 61.0 | 55.0 | 72.0 | 46.0 | 34.0 | 35.0 | 24.0 | 20.0 | 17.0 | 23.0 | 4.0 | 1.0 |
| | Feb | 20.0 | 24.0 | 42.0 | 59.0 | 40.0 | 53.0 | 43.0 | 32.0 | 40.0 | 19.0 | 19.0 | 20.0 | 16.0 | 0.0 | 0.0 |
| | Mar | 13.0 | 12.0 | 37.0 | 41.0 | 49.0 | 60.0 | 53.0 | 39.0 | 36.0 | 35.0 | 26.0 | 21.0 | 32.0 | 5.0 | 0.0 |
| | Apr | 26.0 | 25.0 | 48.0 | 24.0 | 35.0 | 35.0 | 39.0 | 39.0 | 44.0 | 29.0 | 20.0 | 20.0 | 43.0 | 9.0 | 0.0 |
| | May | 63.0 | 30.0 | 44.0 | 28.0 | 25.0 | 32.0 | 20.0 | 24.0 | 38.0 | 18.0 | 28.0 | 14.0 | 66.0 | 7.0 | 2.0 |
| | Jun | 62.0 | 45.0 | 22.0 | 10.0 | 5.0 | 3.0 | 1.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jul | 36.0 | 21.0 | 49.0 | 41.0 | 55.0 | 47.0 | 56.0 | 38.0 | 47.0 | 22.0 | 17.0 | 8.0 | 13.0 | 0.0 | 0.0 |
| | Aug | 31.0 | 47.0 | 49.0 | 64.0 | 55.0 | 63.0 | 46.0 | 45.0 | 29.0 | 12.0 | 3.0 | 2.0 | 2.0 | 0.0 | 0.0 |
| | Sep | 43.0 | 41.0 | 61.0 | 87.0 | 67.0 | 51.0 | 35.0 | 15.0 | 14.0 | 0.0 | 2.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oct | 16.0 | 31.0 | 42.0 | 57.0 | 95.0 | 101.0 | 59.0 | 28.0 | 16.0 | 11.0 | 4.0 | 1.0 | 4.0 | 0.0 | 0.0 |
| | Nov | 29.0 | 44.0 | 66.0 | 78.0 | 69.0 | 61.0 | 38.0 | 30.0 | 20.0 | 11.0 | 3.0 | 1.0 | 4.0 | 0.0 | 0.0 |
| | Dec | 27.0 | 21.0 | 48.0 | 34.0 | 36.0 | 34.0 | 38.0 | 23.0 | 28.0 | 33.0 | 22.0 | 19.0 | 52.0 | 0.0 | 0.0 |
| | Annual | 381.0 | 367.0 | 551.0 | 584.0 | 586.0 | 612.0 | 474.0 | 347.0 | 348.0 | 214.0 | 164.0 | 123.0 | 255.0 | 25.0 | 3.0 |

Reach # 2 - Canyon

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 13.1 | 24.2 | 48.6 | 59.2 | 57.6 | 68.3 | 47.5 | 37.6 | 34.9 | 24.5 | 19.0 | 15.0 | 20.6 | 4.1 | 0.8 |
| | Feb | 20.5 | 26.4 | 39.7 | 61.8 | 43.2 | 48.5 | 45.9 | 37.3 | 34.6 | 18.4 | 18.5 | 20.4 | 13.5 | 0.0 | 0.0 |
| | Mar | 12.9 | 14.7 | 30.8 | 49.0 | 50.6 | 56.6 | 52.4 | 44.1 | 37.4 | 31.7 | 24.5 | 21.5 | 29.8 | 3.8 | 0.0 |
| | Apr | 28.0 | 20.2 | 49.4 | 33.0 | 36.0 | 37.0 | 33.6 | 38.8 | 47.1 | 30.8 | 18.3 | 20.2 | 38.4 | 6.7 | 0.0 |
| | May | 63.4 | 36.2 | 39.4 | 29.9 | 22.7 | 30.7 | 22.8 | 27.3 | 36.7 | 19.8 | 21.3 | 17.0 | 60.2 | 7.1 | 1.6 |
| | Jun | 69.8 | 45.9 | 18.1 | 8.6 | 3.6 | 2.0 | 0.8 | 0.3 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jul | 37.7 | 22.1 | 47.9 | 50.7 | 52.0 | 52.4 | 54.3 | 38.7 | 41.4 | 20.9 | 17.3 | 6.7 | 9.5 | 0.0 | 0.0 |
| | Aug | 31.5 | 44.6 | 53.3 | 64.3 | 54.1 | 60.7 | 50.6 | 43.2 | 29.5 | 9.2 | 3.5 | 1.5 | 2.0 | 0.0 | 0.0 |
| | Sep | 46.0 | 40.4 | 64.2 | 90.0 | 62.1 | 53.4 | 33.8 | 13.8 | 12.7 | 0.5 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oct | 20.6 | 25.6 | 42.1 | 61.9 | 96.7 | 104.4 | 52.3 | 27.1 | 19.0 | 7.4 | 3.9 | 0.9 | 3.2 | 0.0 | 0.0 |
| | Nov | 28.0 | 48.1 | 64.8 | 80.6 | 74.8 | 55.6 | 39.5 | 29.1 | 21.2 | 9.5 | 1.4 | 1.4 | 3.6 | 0.0 | 0.0 |
| | Dec | 26.8 | 21.0 | 45.6 | 38.1 | 35.4 | 34.4 | 37.9 | 27.8 | 28.9 | 30.6 | 21.6 | 22.1 | 44.4 | 0.0 | 0.0 |
| | Annual | 398.4 | 369.5 | 543.8 | 627.1 | 588.7 | 604.0 | 471.3 | 365.2 | 343.9 | 203.3 | 150.9 | 126.6 | 225.2 | 21.6 | 2.4 |

Reach # 3 - Upper_Reservoir

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 22.7 | 60.4 | 110.4 | 116.5 | 97.1 | 55.0 | 13.0 | 6.9 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Feb | 30.7 | 50.2 | 101.0 | 95.3 | 82.9 | 46.8 | 21.5 | 7.7 | 2.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Mar | 38.7 | 70.8 | 124.3 | 101.1 | 79.7 | 46.2 | 12.8 | 6.4 | 4.0 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Apr | 94.0 | 126.2 | 97.7 | 55.8 | 33.3 | 24.1 | 10.6 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | May | 140.3 | 101.7 | 79.7 | 43.2 | 33.5 | 12.0 | 2.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jun | 100.2 | 10.2 | 0.5 | 0.7 | 0.3 | 0.5 | 1.0 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Jul | 148.7 | 102.5 | 127.1 | 69.6 | 28.5 | 23.7 | 5.4 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Aug | 34.2 | 57.3 | 79.6 | 90.2 | 78.7 | 82.9 | 24.7 | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Sep | 46.5 | 57.9 | 112.6 | 79.1 | 77.5 | 38.7 | 11.2 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Oct | 40.0 | 33.9 | 99.6 | 166.5 | 99.6 | 35.5 | 3.7 | 2.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Nov | 33.6 | 69.4 | 119.8 | 120.5 | 83.6 | 31.8 | 9.3 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Dec | 46.3 | 54.0 | 81.8 | 86.2 | 76.0 | 66.4 | 27.8 | 16.1 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Annual | 775.8 | 794.6 | 1134.2 | 1024.6 | 770.6 | 463.7 | 143.4 | 52.9 | 11.4 | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Boundary Hydroelectric Project (FERC No. 2144)
Historical Downramping Analysis in Support of Study 7 (Q <= 80,000 cfs)
Boundary Tailrace - Average Year 2002

TIME/DATE OF STUDY: 07:03 10/23/2008

Downramping Analysis: Full Range of Water Surface Elevations
Reach Averaging Results

Reach # 1 - Tailrace

| Starting | Ending | (0,1] | (1,2] | (2,3] | (3,4] | (4,5] | (5,6] | (6,7] | (7,8] | (8,9] | (9,10] | (10,11] | (11,12] | (12,18] | (18,24] | (>24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | 39.3 | 25.3 | 26.7 | 18.0 | 10.9 | 13.4 | 17.6 | 22.9 | 18.5 | 12.5 | 8.9 | 7.5 | 36.7 | 26.8 | 14.1 |
| | Feb | 33.6 | 26.0 | 26.4 | 15.3 | 12.8 | 14.7 | 19.8 | 24.2 | 29.7 | 9.7 | 6.2 | 3.4 | 34.9 | 20.2 | 5.9 |
| | Mar | 38.6 | 29.8 | 22.2 | 19.0 | 17.9 | 21.4 | 15.5 | 24.1 | 20.7 | 12.0 | 5.6 | 8.2 | 58.1 | 19.4 | 12.1 |
| | Apr | 42.5 | 38.1 | 37.0 | 28.1 | 23.2 | 21.3 | 15.9 | 16.0 | 17.6 | 8.6 | 7.3 | 8.8 | 37.0 | 14.9 | 18.6 |
| | May | 66.6 | 39.1 | 31.4 | 20.4 | 14.1 | 11.6 | 6.9 | 6.9 | 7.5 | 4.2 | 5.0 | 6.2 | 34.4 | 32.5 | 17.4 |
| | Jun | 63.6 | 33.7 | 22.3 | 8.8 | 4.5 | 3.7 | 1.7 | 1.1 | 0.6 | 0.3 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 |
| | Jul | 40.1 | 35.1 | 32.2 | 27.1 | 21.2 | 20.4 | 12.3 | 17.0 | 13.0 | 13.7 | 11.2 | 10.2 | 47.1 | 17.4 | 12.5 |
| | Aug | 48.2 | 33.0 | 32.8 | 25.1 | 22.5 | 16.4 | 15.6 | 35.5 | 33.9 | 11.1 | 5.8 | 5.6 | 14.9 | 3.3 | 1.6 |
| | Sep | 69.6 | 50.4 | 47.1 | 34.7 | 25.1 | 23.2 | 17.7 | 16.7 | 18.5 | 8.6 | 6.5 | 5.7 | 13.2 | 7.0 | 7.5 |
| | Oct | 53.1 | 34.0 | 28.3 | 18.6 | 17.4 | 11.1 | 16.9 | 22.6 | 22.7 | 15.7 | 8.1 | 4.4 | 36.1 | 10.0 | 5.4 |
| | Nov | 59.1 | 33.9 | 34.0 | 26.6 | 24.5 | 20.3 | 21.8 | 23.2 | 20.1 | 12.5 | 9.4 | 6.8 | 20.1 | 8.2 | 11.0 |
| | Dec | 46.1 | 30.3 | 34.6 | 23.9 | 25.5 | 26.3 | 23.5 | 32.8 | 29.5 | 12.5 | 5.5 | 6.4 | 34.8 | 6.5 | 7.1 |
| | Annual | 600.2 | 408.7 | 375.0 | 265.6 | 219.7 | 203.6 | 185.2 | 243.1 | 232.4 | 121.3 | 79.6 | 73.3 | 367.6 | 166.1 | 113.2 |

# Attachment B: Figures of Hourly Downramping Time Series

This attachment contains the following figures:

Figure B-1. Hourly time series of downramping rates in Boundary Dam forebay for 1997 (wet year).
Figure B-2. Hourly time series of downramping rates in Boundary Dam forebay for 2001 (dry year).
Figure B-3. Hourly time series of downramping rates in Boundary Dam forebay for 2002 (average year).
Figure B-4. Hourly time series of downramping rates downstream of Metaline Falls for 1997 (wet year).
Figure B-5. Hourly time series of downramping rates downstream of Metaline Falls for 2001 (dry year).
Figure B-6. Hourly time series of downramping rates downstream of Metaline Falls for 2002 (average year).
Figure B-7. Hourly time series of downramping rates upstream of Metaline Falls for 1997 (wet year).
Figure B-8. Hourly time series of downramping rates upstream of Metaline Falls for 2001 (dry year).
Figure B-9. Hourly time series of downramping rates upstream of Metaline Falls for 2002 (average year).
Figure B-10. Hourly time series of downramping rates at Box Canyon tailrace for 1997 (wet year).
Figure B-11. Hourly time series of downramping rates at Box Canyon tailrace for 2001 (dry year).
Figure B-12. Hourly time series of downramping rates at Box Canyon tailrace for 2002 (average year).
Figure B-13. Hourly time series of downramping rates at U.S.-Canada border for 1997 (wet year).
Figure B-14. Hourly time series of downramping rates at U.S.-Canada border for 2001 (dry year).
Figure B-15. Hourly time series of downramping rates at U.S.-Canada border for 2002 (average year).
Figure B-16. Hourly time series of downramping rates at Boundary Dam tailrace for 1997 (wet year).
Figure B-17. Hourly time series of downramping rates at Boundary Dam tailrace for 2001 (dry year).
Figure B-18. Hourly time series of downramping rates at Boundary Dam tailrace for 2002 (average year).

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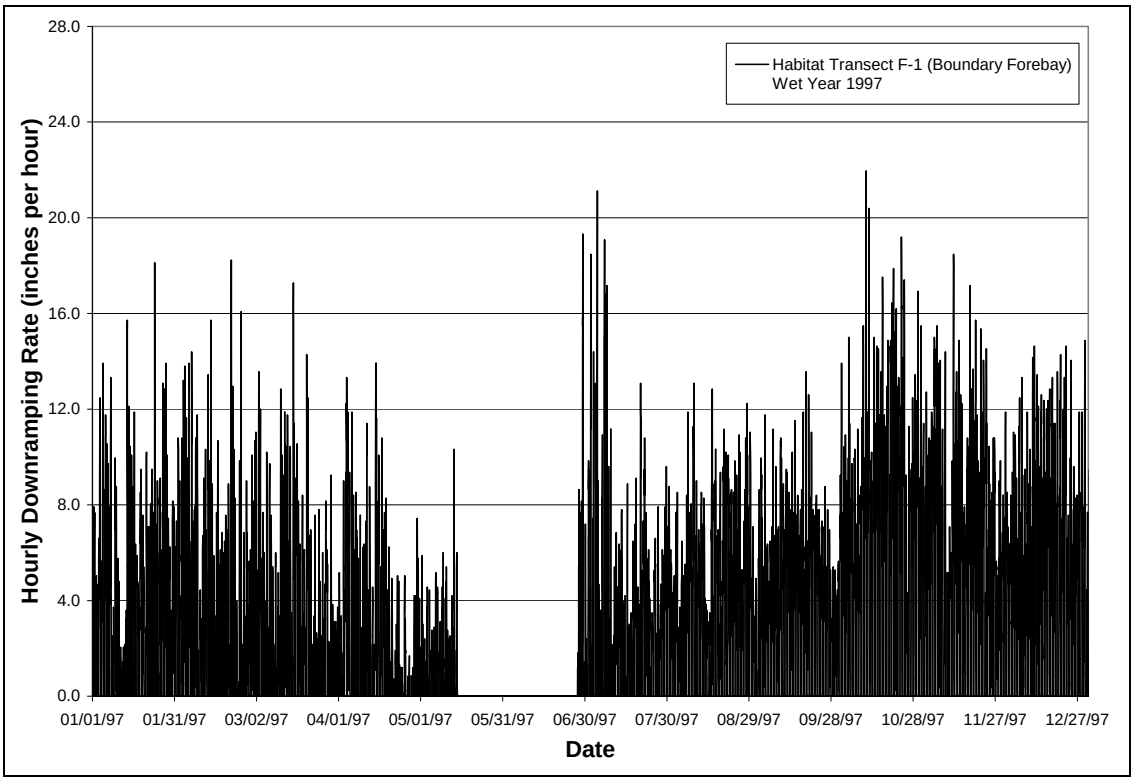


**Figure B-1.** Hourly time series of downramping rates in Boundary Dam forebay for 1997 (wet year).

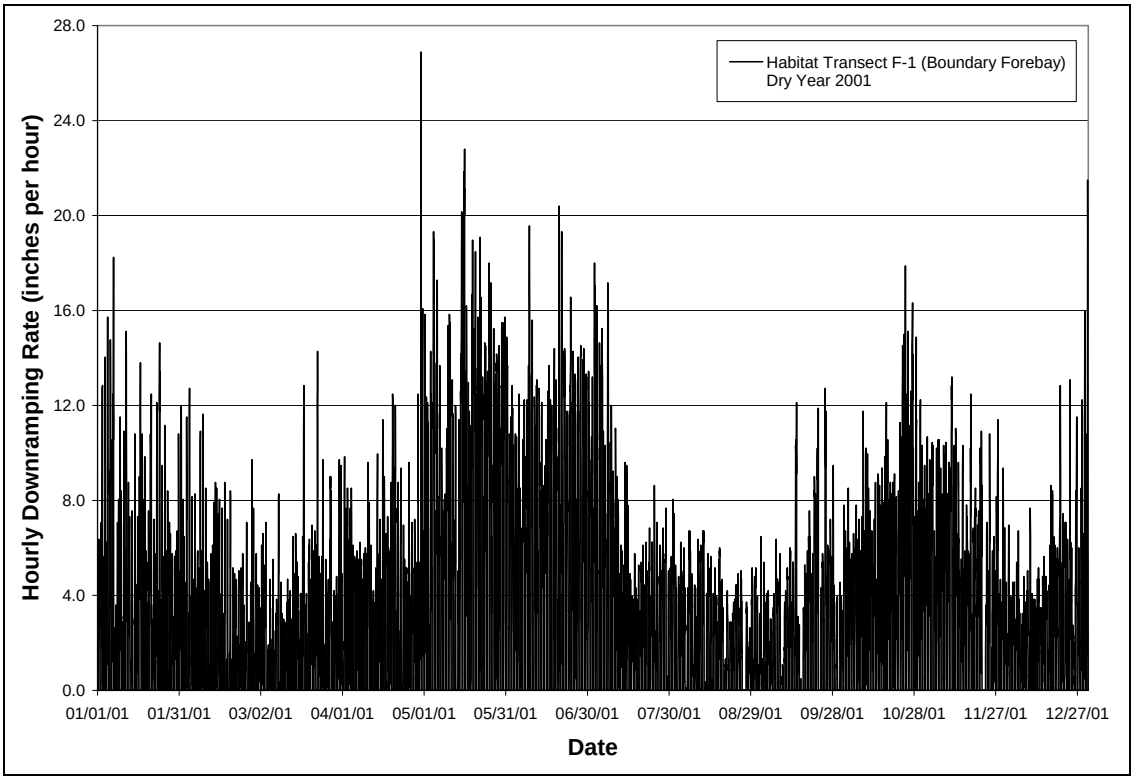


**Figure B-2.** Hourly time series of downramping rates in Boundary Dam forebay for 2001 (dry year).

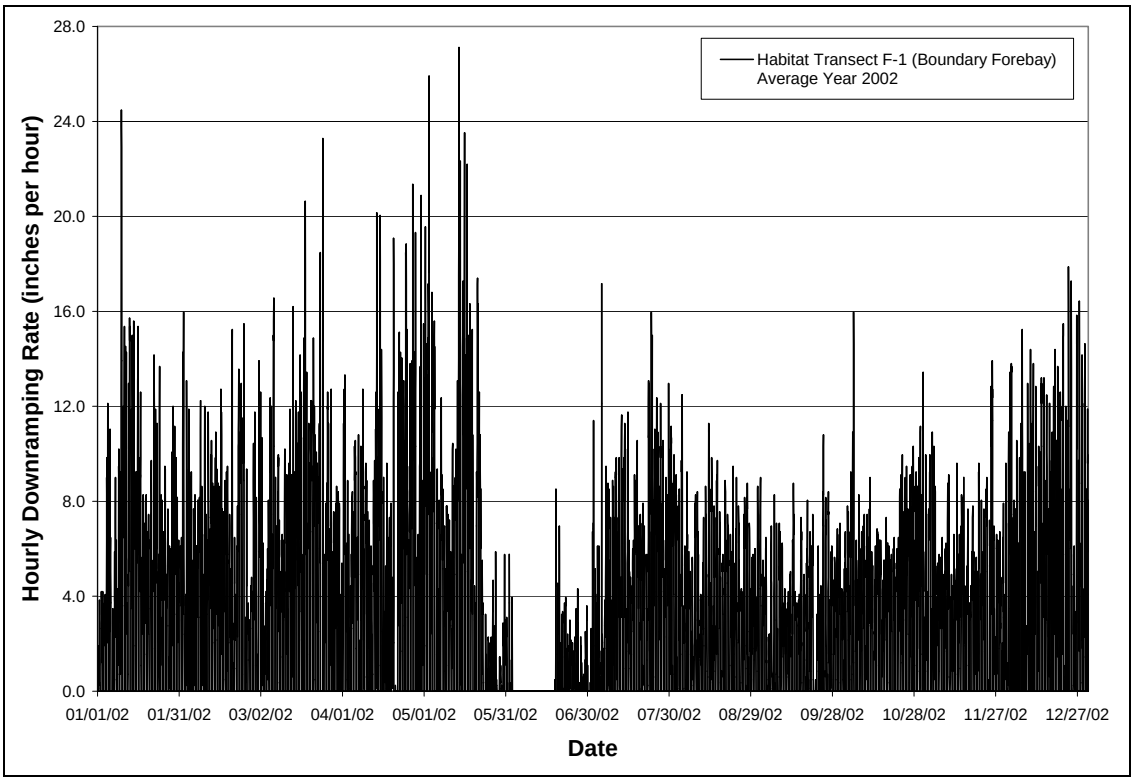


**Figure B-3.** Hourly time series of downramping rates in Boundary Dam forebay for 2002 (average year).

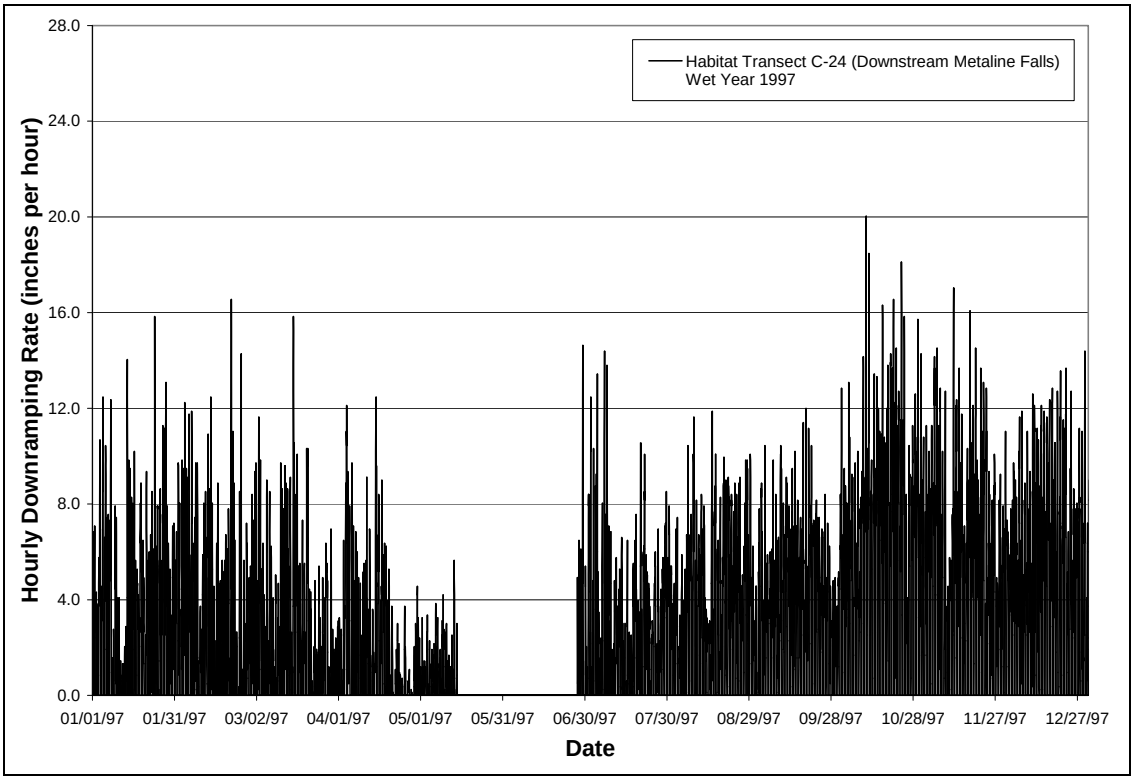


**Figure B-4.** Hourly time series of downramping rates downstream of Metaline Falls for 1997 (wet year).

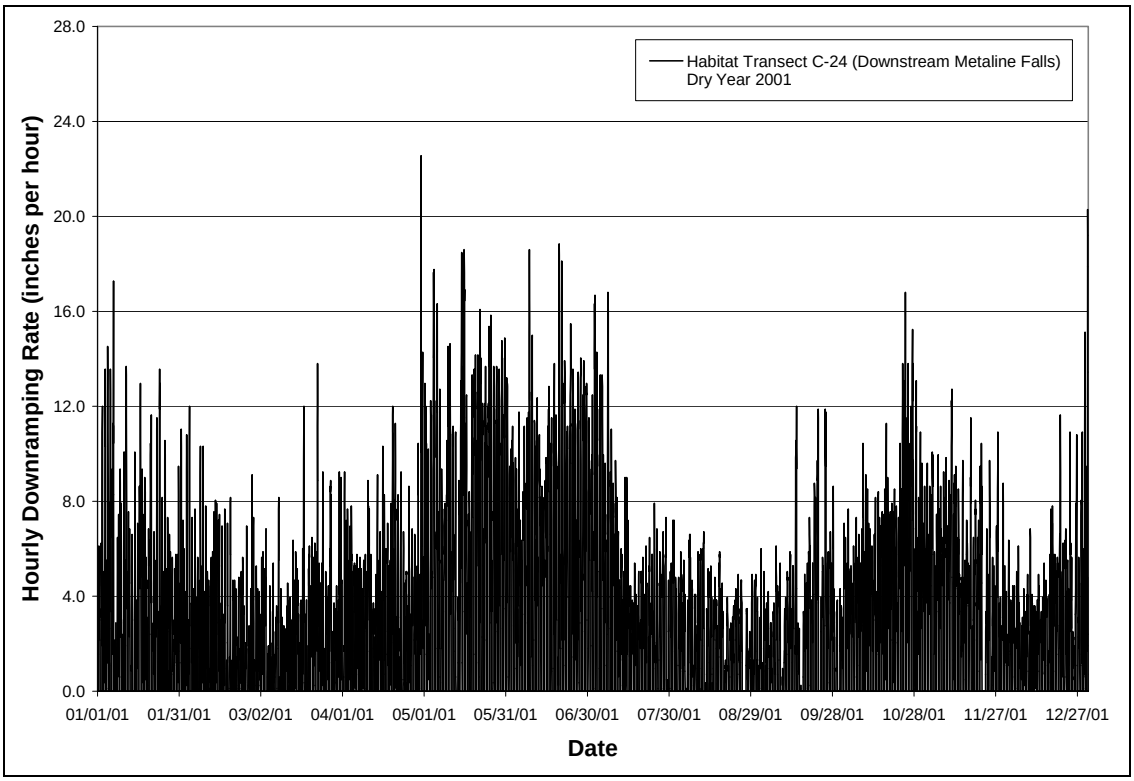


**Figure B-5.** Hourly time series of downramping rates downstream of Metaline Falls for 2001 (dry year).

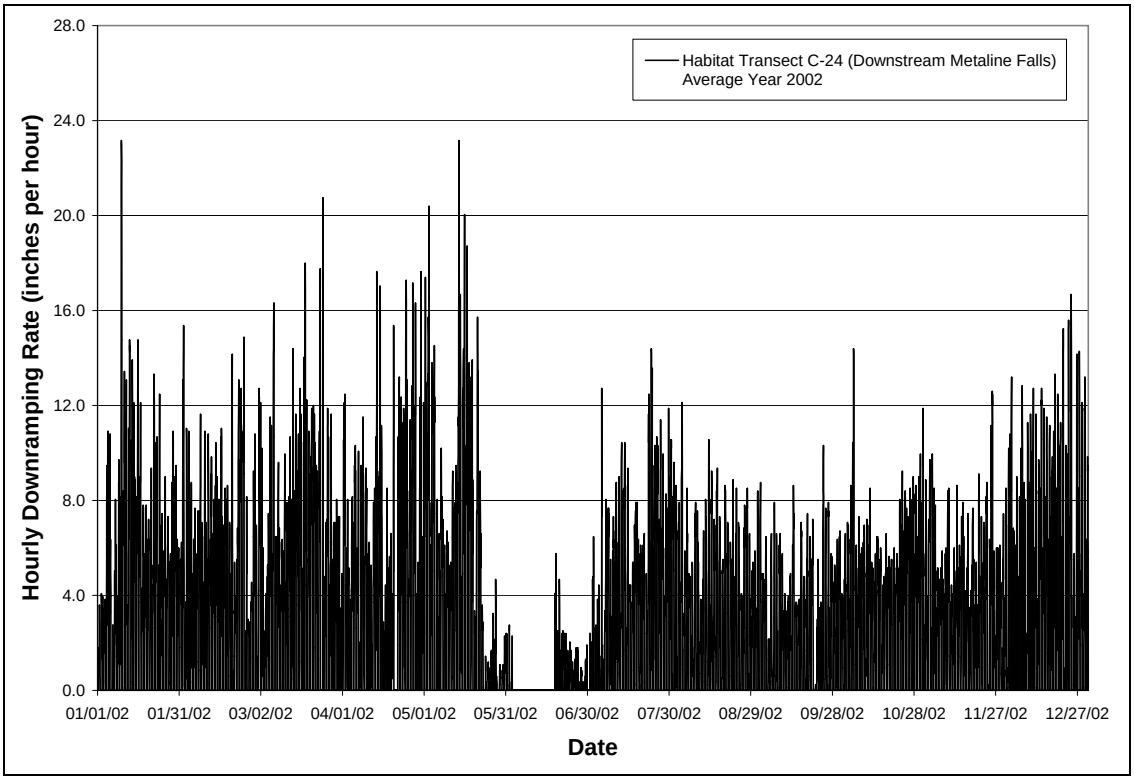


**Figure B-6.** Hourly time series of downramping rates downstream of Metaline Falls for 2002 (average year).

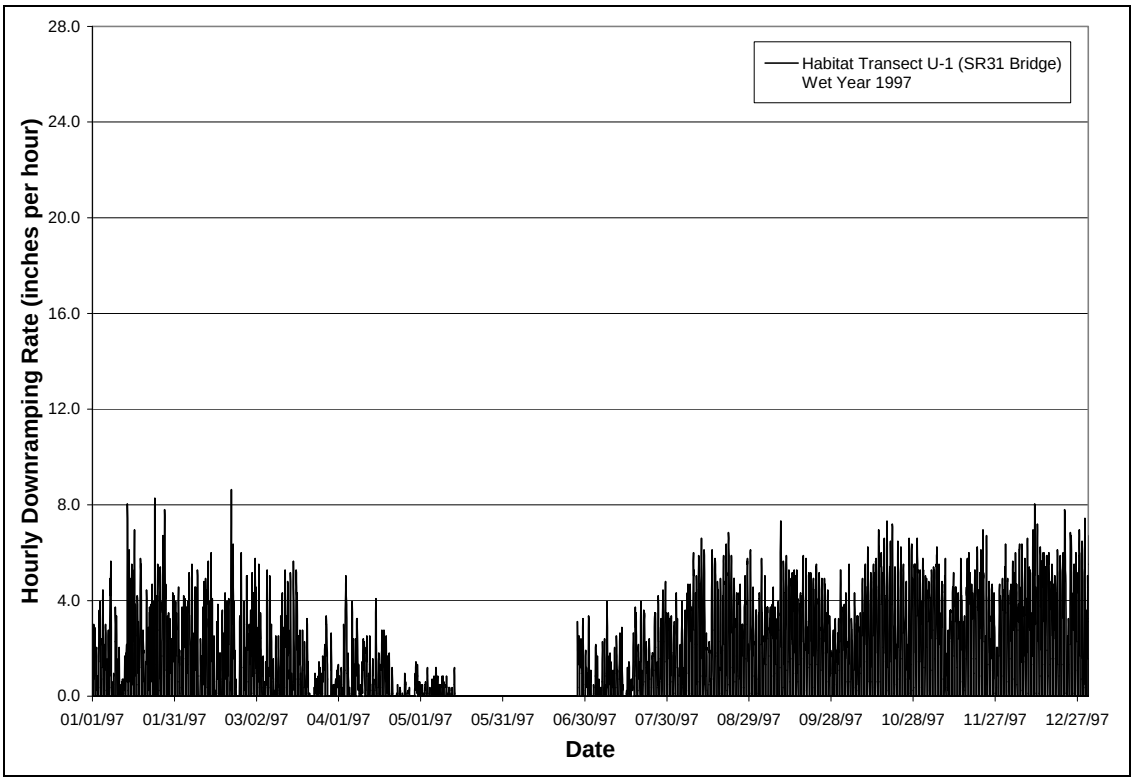


**Figure B-7.** Hourly time series of downramping rates upstream of Metaline Falls for 1997 (wet year).

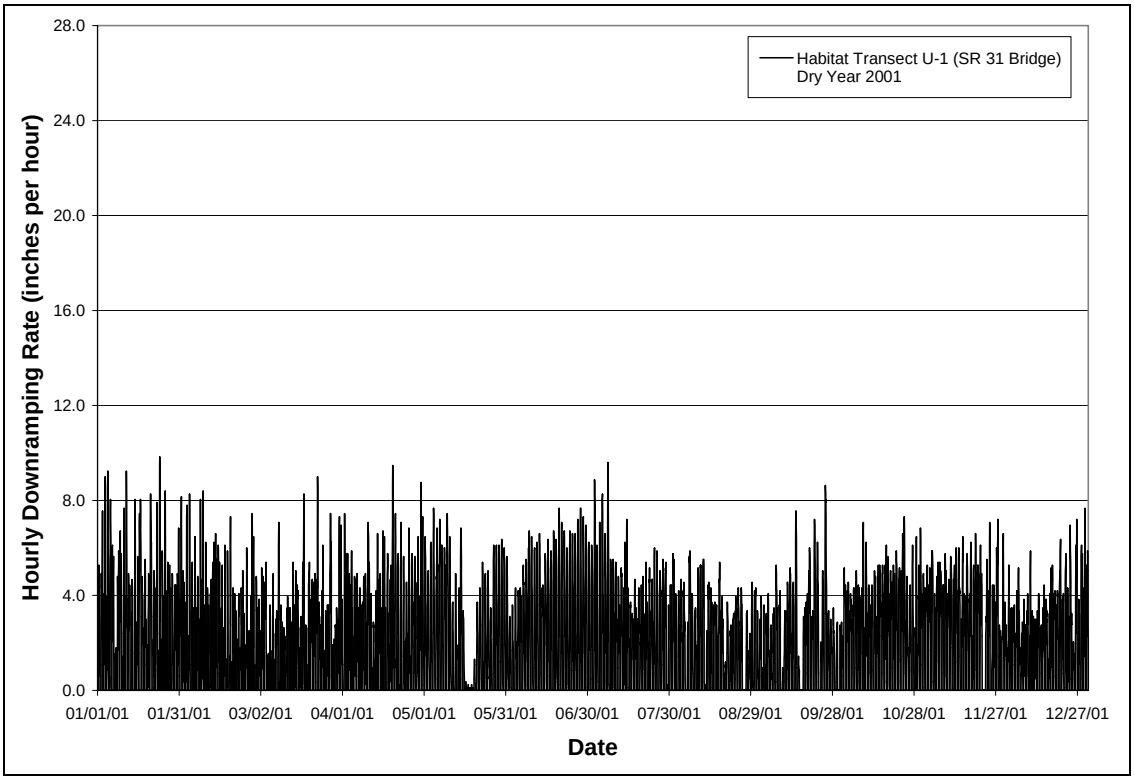


**Figure B-8.** Hourly time series of downramping rates upstream of Metaline Falls for 2001 (dry year).

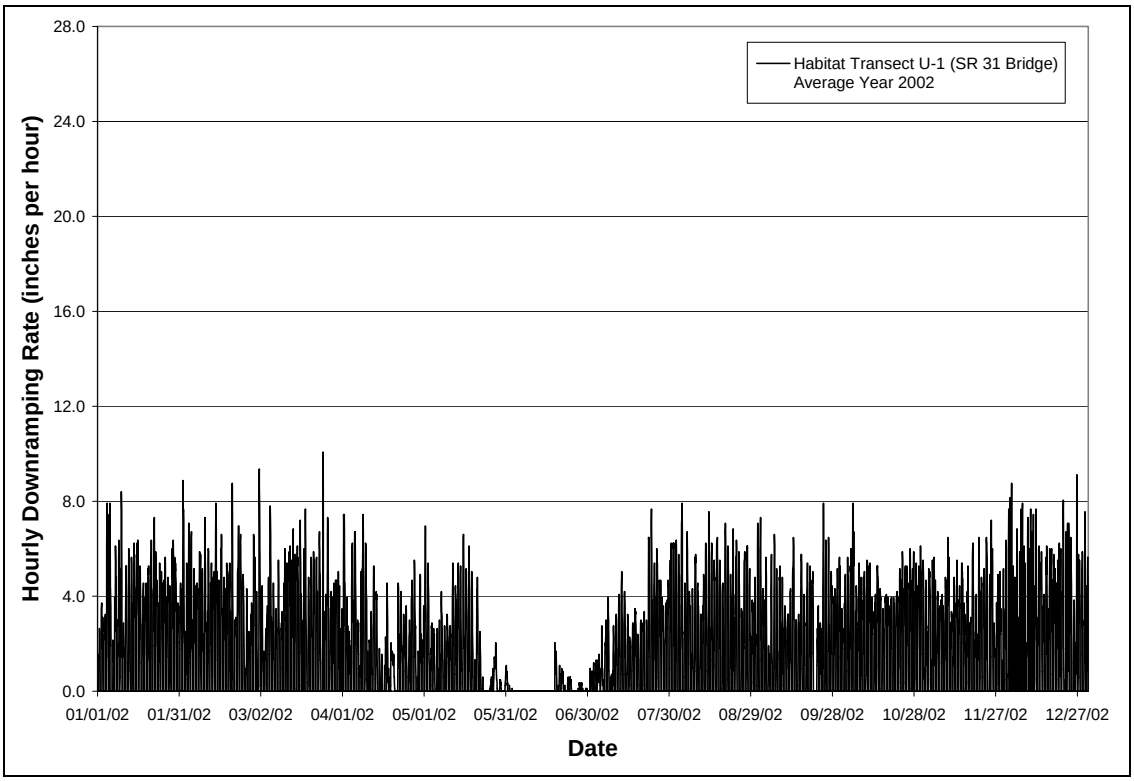


**Figure B-9.** Hourly time series of downramping rates upstream of Metaline Falls for 2002 (average year).

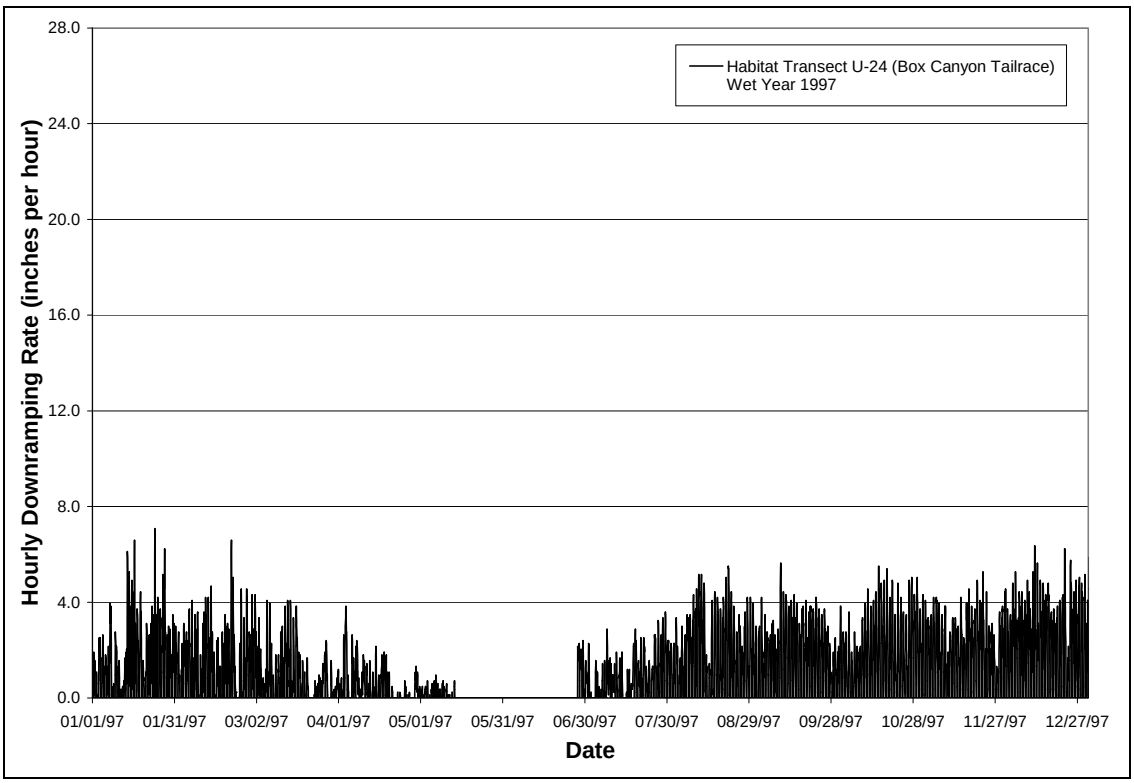


**Figure B-10.** Hourly time series of downramping rates at Box Canyon tailrace for 1997 (wet year).

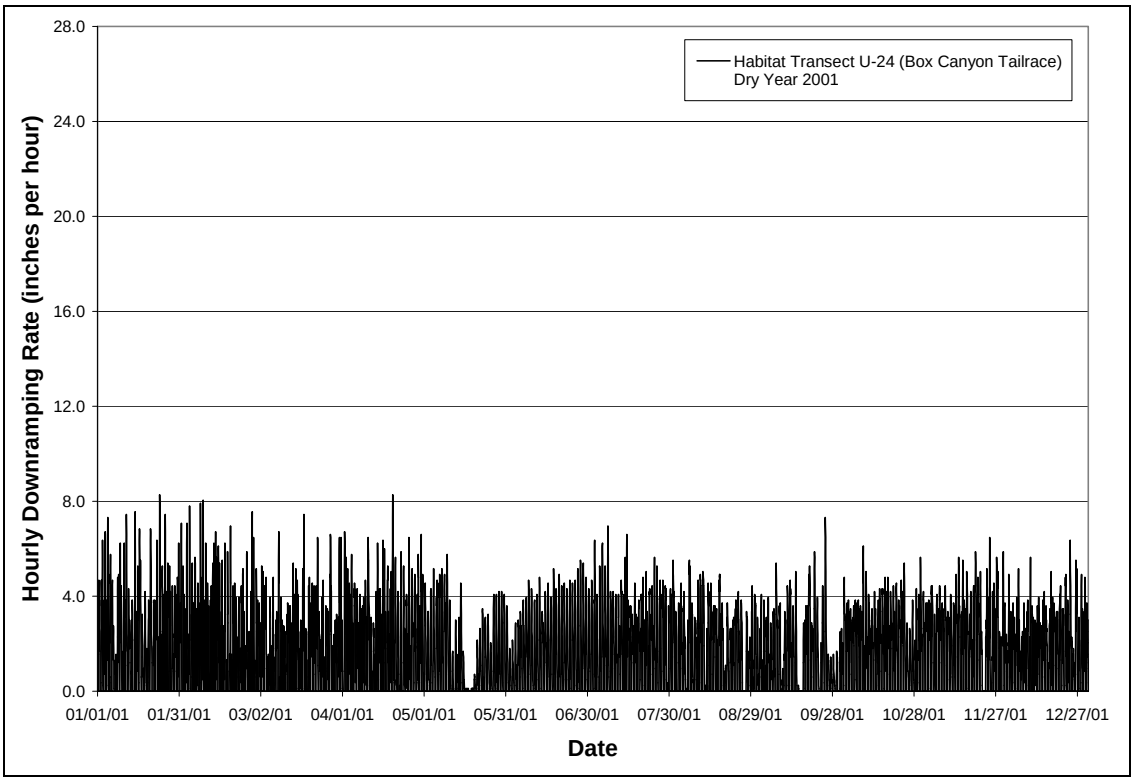


**Figure B-11.** Hourly time series of downramping rates at Box Canyon tailrace for 2001 (dry year).

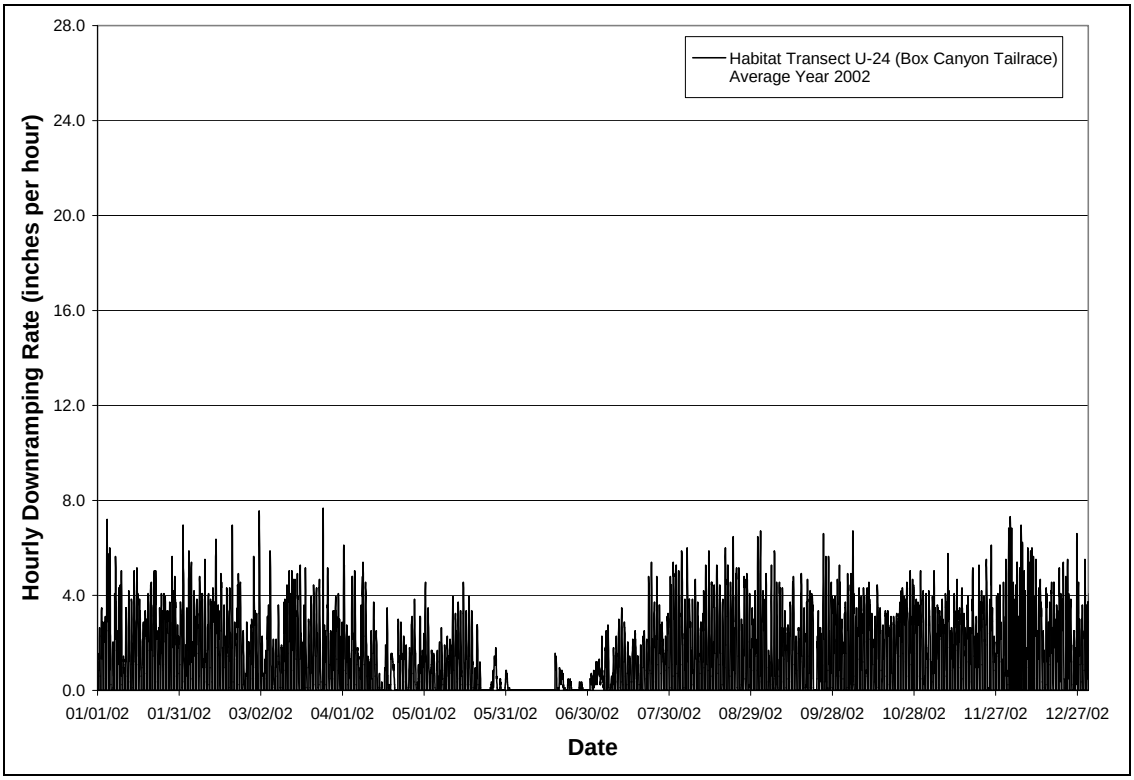


**Figure B-12.** Hourly time series of downramping rates at Box Canyon tailrace for 2002 (average year).

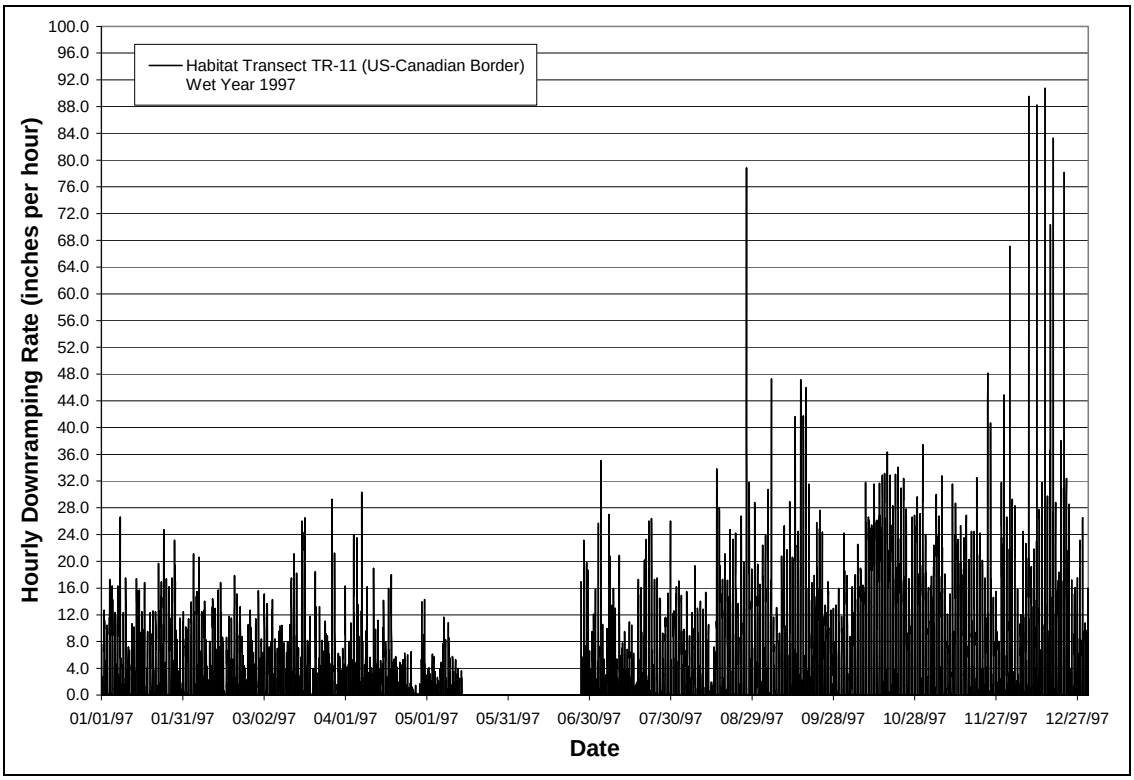


**Figure B-13.** Hourly time series of downramping rates at U.S.-Canada border for 1997 (wet year).

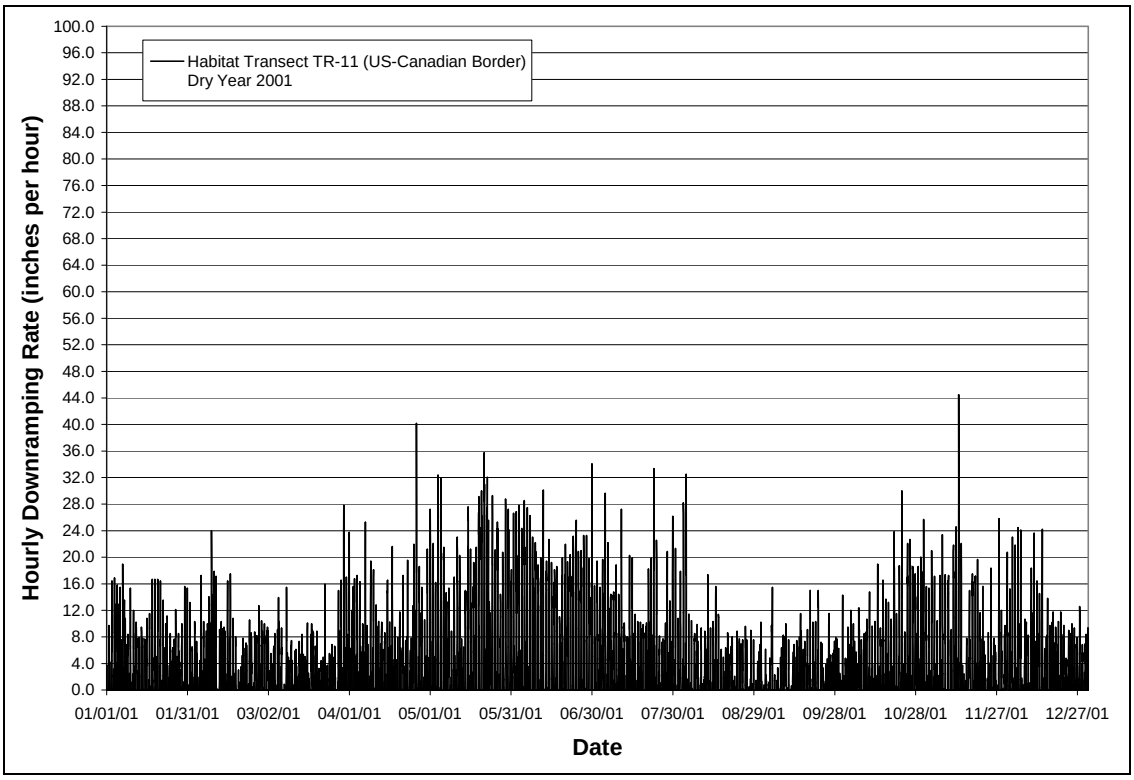


**Figure B-14.** Hourly time series of downramping rates at U.S.-Canada border for 2001 (dry year).

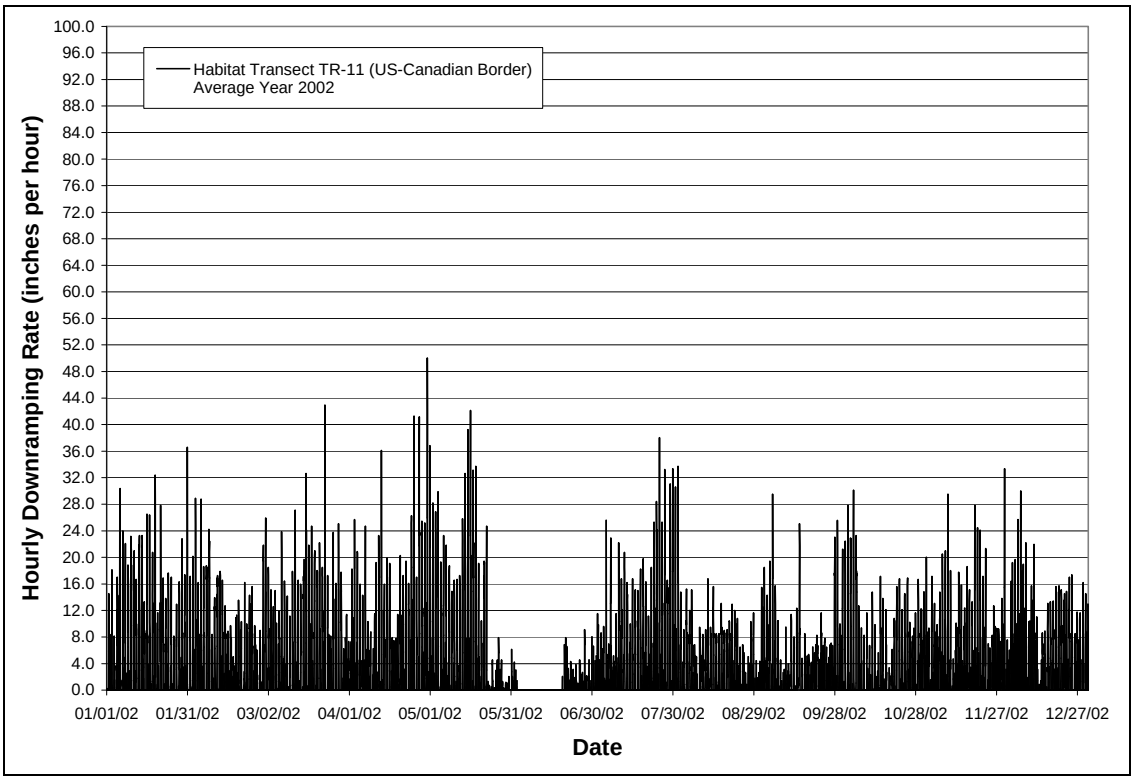


**Figure B-15.** Hourly time series of downramping rates at U.S.-Canada border for 2002 (average year).

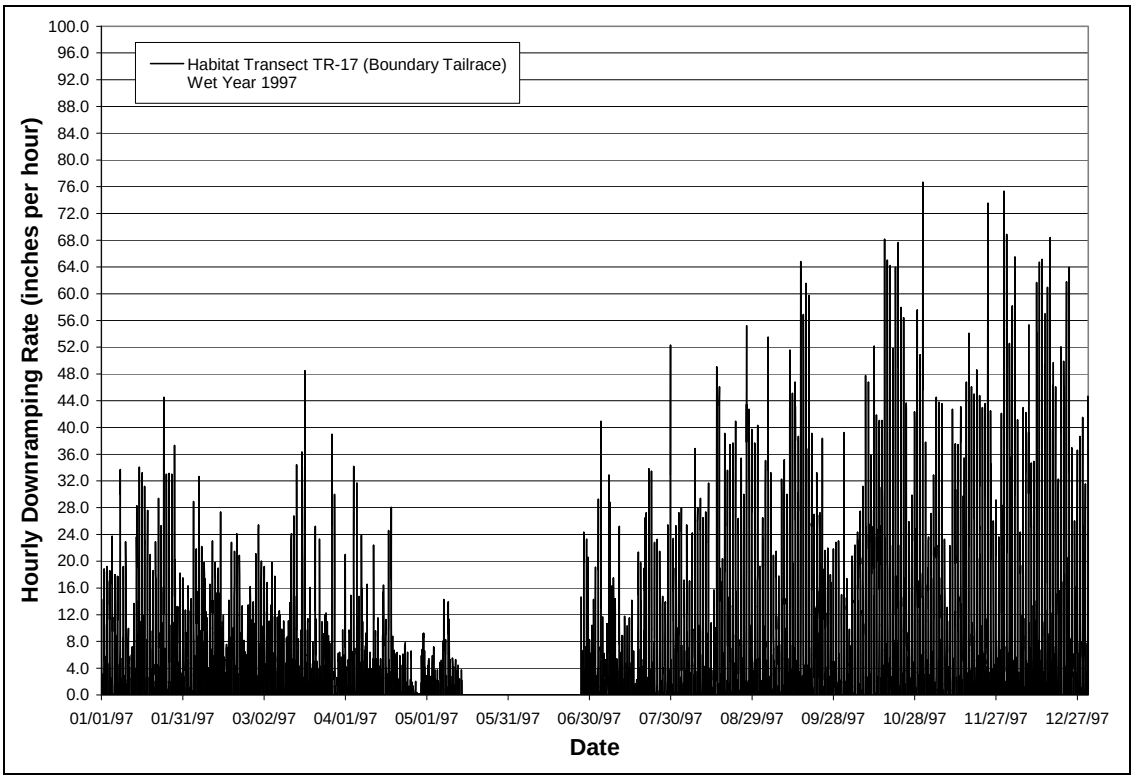


**Figure B-16.** Hourly time series of downramping rates at Boundary Dam tailrace for 1997 (wet year).

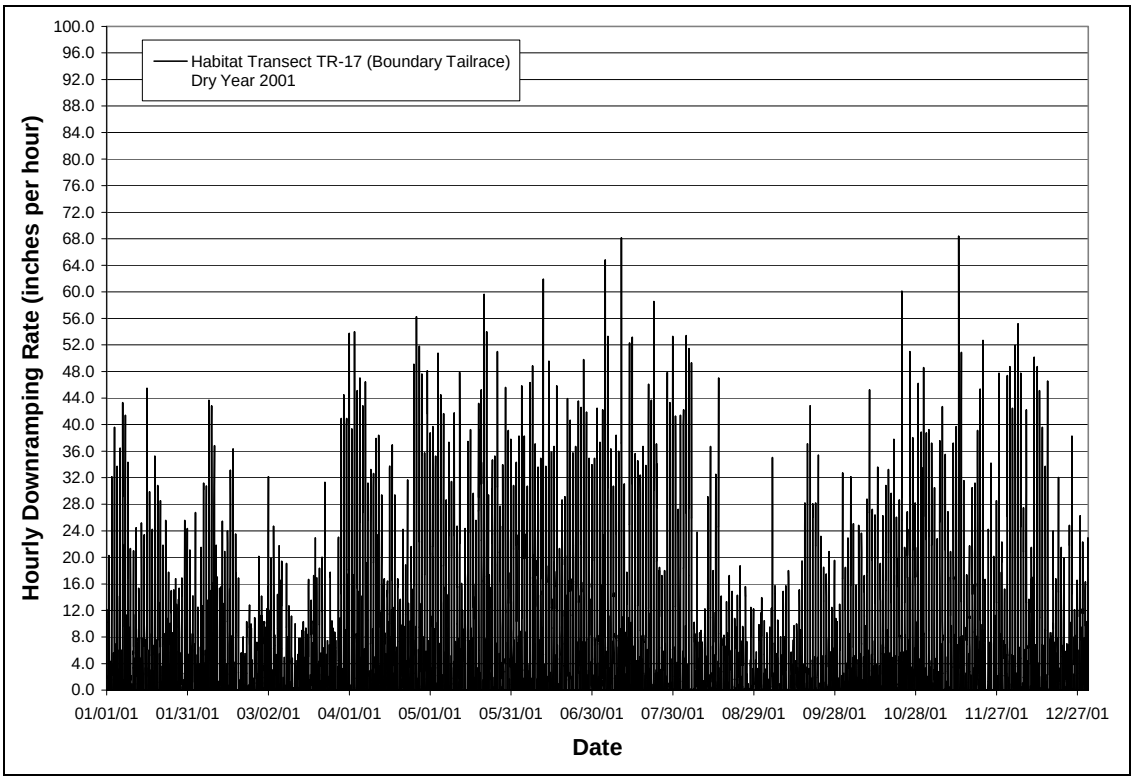


**Figure B-17.** Hourly time series of downramping rates at Boundary Dam tailrace for 2001 (dry year).

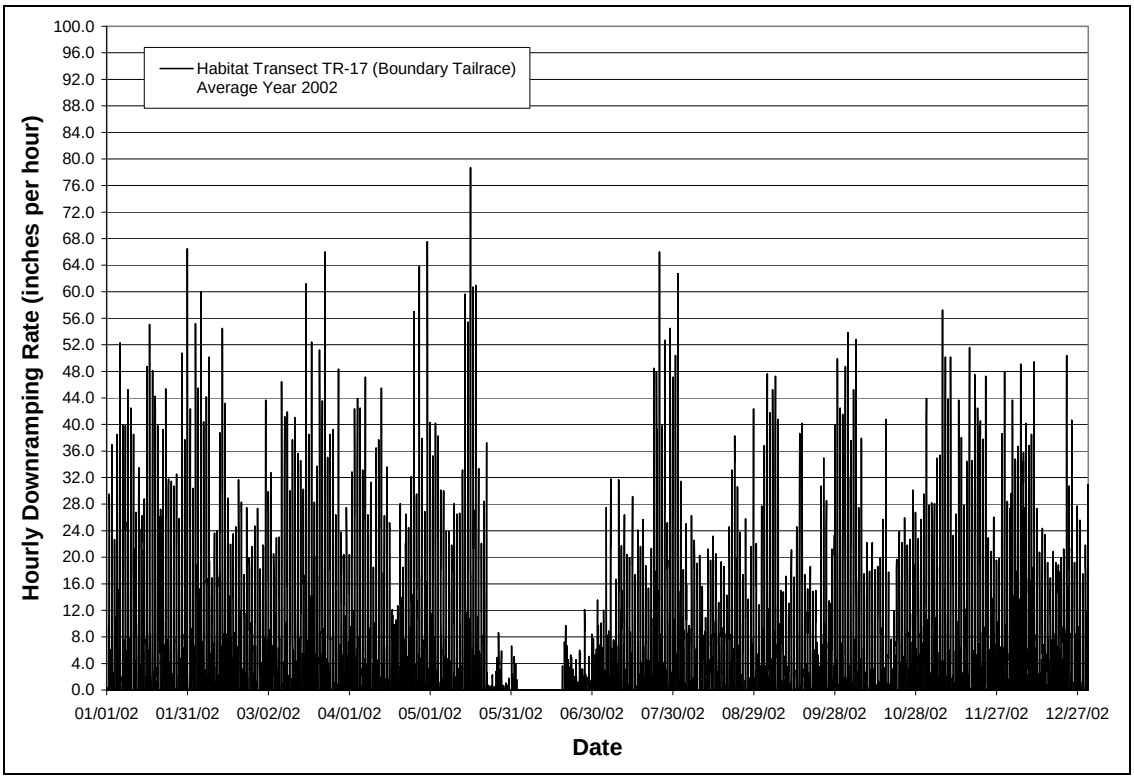


**Figure B-18.** Hourly time series of downramping rates at Boundary Dam tailrace for 2002 (average year).

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# Attachment C: Figures of Transect-Weighted, Reach-Averaged Downramping Rate Exceedance Curves by Month

This attachment contains the following figures:

Figure C-1. January of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-2. February of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-3. March of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-4. April of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-5. May of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-6. June of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-7. July of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-8. August of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-9. September of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-10. October of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-11. November of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-12. December of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-13. January of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-14. February of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-15. March of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-16. April of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-17. May of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-18. June of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-19. July of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-20. August of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-21. September of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-22. October of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

Figure C-23. November of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-24. December of wet year 2001 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-25. January of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-26. February of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-27. March of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-28. April of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-29. May of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-30. June of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-31. July of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-32. August of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-33. September of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-34. October of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-35. November of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.
Figure C-36. December of wet year 2002 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

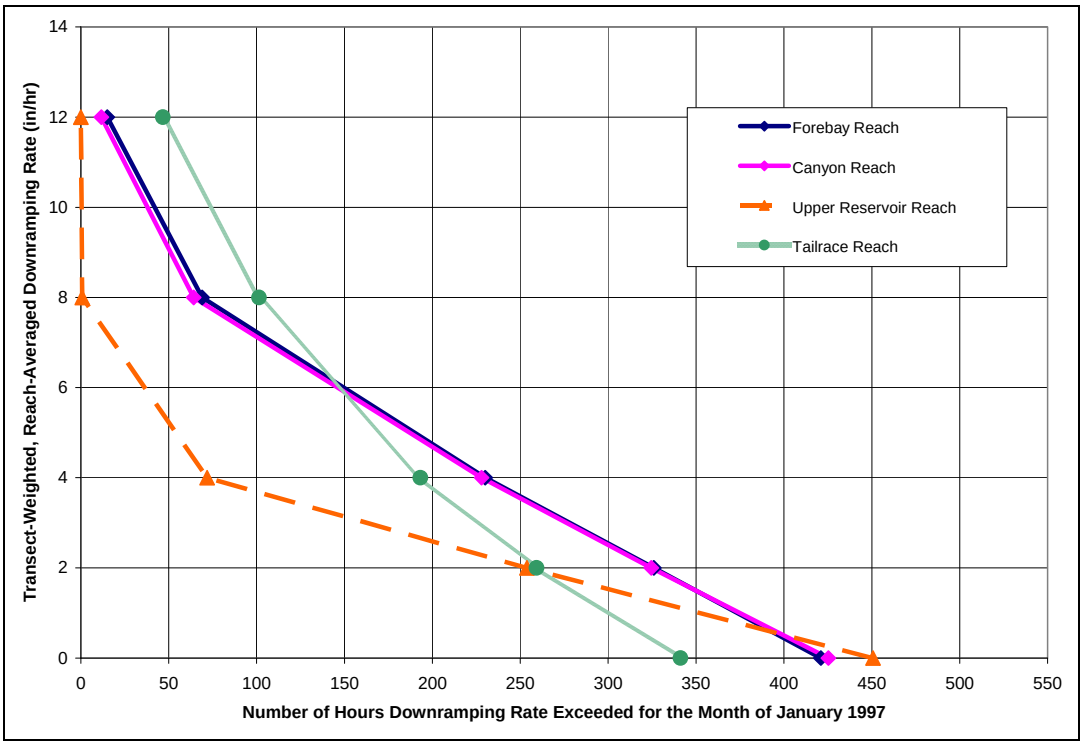



**Figure C-1.** January of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

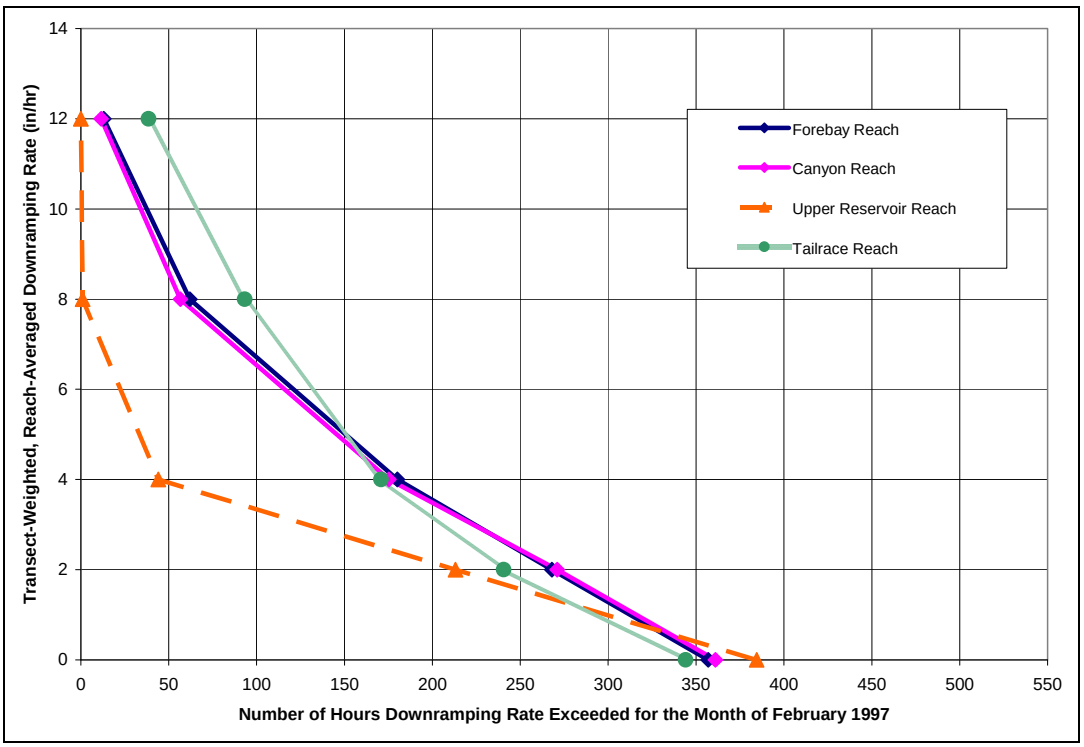



**Figure C-2.** February of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

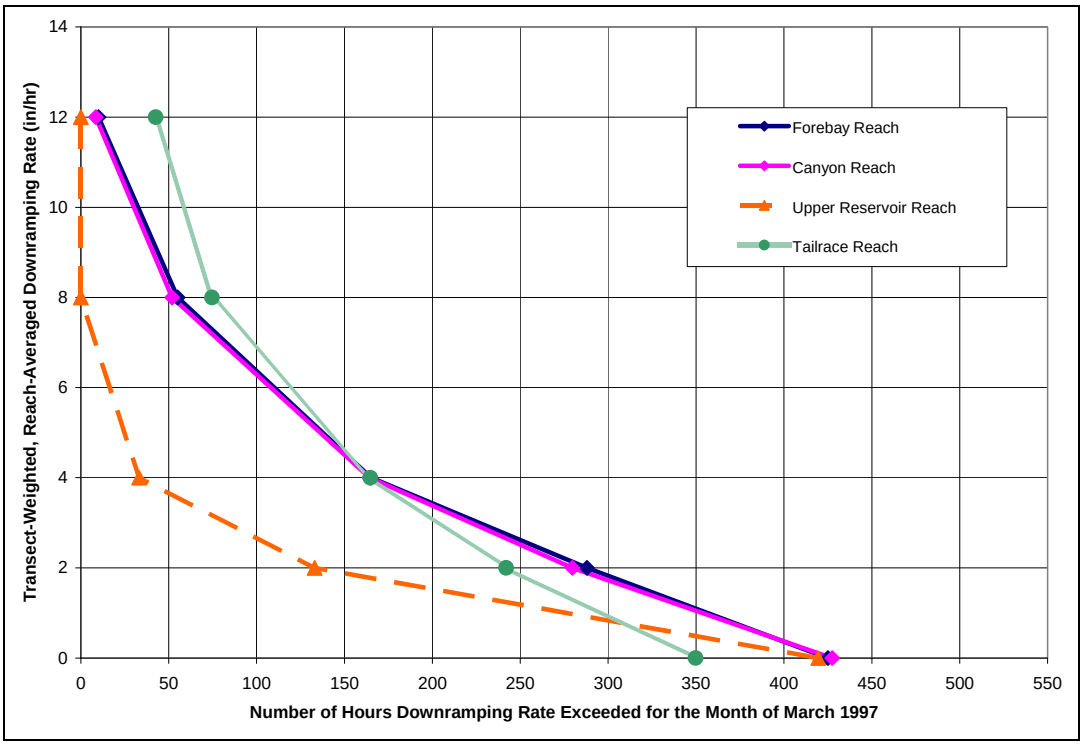



**Figure C-3.** March of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

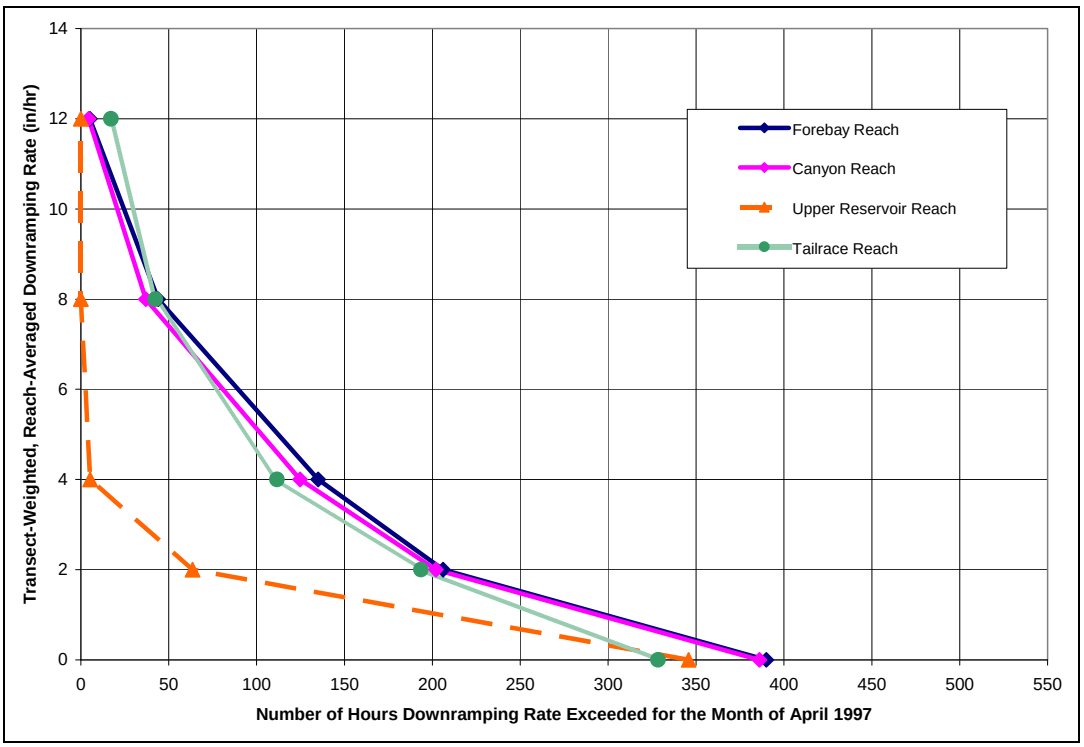



**Figure C-4.** April of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

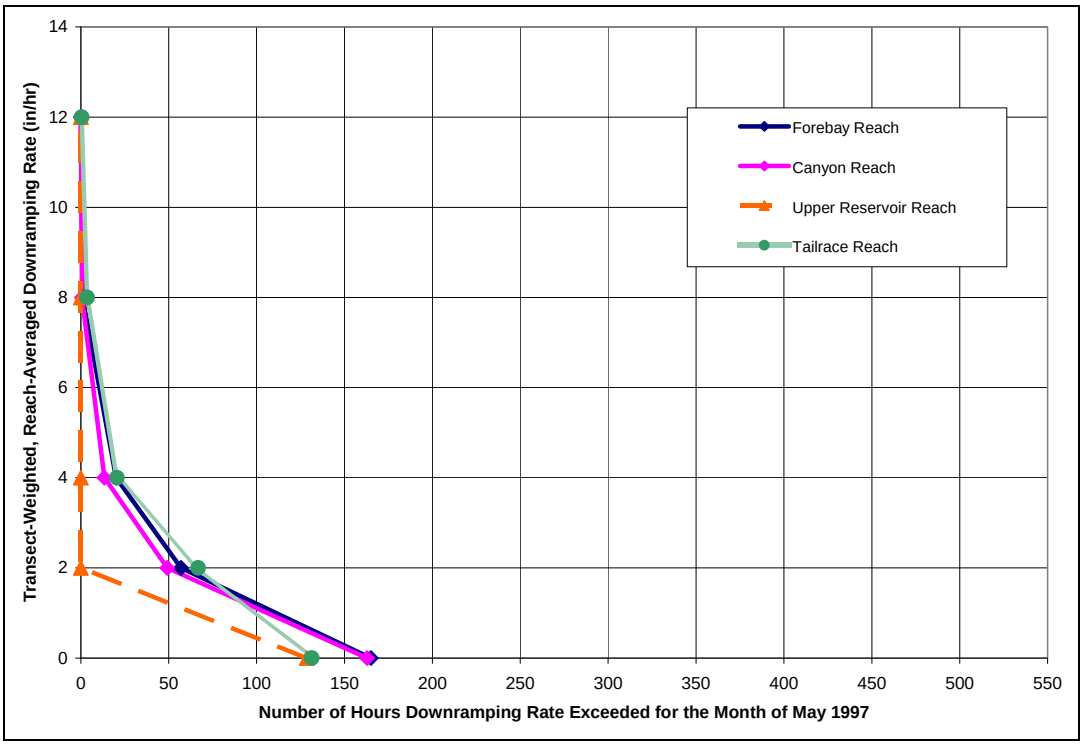



**Figure C-5.** May of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

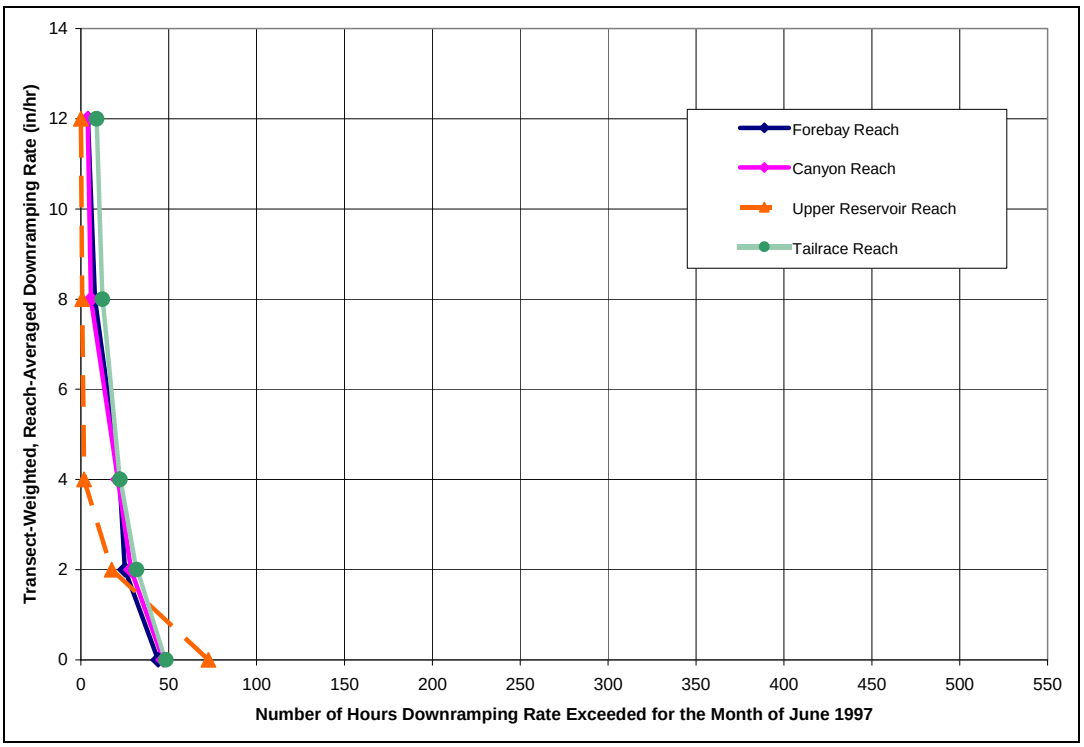



**Figure C-6.** June of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

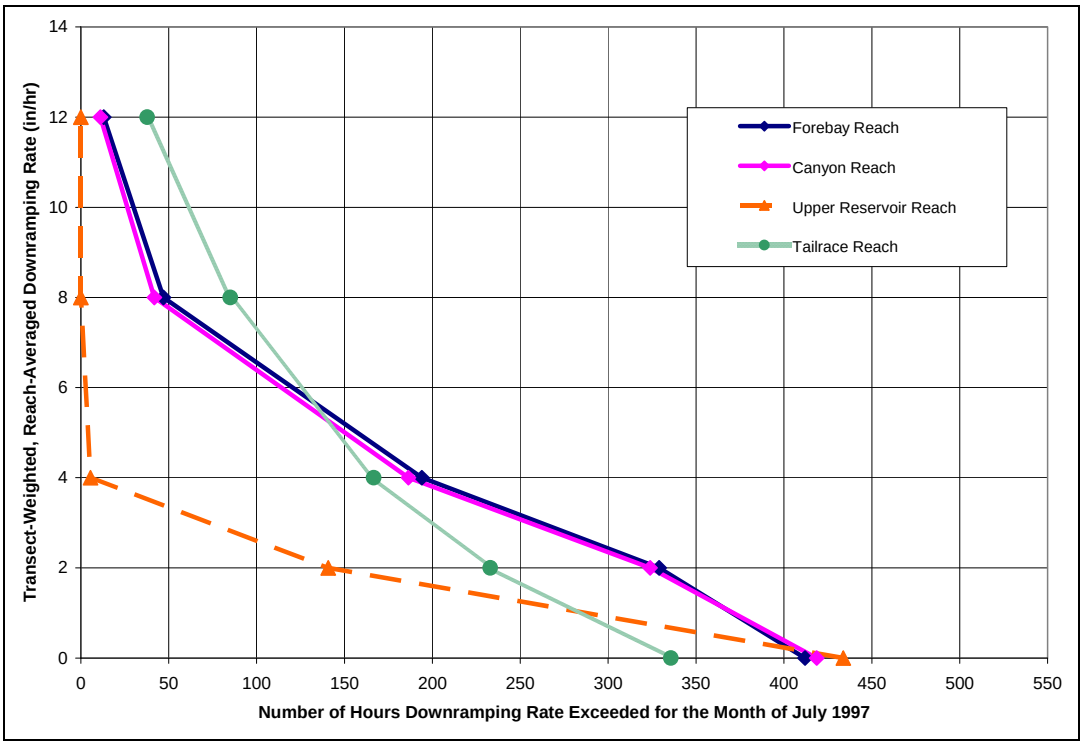



**Figure C-7.** July of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

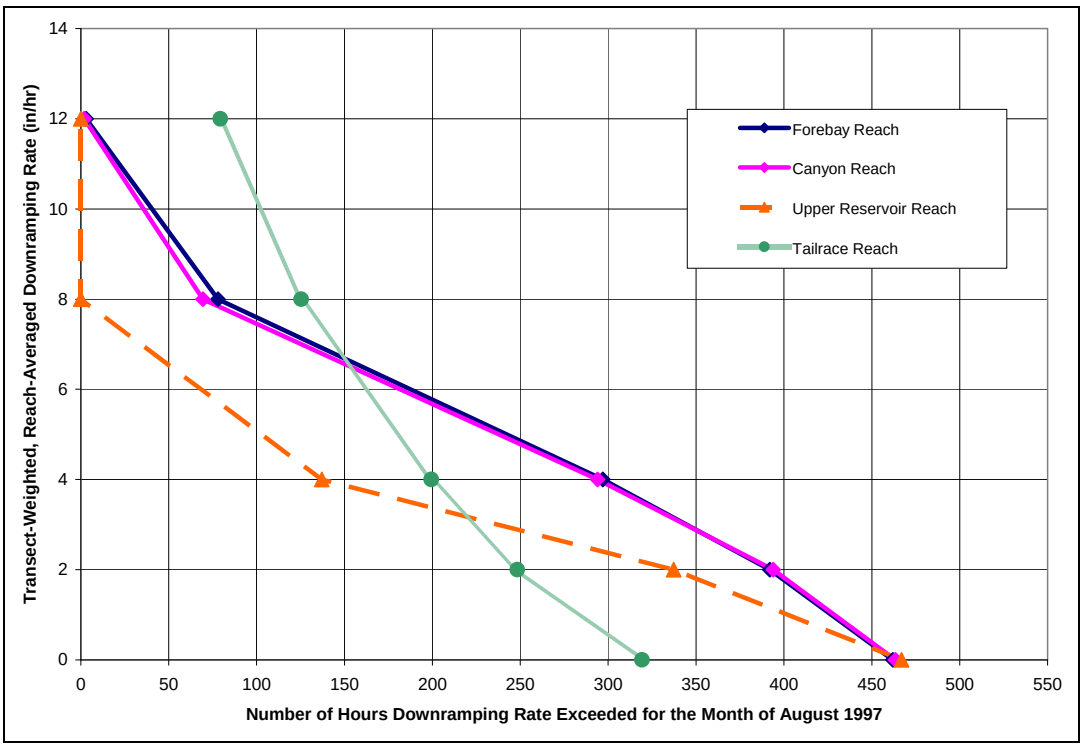



**Figure C-8.** August of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

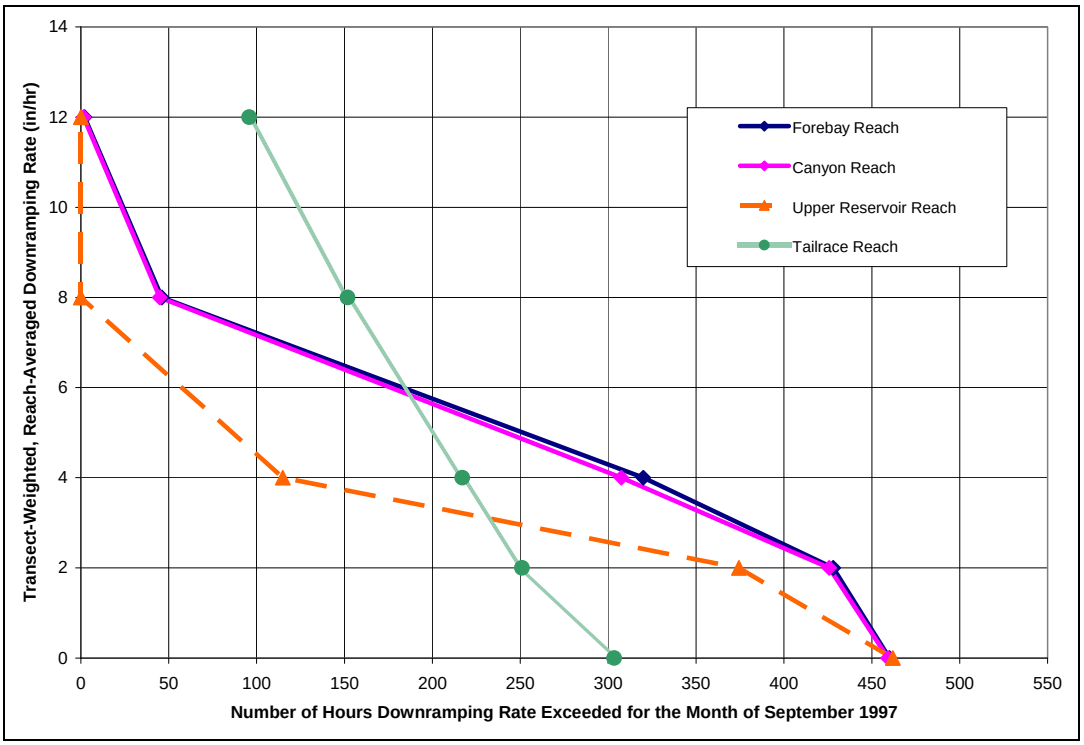



**Figure C-9.** September of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

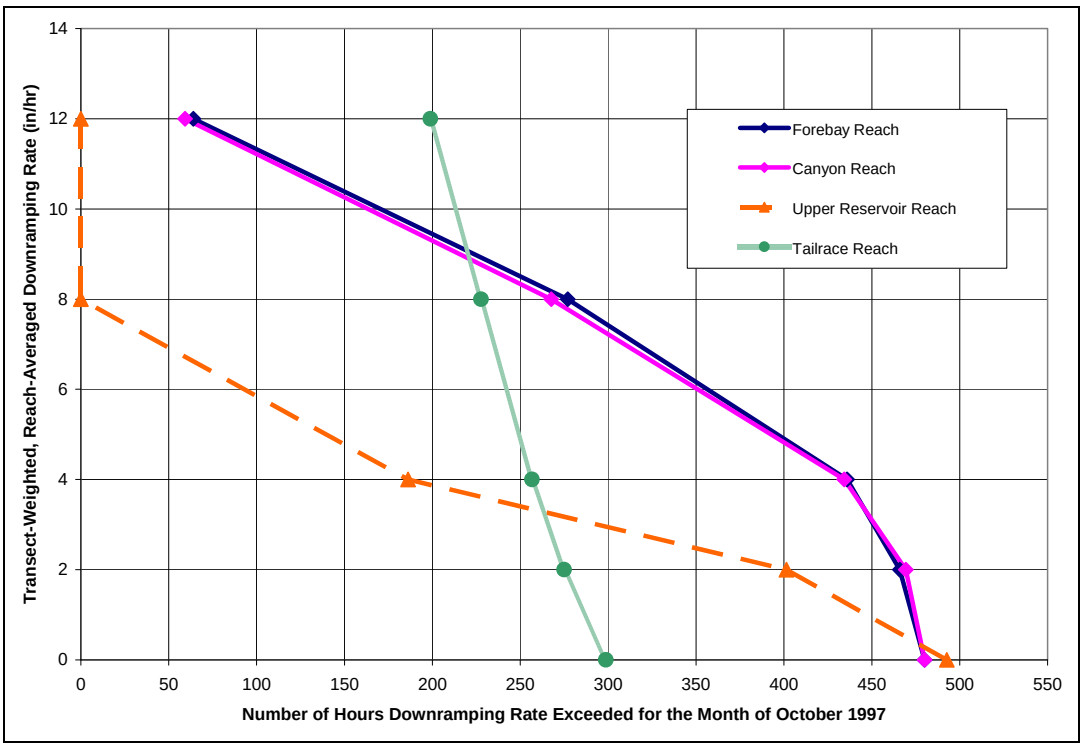



**Figure C-10.** October of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

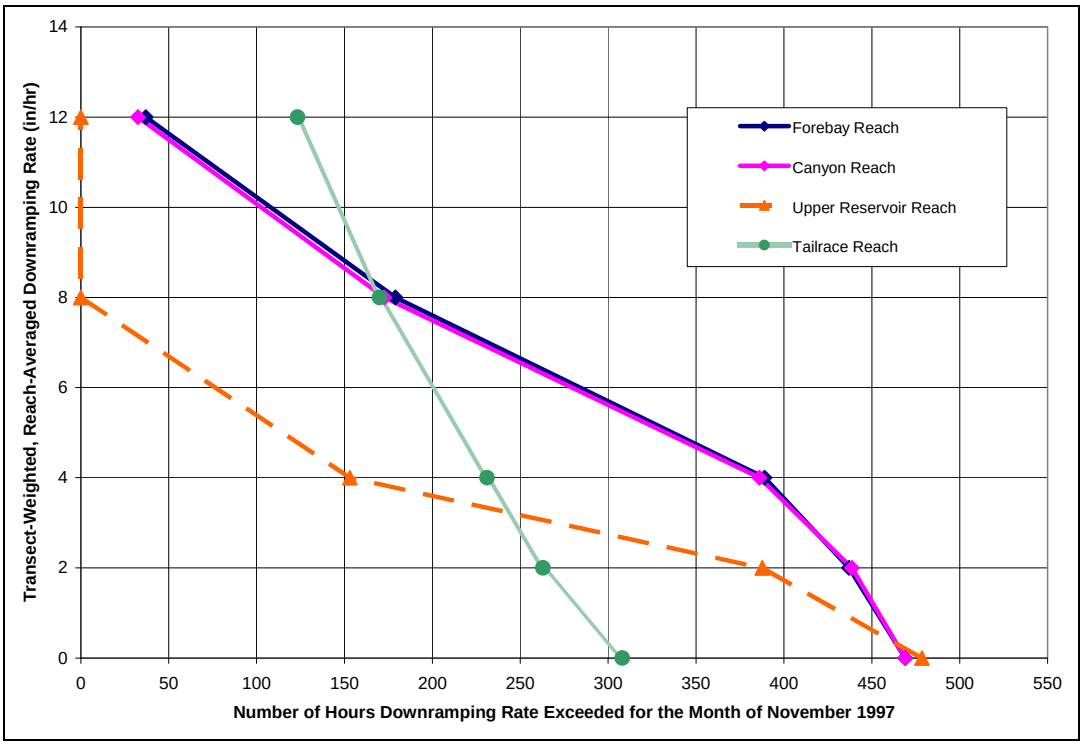



**Figure C-11.** November of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

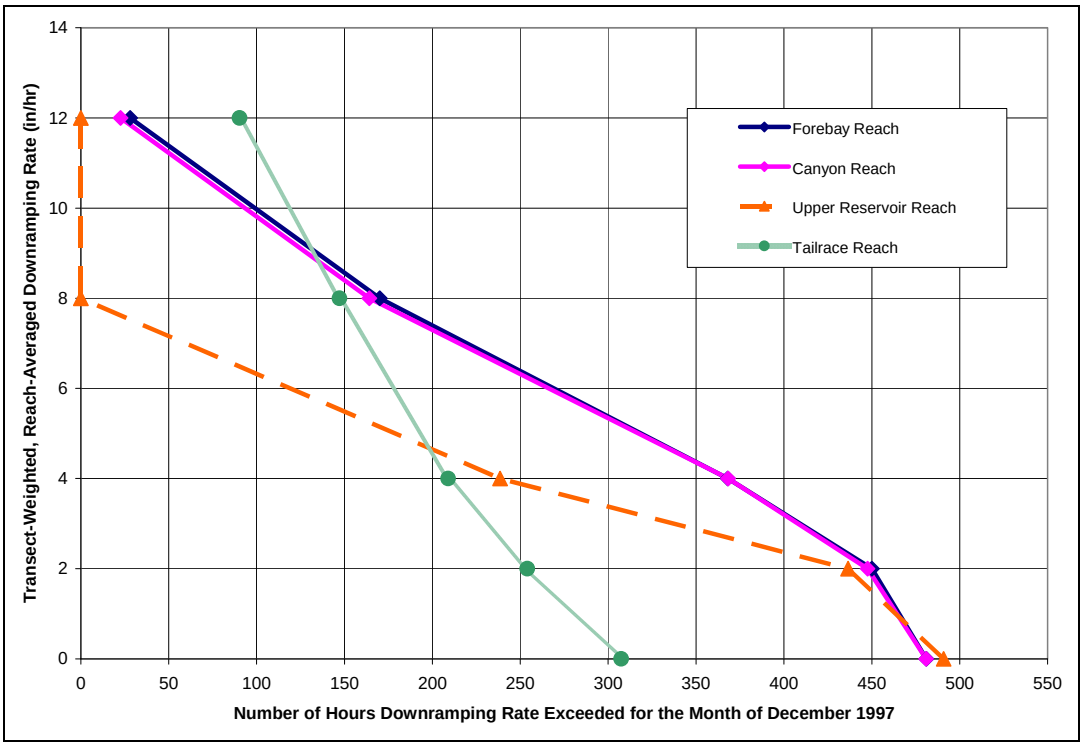
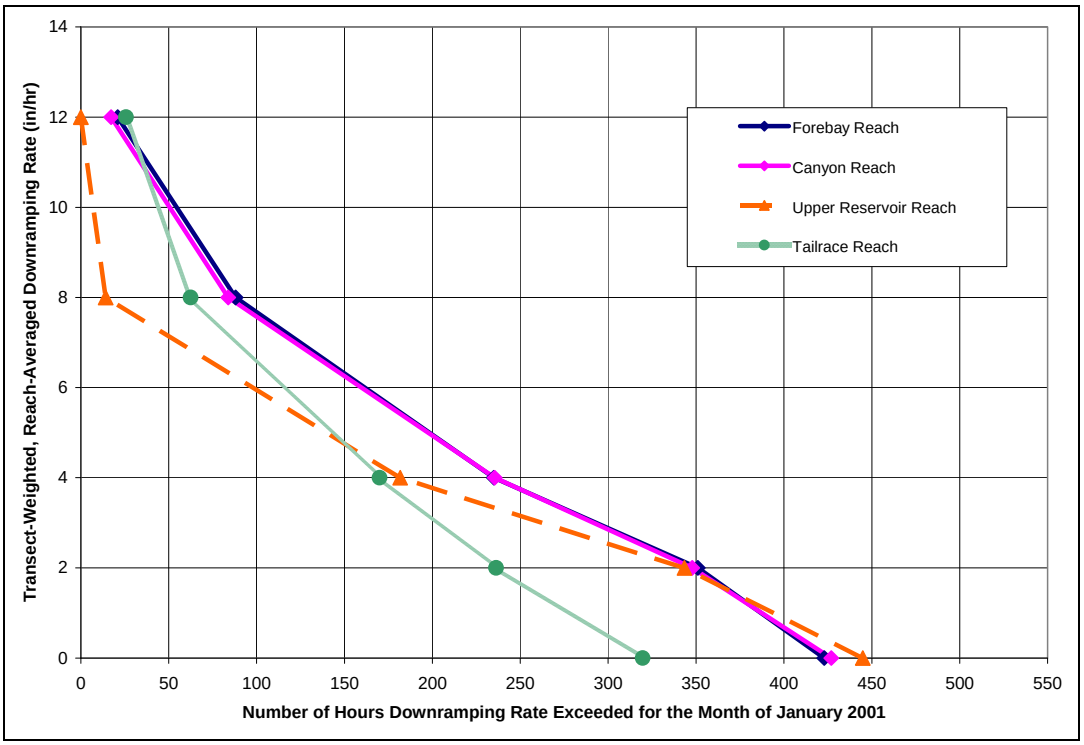



**Figure C-12.** December of wet year 1997 transect-weighted, reach-averaged downramping rate exceedance curves by Project reach.

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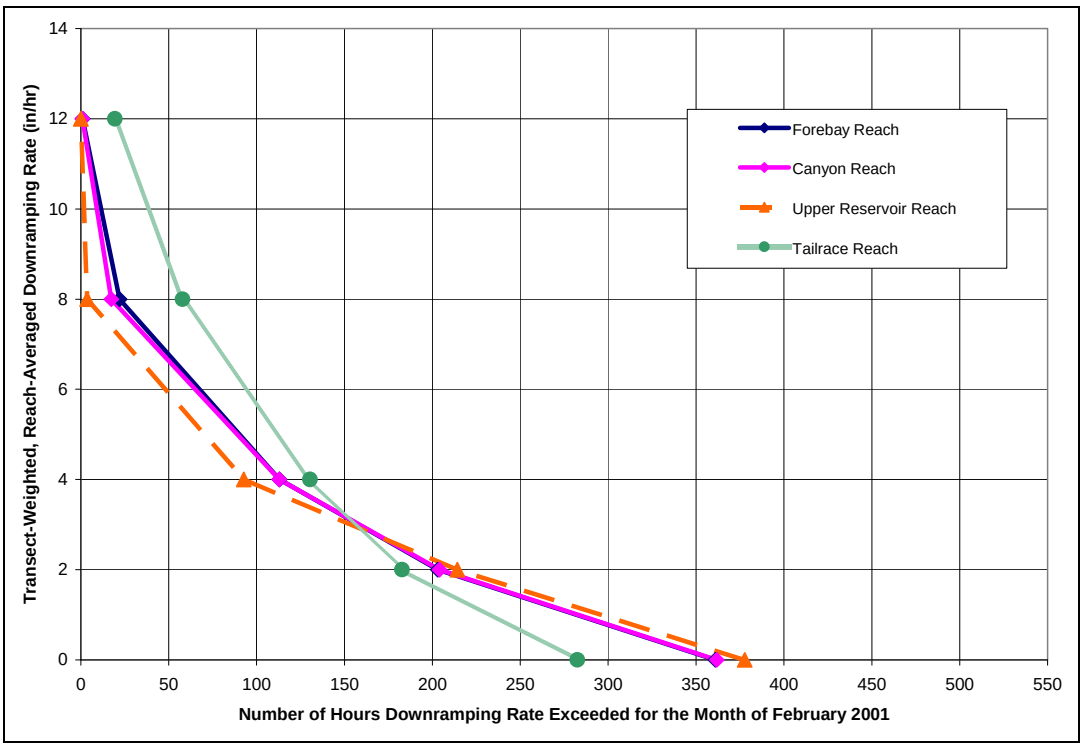


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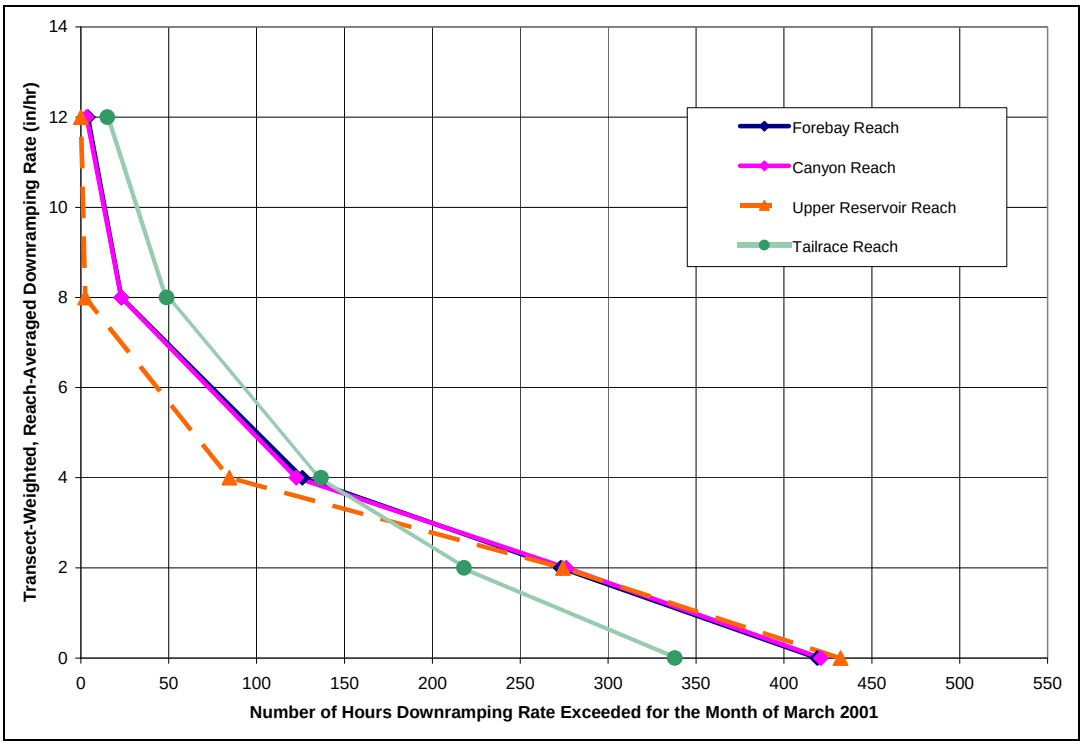


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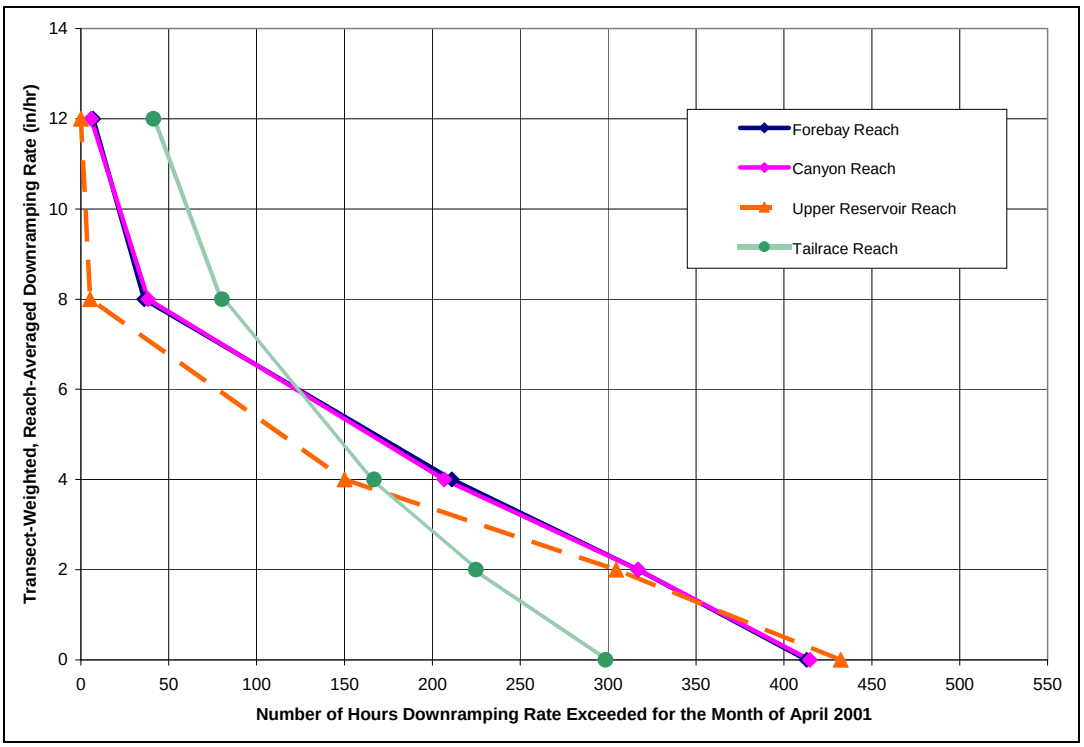


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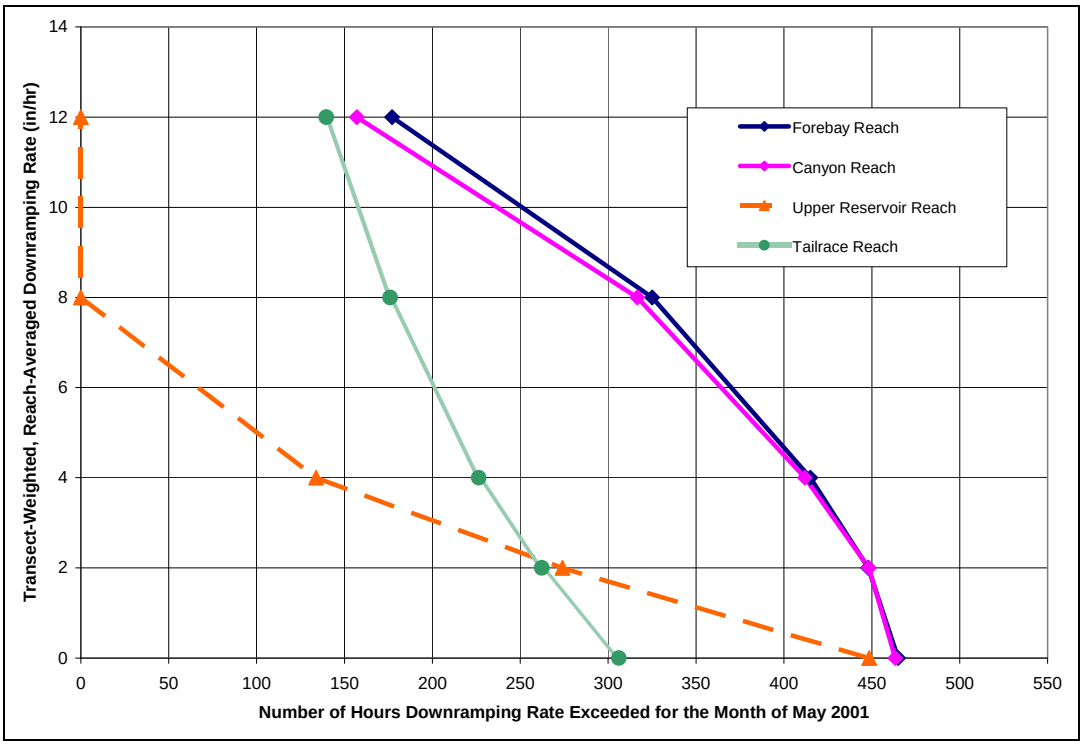


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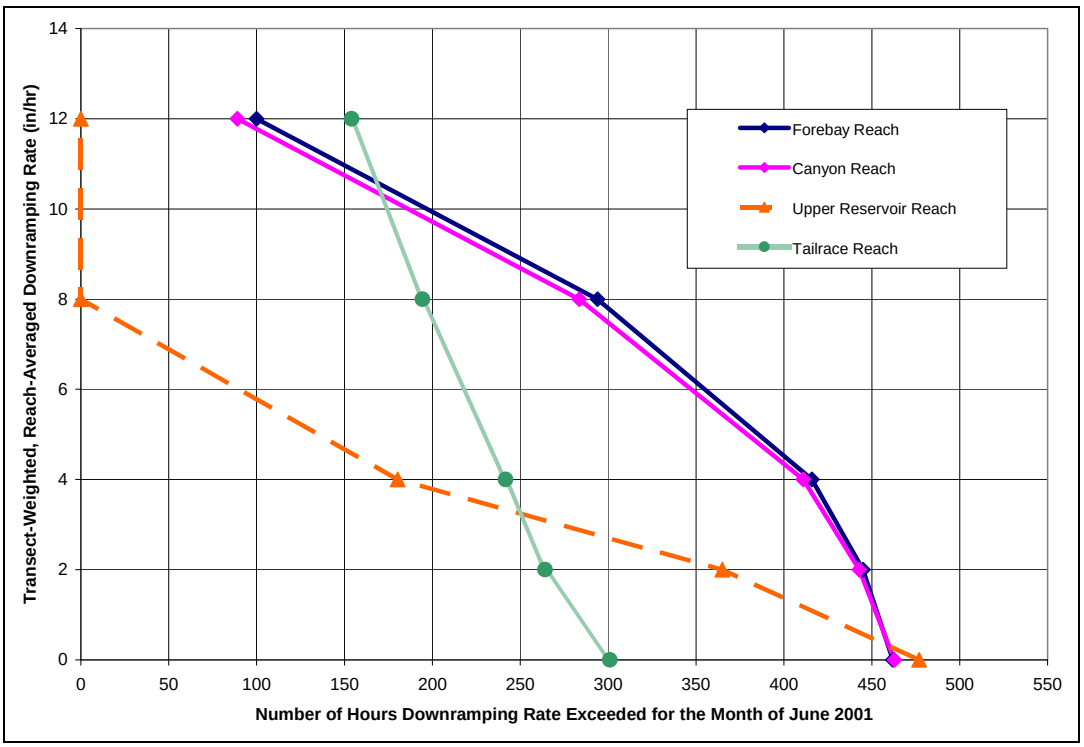


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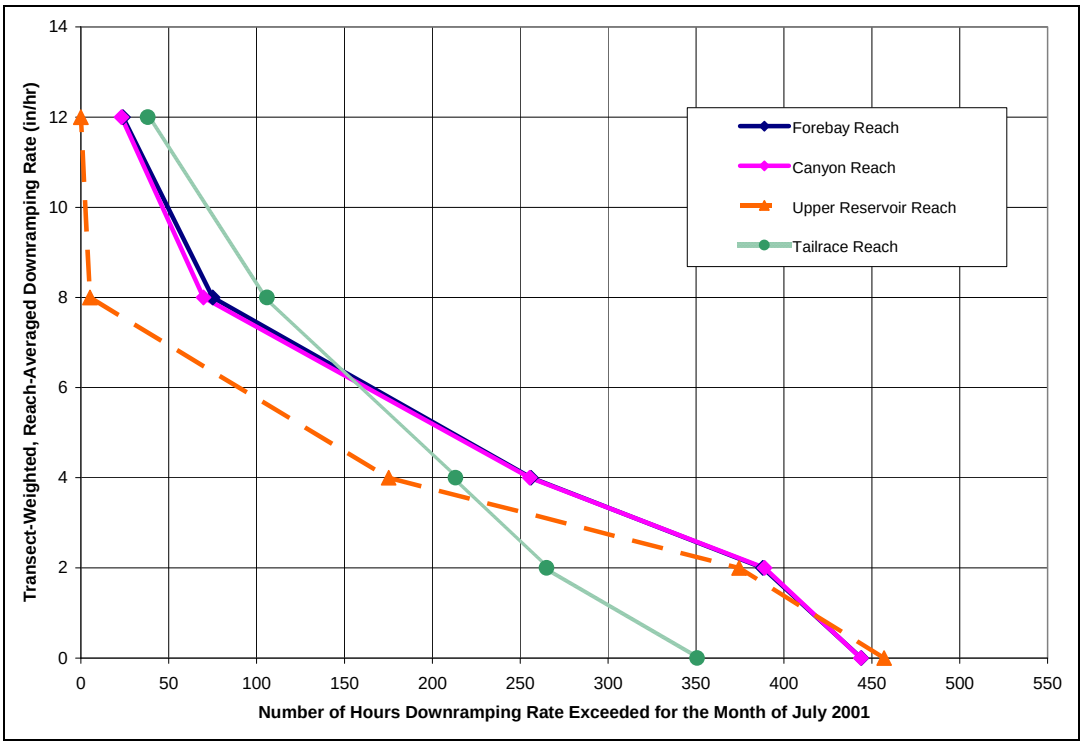


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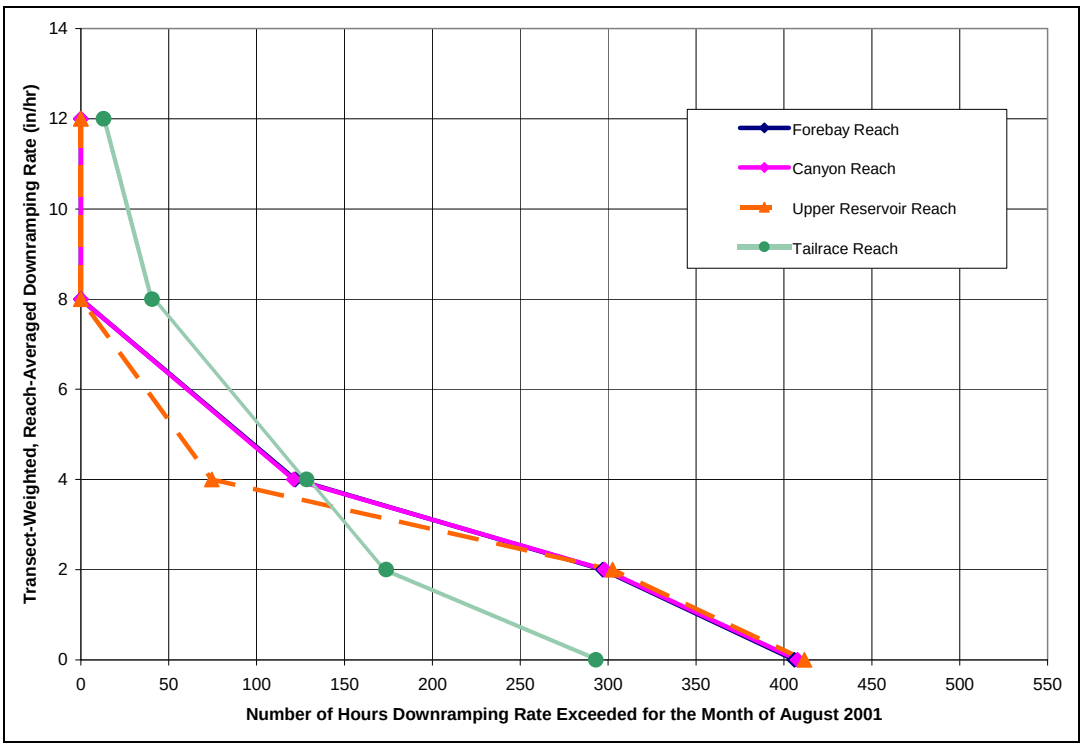


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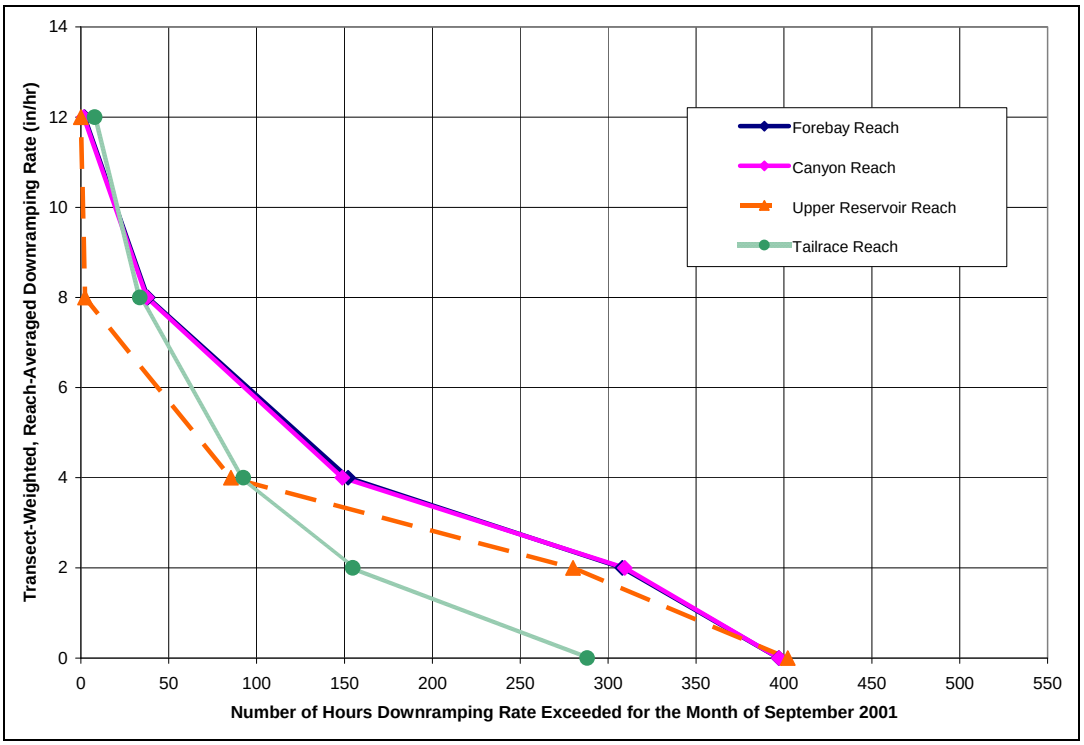


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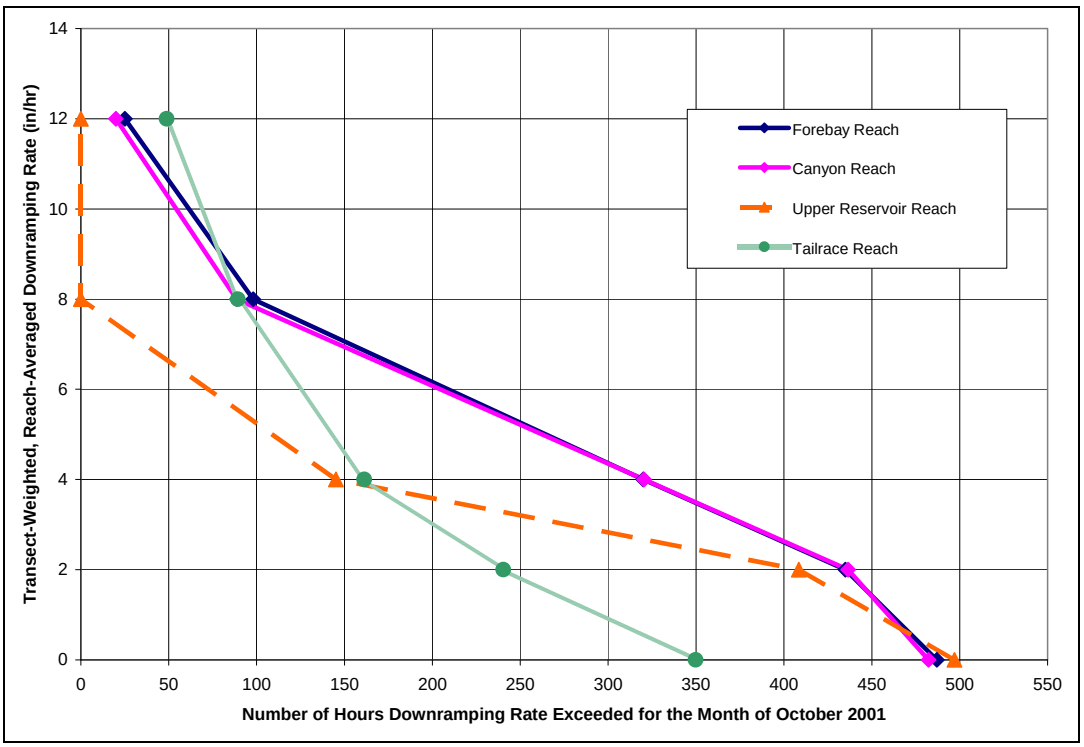


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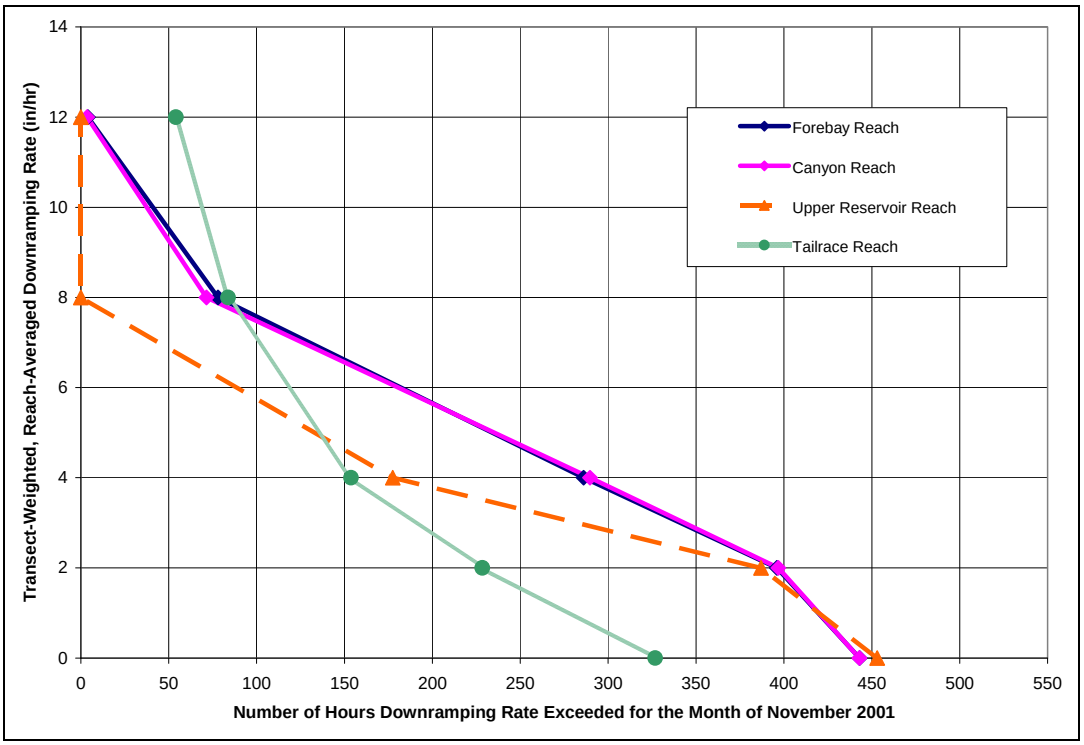


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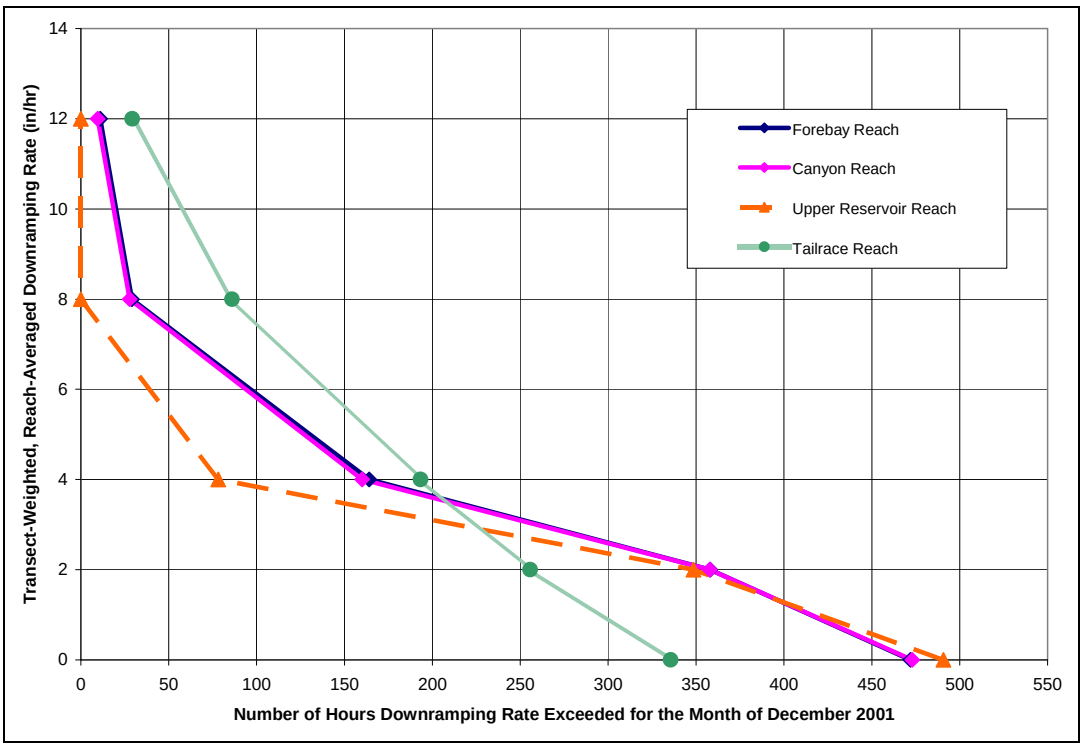


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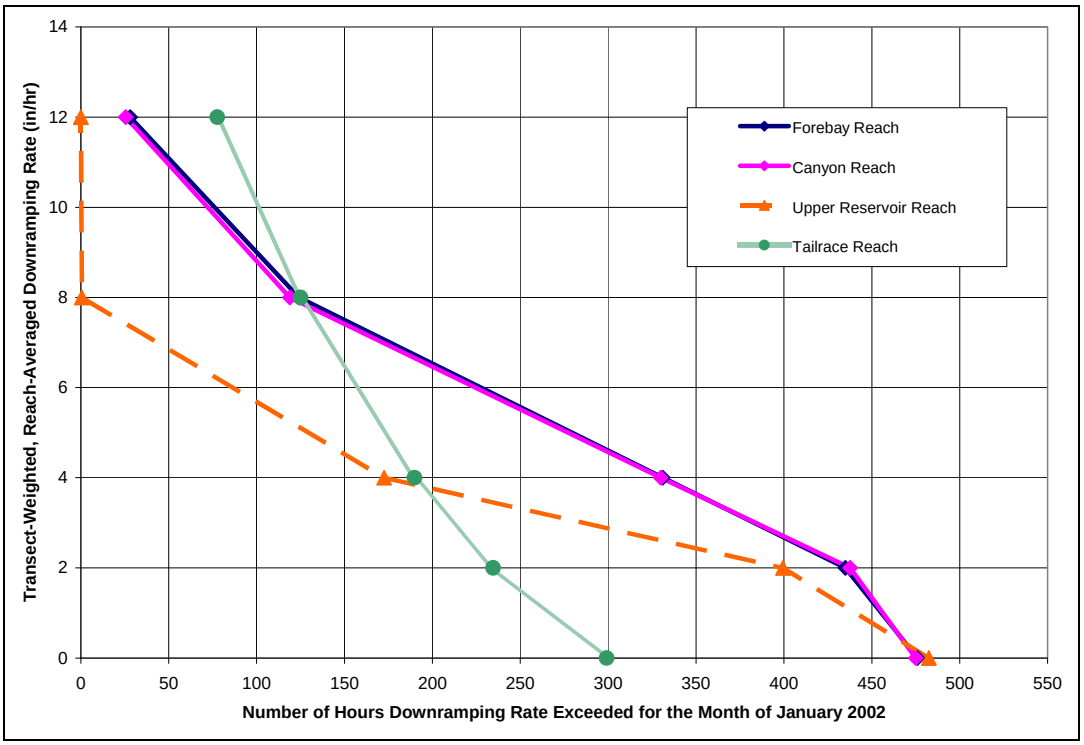


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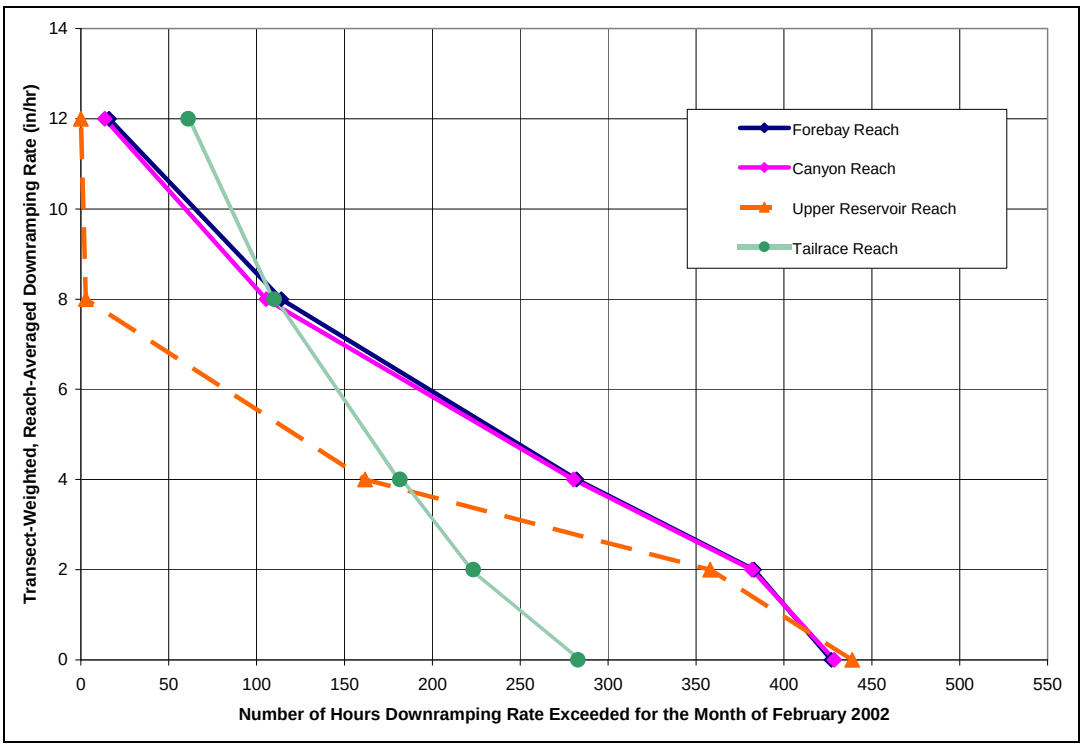


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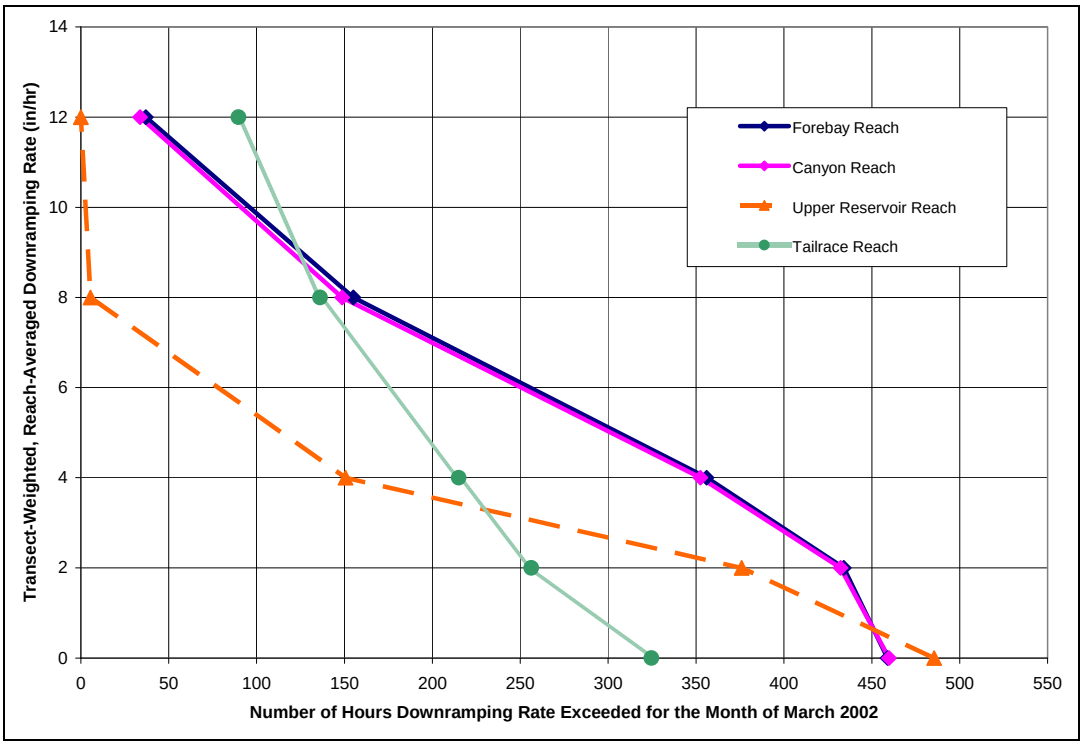


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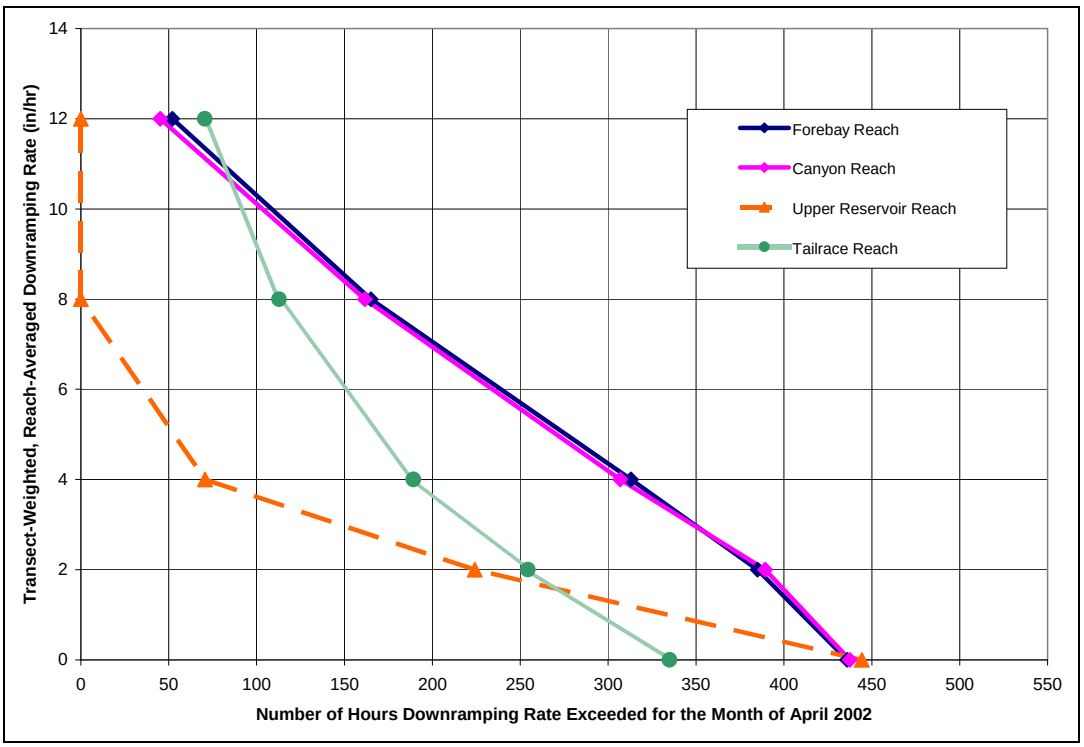


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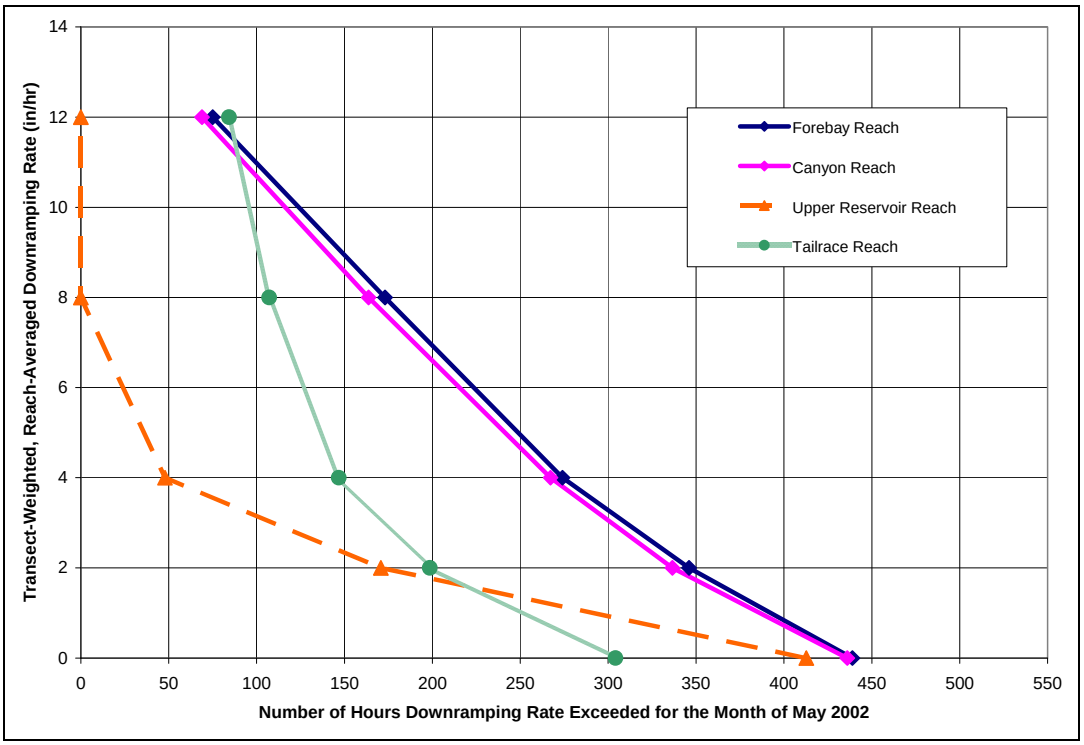


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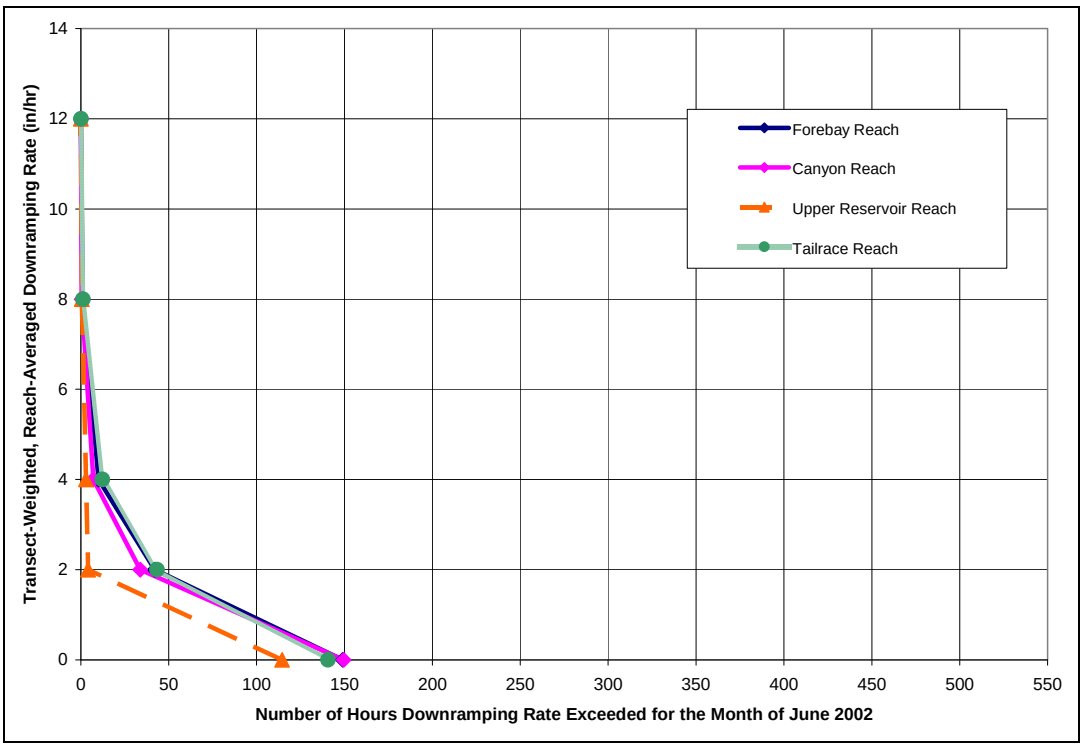


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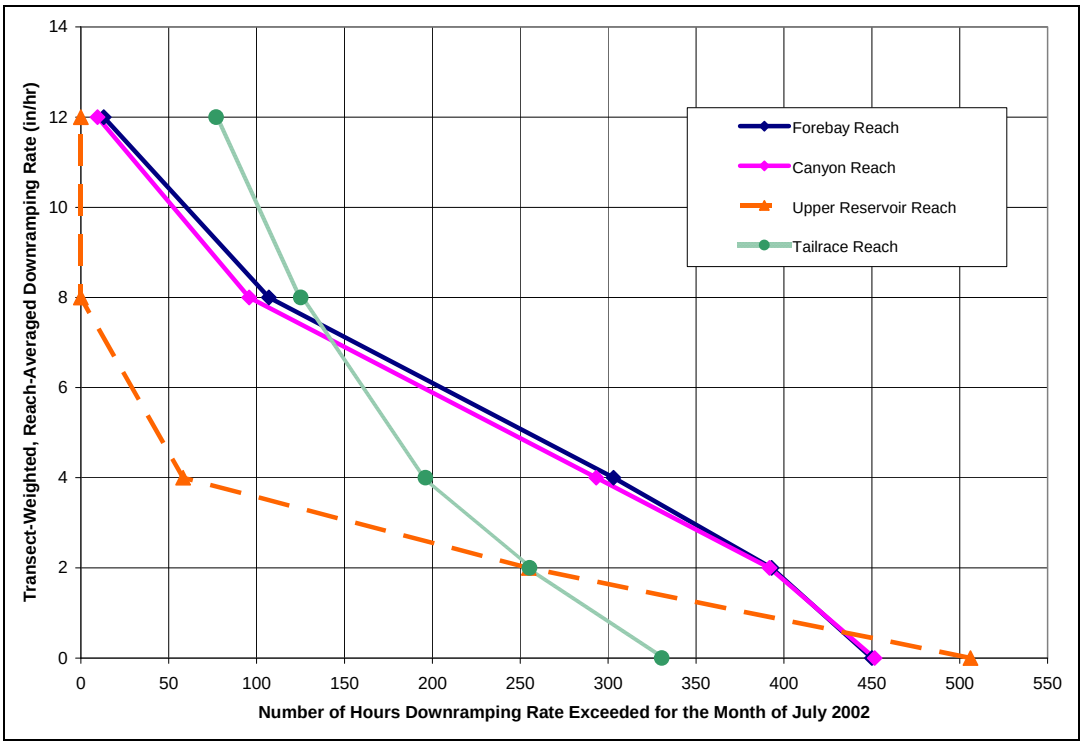


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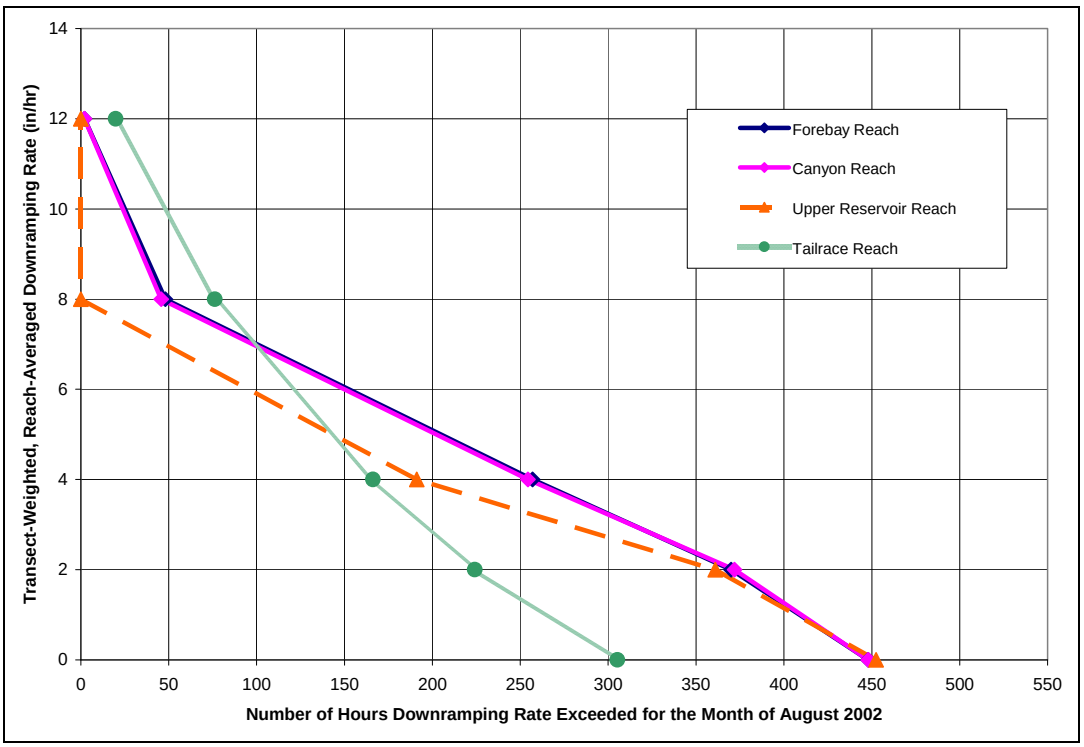


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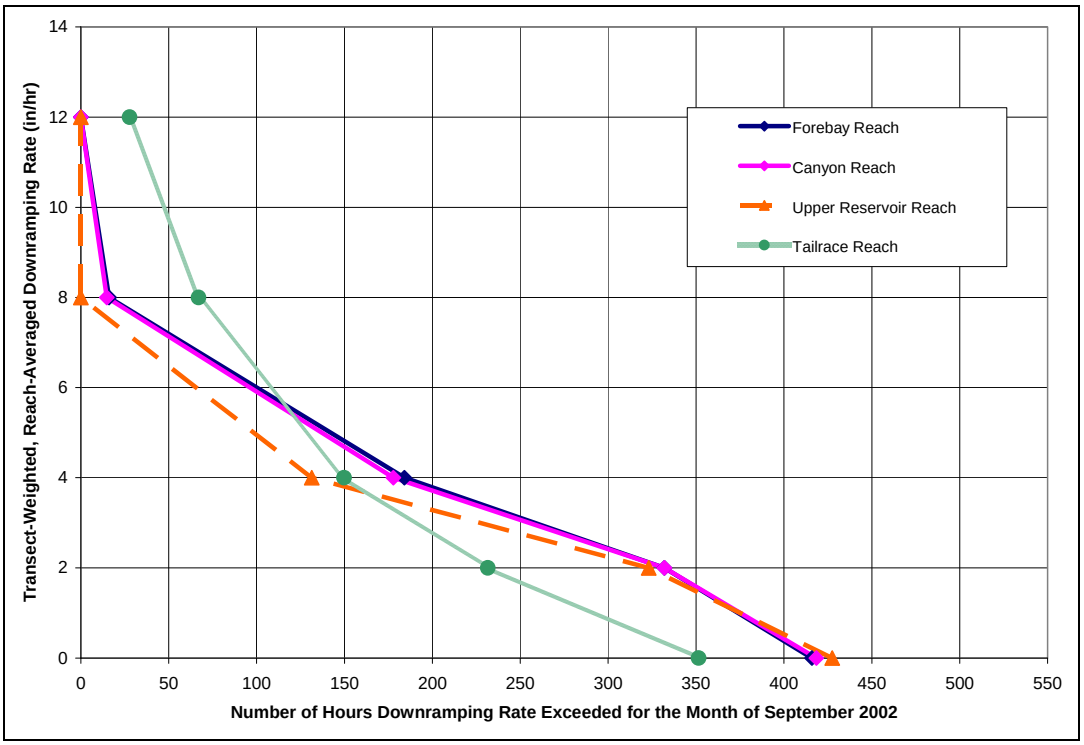


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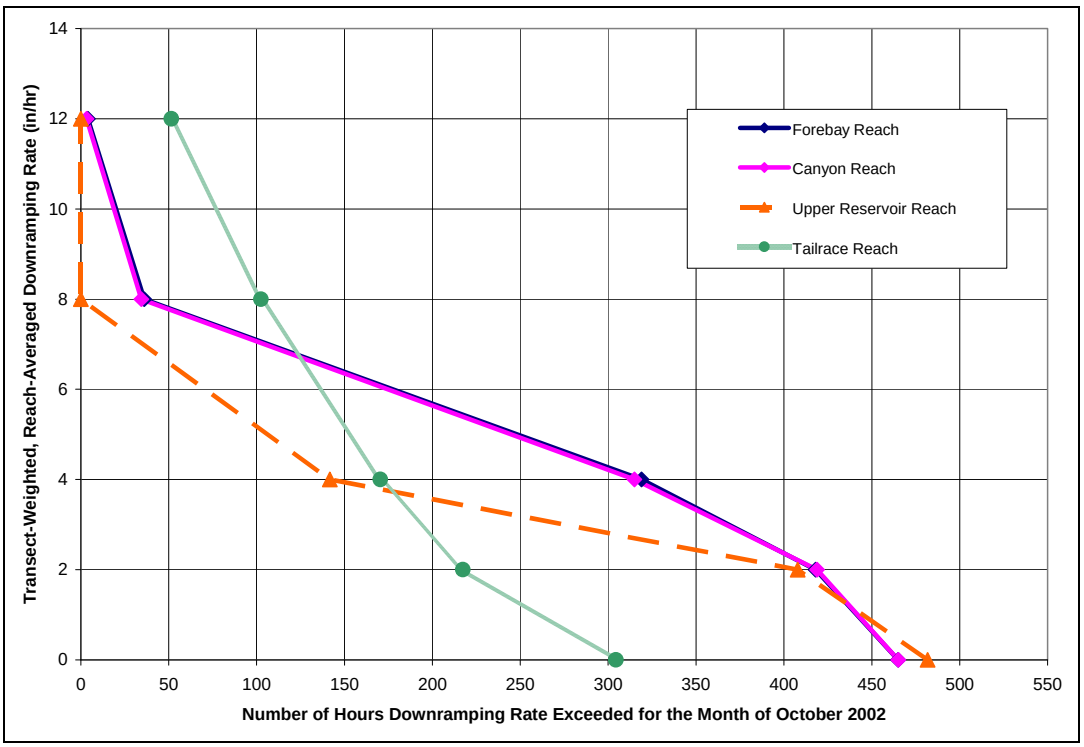


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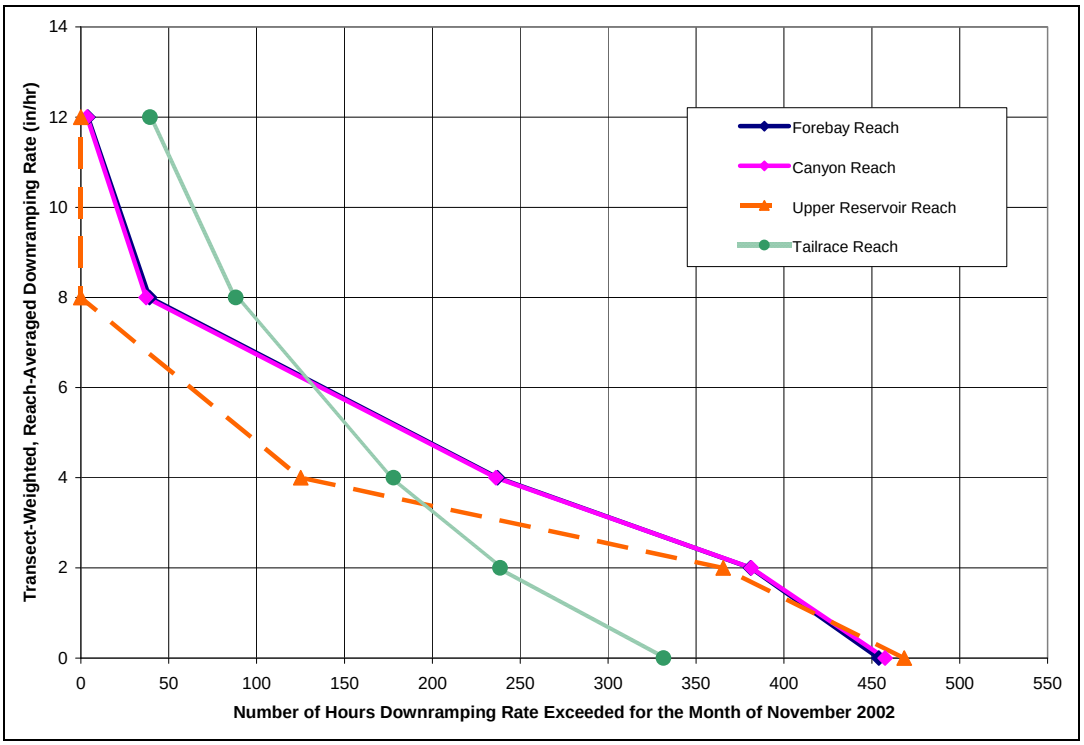


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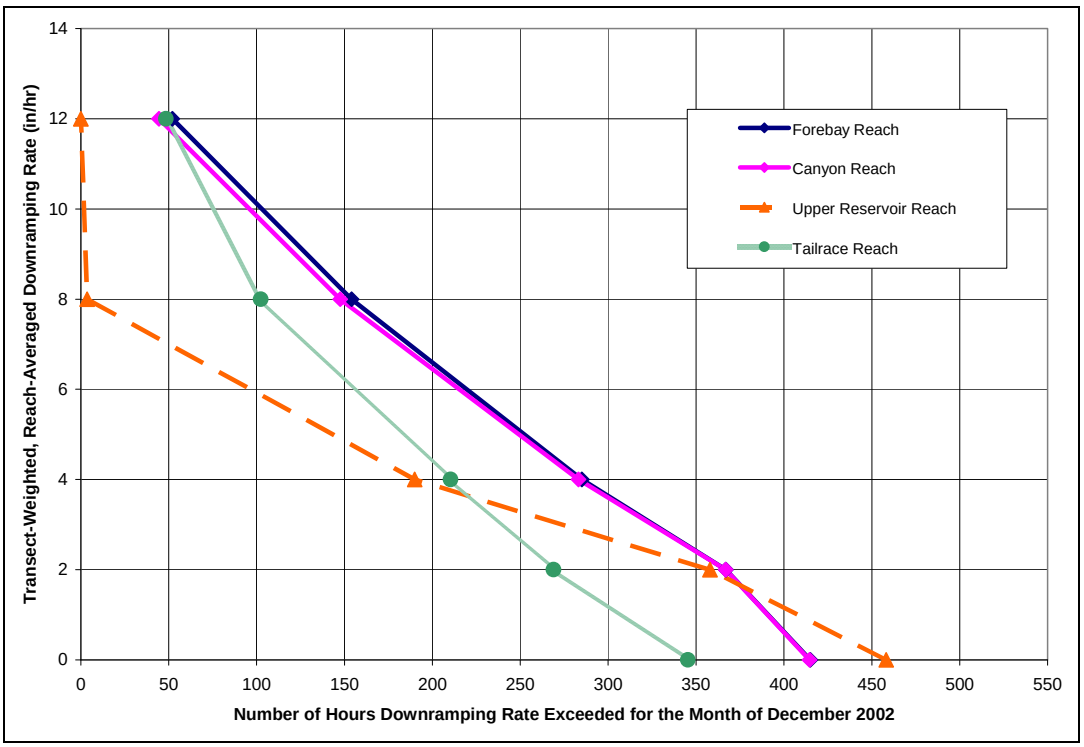


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# Appendix 6: Macrophyte Habitat Suitability Index (HSI) Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 6*

## *Macrophyte Habitat Suitability Index (HSI)*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**

**Darlene Siegel, Harry Gibbons, Robert Plotnikoff, and**
**Shannon Brattebo**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 6
# Macrophyte Habitat Suitability Index
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

Study No. 7.4.2, Macrophyte Habitat Suitability Index (HSI), was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007 and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This final report describes all study efforts of the Mainstem Aquatic Habitat Modeling: Macrophyte HSI.

### 1.1. Study Background

An HSI was developed to describe the response of macrophytes to various reservoir management scenarios, for use in the Boundary Reservoir mainstem aquatic habitat model. Specifically the scenarios including cyclic inundation and dewatering that may change physical parameters that the macrophytes are exposed to, such as, depth, water velocity, light, etc. An HSI is a model for calculating the habitat suitability of an area for a single species or assemblage of species. A set of variables that represent the life requisites for the species (e.g., percent cover, water depth, water quality) is combined into a mathematical habitat model. The variables are then measured in the field and their corresponding index values are inserted into the model to produce a score that describes existing habitat suitability. The value is an index score between 0 and 1. The mathematical model used for developing HSI curves for macrophytes was based upon literature addressing the species' habitat requirements and preferences.

Aquatic macrophytes comprise a diverse assemblage of macroscopic flora that has become adapted from terrestrial species to live wholly, or partially, in fresh water (Fox 1996). Macrophytes are classified as emergent, floating-leaved, free-floating, or submersed. Macrophytes can be beneficial to lakes and reservoir systems because they provide cover for fish and substrate for aquatic invertebrates, but the overabundance of macrophytes can become problematic by interfering with recreational activities, affecting water quality and enhancing internal nutrient loading from the sediments, and reducing the mobility of some fish species and sizes. Problems caused by non-native invasive species are especially severe. Macrophytes have become an increasing problem in Boundary Reservoir because the shallow water areas of the reservoir system are conducive to non-native invasive plant colonization and growth.

Aquatic macrophyte biomass has been found to be greatest in the littoral regions of the Pend Oreille River at depths of less than 10 feet (Falter et al. 1991). The littoral habitat of lakes, reservoirs, and large rivers is the bottom area along the shoreline where the level of light penetration is sufficient for photosynthesis to occur (Wright and Szluha 1980; Wetzel 2001).

Maximum macrophyte biomass in the mainstem occurs in the latter part of July and in August (Pelletier and Coots 1990).

The dominance of non-native invasive macrophyte species, such as Eurasian water milfoil (*Myriophyllum spicatum*) and curly pondweed (*Potamogeton crispus*) in Boundary Reservoir have displaced native aquatic plant beds. Not only are the native plant species displaced, but the non-native plant growth patterns may not be conducive to the productivity of native aquatic species, such as fish and insects, because of dense plant structure and lack of food base and overall habitat. Eurasian water milfoil and curly pondweed taxa have spread in significant portions of the shallow areas throughout the Pend Oreille River system (EPA 1993; Pelletier and Coots 1990) and have been found in shallow coves and bays of Boundary Reservoir. Milfoil forms dense mats of vegetation on the water surface, which reduces light penetration and can displace native species of aquatic vegetation (CWS 2003). The dense biomass of milfoil slows water velocities and allows nutrients and sediments to precipitate out of the water column (EPA 1993). Milfoil can disperse by fragmentation of plant parts (Hamel 1990). Its growth begins in early spring, often earlier than other aquatic plants, as temperatures reach 15°C, and reaches a maximum June through August (WSNWCB n.d.). Each fragment within an intact node can grow roots and develop into a new plant, allowing it to disperse quickly and aggressively. In the late summer and fall the plants become brittle and naturally break apart, promoting colonization of new areas. Another non-native invasive species, curly pondweed, is found in the project vicinity and begins growth in early spring and spreads by vegetative turions or seeds (WSNWCB 2004). Both of these non-native species are generalists relative to their substrate and nutrient requirements facilitating their opportunistic community dominance.

### 1.2. Study Description

Macrophyte HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data, 3) calibration of the literature-based HSI curves using field data, and 4) finalization of the macrophyte HSI for Boundary Reservoir. Field surveys were conducted of aquatic plant distribution and abundance data along depth, velocity, and substrate gradients extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions. This portion of the study was designed to measure a biological response to the range of conditions and periods of inundation and exposure that are likely to occur for operations scenarios within Boundary Reservoir.

## 2 STUDY OBJECTIVES

The objective of this study was to develop HSI curves for macrophytes based on literature, existing data, and site-specific data that address macrophyte responses to operations scenarios within Boundary Reservoir. The HSI curves were used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for macrophytes under operations scenarios. The information collected during this study was also used to support Study 11, Productivity Assessment (SCL 2009a). This study included the following four primary elements necessary to develop accurate and comprehensive HSI:

- Literature-based macrophyte HSI curves

- Sampling of macrophyte distribution and abundance along habitat gradients
- Calibration of macrophyte HSI curves
- Finalization of macrophyte HSI curves.

## 3 STUDY AREA

Field surveys of aquatic plant distribution and abundance were conducted in both the upper and lower Boundary Reservoir (upstream and downstream of Metaline Falls).

Where possible, HSI field surveys were integrated into ongoing mainstem habitat transect measurement efforts or other macrophyte study efforts. HSI field transect methods and locations are presented in Appendix 1a of the main report. See Section 3 of Study 7, Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009b) for definition of the Project reaches referred to in this report.

## 4 METHODS

In the following sections the methods that were used to develop the macrophyte HSI curves for Boundary Reservoir are discussed in detail.

The Boundary Project macrophyte model combines a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.0-1). The model is designed to integrate the HSC and HSI values to develop a composite suitability index for each cell within a mainstem habitat transect using hourly time steps.

**Table 4.0-1.** Project macrophyte model.

| **Macrophyte Composite Suitability Index** | $CSI_{Macrophyte} = HSC_i * HSI_i$ |
|---|---|
| Macrophyte HSC | $HSC_i = D_i * Vo_i * S_i$ |
| Macrophyte HSI | $HSI_i = f(DI_i, DD_i)$[1] |
| Macrophyte Variables | $D_i$ = Depth of Light<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

Note:
1 See Study 7 Final Report (SCL 2009b) discussion of the varial zone analysis for details on integrating inundation and dewatering factors.

The methods used to determine provisional values for each of the five variables are described in the next paragraphs, and the results from literature review are described in further detail in Section 4.

The most common method of calculating weighted usable area values in PHABSIM studies is a multiplicative aggregation given by:

$$HSC_i = D_i * Vo_i * S_i$$

Where:

HSCi = composite habitat suitability of cell i

$D_i$ = suitability associated with depth in cell i
$Vo_i$ = suitability associated with velocity in cell i
$S_i$ = suitability associated with substrate in cell i

Using a multiplicative aggregation, if any of the variables results in a score of zero, the composite value will become zero and the habitat would be rated as unsuitable for use for that time step. This composite HSC approach will be used for the Boundary macrophyte model to calculate the suitability of a cell to support macrophytes at a given hour. However, the value of a cell for use by macrophytes is also affected by the length of time that the cell has been inundated. Cells that have been inundated for several weeks or more typically support a higher macrophyte biomass than cells that are newly inundated. Cells that have been dewatered for even a period of a few hours will have a lower macrophyte suitability than cells that have not been dewatered. Frequent cycles of dewatering and inundation will affect macrophyte productivity in a cell regardless of its suitability as defined by depth, velocity, and substrate.

In order to evaluate the effects of pool surface elevation fluctuations on macrophyte productivity, the prior inundation history of the cell will be tracked using hourly time steps. As the duration of continuous inundation increases, the macrophyte suitability is assumed to increase up to a maximum of 1.0. The rate of macrophyte suitability increase is determined from a Duration of Inundation (DI) HSI. While macrophyte suitability in a cell increases as the duration of continuous inundation increases, dewatering of the cell will reduce macrophyte suitability through plant decline or mortality. The rate of macrophyte suitability decreases in response to dewatering is determined from a Duration of Dewatering (DD) HSI that decays from a maximum suitability of 1.0 to a suitability of zero.

The pattern of prior inundation and dewatering will determine the relative status of a cell at a given time step as indicated by an HSI value between 1.0 and zero (see Study 7 Final Report [SCL 2009b] discussion of varial zone analysis for details on integrating inundation and dewatering). An integrated HSI value of less than 1.0 will indicate that the prior history of inundation and dewatering has reduced macrophyte suitability in that cell at the specific time step. The HSI value and the HSC value will be multiplied to determine a composite suitability index for that cell at the given hour.

## 4.1. Development of Literature-Based Macrophyte HSI Curves

A literature review was conducted to compile existing information on macrophyte ecology and habitat requirements in order to develop seasonal periodicity and habitat requirements for macrophytes within the Pend Oreille River. Available information was complied on the influence of habitat factors that may affect macrophyte growth including depth, velocity,

substrate, and duration of inundation and dewatering (rates of macrophyte colonization and dewatering mortality). Available information on the duration and severity of freezing and desiccation necessary to retard growth was also compiled to assist in the evaluation of reservoir drawdown as a potential opportunity for control of invasive macrophytes. This information was then used to develop literature-based (provisional) HSI curves that address habitat conditions expected to exist in Boundary Reservoir.

## 4.2. Field Data Collection

The study area for this study encompasses both the upper and lower Boundary Reservoir (upstream and downstream of Metaline Falls). Where possible, HSI field surveys were integrated into ongoing mainstem habitat transect measurement efforts or other macrophyte study efforts. HSI field transect methods and locations are presented in Appendix 1c.

Field surveys were conducted to assess aquatic plant distribution and abundance data along with depth, velocity, and substrate gradients extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions. Selection of macrophyte HSI study sites were determined based on the habitat mapping and were selected based on presence of macrophytes and representativeness of the study reach. Measurements of aquatic vegetation density, depth, velocity, and substrate were conducted in August, 2007, in combination with the Mainstem Aquatic Habitat Model development (see Study 7 Final Report, Sections 4.3.3 and 4.3.4 [SCL 2009b] for detailed methods). Aquatic vegetation and habitat were characterized with the mainstem habitat transect measurement effort along a total of 63 transects.

Measurement of macrophyte abundance and macrophyte mapping surveys were conducted in August during peak macrophyte growth. The entire shoreline from Box Canyon Tailrace to Boundary Dam was surveyed for the presence of macrophytes. A GPS point was taken every 1,000 meters or when macrophytes were encountered. When macrophytes were present, GPS points were taken at the boundaries of these beds and at least every 100 meters along the outside of the beds. Enough points were taken to clearly define the limits of each bed. At each GPS point within the beds, species present and the respective percent cover were recorded. If dewatered and dry macrophytes were encountered the species identification and the respective percent cover was estimated.

## 4.3. Calibration of Macrophyte HSI Curves

Using the site-specific data collected during field surveys, a histogram or line graph for each of the habitat parameters researched was developed. The histograms and line graphs incorporated the site-specific field data collected in order to validate original provisional curves. Site-specific data for velocity were not collected as part of study components 7 and 8, but was estimated from the hydraulic routing model. The histograms and line graphs were compared with the literature-based (provisional) HSI curves to validate the applicability of the literature-based HSI curve used for aquatic habitat modeling. In order to validate literature-based habitat suitability information with site-specific observations, it will be assumed that all suitable habitats, under existing Project operations and Pend Oreille River hydrology, had been colonized by aquatic macrophytes within the Boundary Reservoir.

### 4.4. Finalization of Macrophyte HSI Curves

The HSI curve for each metric was reviewed by a panel of relicensing participants and regional experts. Panel members reviewed the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. The panel consisted of relicensing participants and regional experts (agency, tribal, and industry) on April 23 and July 17, 2008. Once the final macrophyte HSI curves were developed, they were used in the aquatic habitat modeling study to define the habitat of aquatic macrophytes, as they relate to selected metrics, in relation to operations scenarios.

## 5 LITERATURE-BASED HSI CURVES

Suitability curves are graphical relationships between physical habitat components and an index of biological response scaled between 0 and 1.0, with 1.0 representing the maximum habitat suitability. Based on an extensive literature review, suitability curves for macrophytes were developed. However, these studies primarily documented macrophyte habitat suitability for lotic and unmanaged environments; therefore, no habitat conditions that would directly apply to the conditions in the Boundary Reservoir. The focus of this model is to determine the response of macrophytes as a whole. As such, the HSC and HSI curves provided here focus on the suitability for macrophytes as a group based, in part, on information from literature and professional experience and judgment. Plots of existing data sets, combined with professional judgment and literature, were used to determine ranges for each of the five model variables and provisional suitability values. Section 4 includes a summary of the information from literature sources and the provisional suitability curves.

### 5.1. Depth of Light

Macrophytes generally grow best in high light levels (Welch and Jacoby 2004). Submersed macrophytes have been found to grow to a depth of two to three times the Secchi depth (Nichols 2001), Canfield et al. (1985) found depth of colonization to be slightly more than the Secchi depth. This study developed the following regression model between the maximum depth of plant colonization (MDC, meters) and Secchi depth (SD, meters): Log MDC = 0.62 log SD + 0.26 (Canfield et al. 1985). Figure 5.1-1 (e.g., for May SD [4.8/3 = 1.6 meters]) gives a colonization depth of 7.9 feet (2.4 meters). Similar results were produced by Chambers and Kalff (1985): $Z_c^{0.5}$ = 1.33 log SD +1.4, where $Z_c$ is depth of colonization. Consistent with this, Falter et al. (1991) found little or no growth of macrophytes at depths greater than 18 feet (5.5 meters), whereas the greatest biomass was found less than 10 feet (3 meters).

Riis and Biggs (2003) found the lowest optimum depth suitability varied among species with *Ranunculus trichophyllus* at 1 foot (0.3 meter), *Myriophyllum triphyllum* at 1.6 feet (0.5 meter), *Potamogeton cheesemanii* at 2.3 feet (0.7 meter), and *Elodea canadensis* preferred deeper water (3 feet [0.9 meter] optimum). However, these studies were conducted in small, shallow water bodies, with zero surface water flocculation and with low wind induced wave action. The conditions differ from those found in Boundary and Box Canyon reservoirs. For example, in

Box Canyon Reservoir, the maximum biomass depth for *Ranunculus sp.* was 1 meter, demonstrating impact of water level and wave action.

For Eurasian watermilfoil (*Myriophyllum spicatum)*, abundant growth appeared between depths of 1.6 to 11.5 feet (0.5 to 3.5 meters) (CWS 2003), but some growth has been found at depths as great as 16.4 feet (5 meters) (Pend Oreille County 2003), which corresponds to Secchi disk transparency of 5 to 6.5 feet (1.5 to 2.0 meters) during the spring growth period where the maximum extent of macrophyte bed growth occurs. Growth has been found to be poor in shallow water less than 3.28 feet (1 meter) (Smith and Barko 1990). Milfoil's light compensation point (photosynthetic light limit) of only 1 to 2 percent of surface intensity allows milfoil to photosynthesize in deeper water than other rooted plants (Engel 1995).

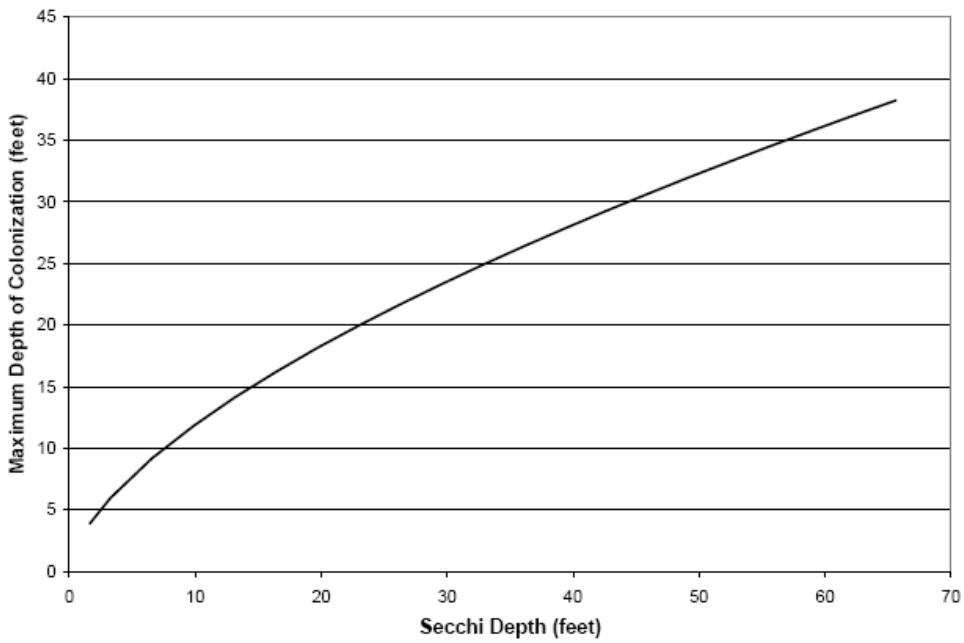


**Figure 5.1-1.** Regression model relationship developed by Canfield et al. (1985) between Secchi depth and the maximum depth of colonization.

Provisional suitability values were selected based on Secchi depth and estimates of euphotic zone depth in Boundary Reservoir (Table 5.1-1). The provisional suitability values selected were based on literature and professional judgment and will be refined further based on data collected in the field to determine ranges of depth of light suitable for macrophyte growth in Boundary Reservoir.

Assuming a Secchi transparency of about 4.9 to 9.8 feet during May through July, the maximum depth of colonization should be about 16.4 to 29.5 feet according to Canfield et al. The usual range of drawdown in Boundary Reservoir is 2.0 to 11.8 feet during the summer, which means that macrophytes colonized to those depths will not survive throughout the summer. So limitations due to light transmission are the basis for the provisional suitability values given in

the following Table 5.1-2. Figure 5.1-2 displays the provisional depth of light suitability curve for macrophytes which is based on literature and professional judgment.

**Table 5.1-1.** Estimated monthly euphotic depth of Boundary Reservoir based on Secchi disk readings and extrapolations of turbidity readings that reduce euphotic depth.

| | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimated Euphotic Depth (feet) | 34.4 | 34.4 | 27.2 | 19.7 | 15.8[1] | 16.7[1] | 28.5[1] | 44.3[1] | 39.7[1] | 34.5[1] | 34.5 | 34.5 |

Note:

1 Estimated euphotic depth based on three times the Secchi disk readings reported by McLellan and O'Conner (2001).

**Table 5.1-2.** Depth of light ranges and provisional suitability values for macrophytes.

| **Depth of Light** | **Provisional Suitability Values** |
|---|---|
| 0 | 0.5 |
| 0.33 ft | 0.6 |
| 0.66 ft | 1.0 |
| 3.28 ft | 0.75 |
| 6.6 ft | 0.3 |
| >16.5 ft | 0.01 |

Source: Falter et al. 1991; Nichols 2001; Canfield et al. 1985; Riis and Biggs 2003; CWS 2003

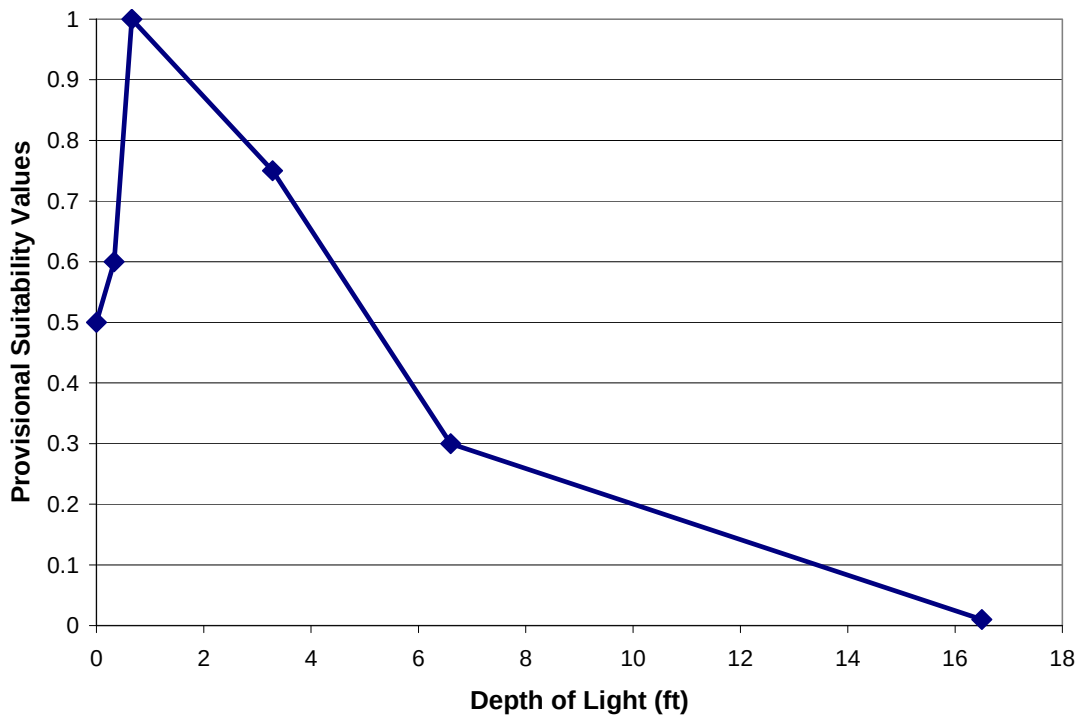


**Figure 5.1-2.** Provisional depth of light suitability curve for macrophytes.

## 5.2. Velocity

Henriques (1987) found that at velocities less than 0.66 foot per second (fps) (0.2 meter per second [m/s]), 75 percent of the reach was occupied by aquatic vegetation, but that percentage decreased to only 10 percent in areas with velocities greater than 2.9 fps (0.9 m/s). However, macrophytes were recorded in velocities of up to 3.9 fps (1.2 m/s) at the time of peak biomass. In another study, data from 29 transects for five hydrologically stable streams were compiled and a curve developed for habitat preference as a function of mean water velocity. Habitat preference was analyzed for *Elodea canadensis*, *Myriophyllum triphyllum*, *Potamogeton cheesemanii*, and *Ranunculus trichophyllus*. Habitat suitability was lowest at velocities less than 0.16 fps (0.05 m/s), it increased steadily to approximately 1.3 fps (0.4 m/s), and decreased slightly up to 1.97 fps (0.6 m/s) (Riis and Biggs 2003). In addition, this study found a threshold velocity of 2.6 fps (0.8 m/s) above which no macrophyte growth occurred (constant velocity; intermittent floods of higher velocities did not restrict growth as much).

Provisional suitability values were selected based on a synthesis of the above information (Table 5.2-1). Further calibration of the index values will be supported with data collected in the field evaluating the differences in macrophytes and the associated water velocity. Figure 5.2-1 displays the provisional velocity suitability curve for macrophytes. The velocity suitability curve is based on literature and professional judgment for macrophyte growth in Boundary Reservoir.

**Table 5.2-1.** Velocity ranges and provisional suitability values for macrophytes.

| Velocity | Provisional Suitability values |
|---|---|
| 0 | 0.1 |
| 0.164 fps | 1.0 |
| 1.31 fps | 0.75 |
| 1.97 fps | 0.3 |
| 2.62 fps | 0.1 |
| 7.7 fps | 0.0 |

Source: Henriques 1987; Riis and Biggs 2003

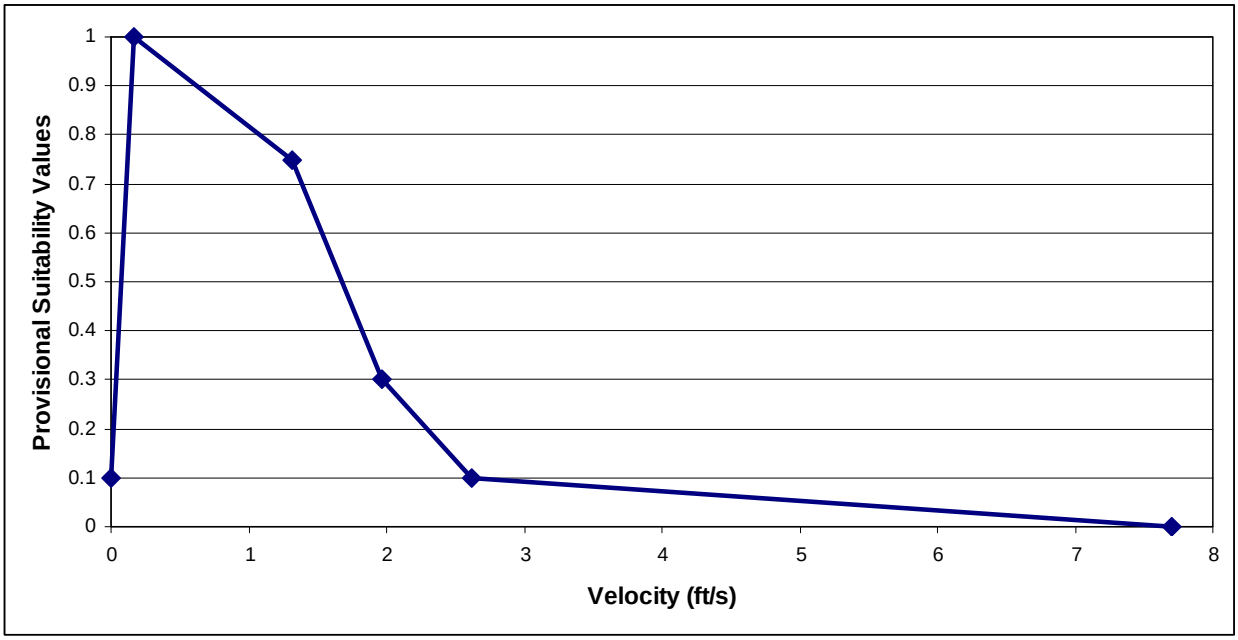


**Figure 5.2-1.** Provisional velocity suitability curve for macrophytes.

## 5.3. Substrate

Rooted macrophytes obtain their nutrients primarily from bottom sediments rather than from overlying water (Welch and Jacoby 2004). Substrate, the substrata upon which the macrophytes grow, is also important for attachment. Rooted macrophytes prefer loose textured enriched sediment of intermediate organic content and low for maximum growth (Welch and Jacoby 2004; Barko and Smart 1986). Dilution of lake bed sediment with sand has shown poor growth (Welch and Jacoby 2004). Eurasian water milfoil grows best on fine-textured intermediate organic sediments and relatively poorly on highly organic sediments (greater than 20 percent organic content) or coarse or sand substrates (WSNWCB n.d.; Smith and Barko 1990; Pend Oreille County 2003). However, some species of macrophytes colonize coarse bed substrate in running water. Riis and Biggs (2003) found that streams, sand and small gravel are preferred by *Elodea canadensis*, *Myriophyllum triphyllum*, and *Potamogeton cheesemanii*, whereas

*Ranunculus trichophyllus* prefer gravel and cobble substrata. These findings conform to Haslam (1978), who found that *E. canadensis* prefer silt and *Ranunculus* spp. prefer gravel.

Generally, species are distributed by their preferences for substrate types, which is affected by velocity (Biggs and Stokseth 1996). Low velocity waters with soft, deep, substrates have mainly floating and/or deeply rooted plants (e.g., *Rorripa* spp.). Areas of higher velocity have species which are better at anchoring to the coarser substrates in these areas (e.g., *Rannunculus* spp). Provisional suitability values for substrate were identified to be a limiting factor whereas, if suitable substrate is not present for colonization the HSI value is zero; otherwise assume 1 (Table 5.3-1). Figure 5.3-1 displays the provisional substrate suitability curve for macrophytes.

**Table 5.3-1.** Substrate types and provisional suitability values for macrophytes.

| Substrate Type | Provisional Suitability Values |
|---|---|
| Intermediate organic and fine texture substrates | 1.0 |
| Sandy, gravel, cobble | 0.5 |
| Bedrock | 0 |

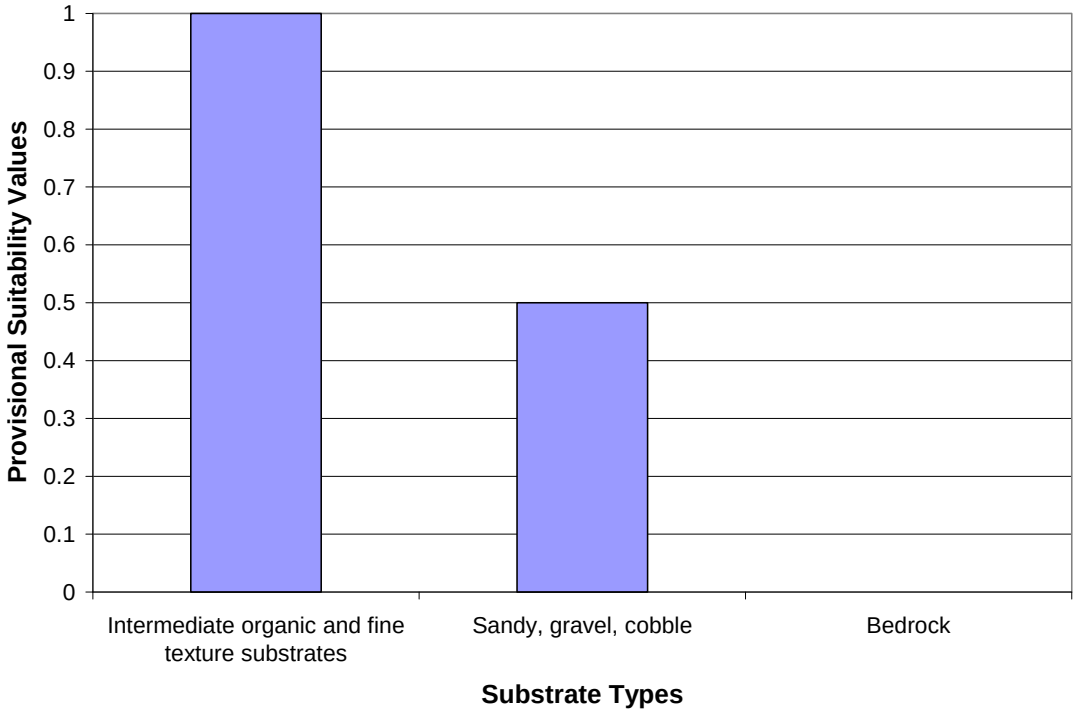


**Figure 5.3-1.** Provisional substrate suitability values for macrophytes.

## 5.4. Duration of Dewatering

Macrophyte communities have been shown to be affected by management regimes that alter natural water surface elevation fluctuations. Wilcox and Meeker (1991) found that macrophyte communities of regulated lakes differed from those in an unregulated lake. The unregulated lake supported structurally diverse plant communities at all sampled depths. In the regulated lake with increased fluctuations above natural levels, rosette and mat-forming species dominated where drawdown occurred in early winter and disturbance resulted from ice formation in the sediments.

Several studies found that exposure duration of as little as 3 to 4 days is sufficient to kill submersed macrophytes (CWS 2003; WSNWCB n.d.), whereas others suggest that only prolonged (one month or more) exposure is sufficient to achieve macrophyte control (Cooke 1980).

Riis and Hawes (2002) found that the relationship between species richness and water level variation followed a hump-backed curve, with richness rising with increased water level fluctuation up to 1 meter and the most extreme monthly water level fluctuation of 2.4 meters showing the lowest species richness. Van Geese et al. (2005) found submersed macrophyte and total macrophyte species richness highest at fluctuations from 0.4 to 0.6 meter and lower at fluctuations less than 0.2 meter or from 1.0 to 1.2 meters. Floating leaved macrophytes and helophytes (emergent) did not show a significant preference.

Eurasian watermilfoil is particularly resistant to exposure and may require three or more weeks of exposure to achieve control (Cooke 1980). In addition, some studies suggest that some species, such as milfoil, may be enhanced by diurnal water level drawdown by creating favorable habitat conditions where they can out-compete other macrophytes (Smith and Barko 1990; WSNWCB n.d.).

Figure 5.4-1 displays the provisional duration of dewatering suitability curves for submersed macrophytes. The provisional duration of dewatering suitability curve in Figure 5.4-1 was based on literature and professional judgment and will be refined further based on data collected in the field to determine ranges of suitability for macrophyte growth in Boundary Reservoir.

**Table 5.4-1.** Duration of dewatering provisional suitability values for submersed macrophytes.

| Time (hours) | Provisional Suitability Values |
|---|---|
| 0 | 1.0 |
| 6 | 0.8 |
| 12 | 0.6 |
| 24 | 0.4 |
| 72 | 0.1 |
| 720 | 0.0 |

Source: CWS 2003; WSNWCB n.d.

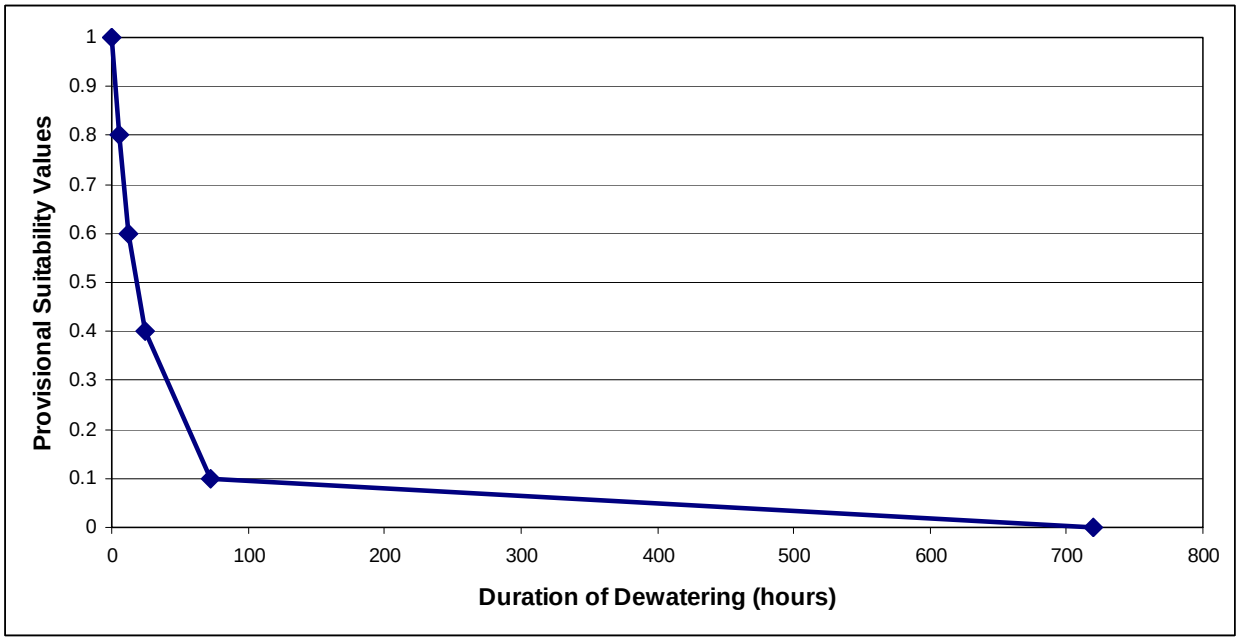


**Figure 5.4-1**. Provisional duration of dewatering suitability curve for submersed macrophytes.

## 5.5. Duration of Inundation

Establishment of macrophytes occurs in the spring. Macrophytes will establish at a water surface elevation of constant inundation. Therefore, the duration of inundation provisional suitability values for macrophytes are based upon the presence and absence of constant inundation (Table 5.5-1). The duration of inundation HSI factor will only be included during spring time steps in the Boundary Reservoir Mainstem Aquatic Habitat Model.

**Table 5.5-1.** Duration of inundation provisional suitability values for macrophytes.

| Constant Inundation | Provisional Suitability Values |
|---|---|
| yes | 1.0 |
| no | 0 |

# 6 FIELD DATA RESULTS

## 6.1. Existing Macrophyte Distribution and Abundance Conditions in Boundary Reservoir

The existing distribution and abundance of macrophytes in upper and lower Boundary Reservoir was assessed during field surveys conducted in August 2007 and August 2008. As a result of the macrophyte mapping effort, macrophyte distribution, abundance, and species present in the

Boundary Reservoir are presented in Figure A.1b-1 in Appendix 1b. Table 6.1-1 also summarizes the macrophyte species found in the upper and lower Boundary Reservoir.

**Table 6.1-1.** Macrophyte species in Boundary Reservoir.

| Scientific Name | Common Name | Status |
|---|---|---|
| *Myriophyllum sibericum* | Northern Milfoil | Native |
| *Myriophyllum spicatum* | Eurasian Watermilfoil | Non-native |
| *Ceratophyllum demersum* | Coontail | Native |
| *Elodea canadensis* | Common Waterweed | Native |
| *Potamogeton crispus* | Curly Pondweed | Non-native |
| *Potamogeton pectinatus* | Sago Pondweed | Native |
| *Potamogeton vaginatus* | Sheathing Pondweed | Native |
| *Potamogeton richardsonii* | Richardson's Pondweed | Native |
| *Potamogeton zosteriformis* | Flat-stem Pondweed | Native |
| *Ranunculus aquatilis* | White Water Buttercup | Native |

Macrophyte beds within the main Reservoir covered 20.7 acres downstream of Metaline Falls and 202.5 acres upstream of Metaline Falls. Aquatic macrophyte beds, mainly in the Upper Boundary Reservoir within stranding and trapping areas cover an additional 25.3 acres. Eurasian watermilfoil, Potamogeton species, and coontail were the dominant plant species found in Boundary Reservoir (Figure A.1b-1 in Appendix 1b). Curly pondweed appears to be invading areas of established Eurasian watermilfoil beds displacing both Eurasian and coontail in these more established beds. Table 6.1-2 summarizes the relative number of macrophyte beds found above and below Metaline Falls.

**Table 6.1-2.** Date and locations of macrophyte bed sampling during 2007 and 2008.

| Collection Date | Reservoir Zone | No. of Macrophyte Beds | Macrophyte Bed Size Range (acres) | Total Macrophyte Area (acres) |
|---|---|---|---|---|
| August 25-27, 2007 | Box Canyon Tailrace | 0 | 0 | 0 |
| August 25-27, 2007 | Above Metaline Falls | 33 | 0.02-61.7 | 202.5 |
| August 25-27, 2007 | Canyon Reach | 27 | 0.001-7.9 | 12.3 |
| August 25-27, 2007 | Boundary Forebay | 12 | 0.001-8.4 | 8.4 |
| August 25-27, 2007 | Boundary Tailrace | 0 | 0 | 0 |
| August 18-19, 2008 | Fish Stranding and Trapping Areas Above Metaline Falls | 14 | 0.001-9.5 | 24.0 |
| August 18-19, 2008 | Fish Stranding and Trapping Areas Below Metaline Falls | 4 | 0.001-1.0 | 1.3 |
| | **Total[1]** | | | **223.2** |

Note:

1 Stranding and trapping areas are included in all reservoir zones.

The distribution and abundance measures were correlated with habitat features in the reservoir including depth, velocity, substrate, and duration of inundation and dewatering. Depths at which macrophytes were found in the 2007 August survey calculated using GPS and bathymetry were crossed-checked with actual depth data collected at habitat transects in August 2007. This cross-check ensures that the most accurate determination of macrophyte habitat was achieved.

## 6.2. Existing Macrophyte Habitat Conditions in Boundary Reservoir

Field data were collected to validate the HSI curves for the following parameters: depth, velocity, substrate, and duration of inundation and dewatering as a function of macrophyte abundance. Depth, velocity, and substrate data was collected along a total of 63 transects throughout the study area. Along each transect when aquatic plants were observed, additional descriptive and density data was recorded. In order to acquire data along depth, velocity, and substrate gradients, measurements were taken under both high and low pool elevations.

Velocities, water surface elevations, and transect bottom profiles were measured under a target stable high river flow at full pool elevation (approximately elevation 1,992 feet NAVD 88 [1,988 feet NGVD 29])[1] at all transects upstream of Boundary Dam, and again under target stable high flow, middle flow, and low flow at low pool elevation (less than approximately 1,984 feet NAVD 88 [1,980 feet NGVD 29]) on transects in the Upper Reservoir Reach above Metaline Falls.

Habitat transect data was collected during August 2007 as per the RSP (SCL 2007). Macrophyte habitat data (depth, velocity, and substrate) along with the duration of inundation and dewatering calculated from the Hydraulic Routing Model Study were utilized to calibrate and refine the macrophyte HSI curves for Boundary Reservoir. Macrophyte distribution and abundance mapping efforts (see Section 5.2) were also used to further refine macrophyte HSI curves for Boundary Reservoir.

# 7 FINAL MACROPHYTE HSI CURVES

This section details the process that was used to calibrate and finalize the macrophyte HSI curves for Boundary Reservoir. The final curves for macrophytes are also presented in this section.

Adjustments to the provisional macrophyte HSI curves were made based on the macrophyte coverage map, the cross section and routing model data, existing conditions within Boundary Reservoir, and the biological growth requirements of aquatic macrophytes. A roundtable discussion with relicensing participants and regional experts assisted with the development of final HSI curves.

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

## 7.1. Depth

A histogram for depth was developed using site-specific data collected during field studies (Figure 7.1-1). These data were then used to create an observed HSI curve that varied from the provisional literature-based curve (Figure 7.1-2). The factors considered for the refinement of the depth HSI curve were ice, winter/late spring pool levels, water clarity, hydrostatic pressure, and survival of plants during their resting stage and as seeds and fragments. Considering both the observed and literature-based curves, a proposed-final curve was presented to the roundtable (Figure 7.1-2).

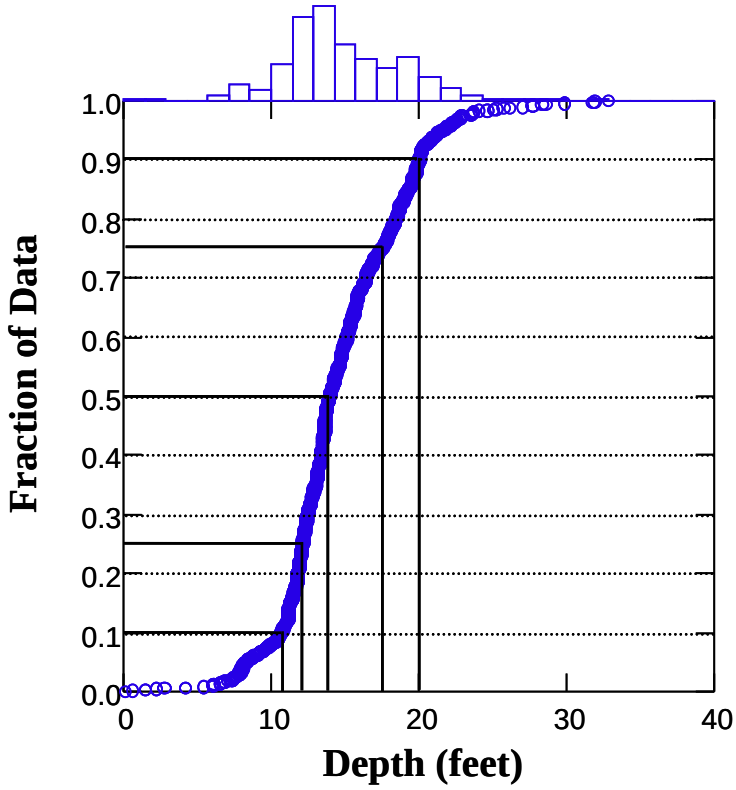


**Figure 7.1-1**. Histogram of depth values recorded where macrophytes were observed.

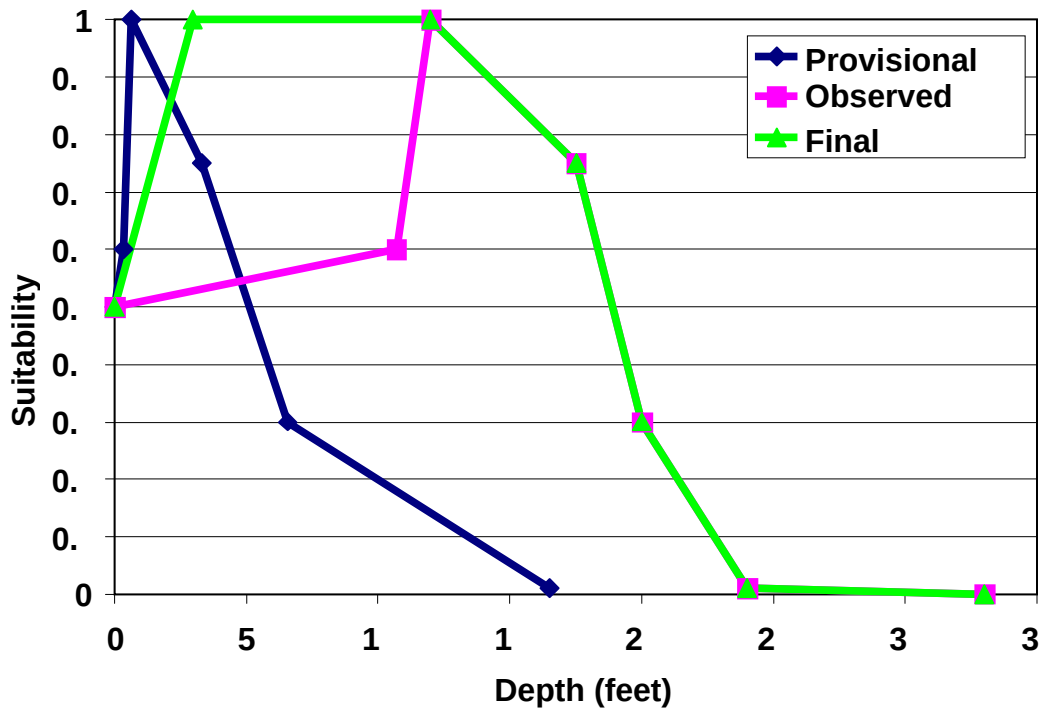


**Figure 7.1-2.** Provisional, observed and proposed-final macrophyte HSI curves for depth.

Relicensing participants agreed to adopt the proposed depth curve with one change: expanding the range of optimum stability (HSI value of 1.0) from 3.5–12.0 feet to 2.0–12.0 feet. The final HSI depth curve for macrophytes is presented in Figure 7.1-3.

The final depth of light HSI curve for macrophytes was revised in January 2009 (presented to relicensing participants at the January 28, 2009, Fish and Aquatics Workgroup meeting). These revisions to the HSI curve were necessary to separate the effect of depth of light from the duration of dewatering scores used to estimate weighted useable area for macrophytes on hourly time intervals and from each transect with the Mainstem Aquatic Habitat Model. Final revisions to the depth of light HSI curve included assigning a suitability value of 0 when depth of light is 0 feet (Figure 7.1-4). This HSI score differs from the final curve that was co-developed with relicensing participants where a suitability value of 0.5 was assigned when depth was 0 feet (Figure 7.1-3). Both depth of light and duration of dewatering contribute HSI scores that describe availability of aquatic habitat. This relationship between the two variables used in generating suitability scores through the Mainstem Aquatic Habitat Model needed to be separated so that effects of each variable were independent of the other. The revised final macrophyte suitability values for depth are presented in Table 7.1-1, and the revised final HSI curve is presented in Figure 7.1-4.

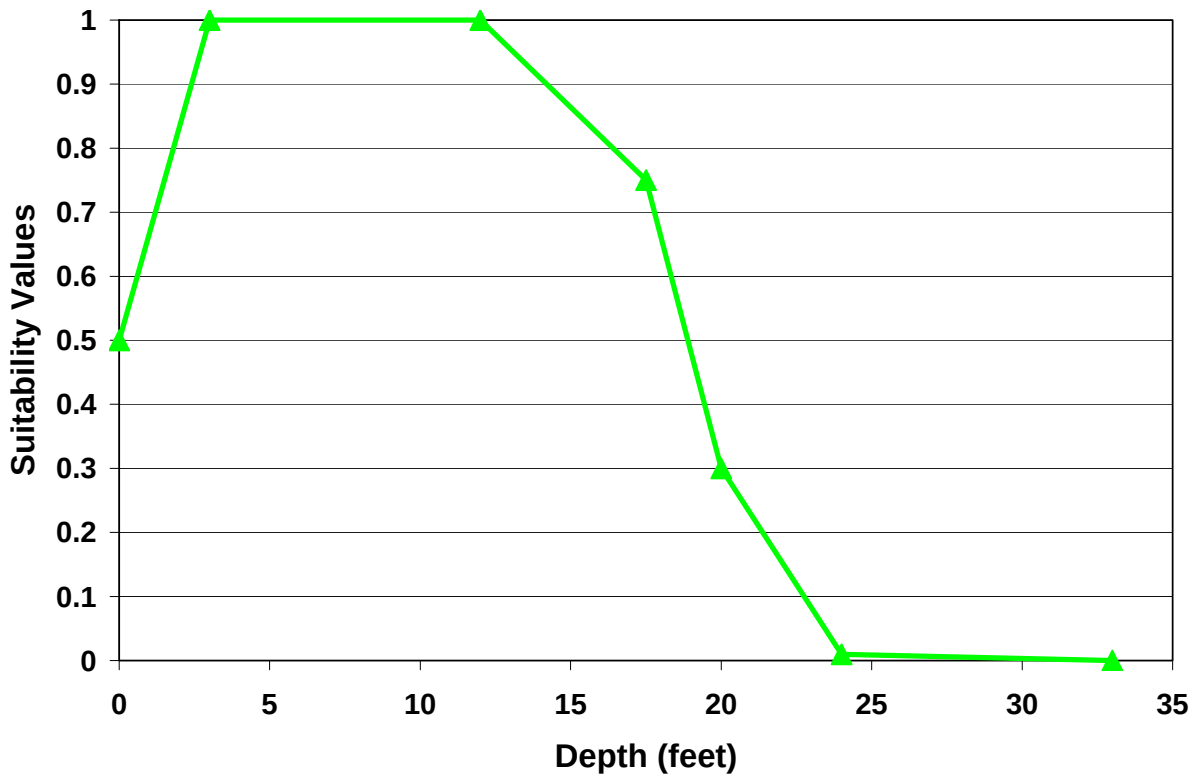


**Figure 7.1-3.** Final macrophyte HSI curve for depth.

**Table 7.1-1.** Revised depth of light final suitability values for macrophytes (revisions approved by relicensing participants at January 28, 2009, 2009 Fish and Aquatics Workgroup meeting).

| Depth of Light | Final Suitability Values |
|---|---|
| 0 | 0.0 |
| 0.1 ft | 0.5 |
| 3 ft | 1.0 |
| 12 ft | 1.0 |
| 17.5 ft | 0.75 |
| 20 ft | 0.3 |
| 24 ft | 0.01 |
| 33 ft | 0 |

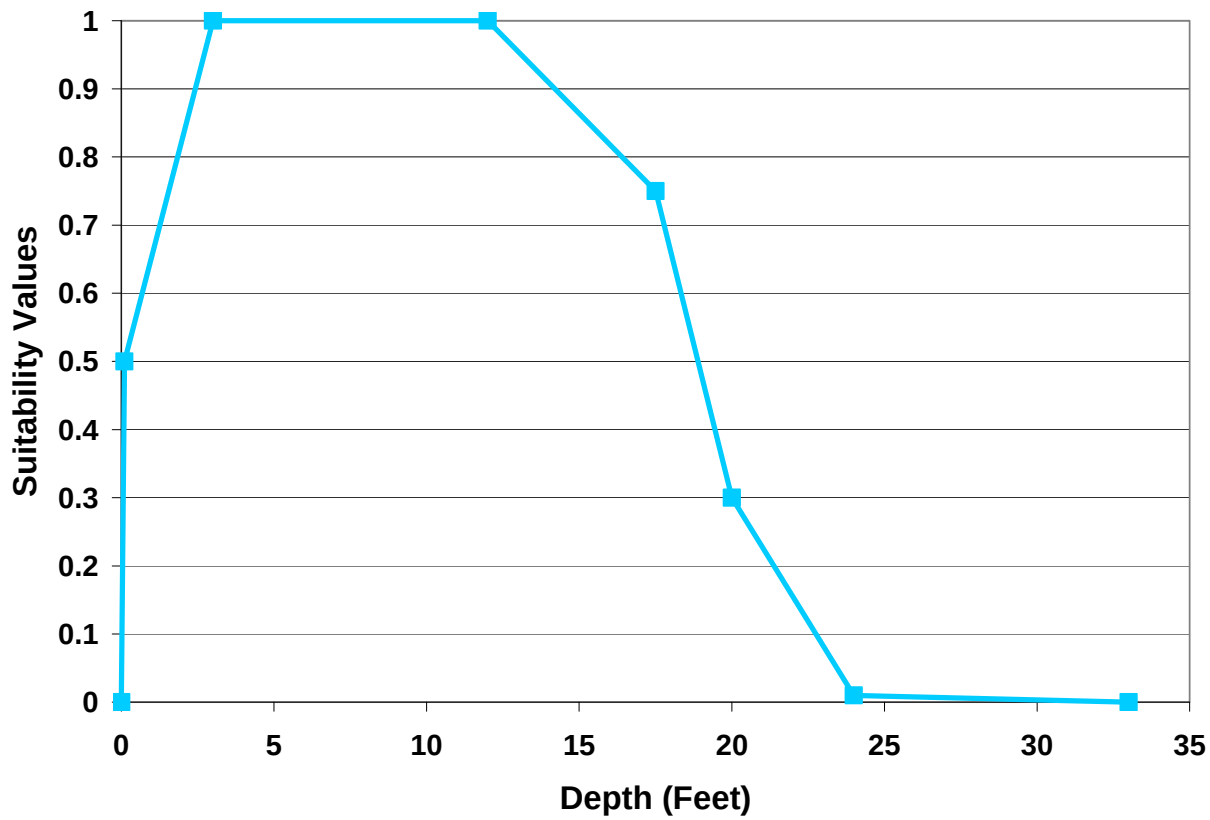


**Figure 7.1-4.** Revised final macrophyte HSI curve for depth.

Minimum depth of macrophyte bed is established based on minimum reservoir elevation at the beginning of the growth season in late winter (March) and early spring (April). Maximum depth of macrophyte bed is established during the same period but is limited by light and or hydrostatic pressure. Light limitation for Boundary Reservoir in the spring was calculated to be 39.4 feet (12 meters). Although species-dependent, in general hydrostatic pressure limitation was between 26.3 feet (8 meters) and 39.4 ft (12 meters).

Therefore, aerial coverage of aquatic submersed macrophyte beds are established and maintained based on additional factors to those used for developing the HSC curves (depth, velocity, and substrate type) within a lake or reservoir. Timing for establishment of beds in Boundary Reservoir occurs in late winter and early spring in response to lengthening daylight hours for seed germination or root crown/turion vegetative growth.

Three critical things have to be in place for submersed plants to survive and establish a plant community or bed. First, the seed/germinating seed or root crown/turion must remain wet and can not be exposed to desiccation. Second, light has to be available to support photosynthesis. Third, substrate stability has to allow seeds, turions, roots, or tubers to remain in place during spring growth. Hence, the hydrologic cycle in part dictates that fall and winter reservoir levels are at minimum stage until the late spring snowmelt runoff occurs. It is this low reservoir level that defines the maximum elevation level of the aquatic plant beds. Conversely, the deeper depth

of macrophyte establishment is also established at this time of low reservoir level, but is also influence by higher hydrostatic pressure when reservoir water level is increase with spring time high water flows. The subsequent increase in reservoir water level and daily fluctuation do not influence the aquatic plant bed expansion after spring growth begins.

When the Boundary Reservoir water levels increase to the summer time highs only temporary expansion of macrophytes is allowed due to the winter drawdown and lack of seed bank and fragment desiccation. Summer dewatering due to operations can be important in controlling the temporal expansion of macrophyte coverage.

## 7.2. Velocity

A histogram for velocity was developed using site-specific data collected during field studies (Figure 7.2-1). These data were then used to create an observed HSI curve that varied from the provisional literature-based curve (Figure 7.2-2). The factors affecting refinement of the velocity HSI curve were substrate stability and seed and fragment rooting and anchoring. At velocities exceeding 2.5 fps substrate instability limits the establishment and persistence of macrophytes. Considering both the observed and literature-based curves, a proposed-final curve was presented to the roundtable (Figure 7.2-2).

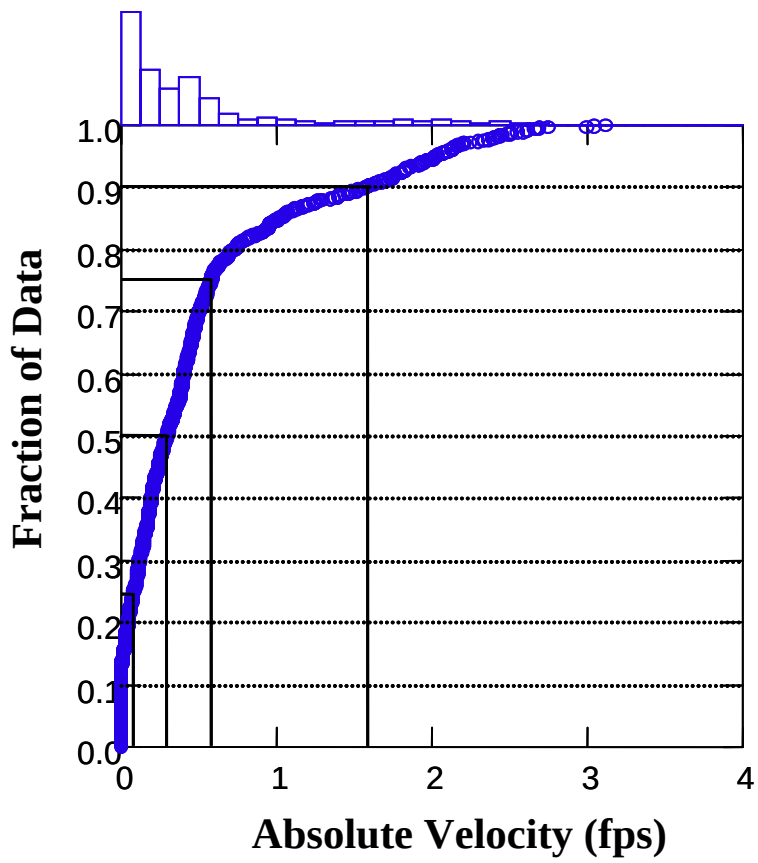


**Figure 7.2-1**. Histogram of velocity values recorded where macrophytes were observed.

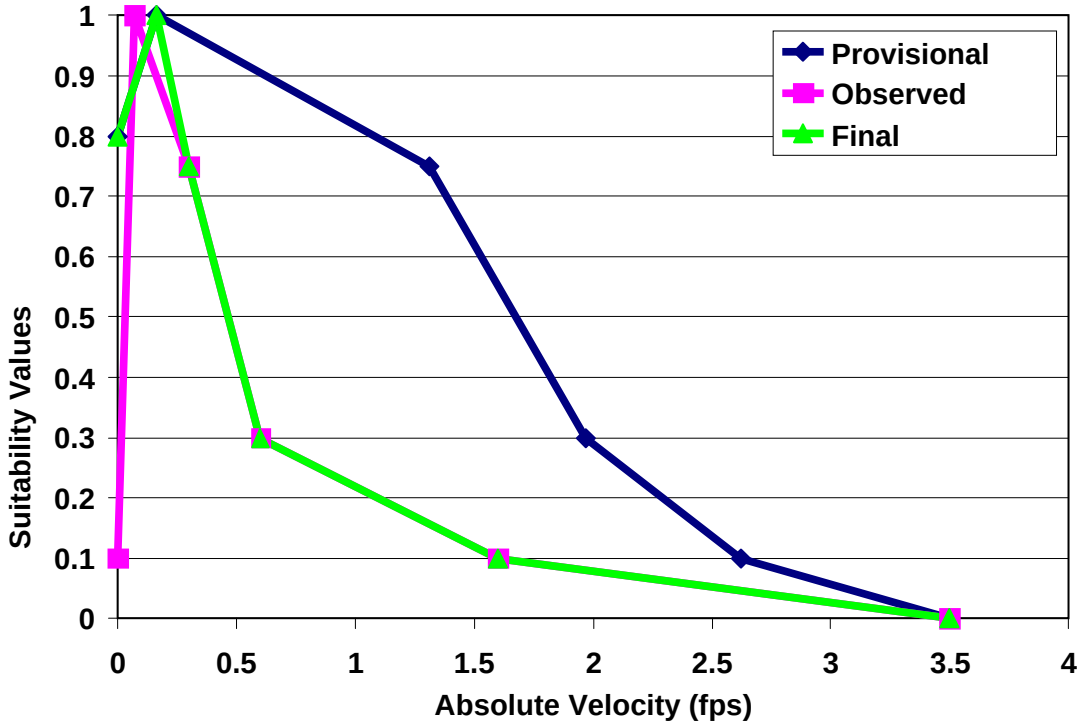


**Figure 7.2-2.** Provisional, observed, and proposed-final macrophyte HSI curves for velocity.

Based on discussions with the roundtable, a literature review was conducted to determine the relative importance of the influence of water velocity on establishment and persistence of aquatic macrophytes. It was possible that two curves for macrophyte velocity would be needed: one for newly colonizing macrophytes and one for existing macrophyte beds. However, it was determined that if velocity were differentially affecting colonizing and existing beds, an bi-modal distribution of macrophyte presence would be observed. As this was not the case, it was determined that two curves would not be needed and that the proposed velocity curve was appropriate for both newly colonizing macrophytes and existing beds.

The relicensing participants agreed to adopt the proposed velocity curve. The final HSI values are presented in Table 7.2-1 and the final HSI curve is presented in Figure 7.2-3.

**Table 7.2-1.** Velocity final suitability values for macrophytes.

| Velocity | Final Suitability Values |
|---|---|
| 0 | 0.8 |
| 0.164 fps | 1.0 |
| 0.3 fps | 0.75 |
| 0.6 fps | 0.3 |
| 1.6 fps | 0.1 |
| 3.5 fps | 0.0 |

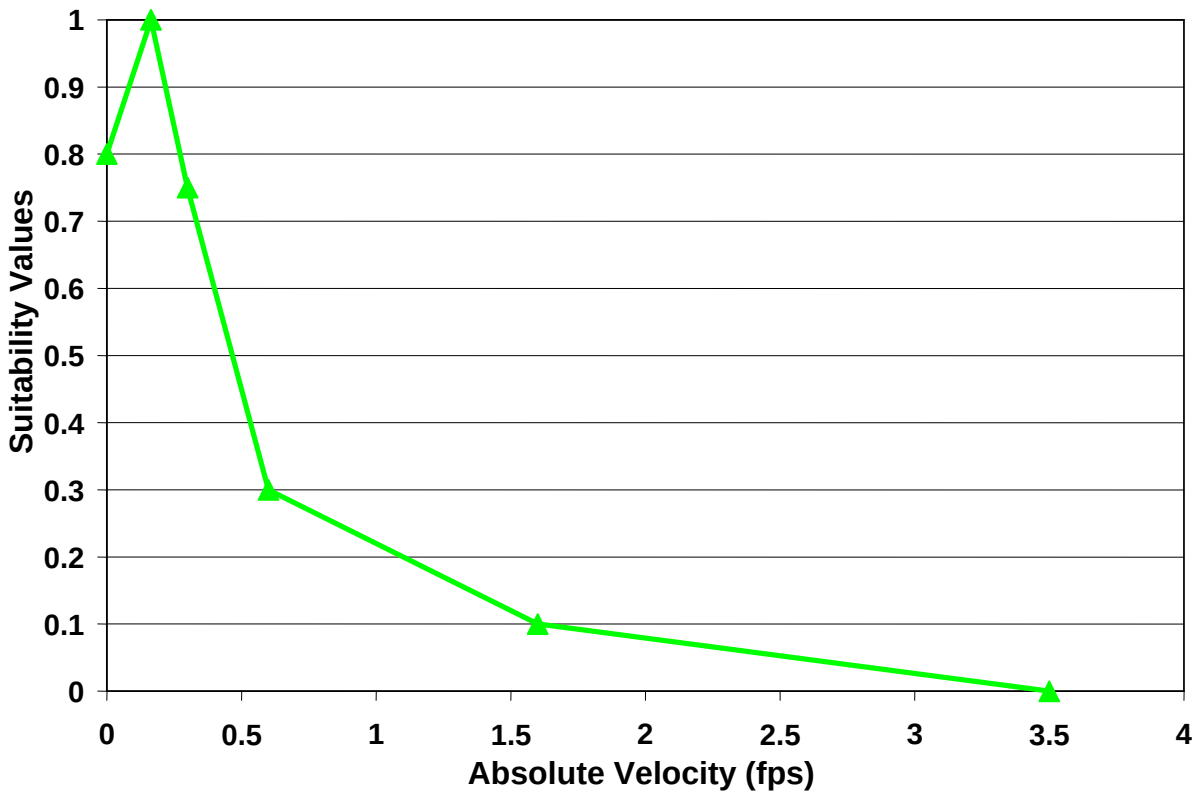


**Figure 7.2-3.** Final macrophyte HSI curve for velocity.

The velocity observed within the Boundary Reservoir does not appear to be a limiting factor once a macrophyte bed is established. Velocity may control establishment of new macrophyte beds by limiting where seeds/turions or viable fragments may settle onto a substrate that is within the euphotic zone or influencing substrate stability. However, the community dominance of non-native species such as Eurasian watermilfoil (EWM) has shown that it is still expanding coverage within the Reservoir by taking advantage of micro-velocity environments that allow it

to establish beds on steep rocky banks within the canyon reach. This is demonstrated by the small pioneering beds. Hence, velocity is not a major consideration for habitat suitability.

## 7.3. Substrate

The literature-based HSI for substrate was revised from the provisional scores to reflect the percentage of macrophyte beds located on each substrate type. Almost three-quarters of the macrophyte beds surveyed were located in fine substrate (e.g., intermediate organic and fine texture substrates). Therefore, the final macrophyte HSI for substrate was revised from the provisional curve to reflect the distribution of macrophyte beds in the final HSI values. The final HSI values are presented in Table 7.3-1 and the final HSI curve is presented in Figure 7.3-1.

**Table 7.3-1.** Substrate types and final suitability values for macrophytes.

| Substrate Type | Final Suitability Values |
|---|---|
| Intermediate organic and fine texture substrates | 1.0 |
| Sandy, gravel, cobble | 0.28 |
| Bedrock | 0 |

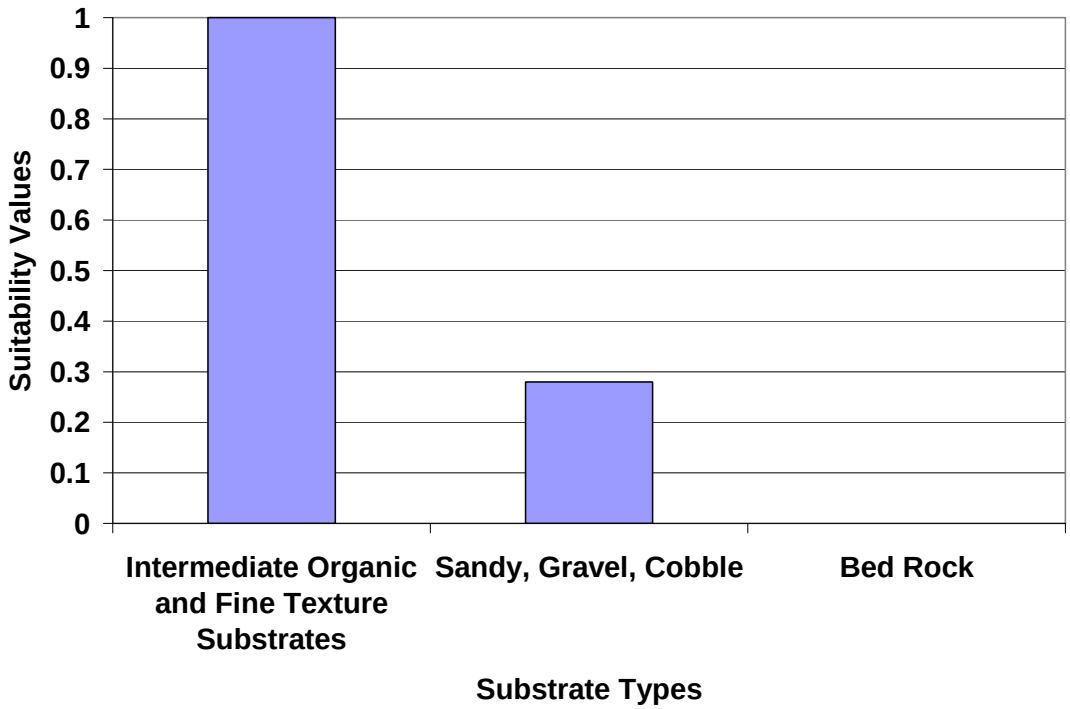


**Figure 7.3-1.** Final macrophyte HSI for substrate.

Substrate type is both a reflection of sedimentation areas and the ability of invasive species, such as EWM, to build sediment by organic deposition and trapping suspended solids from the water column through filtration. There is little influence of operations on substrate type.

## 7.4. Duration of Dewatering

Based on the roundtable discussion it was determined that separate curves would be needed for the HSI for duration of dewatering: one for the establishment of new beds, one for growth of established beds. Table 7.4-1 presents the provisional and proposed-final suitability values. The HSI curves for provisional and proposed-final values are shown in Figure 7.4-1.

**Table 7.4-1.** Duration of dewatering provisional and proposed-final suitability values for submersed macrophytes.

| Provisional | | Final (New Beds) | | Final (Growth and Established Beds) | |
|---|---|---|---|---|---|
| **Hrs** | **Suitability Values** | **Hrs** | **Suitability Values** | **Hrs** | **Suitability Values** |
| 0 | 1 | 0 | 1 | 0 | 1 |
| 6 | 0.8 | 6 | 0.4 | 6 | 0.8 |
| 12 | 0.6 | 12 | 0.3 | 12 | 0.7 |
| 24 | 0.4 | 24 | 0.2 | 24 | 0.6 |
| 72 | 0.1 | 72 | 0 | 72 | 0.5 |
| 720 | 0 | | | 720 | 0 |

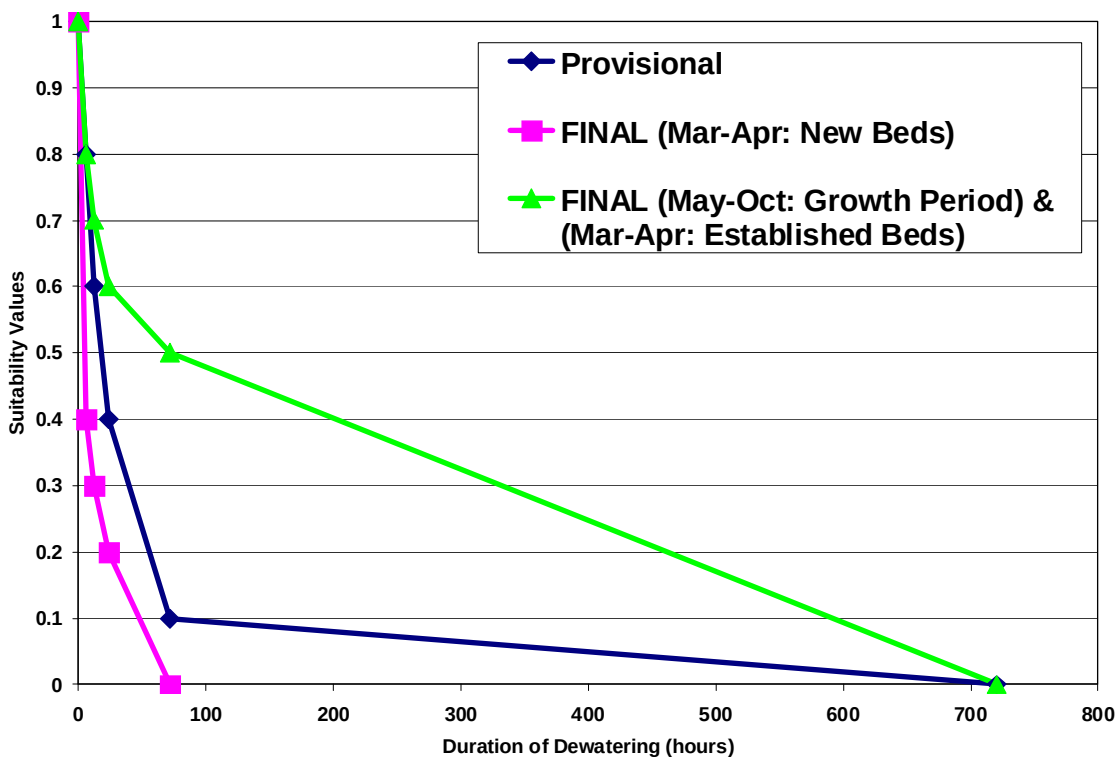


**Figure 7.4-1.** Provisional and proposed-final macrophyte HSI curves for duration of dewatering.

The relicensing participants agreed to adopt the proposed-final duration of dewatering curves. The final HSI values are presented in Table 7.4-2 and the final HSI curves are presented in Figure 7.4-2. Note that because the newly established beds are more sensitive to dewatering only the established beds were used in the habitat model for describing current conditions under normal, dry, and wet precipitation years.

**Table 7.4-2.** Duration of dewatering final suitability values for macrophytes.

| New Beds | | Growth and Established Beds | |
|---|---|---|---|
| **Hours** | **Final Suitability Values** | **Hours** | **Final Suitability Values** |
| 0 | 1 | 0 | 1 |
| 6 | 0.4 | 6 | 0.8 |
| 12 | 0.3 | 12 | 0.7 |
| 24 | 0.2 | 24 | 0.6 |
| 72 | 0 | 72 | 0.5 |
| | | 720 | 0 |

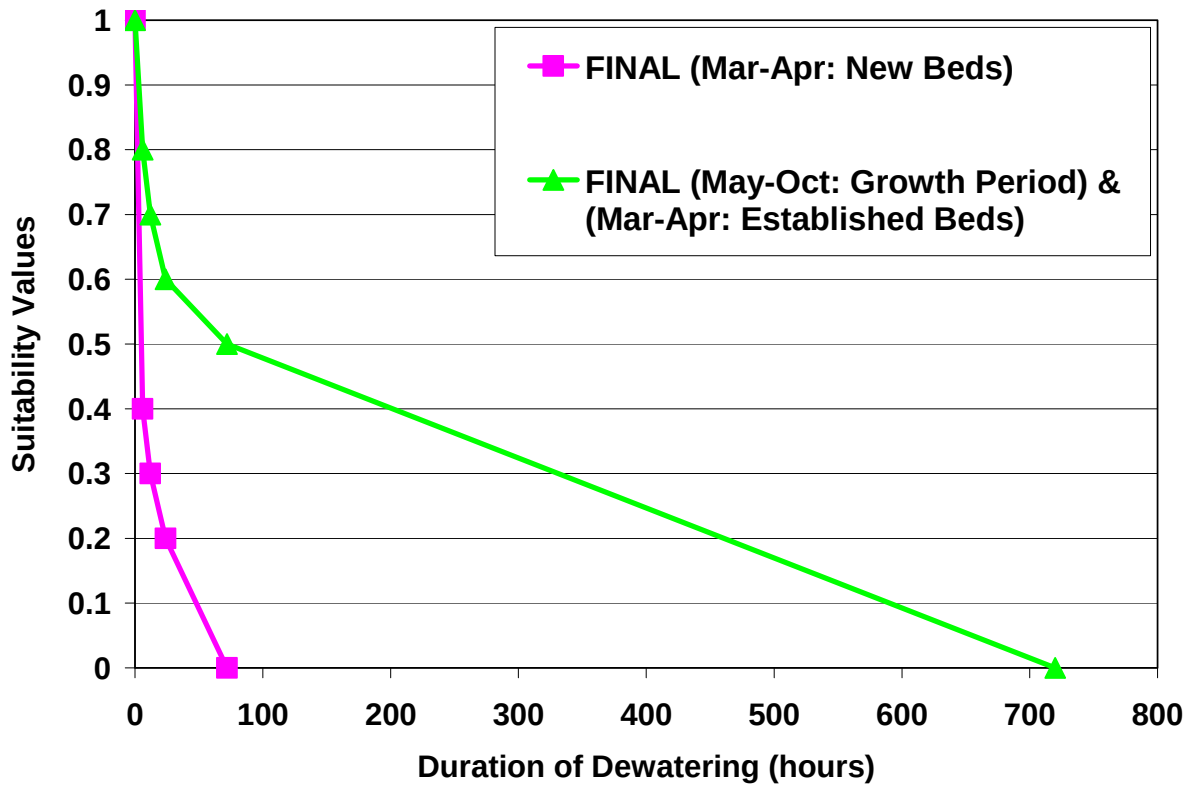


**Figure 7.4-2.** Final macrophyte HSI curves for duration of dewatering.

Macrophytes are most susceptible to prolonged periods of reservoir drawdown during the late winter/early spring establishment period, especially during periods of nighttime drawdown when freezing enhances the effects of desiccation.

## 7.5. Duration of Inundation

The growth rates of non-native macrophytes are up to twice those of native species, and as a result non-native species out-compete native species in most instances. The relicensing participants proposed to base duration of inundation curves on the response of non-native species. The literature-based HSI curve did not differ from that observed in the field; therefore, the provisional HSI curve was accepted as the final. The final HSI values for duration of inundation for non-native macrophytes is presented in Table 7.5-1 and the final HSI curve is presented in Figure 7.5-1.

**Table 7.5-1.** Duration of inundation final suitability values for macrophytes..

| Duration of Inundation (hours) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 144 | 0.15 |
| 288 | 0.5 |
| 432 | 0.85 |
| 576 | 1.0 |

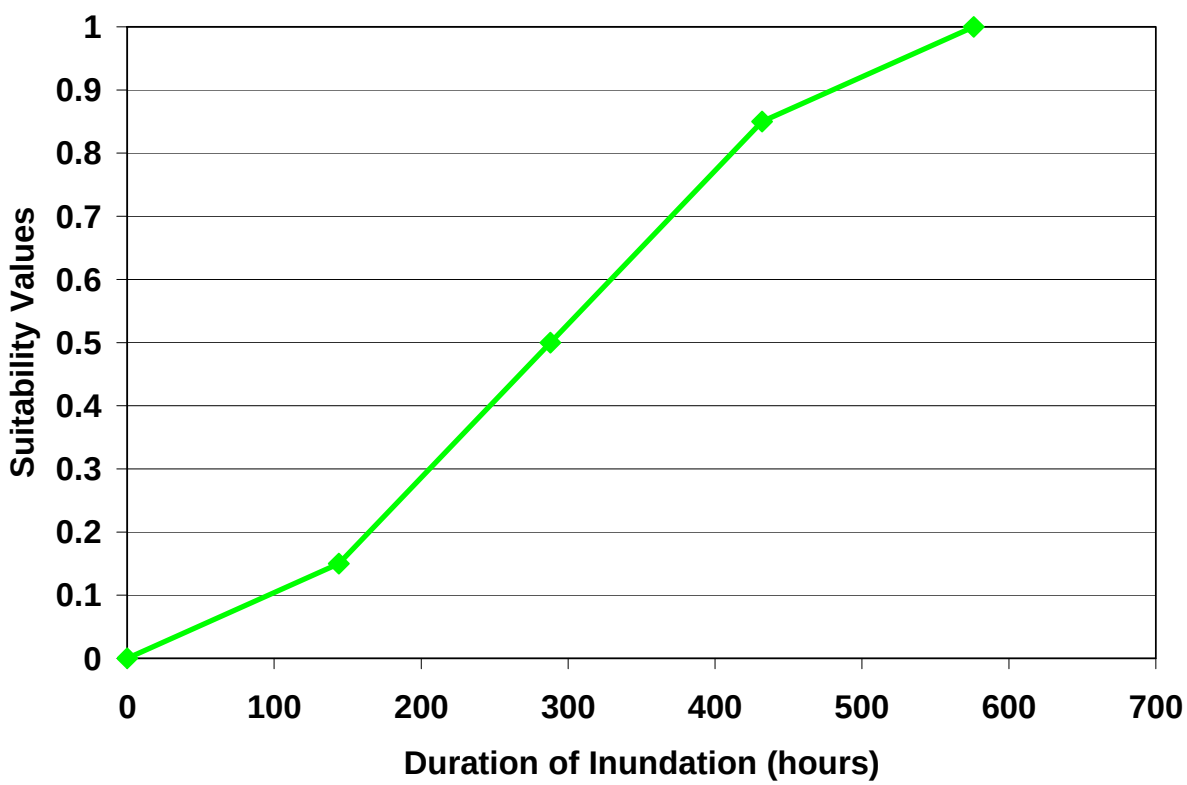


**Figure 7.5-1.** Final macrophyte HSI curve for duration of inundation.

Given that the aquatic macrophyte beds are established during winter low flow periods, shallow extent of the macrophyte beds is defined by the extent inundation that occurs at that time. Hence, daily hydrology variations are as important as daily water level fluctuations.

## 8 MODEL RESULTS

The final macrophyte HSI curves were used in the Mainstem Aquatic Habitat Model to determine the weighted usable area (WUA) available for macrophytes in Boundary Reservoir. The Mainstem Aquatic Habitat Model was run for three water years: a wet year (1997), a dry year (2001) and an average year (2002). An example of model output for macrophyte WUA for the Upper Reservoir Reach in a dry year is presented in Figure 8.1-1. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for macrophytes on the y-axis. Table 8.1-1 is an example of tabular model output for macrophyte WUA. Complete models results and discussion of macrophyte WUA can be found in Section 5.6 of Study 7 Final Report [SCL 2009b]). A more detailed discussion of macrophyte production can be found in the Study 11, Productivity Assessment Final Report (SCL 2009a).

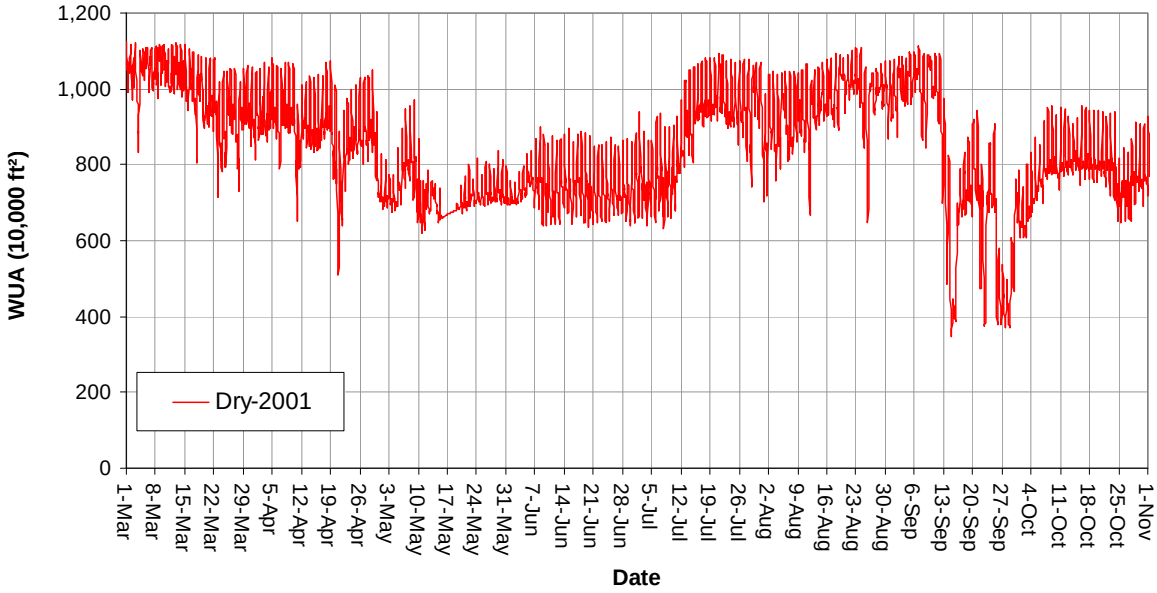


**Figure 8.1-1.** Habitat WUA for macrophytes in the Upper Reservoir Reach of Boundary Reservoir, determined by the Mainstem Aquatic Habitat Model, for a dry water year (2001).

**Table 8.1-1.** Summary of monthly macrophyte WUA (x $10^5$ sq. ft.) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | Max. | Min. | Stdev. | Avg. | Max. | Min. | Stdev. | Avg. | Max. | Min. | Stdev. |
| January | --[1] | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| February | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| March | 677 | 863 | 510 | 96.0 | 998 | 1,122 | 715 | 83.6 | 734 | 934 | 474 | 80.4 |
| April | 563 | 719 | 234 | 131.2 | 896 | 1,080 | 511 | 94.2 | 700 | 968 | 500 | 80.4 |
| May | 315 | 356 | 170 | 33.7 | 721 | 971 | 620 | 52.5 | 566 | 809 | 195 | 180.7 |
| June | 430 | 565 | 180 | 99.0 | 734 | 899 | 637 | 54.9 | 307 | 392 | 199 | 54.6 |
| July | 646 | 838 | 452 | 101.1 | 889 | 1,094 | 631 | 118.5 | 646 | 938 | 230 | 141.0 |
| August | 785 | 1,044 | 594 | 62.3 | 966 | 1,111 | 648 | 80.7 | 870 | 1,056 | 687 | 73.4 |
| September | 792 | 949 | 668 | 48.3 | 780 | 1,113 | 347 | 230.8 | 913 | 1,085 | 682 | 71.4 |
| October | 745 | 892 | 637 | 46.2 | 777 | 956 | 608 | 69.5 | 846 | 1,069 | 692 | 67.8 |
| November | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| December | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

Note:
1 Hyphens indicate no viable macrophyte habitat during the winter months in Boundary Reservoir.

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# Appendix 7: Periphyton Habitat Suitability Index (HSI) Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Study 7: Mainstem Aquatic Habitat Modeling Study*

# *Appendix 7*

# *Periphyton Habitat Suitability Index (HSI)*

# *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Shannon Brattebo, Harry Gibbons, Robert Plotnikoff, Darlene Siegel**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 7
# Periphyton HSI Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

The Mainstem Aquatic Habitat Modeling: Periphyton HSI was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007 and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This final report describes all field efforts and analyses for 2007 and 2008 of the Mainstem Aquatic Habitat Modeling: Periphyton Monitoring.

### 1.1. Study Background

A Habitat Suitability Index (HSI) was developed to describe the response of periphyton to various reservoir management scenarios, for use in the Boundary Reservoir mainstem aquatic habitat model. Specifically the scenarios including cyclic inundation and dewatering that may change physical parameters that the periphyton are exposed to, such as, depth, water velocity, light, etc. An HSI is a model for calculating the habitat suitability of an area for a single species or assemblage of species. A set of variables that represent the life requisites for the species (e.g., percent cover, water depth, water quality) is combined into a mathematical habitat model. The variables are then measured in the field and their corresponding index values are inserted into the model to produce a score that describes existing habitat suitability. The value is an index score between 0 and 1. The mathematical model used for developing HSI curves for periphyton was based upon literature addressing the species' habitat requirements and preferences.

Because periphyton communities are comprised of numerous taxa that vary independently from the five variables under study (depth, velocity, substrate, duration of dewatering, and duration of inundation) such as, nutrient concentration of availability; the HSI for the Project is not specific to any individual species, but was developed for the commonly used chlorophyll *a* (periphyton) metric selected to represent the communities. Chlorophyll *a* is a relative measure of production related to standing crop, but is not a direct measure of biomass. Nevertheless, chlorophyll *a* is a good indicator of relative production and is commonly used in many studies.

Periphyton are attached algae or Cyanobacteria that live on the bottom substrate of a waterbody, or on structures or organisms resting on or attached to the bottom such as logs, rocks, or rooted plants. Periphyton is a complex matrix of algae and bacteria, the photosynthetic algae and Cyanobacteria are the primary producers that are of interest relative to overall aquatic production. Primary production is the base of the food web and refers to the fixation of organic carbon from inorganic carbon through photosynthesis. Periphytic algae use energy from the sun,

carbon dioxide and nutrients for growth, and in turn, are fed upon by benthic macroinvertebrates and some fish, birds, and/or mammals.

The littoral habitat of lakes, reservoirs, rivers, and streams is the bottom area along the shoreline where the level of light penetration is sufficient for photosynthesis to occur (Wright and Szluha 1980; Wetzel 2001). This area usually supports larger and more diverse populations of periphyton than deeper water habitats (Wright and Szluha 1980; Ward 1992; Thorp and Covich 2001; Wetzel 2001) because of the limitation of light in deeper water. The depth of light penetration is dependent on the clarity of the water and varies significantly among waterbodies and seasons of the year.

The varial zone in reservoirs is defined as the area between the high and low surface water elevations over a defined time period due to natural or artificial fluctuations in pool water surface elevation or flow. If the magnitude and duration of water surface elevation fluctuations is low, the varial zone can be highly productive. However, as the magnitude and duration of water surface elevation fluctuations increase, the abundance and diversity of periphyton in the varial zone is reduced (Fisher and LaVoy 1972; Ward 1992).

Varial zone habitats may be subjected to regular exposure to intense sunlight, desiccation or freezing in rivers or reservoirs with fluctuations in discharge (e.g., peak power hydroelectric dams and some irrigation dams) (Blinn et al. 1995). Several studies have reported that load-following flow releases, that shape available water to deliver power during peak-load hours affecting instream flow releases on a daily or hourly interval, can substantially reduce the species diversity and abundance of stream periphyton both above and below hydropower projects (Brusven et al. 1974; Gislason 1985; Perry and Perry 1986; Troelstrup and Hergenrader 1990; Blinn et al. 1995; DeVries, et al. 2001; Grzybkowska and Dukowska 2002) and periphyton within reservoirs subject to drawdown (Fillion 1967; Paterson and Fernando 1969; Kaster and Jacobi 1978; May et al. 1988; Chisholm et al. 1989; Furey et al. 2006).

A study to determine the effects of atmospheric exposure on the gross primary productivity (GPP) of littoral epilithon in the Colorado River below Glen Canyon Dam, Arizona found that the GPP of *Cladophora* epilithon from the zone of permanently inundated channel was 10 times higher than the GPP of epilithon from the zone of daily water surface elevation fluctuation (Angradi and Kubly 2006). Recolonization of the epilithon was also found to be slow under hydropower peaking flow regimes (Angradi and Kubly 2006).

In addition, effects imposed by short-term fluctuating discharge below impoundments may include bed and bank instability with associated increases in turbidity (Troelstrup and Hergenrader 1990). Suspended solids reduce light penetration and enhance scouring downstream further affecting periphyton populations (Horner et al. 1990).

For instance, periphyton will colonize a site if it contains suitable depth, velocity and substrate, but colonization may not occur until the area has been inundated for a period of time. Conversely, the effects of dewatering of the site on periphyton production will depend on the duration of dewatering and conditions at the time of the dewatering (e.g., hot summer day compared to winter).

## 1.2. Study Description

The periphyton HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data, 3) calibration of the literature-based HSI curves using field data, and 4) finalization of the periphyton HSI for Boundary Reservoir. Field data generation included periphyton data with depth and cross-sectional data with depth, velocity, and substrate measurements. Site-specific periphyton monitoring consisted of three different components, artificial substrate sampling on hard substrate surfaces, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

The artificial substrates for periphyton sampling consisted of small rock baskets containing rocks with diameters ranging from 1 to 3 inches. The rocks used for artificial substrate were preconditioned prior to deployment by being placed for 4 weeks in Boundary Reservoir and then air-dried. Where possible, sampling sites were located along mainstem habitat transects measured for the Mainstem Aquatic Habitat Model. The sampling design included three treatments representing the range of depths and inundation/exposure periods likely to occur for operations scenarios. The three treatments included relatively large pool surface elevation fluctuations, moderate pool surface elevation fluctuations, and low pool surface elevation fluctuations. Each site was sampled using fixed sampling units placed along the channel bed.

The artificial substrate rock baskets were installed along the shorelines and on vertical faces in Boundary and Box Canyon reservoirs, with units deployed at depth intervals ranging from full pool to the euphotic depth under maximum expected reservoir drawdown for the sample period. The sampling units were in fixed positions, so some units were dewatered and inundated repeatedly, thereby describing the response of organisms to fluctuating reservoir water surface elevations at that site. Sampling was conducted at a site below Metaline Falls and in the Canyon Reach (see Section 3.0 in the main report for Project reach definitions) to describe the response of periphyton to the effects of pool surface elevation fluctuations in that reach. Artificial substrate sampling was also conducted at a site in the Metaline Reach and in Box Canyon Reservoir to describe the response to a smaller range of pool surface elevation fluctuation.

The periphyton artificial substrate sampling was conducted during spring, summer, and fall for 8-week periods. Winter periphyton sampling was conducted over a 14-week period instead of an 8-week period because baskets could not be retrieved due to reservoir ice cover and winter conditions. Periphyton artificial substrate baskets were deployed during April 2–6, July 6–9, September 11–14, and December 4–7, 2007. The baskets were retrieved 8 weeks later during, May 29–June 1, September 1–6, and November 5–10, 2007 and 14 weeks later during March 10-13, 2008.

The second component of the study included the determination of seasonal periphyton colonization rates within the reservoir. For the summer period, sets of three preconditioned artificial substrates were deployed incrementally for set periods of colonization time (e.g., 8, 6, 4, 2, and 1 weeks) and then pulled simultaneously at the conclusion of the colonization period. For the winter period, sets of three preconditioned artificial substrates were deployed at 14, 12, 10, 8, and 1 weeks. This schedule was different than the summer colonization period due to reservoir ice cover and inaccessibility. Artificial substrate baskets were deployed at three depths at a fixed

site along the shoreline of Box Canyon Reservoir at an elevation within the euphotic zone where they remained wetted through the incubation period. Results from the summer colonization study were used for periphyton HSI development and calibration.

An additional comparison study between artificial and natural substrate was conducted during the spring of 2008. In the results from the 2007 periphyton sampling effort, there was a large variability in shoreline summer and fall periphyton chlorophyll *a* which could not be explained by depth or treatment site location. The wire mesh baskets used to collect periphyton were thought to have created an environmental condition that diverges from velocity gradients present in hard rock substrate within the Boundary Reservoir. This reduction in velocity may have resulted in higher periphyton chlorophyll *a* accumulation in the artificial substrates as compared to existing hard substrates (i.e., rock and cobble) that are exposed to higher shear velocities that occur in the open reservoir. A direct comparison between periphyton colonization within artificial baskets and in situ communities was used to verify the influence of velocity on periphyton accumulation within the substrate. Results from this comparison study were also used in the calibration of HSI curves and to test the hypothesis that the influence of velocity on periphyton growth was being under expressed by the geometry of the baskets.

## 2 STUDY OBJECTIVES

The objective of this study was to develop HSI curves for periphyton based on literature, existing data, and site-specific data that addresses periphyton responses to operations scenarios within Boundary Reservoir. The HSI curves were used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for periphyton under operations scenarios. The information collected during this study was also used to support Study 11, Productivity Assessment (SCL 2009a). This study included the following six primary elements necessary to develop accurate and comprehensive HSI:

- Literature-based periphyton HSI curves
- Sampling of periphyton communities on hard substrate
- Determination of periphyton colonization rates on hard substrate
- Comparison of periphyton communities between artificial and natural hard substrate
- Calibration of periphyton HSI curves
- Finalization of periphyton HSI curves.

## 3 STUDY AREA

Periphyton monitoring and sample collection was conducted in Boundary and Box Canyon Reservoirs. Within Boundary Reservoir there were two Reaches periphyton monitoring was conducted; the Canyon Reach and the Upper Reservoir Reach (see Section 3.0 of the main report for Project Reach definitions). A shoreline sampling site was located in each reach of Boundary Reservoir, upstream of Metaline, and upstream of Boundary forebay. A vertical sampling site was located in the canyon upstream of Boundary forebay but not in the Metaline reach due to geographical constraints. A shoreline and vertical sampling site was located in Box Canyon Reservoir, downstream of the Ione City Park. The seasonal colonization site was located in Box Canyon Reservoir fairly close to the hard substrate shoreline site. The comparison study was conducted at just the shoreline sampling sites in Boundary Reservoir. A site map indicating

periphyton sampling locations is provided in Figure 3.0-1. The sampling sites were chosen based on type of substrate, depth, and geographic area.

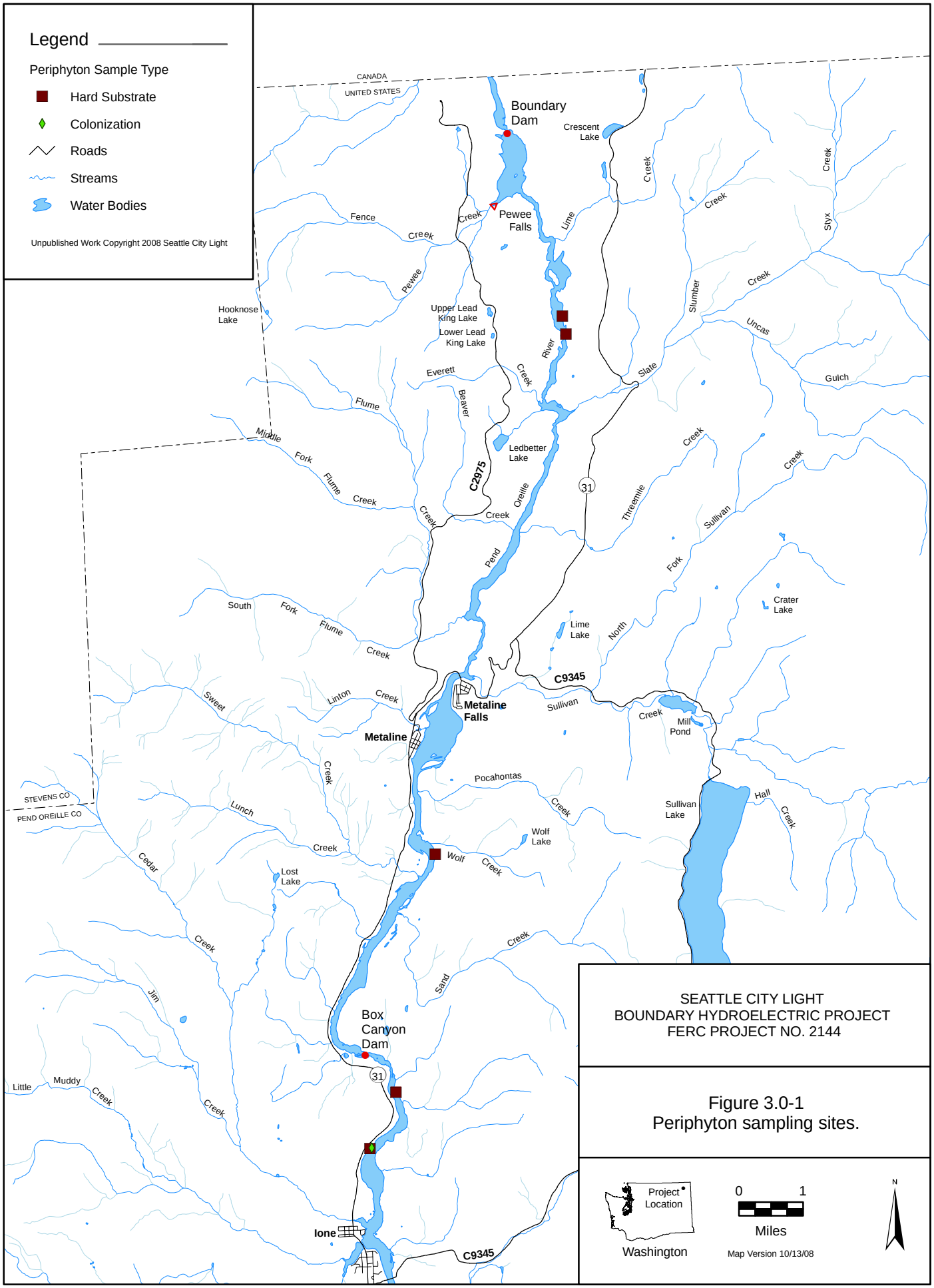


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Figure 3.0-1
Periphyton sampling sites.

# 4 METHODS

In the following sections the methods that were used to develop the periphyton HSI curves for Boundary Reservoir are discussed in detail.

## 4.1. Literature-Based Provisional Periphyton HSI

A literature review was conducted to gather existing information and data on periphyton habitat preferences in terms of depth, substrate, velocity, and duration of inundation and dewatering. The Boundary Reservoir periphyton model combines a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.0-1). During the literature review no appropriate suitability curves were found, so other literature information was used to develop suitability values. The periphyton model is shown in Table 4.0-1 and each variable is described in further detail in subsequent sections. The model is multiplicative, because if any of the variables result in a score of zero, the HSI is zero and habitat is not suitable for periphyton growth.

**Table 4.0-1.** Boundary Reservoir periphyton model.

| **Periphyton Composite Suitability Index** | $CSI_i = HSC_i * HSI_i$ |
|---|---|
| Periphyton HSC | $HSC_i = D_i * Vo_i * S_i$ |
| Periphyton HSI | $HSI_i = f (DI_i, DD_i)$ |
| Periphyton Variables | $D_i$ = Depth<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

The most common method of calculating weighted usable area values in PHABSIM studies is a multiplicative aggregation given by:

$$HSC_i = D_i * Vo_i * S_i$$

Where:

$HSC_i$ = composite habitat suitability of $cell_i$
$D_i$ = suitability associated with depth in $cell_i$
$Vo_i$ = suitability associated with velocity in $cell_i$
$S_i$ = suitability associated with substrate in $cell_i$

Using a multiplicative aggregation, if any of the variables results in a score of zero, the composite value will become zero and the habitat would be rated as unsuitable for use for that time step. This composite HSC approach was used for the Boundary periphyton model to calculate the suitability of a cell to support periphyton at a given hour. However, the value of a

cell for use by periphyton is also affected by the length of time that the cell had been inundated. Cells that have been inundated for several weeks or more typically support a higher periphyton biomass than cells that are newly inundated. Cells that have been dewatered for even a short period of time (hours) will have a lower periphyton biomass than cells that have not been dewatered. Frequent cycles of dewatering and inundation will affect periphyton productivity in a cell regardless of its suitability as defined by depth, velocity, and substrate.

In order to evaluate the effects of pool surface elevation fluctuations on periphyton productivity, the prior inundation history of the cell was tracked using hourly time steps. As the duration of continuous inundation increases, the periphyton biomass is assumed to increase up to a maximum suitability of 1.0. The rate of periphyton increase was determined from a Duration of Inundation (DI) HSI. While periphyton biomass in a cell increases as the duration of continuous inundation increases, dewatering of the cell will reduce periphyton biomass through emigration or mortality. The rate of periphyton decrease in response to dewatering was determined from a Duration of Dewatering (DD) HSI that decays from a maximum suitability of 1.0 to a suitability of zero.

The pattern of prior inundation and dewatering will determine the relative status of a cell at a given time step as indicated by an HSI value between 1.0 and zero. An integrated HSI value of less than 1.0 indicates that the prior history of inundation and dewatering has reduced periphyton production in that cell at the specific time step. The HSI value and the HSC value was multiplied to determine a composite suitability index for that cell at the given hour.

Suitability curves are graphical relationships between physical habitat components and an index of biological response scaled between 0 and 1.0, with 1.0 representing the maximum habitat suitability. Based on an extensive literature review, suitability curves for periphyton were developed. The focus of this model was to determine the response of periphyton as a whole. As such, the HSC and HSI curves provided in this study focus on the suitability for periphyton as a group, based in part on information from literature and professional experience and judgment.

## 4.2. Field Data Collection

Site-specific periphyton monitoring consisted of three different components, artificial substrate sampling on hard substrate surfaces, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

### 4.2.1. Hard Substrate Periphyton Monitoring

The artificial hard substrate for periphyton sampling consisted of small rock baskets containing rocks with diameters ranging from 1 to 3 inches. The rocks used for artificial substrate were preconditioned prior to deployment by being placed for 4 weeks in Boundary Reservoir and then air-dried. The rock baskets were assembled on-site. Frames were outfitted with three rock baskets, each loaded with a fixed volume of rocks. Each frame was attached with a bridal of four attachment points to insure it was lowered and raised in a horizontal manner.

At each vertical rock face site in Boundary and Box Canyon Reservoirs two rock anchors were set for rope attachment of artificial substrate baskets. Shoreline sites typically included a large

tree as the anchor point for the attachment line to the frame and rock baskets. The ropes for each shoreline site were buried under the sediment and existing vegetation as much as possible to reduce visibility. Weighted lead rope was used to insure it remained on the bottom of the reservoir and did not float to the surface.

Samples were set at elevation intervals of 2, 5, 10, 15, 25, and 40 feet at each vertical and shoreline site with the exception of the vertical face site in Box Canyon reservoir. A 40-foot vertical face could not be found in Box Canyon reservoir so samples were set at elevation intervals of 2, 5, 10, 15, 20, and 25 feet at this location. The elevations at which samples were located were intended to encompass the fluctuation zones in the upper and lower Boundary reservoir reaches. On the first deployment date (April 2007), the water surface elevation in both Boundary and Box Canyon reservoirs were marked using orange spray paint. These water marks were set as the zero mark for the remaining deployments and all baskets were placed at elevation intervals from these marks. The water surface elevation on the first day of deployment for the Canyon Reach and Metaline Reach was determined from the Hydraulic Routing Model (HRM). The 2007 and 2008 water elevation records from Box Canyon Dam have were obtained for Pend Oreille Public Utility District (PUD) and adjusted to ensure that they were reported in the same datum as the records from Boundary Dam. Water surface elevations from Boundary and Box Canyon Reservoirs were used to determine depth and duration of inundation and exposure at sampling sites. Additionally on the first deployment date, an underwater video camera was used to verify the type of substrate at sampling site.

The schedule for deployment and retrieval of hard substrate samples is shown in Tables 4.2-1 and 4.2-2. All hard substrate samples (shoreline and vertical face sites) were retrieved 8 weeks following deployment except for winter samples which were retrieved 14 weeks after deployment to due ice cover. When hard substrate samples were retrieved the following steps were followed:

- For vertical face sites the anchor line was released and attached to a davit and winch combination on the boat. The sample frame was slowly raised to a level just below the water surface. At the shoreline sites the anchor line was released from the shore anchor. Then the boat, with line, was positioned to a point over the basket frame and the frame was slowly raised to minimize disturbance of the sample.

- When the basket frame was near the surface the zip ties were cut from the first basket and a mesh bag slipped over a basket. The bag and basket was then lifted out of the water and secured to prevent escape of invertebrates. This procedure was followed for the remaining two baskets on the frame.

Samples were processed for one elevation interval at a time. All sampling processing occurred on the boat. The following steps were followed during sample processing:

- The mesh bag with basket was placed into a bucket. The mesh bag was opened and the remaining zip ties cut to open the basket. While in a horizontal position, a rock was chosen from the basket for periphyton analysis. Rocks chosen for periphyton analysis were based on their location in the basket (on the top of the rock pile) and

their shape. If possible, relatively flat, oblong shaped rocks were chosen for periphyton analysis.

- Periphyton samples were processed by placing the chosen rock in a plastic tub, wetting the rock with distilled water and then scrubbing the entire surface of the rock with a wire brush. After every surface of the rock was scrubbed, the wire brush and rock was rinsed three times with distilled water into the tub. The water and periphyton remaining in the tub was transferred into a 250 ml amber-colored plastic sample bottle and labeled. The tub was then rinsed three times to ensure a complete sample. The two major axes and the minor axis of the scrubbed rock was then measured with calipers and recorded in a field notebook. These measurements were used to estimate the surface area of the rock and the surface area of periphyton colonization. The periphyton sample was placed on ice while in the field.

- Upon return to the field office each periphyton sample was filtered. A portion of each sample was filtered through a 0.45 µm membrane filter. A magnesium carbonate solution was used during the filtering process to preserve the sample. After filtering was complete the filter was removed from the apparatus and placed into a 50ml amber-colored plastic bottle and frozen. Once samples were thoroughly frozen they were placed into a cooler with ice and shipped to Aquatic Research Laboratories in Seattle for analysis. Each periphyton sample was analyzed for chlorophyll *a*.

**Table 4.2-1.** Hard substrate sample deployment and retrieval schedule for shoreline sites.

| Deployment Date | Macroinvertebrates/Periphyton Shoreline Sites | | | | Retrieval Date |
|---|---|---|---|---|---|
| | **Treatments** | **Elevations** | **Replicates** | **# of samples** | |
| April | 3 | 6 | 3 | 54 | May |
| July | 3 | 6 | 3 | 54 | September |
| September | 3 | 6 | 3 | 54 | November |
| December | 3 | 6 | 3 | 54 | March |
| **Total** | | | | **216** | |

**Treatments/Sites**
A) High Fluctuation-Downstream of Metaline Falls
B) Moderate Fluctuation-Upstream of Metaline Falls
C) Low Fluctuation-Box Canyon Reservoir

**Table 4.2-2.** Hard substrate sample deployment and retrieval schedule for vertical face sites.

| Deployment Date | Macroinvertebrates/Periphyton Shoreline Sites | | | | Retrieval Date |
|---|---|---|---|---|---|
| | Treatments | Elevations | Replicates | # of samples | |
| April | 2 | 6 | 3 | 36 | May |
| July | 2 | 6 | 3 | 36 | September |
| September | 2 | 6 | 3 | 36 | November |
| December | 2 | 6 | 3 | 36 | March |
| **Total** | | | | **144** | |
| **Treatments/Sites**<br>A) High Fluctuation-Canyon Reach<br>B) Low Fluctuation-Box Canyon Reservoir | | | | | |

## 4.2.2. Periphyton Colonization Monitoring

Colonization samples utilized the same frame and rock basket set up as the hard substrate samples. All colonization samples were deployed in one location within Box Canyon Reservoir. The schedule of colonization sample deployment and retrieval is shown in Table 4.2-3. For the summer period, sets of three frame and rock baskets were deployed incrementally for set periods of colonization time (e.g., 8, 6, 4, 2, and 1 weeks) and then pulled simultaneously at the conclusion of the colonization period. For the winter period, sets of three frame and rock baskets were deployed at 14, 12, 10, 8, and 1 weeks. Colonization samples were placed at elevation intervals of 5, 15, and 25 feet from the zero elevation mark that was set at the Box Canyon shoreline treatment site. The same deployment and retrieval procedures were used for the colonization samples as for the hard substrate shoreline samples.

**Table 4.2-3.** Colonization sample deployment and retrieval schedule.

| Season | Colonization Period | Deployment Date | Retrieval Date |
|---|---|---|---|
| Summer | 8 weeks | July 6 | September 1 |
| | 6 weeks | July 20 | September 1 |
| | 4 weeks | August 3 | September 1 |
| | 2 weeks | August 16 | September 1 |
| | 1 week | August 23 | September 1 |
| | 3 days | August 28 | September 1 |
| Winter[1] | 14 weeks | December 8 | March 13 |
| | 12 weeks | December 21 | March 13 |
| | 10 weeks | January 4 | March 13 |
| | 8 weeks | January 18 | March 13 |
| | 1 week | March 7 | March 13 |
| | 3 days | March 10 | March 13 |

Note:
1 Winter colonization basket deployment schedule was revised due to reservoir inaccessibility and ice cover.

### 4.2.3. Periphyton Comparison Study

An additional element of this study was initiated in 2008 to determine how the artificial substrate versus natural substrate influenced colonization of periphyton communities. This comparison study included two sets of samples deployed in the spring to evaluate colonization response of biological communities on natural substrate rock versus rock within mesh baskets. The colonization intervals were planned for an 8-week and 4-week exposure (at both 17-foot and 25-foot elevation intervals) at two locations in Boundary Reservoir.

#### *4.2.3.1. Artificial Substrate*

Sampling of artificial hard substrate was completed at two sampling locations along the shoreline. Two sets of sampling units were placed along the bottom of the reservoir at each of the 17- and 25-foot elevation intervals for planned exposure periods of 4 weeks and 8 weeks. The artificial sampling units were the same design and construction as those used in the 2007 sampling efforts. One set of baskets (a sampling unit) per elevation interval and location contained a set volume of rocks similar to those samplers used in 2007. The other set of baskets per elevation interval contained a single layer of rocks within the basket that simulated a surface area equal to the sampled natural substrate. Two different depths and sites were included in the comparison of natural substrate and sampling baskets to examine consistency in the biological response to the treatments.

After the initial deployment of baskets, a second group of baskets was planned for deployment 4 weeks later at the 17-foot and 25-foot elevation intervals. Flows were monitored following the April 2008 deployment of 17-foot and 25-foot sets of baskets to determine potential for deployment of the next sample sets (4-week samples). Increases in reservoir flows by early May 2008 were used to determine whether further deployment of 4-week samples would be safe and if the original samples could be collected. Flow levels higher than those safe for sample collection would preclude further colonization studies past early May 2008 and result in characterization of BMI colonization for a 4-week interval. Projected flows for June 2008 that presented unsafe site conditions for retrieval of basket sets forced collection of baskets during the beginning of May 2008.

The first set of baskets deployed was intended to have an exposure period of 8 weeks prior to collection, and the second deployment of baskets was planned to have an exposure period of 4 weeks prior to retrieval. The original plan for deployment and retrieval of basket sets included a 4- and 8-week interval for colonization as described in Table 4.2-4. However, following initial deployment of the first set of baskets, projected June water flows exceeded the safe threshold for diving and retrieval of the first set of baskets and deployment of the second set of baskets. The actual deployment and retrieval dates are reported in Table 4.2-5.

Although 8-week colonization interval samples were not collected for periphyton communities, the 4-week time for both depths ensured uniform results. The relationship between the production on the natural substrate and the artificial substrate was maintained regardless of exposure time, and adjustments to the HSI curves were possible based on data collected from this study. The rocks from basket sets were processed for BMI following the same procedures used in the 2007 sampling efforts.

**Table 4.2-4.** Proposed sampling schedule for the comparison study.

| Event | Date |
|---|---|
| Spring deployment/natural substrate preparation – 25 ft (for the 8-week samples) | April 7–9, 2008 |
| Spring deployment/natural substrate preparation – 17 ft (for the 8-week samples) | April 17–19, 2008 |
| Planned spring deployment/natural substrate preparation – 25 ft and 17 ft (for the 4-week samples) | May 5–8, 2008 |
| Planned first collection of samples (4-week 17 ft and 25 ft, 8-week 25 ft) | June 1–4, 2008 |
| Second collection of samples (8-week 17 ft) | June 16–18, 2008 |
| Send samples to lab | June 18, 2008 |

**Table 4.2-5.** Actual sampling schedule for the comparison study.

| Event | Date |
|---|---|
| Spring deployment/natural substrate preparation – 25 ft and 17 ft (4-week samples) | April 8, 2008 |
| Collection of samples (4-week 17 ft and 25 ft) | May 8, 2008 |
| Send samples to lab | May 9, 2008 |

#### *4.2.3.2. Natural Rock Substrate*

In addition to artificial substrate, natural rock substrate was sampled at each of the two locations. Prior to deployment of the rock baskets, a set area (1.0 square meter) of natural rock was cleaned by a diver and marked for relocation. This area was located just upstream of where the rock baskets were placed at each site. This procedure was intended to be conducted approximately 8 weeks prior to collection, and again at approximately 4 weeks prior to collection. After the 8-week period, all natural rock samples (4-week and 8-week) were to be collected simultaneously. A diver collected rocks from within the previously defined area (using a surface area measurement device that kept the surface area a uniform size as the artificial sampler) and placed them into 500-micron mesh bags. Three rocks were chosen from this mesh bags for periphyton analysis.

#### *4.2.3.3. Statistical Analysis*

Data was collected from each site from two different artificial substrate types and from natural substrate. In addition, these collections were made at two depths (17 feet and 25 feet). Statistical evaluations at two depths and from three substrate collection types were analyzed for effect on periphyton chlorophyll *a*. The purpose for this comparison was to determine if the geometry of the artificial samplers used in earlier sampling efforts had any influence on response to environmental gradients such as depth and velocity.

Statistical comparisons of depth and substrate types were conducted using parametric analysis of variance (ANOVA) evaluation methods. Each data set generated for chlorophyll *a* estimates was transformed as needed to meet the normal distribution requirements for parametric statistical tests.

#### *4.2.3.4. Effect of Artificial vs. Natural Substrate and Depth on Results*

Biological samples describing properties of periphyton communities can be highly variable depending on their response to multiple environmental gradients. Properties of this variability in the biological response (e.g., chlorophyll *a*) were evaluated by using simple ANOVA and testing for effects from artificial vs. natural substrates and for depth of deployment. Depth and substrate type effects were tested for influence on biological response as well as any interaction between these two effects. An interaction is defined as a biological response (chlorophyll *a*) collected with artificial and natural substrates that do not respond consistently with change in depth. Significant interactions between the two variables (e.g., artificial vs. natural substrates and depth) indicates an influence on results from one (e.g., artificial vs. natural substrates) as mediated by the other variable (e.g., depth).

#### *4.2.3.5. Influence of Results on Developing HSI Curves*

The initial assumption for use of artificial substrates in characterizing periphyton chlorophyll *a* as a biological response to environmental gradients was that estimates are representative of: 1) results that would be collected from natural substrates and 2) that direction of response (e.g., increased or decreased chlorophyll *a*) would be consistent with those found from natural substrate. This assumption was further tested by partitioning data into reach responses and by depths of collection.

Statistical results addressed the potential for differential biological response at locations in the Canyon and Metaline reaches of Boundary Reservoir. These results determined whether HSI curves should be developed for each of these two zones in the reservoir or if the response from periphyton communities to depth was consistent throughout the reservoir. Because this test used an environmental variable consistently used throughout the study area (i.e., depth), the statistical test evaluated a zone effect (i.e., Canyon vs. Metaline).

A set of graphical presentations was developed for each of the analyses to determine the direction of the response in each of the artificial vs. natural substrates to depth intervals. These results evaluated the level of colonization on the substrates (e.g., chlorophyll *a* accumulated during deployment) and the strength of biological signal to the depth gradient on each of the artificial vs. natural substrates. Results from this evaluation were used to determine how well the use of previous artificial substrate results reflected natural substrate responses.

## 4.3. Calibration of Periphyton HSI Curves

Using the site-specific data collected during field surveys, a histogram or line graph for each of the habitat parameters researched was developed. The histograms and line graphs incorporated the site-specific field data collected in order to calibrate original provisional curves. Site-specific data for velocity was not collected as part of this study, but was estimated from the HRM. The histograms and line graphs were compared with the literature-based (provisional) HSI curves to evaluate the applicability of the literature-based HSI curve used for aquatic habitat modeling. In order to calibrate literature-based habitat suitability information with site-specific observations, it was assumed that all suitable habitats, under existing Project operations and Pend Oreille River hydrology, had been colonized by periphyton communities within the Boundary Reservoir.

### 4.4. Finalization of Periphyton HSI Curves

The HSI curve for each habitat parameter was reviewed by a panel of relicensing participants and regional experts. Panel members reviewed the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. The panel consisted of relicensing participants and regional experts (agency, tribal, and industry) and met on July 15, 2008, August 7, 2008, and August 27, 2008. Further clarification was provided to Washington Department of Fish and Wildlife relicensing participants on how the substrate comparison study results were used to develop the final depth HSI curve (teleconference on September 5, 2008). Once the final macrophyte HSI curves were developed, they were used in the aquatic habitat modeling study to define the habitat of periphyton, as they relate to selected metrics, in relation to operations scenarios.

## 5 LITERATURE RESULTS

A literature review was conducted to gather existing information and data on periphyton habitat preferences in terms of depth, substrate, velocity, and duration of inundation and dewatering. The Boundary Reservoir periphyton model combines a standard composite HSC value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering. During the literature review no appropriate suitability curves were found, so other literature information was used to develop suitability values. Results of the literature review and provisional periphyton HSI curves are summarized in the following section.

A provisional, literature-based periphyton HSI was created for Boundary Reservoir. The HSI developed addressed periphyton responses to changes in depth, velocity, substrate, and duration of inundation and dewatering to further our understanding of the effects of operations scenarios on aquatic resources at the Boundary Project. During the literature review, no appropriate suitability curves were found for periphyton; therefore, other literature information was used to develop suitability values. The HSI model is shown in Table 4.0-1. The literature-based model is multiplicative, because if any of the variables result in a score of zero, the HSI is zero and habitat is not suitable for periphyton growth.

### 5.1. Depth

The littoral areas, where the level of light penetration is sufficient for photosynthesis (euphotic zone), supports larger and more diverse populations of periphyton than deeper water habitats (Wright and Szluha 1980; Ward 1992; Thorp and Covich 2001; Wetzel 2001). The euphotic zone is generally considered to be the relatively shallow nearshore zone because light reflects off of the surface of the water, and then is further absorbed and scattered within the water column depending on turbidity, water color, and concentration of suspended algae in the waterbody (Reynolds 1996). The euphotic zone can vary from a few meters to over 30 meters (greater than 100 feet) in extremely clear waters, such as Crater Lake, Oregon (Larson et al. 1993). In Boundary Reservoir, the monthly euphotic depth has been estimated based on Secchi disk readings and extrapolations of turbidity readings (Table 5.1-1).

Provisional suitability values (Table 5.1-2) were selected based on these estimates of the depth of the euphotic zone in Boundary Reservoir and literature values (Wright and Szluha 1980; Ward

1992; Thorp and Covich 2001; Wetzel 2001; McLellan and O'Conner 2001). These index values consider light attenuation only and not substrata effects from elevation change. Zero depth refers to a condition of continuous inundation referencing light availability above and below that depth. Figure 5.1-1 displays the provisional depth suitability curve for periphyton.

**Table 5.1-1.** Estimated monthly euphotic depth of Boundary Reservoir based on Secchi disk readings and extrapolations of turbidity readings that reduce euphotic depth.

| | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimated Euphotic Depth (feet) | 34.5 | 34.5 | 27.2 | 19.7 | 15.8[1] | 16.7[1] | 28.5[1] | 44.3[1] | 39.4[1] | 34.5[1] | 34.5 | 34.5 |

Note:
1 Estimated euphotic depth based on three times the Secchi disk readings reported by McLellan and O'Connor (2001).

**Table 5.1-2.** Depth ranges and provisional suitability values for periphyton.

| **Depth** | **Provisional Suitability Values** |
|---|---|
| 0 | 0.75 |
| 3.28 ft | 1.0 |
| 16.4 ft | 1.0 |
| 32.8 ft | 0.6 |
| 49.2 ft | 0.01 |
| 98.4 ft | 0.0 |

Source: Wright and Szluha 1980, Ward 1992, Thorp and Covich 2001, Wetzel 2001, McLellan and O'Connor 2001

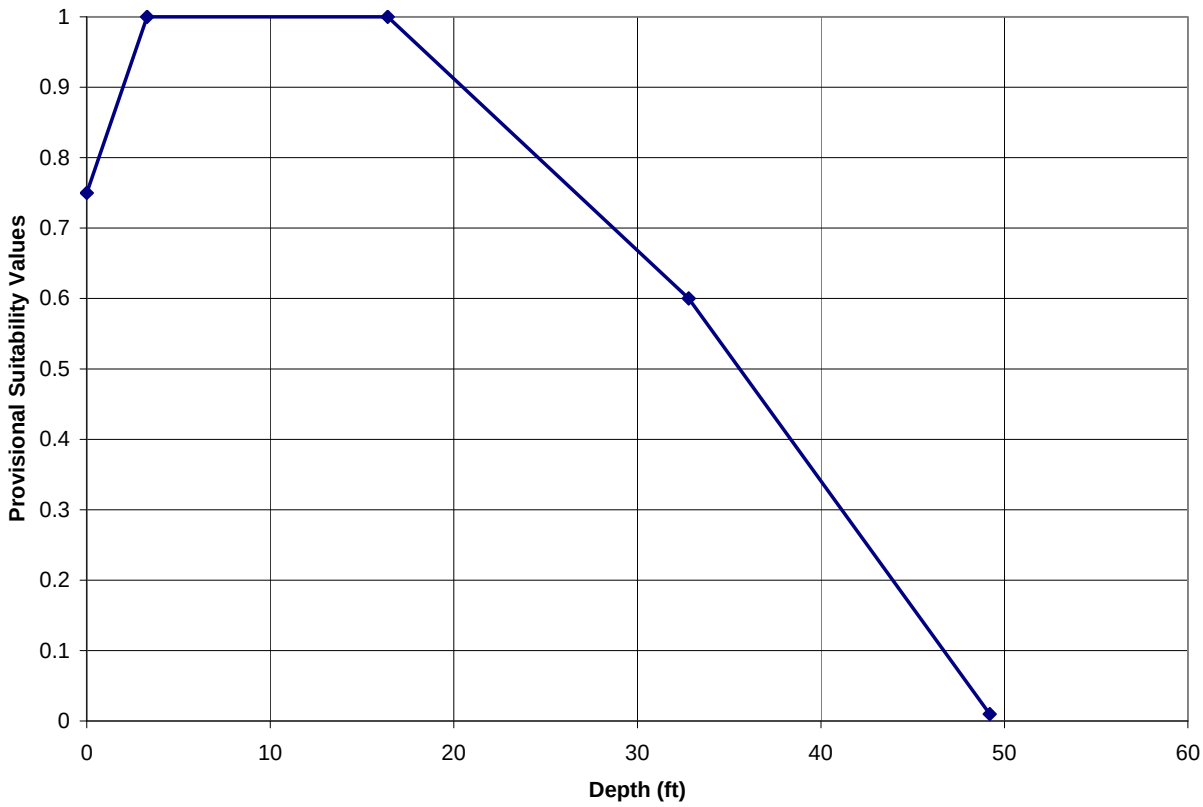


**Figure 5.1-1.** Provisional depth suitability curve for periphyton, note value is zero at 98 feet where light is insufficient for photosynthesis.

## 5.2. Velocity

Relatively minor changes in velocity can result in major changes in near-bed physics and this can be an important influence on periphyton accrual in rivers. However, the functional significance of velocity appears to vary depending on the age of the community and the dominant growth process (Biggs and Stokseth 1996). The current status of the periphyton community along the successional sequence, the velocity regime it developed under, and the magnitude of the velocity increase, all influence whether a particular velocity will stimulate or retard periphyton development (Biggs 1998).

In the recolonization phase, high velocities can inhibit the settlement of propagules and then development of high periphyton biomass (Stevenson 1983; Biggs and Gerbeaux 1993). Immigration tends to be positively correlated to the abundance of propagules, which concentrate in low velocity areas and negatively correlated with stream velocity (Biggs 1996). At the end of the colonization period, Biggs and Stokseth (1996) determined a gradient from highest biomass at low velocities (greater than 0.98 feet per second [fps]) to lowest biomass at highest velocities (greater than 2.30 fps). However, Horner and Welch (1981) suggest that the influence of velocity on periphyton accrual will change depending on the ambient nutrient concentrations.

They concluded that higher velocities especially benefit periphyton growth in nutrient-poor streams.

Once bare substrates have been colonized, then the framework for water velocity effects on plants shifts (Biggs 1996). Biggs and Stokseth (1996) found when periphyton communities reached maturity (day 92) there was a unimodal distribution of biomass as a function of velocity with a peak in biomass at 1.64 to 2.30 fps (0.5 to 0.7 meter per second [m/s]). In addition, Horner and Welch (1981) found that the optimum velocity (i.e., where mass transfer is enhanced, but shear stress is not excessive) for mature periphyton communities on artificial substrata in unenriched streams to be around 1.64 fps (0.5 m/s). In laboratory flumes Horner et al. (1990) found the maximum biomass at 1.97 fps (0.6 m/s). However, abrupt increases to higher velocities especially with suspended solids can detach periphyton and cause sloughing.

Provisional suitability values (Table 5.2-1) were selected based on a synthesis of the above information with an emphasis on the point during the accrual cycle of peak biomass as suggested by Biggs (1996). At this stage the strongest relationships between periphyton biomass and hydraulic constraints are manifested where the lower velocities, the higher the peak biomass that can accrue (Biggs 1996; Biggs and Gerbeaux 1993). Figure 5.2-1 displays the provisional velocity suitability curve for periphyton.

**Table 5.2-1.** Velocity ranges and provisional suitability values for periphyton.

| Velocity | Provisional Suitability Values |
|---|---|
| 0 fps | 0.9 |
| 0.82 fps | 1.0 |
| 1.64 fps | 1.0 |
| 2.46 fps | 0.5 |
| 3.28 fps | 0 |

Source: Biggs 1996; Biggs and Stokseth 1996; Biggs and Gerbeaux 1993

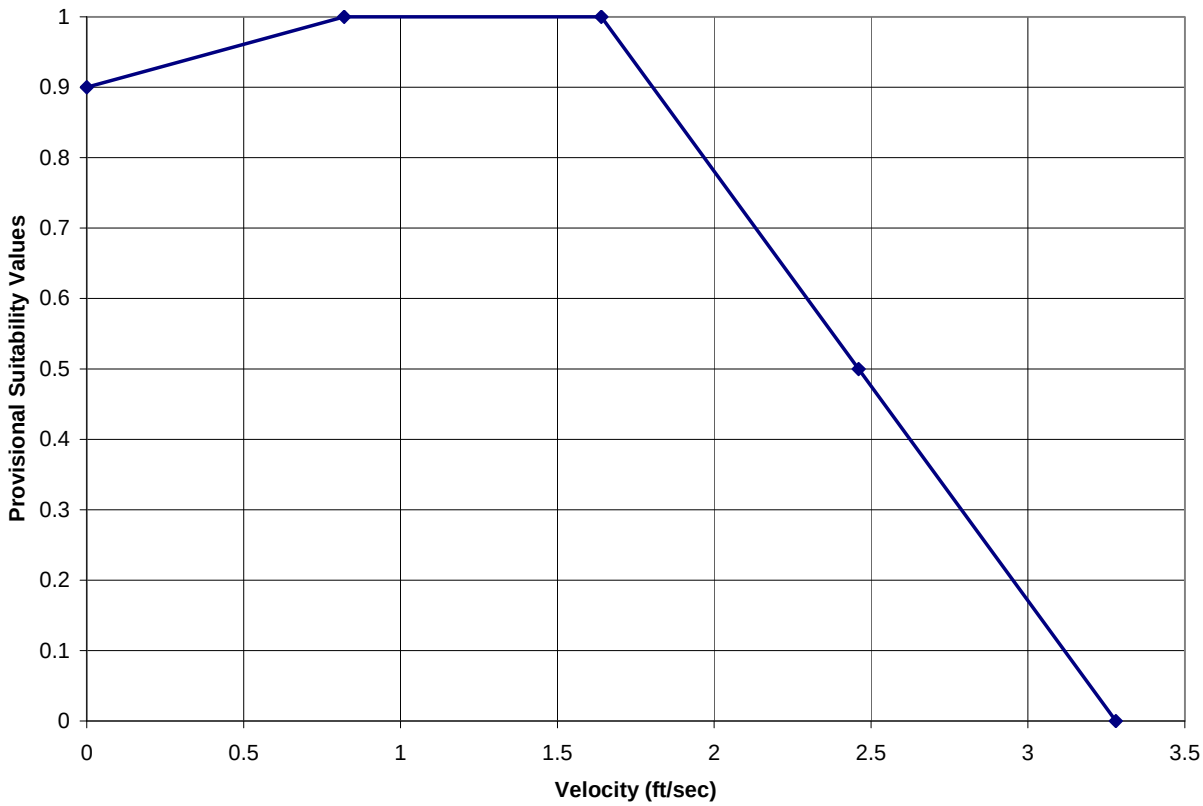


**Figure 5.2-1.** Provisional velocity suitability curve for periphyton.

## 5.3. Substrate

By definition, periphyton includes algae growing on solid or hard substrates (rock, wood, sediment, macrophytes) (EPA 1998). Colonization may be slowed when the bed substrata are unstable and suspended solids provide scouring (such as silt or organic detritus). Therefore, more severe disturbances may occur during an inundation event (Biggs and Stokseth 1996). The provisional suitability values for substrata were identified to be a limiting factor whereas, if suitable substrata are not present for colonization the HSI value for substrate is zero; otherwise, the value is 1 (Table 5.3-1). Figure 5.3-1 displays the provisional substrate suitability curve for periphyton.

**Table 5.3-1.** Substrate types and provisional suitability values for periphyton.

| Substrate Type | Provisional Suitability Values |
|---|---|
| Hard Substrates | 1.0 |
| Silt or Organic Substrate | 0 |

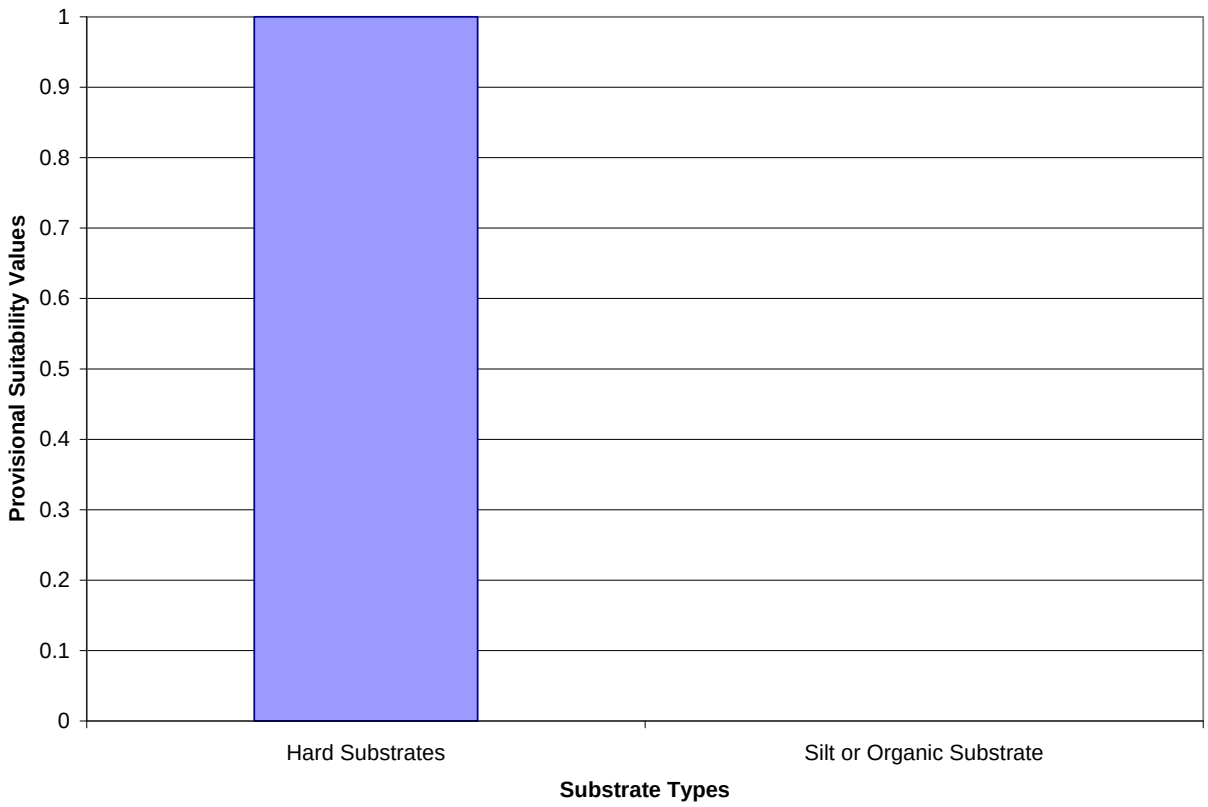


**Figure 5.3-1.** Provisional substrate suitability values for periphyton.

## 5.4. Duration of Dewatering

Dewatering of periphyton has been found to show significant reductions in biomass (grams of ash free dry mass per square meter [AFDM/$m^2$]) and chlorophyll *a* content even after short periods of exposure. Usher and Blinn (1990) found that repeated 12-hour per day dewatering/exposures of *Cladophera glomerata* for 3 days resulted in ≥ 40 percent losses in biomass and chlorophyll *a*, and Angradi and Kubly (2006) reported significant reductions in chlorophyll *a* after daytime exposures of less than 6 hours. Furthermore, Blinn et al. (1995) determined that discharge fluctuations during the summer and winter influenced the benthic community in the Colorado River downstream of Glen Canyon Dam, Arizona with algal communities showing a 50 percent reduction in biomass after two days of repeated 12-hour exposures, and more than 70 percent reductions in biomass after five days. Usher and Blinn (1990) reported similar losses of *C. glomerata* mass after repeated 12-hour exposures in laboratory stream tanks. Angradi and Kubly (2006) reported that only 57 percent of the initial chlorophyll *a* remained after a 10-hour exposure in the Colorado River downstream of Glen Canyon Dam at Lees Ferry, Arizona.

Depending on the season, effects of exposure can be more extreme. Standing crops (g AFDM/$m^2$) of *C. glomerata* and chlorophyll *a* were reduced by 50 percent within 1 day after a 3-hour exposure to freezing temperatures (-2 °C) (Blinn et al. 1995).

Provisional suitability values for duration of dewatering were selected based on the effects of varying exposure times found in the literature (Table 5.4-1). Figure 5.4-1 displays the provisional duration of dewatering suitability curve for periphyton.

**Table 5.4-1.** Duration of dewatering provisional suitability values for periphyton.

| Duration of Dewatering (hours) | Provisional Suitability Values |
|---|---|
| 0 | 1.0 |
| 6 | 0.9 |
| 8 | 0.6 |
| 12 | 0.4 |
| 24 | 0.0 |

Source: Blinn et al. 1995; Usher and Blinn 1990; Angradi and Kubly 2006

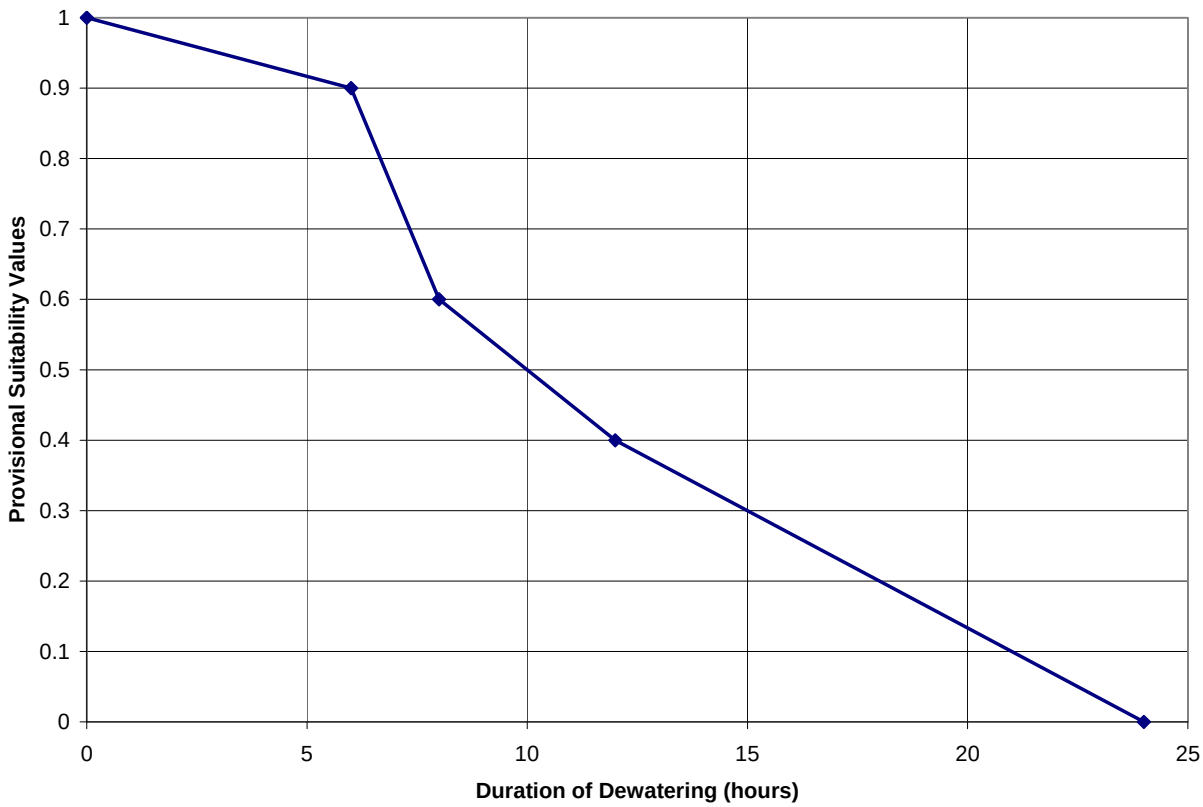


**Figure 5.4-1.** Provisional duration of dewatering suitability curve for periphyton (note at 24 hours of exposure it is assumed that viable periphyton is zero).

## 5.5. Duration of Inundation

Stevenson (1990) has suggested that the duration to achieve colonization depends to some extent on the magnitude of the foregoing disturbance. Blinn et al. (1995) found that after 6 months of exposure, chlorophyll *a* on cobble substrata recovered to control levels after 1 month of resubmergence. However, differences between exposed samples and controls for both epiphyton and *C. glomerata* mass (g AFDM/$m^2$) remained significant throughout the 4 months of resubmergence.

Biggs (1998) argued that in unenriched and enriched rivers, biomass on artificial substrate approximated natural communities after 4 weeks. However, he found that in moderately enriched rivers results were highly variable and biomass on artificial substrate gave only a fair representation of natural substrate levels after 8 weeks of accrual. In addition he found that results varied greatly among rivers indicating that the accrual process on artificial substrates was unpredictable.

Falter (2004) observed accrual rates of periphytic chlorophyll *a* on clean substrate in Lake Pend Oreille, Idaho through the accrual rates of chlorophyll *a* on clean substrate. Chlorophyll *a* accrual rates in 2003 averaged 0.048 mg $m^{-2}$ chlorophyll *a*/day. However these results varied significantly from previous studies where growth rates were found to be 0.091 mg $m^{-2}$ chlorophyll *a*/day in 1989-90, and 0.122 mg $m^{-2}$ chlorophyll *a*/day in 1986. The 2003 periphyton growth rates were 53 percent of 1989-90 rates and 39 percent of 1986 rates. This high variability among years was explained by the dependence on other environmental variables such as water temperature and nutrient availability (Falter 2004; Tri-State Water Quality Council 2004).

The rate of colonization for periphyton is highly dependent on the other physical and environmental variables. In particular, nutrient content is an important determinant of periphyton biomass and is the main cause for nuisance periphyton problems in streams and lakes (Welch and Jacoby 2004). For Boundary Dam, however, the nutrient regime is considered stable, usually with low concentrations prevailing. Therefore, physical factors are expected to have more effect on seasonal fluctuations in periphyton.

Provisional suitability values for duration of inundation were selected based on the effects of varying colonization rates found in the literature (Table 5.5-1). Figure 5.5-1 displays the provisional duration of inundation suitability curve for periphyton.

**Table 5.5-1.** Duration of inundation provisional suitability values for periphyton.

| Duration of Inundation | Provisional Suitability Values |
|---|---|
| 0 hours | 0.0 |
| 24 hours | 0.1 |
| 72 hours | 0.5 |
| 168 hours | 0.8 |
| >504 hours | 1.0 |

Source: Blinn et al. 1995; Biggs 1998; Falter 2004

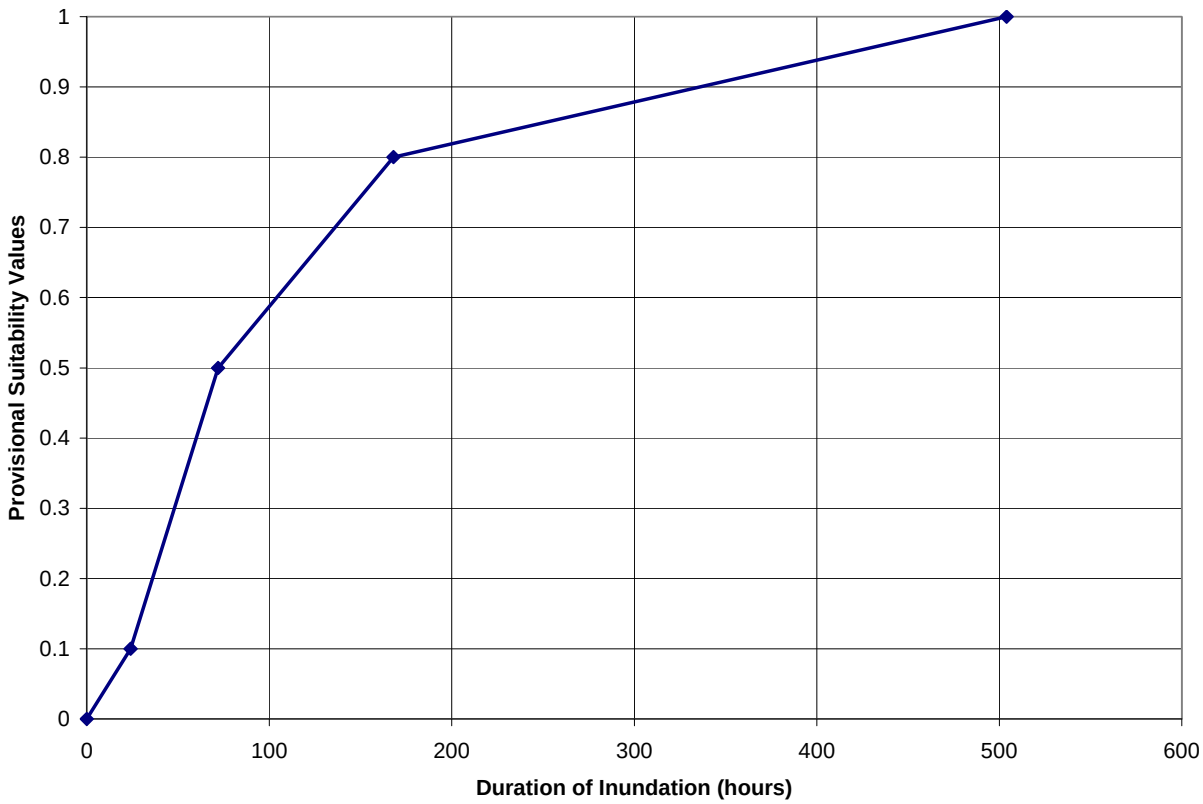


**Figure 5.5-1.** Provisional duration of inundation suitability curve for periphyton.

# 6 FIELD DATA RESULTS

This section presents the results and analysis of periphyton data collected for this study during 2007 and 2008. All periphyton data were evaluated to address the objectives of the study and are presented below. Site-specific periphyton data are presented below by treatment site, elevation, and season.

## 6.1. Periphyton Communities on Hard Substrate

Periphyton monitoring on artificial hard substrate was conducted during four different seasons: spring, summer, fall, and winter. Periphyton artificial substrate baskets were retrieved from both Boundary Reservoir and Box Canyon Reservoir after 8 weeks of incubation in the spring, summer, and fall, and after 14 weeks of incubation in winter. The longer exposure period in winter was due to reservoir ice cover and access restrictions. Spring periphyton samples were retrieved at the end of May, summer samples the first of September, and fall samples the first of November 2007. Winter samples were retrieved in the middle of March 2008.

As part of the experimental design, artificial substrate baskets were placed at elevations (2- and 5-foot elevation intervals) where baskets would be subject to dewatering with varying water

surface elevations. This was done to help better understand the impacts of inundation and dewatering on periphyton growth in Boundary Reservoir. Samples that were dewatered at the time of retrieval during the summer, fall, and winter were analyzed for chlorophyll *a* in order to determine whether viable chlorophyll *a* cells were present. It was determined from these analyses that samples collected from dewatered baskets have little viable chlorophyll *a* present and laboratory results were near detection limits. Results from the HRM were used to determine the length of time the baskets were dry or the average time of dewatering over the incubation period. This information was used in validating the provisional HSI curves for duration of inundation and duration of dewatering.

All periphyton data collected during 2007 and 2008, with the exception of data collected during winter, were used along with results from the HRM to further refine the literature-based HSI curves. The HRM provided information on water surface elevations, water velocities, and duration of inundation and dewatering that was used in conjunction with the site-specific periphyton data collected to validate the periphyton HSI model for Boundary Reservoir. The HRM also provided the zero water surface elevation mark set in April 2007 at all sites and therefore the specific elevations of each artificial substrate basket were determined. Periphyton data are presented graphically by specific basket elevations and summarized in tables by both specific basket elevation and elevation interval.

Figures 6.1-1 through 6.1-3 show the basket elevations in Box Canyon and Boundary reservoirs, respectively, in comparison to water surface fluctuations during the sample period. The fluctuation zone in Box Canyon Reservoir was much smaller than the fluctuation zones seen in both the Metaline and Canyon reaches in Boundary Reservoir. As per the experimental design, the highest fluctuation zone was located in the Canyon Reach of Boundary Reservoir. The Metaline Reach of Boundary Reservoir had a moderate level of fluctuation and Box Canyon Reservoir had the lowest level of fluctuation in water surface elevation.

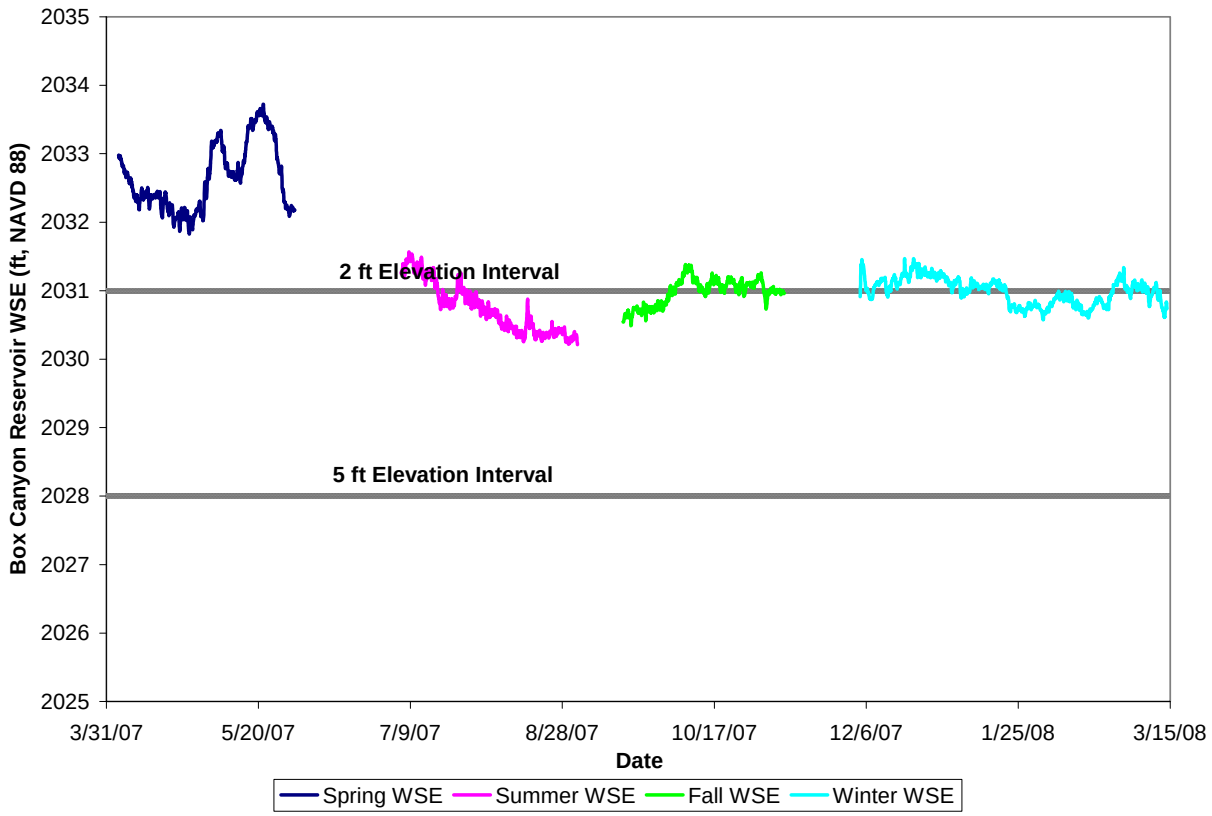


**Figure 6.1-1.** Box Canyon Reservoir hourly water surface elevations compared to basket locations at shoreline and vertical treatment sites.

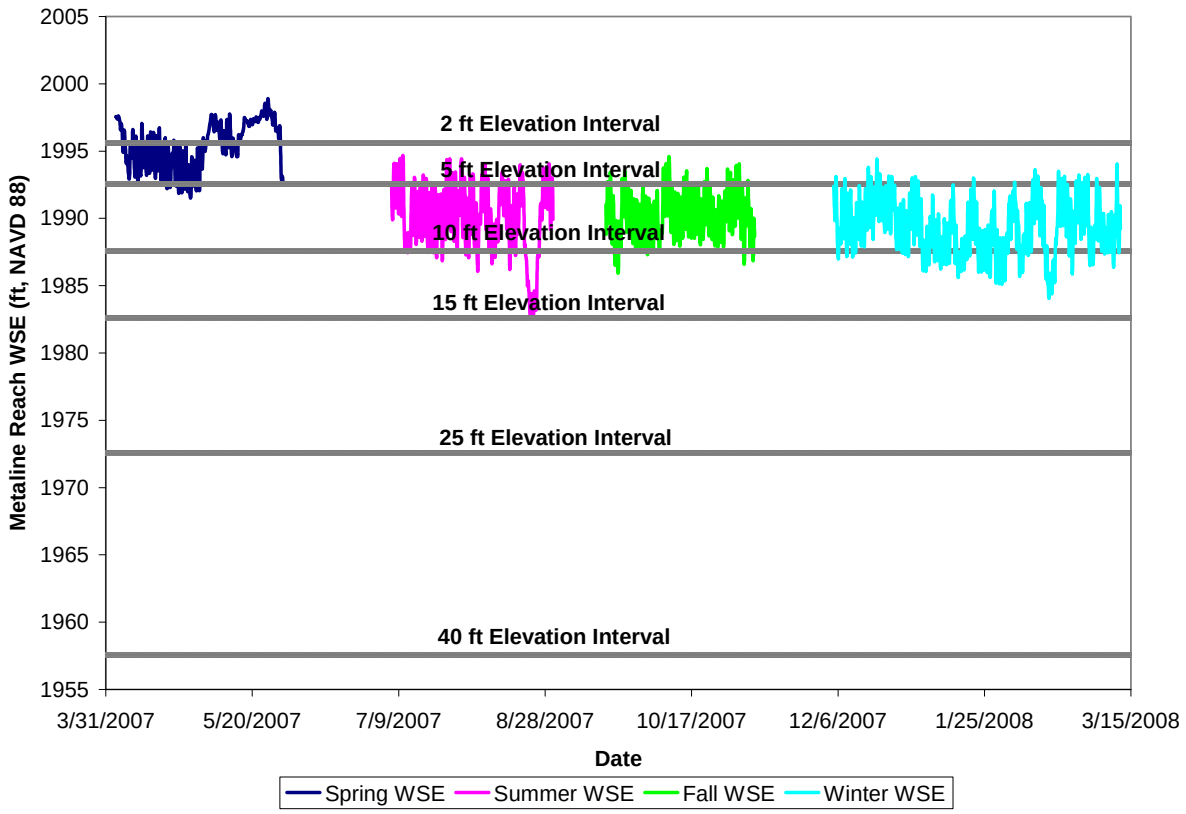


**Figure 6.1-2.** Metaline Reach (Boundary Reservoir) hourly water surface elevations compared to basket locations at the shoreline treatment site.

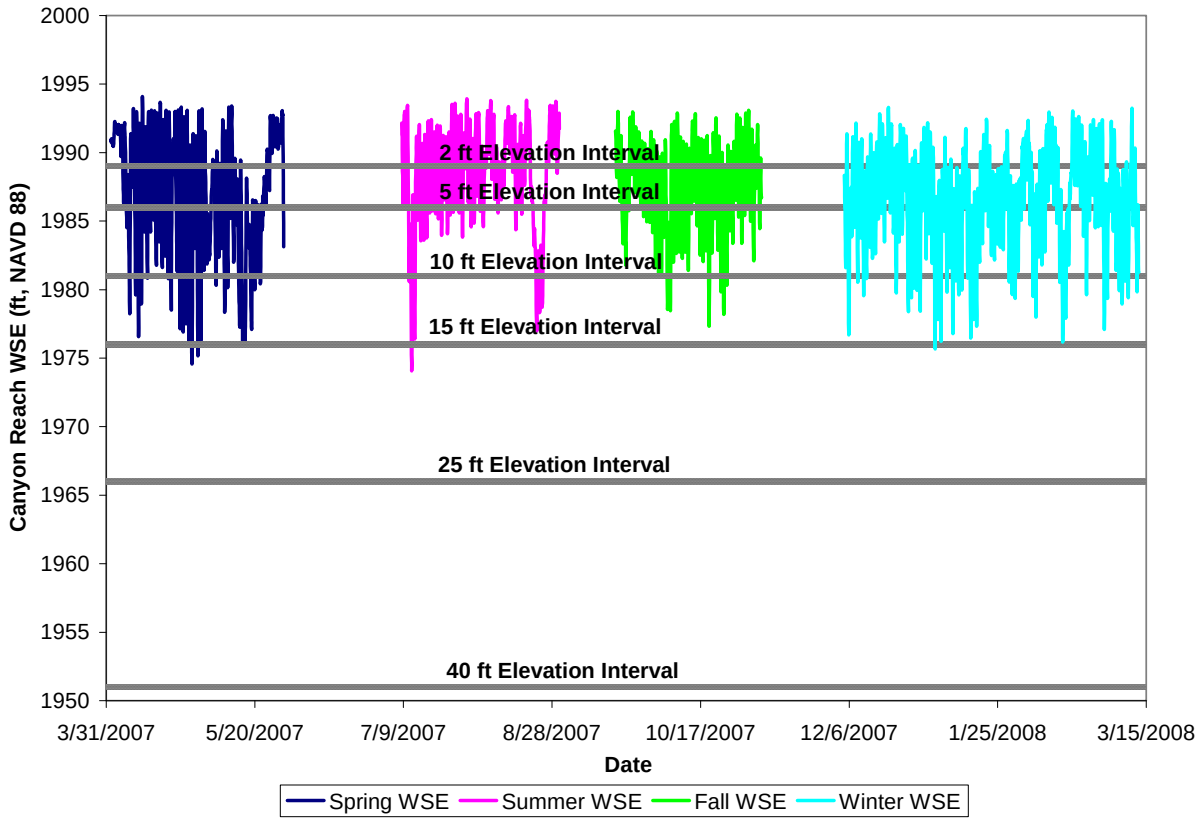


**Figure 6.1-3.** Canyon Reach (Boundary Reservoir) hourly water surface elevations compared to basket locations at shoreline and vertical treatment sites.

### 6.1.1. Vertical Treatment Sites

Figures 6.1-4 and 6.1-5 graphically present the average periphyton biomass measured by chlorophyll *a* (mg/m$^2$) by elevation at each vertical treatment site for samples collected in 2007 and 2008. Tables 6.1-1 and 6.1-2 summarize the periphyton chlorophyll *a* found in vertical treatment samples collected in the Canyon Reach and Box Canyon Reservoir, respectively.

Average periphyton chlorophyll *a* at vertical treatment sites ranged from 0.55 to 29.0 mg/m$^2$ in the Canyon Reach and 1.44 to 25.3 mg/m$^2$ in Box Canyon, disregarding dry baskets and winter concentrations. The high chlorophyll *a* concentrations during the winter study period were attributed to the longer exposure time and are not comparable to results from the rest of the study period. Winter results were not used in the calibration of the periphyton HSI curves and are not discussed in detail below.

Spring periphyton chlorophyll *a* at the vertical treatment site in the Canyon Reach ranged from 1.68 to 3.28 mg/m$^2$, with a maximum concentration at the 10 foot elevation interval (1,981 feet

NAVD 88 [1,977 feet NGVD 29])[1]. Spring periphyton chlorophyll *a* was much lower than summer and fall average periphyton chlorophyll *a* which ranged from 1.19 to 22.9 mg/m$^2$ and 1.45 to 29.0 mg/m$^2$, respectively (Figure 6.1-4). Summer and fall periphyton chlorophyll *a* was also much more variable at elevation than spring periphyton at the Canyon Reach vertical site. Summer maximum periphyton chlorophyll *a* occurred at the 5 foot elevation interval (1,986 feet NAVD 88 [1,982 feet NGVD 29]) and the fall maximum at the 10 foot elevation interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]). During all seasons, a decreasing trend in periphyton chlorophyll *a* was observed in the Canyon Reach with decreasing elevation (49 percent decrease in spring, 95 percent decrease in summer, and an 89 percent decrease in fall).

At the vertical treatment site in Box Canyon Reservoir, spring average periphyton chlorophyll *a* ranged from 1.44 to 3.86 mg/m$^2$ (Figure 6.1-5). This is very similar to spring periphyton chlorophyll *a* concentrations seen at the vertical treatment site in Boundary Reservoir. Summer average periphyton chlorophyll *a* at the vertical site in Box Canyon Reservoir ranged from 1.71 to 9.53 mg/m$^2$ and for most elevations there was little difference between summer and spring chlorophyll *a* (Figure 6.1-5). Except for the maximum chlorophyll *a* concentration of 9.53 mg/m$^2$ at the 5 foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]), chlorophyll *a* concentrations in the summer were very similar to concentrations in the spring in Box Canyon Reservoir.

Fall periphyton chlorophyll *a* was higher in Box Canyon Reservoir than in any other season, including winter at some elevations. Average fall periphyton chlorophyll *a* ranged from 4.08 to 25.3 mg/m$^2$ at the Box Canyon vertical treatment site (Figure 6.1-5). The maximum periphyton chlorophyll *a* during the fall occurred at the 20-foot elevation interval (2,013 feet NAVD 88 [2,009 feet NGVD 29]), which is much lower in the water column than was expected. Unlike spring and summer periphyton chlorophyll *a*, which decreased with decreasing depth (63 percent and 83 percent decrease, respectively), fall periphyton chlorophyll *a* increased with increasing depth.

Overall, periphyton chlorophyll *a* at both vertical treatment sites were similar during the spring and summer seasons. During the fall season, periphyton chlorophyll *a* tended to be higher and much more variable at the Box Canyon Reservoir site, especially at the lower depths. All periphyton chlorophyll *a* data for vertical treatment sites are available in spreadsheet form upon request.

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

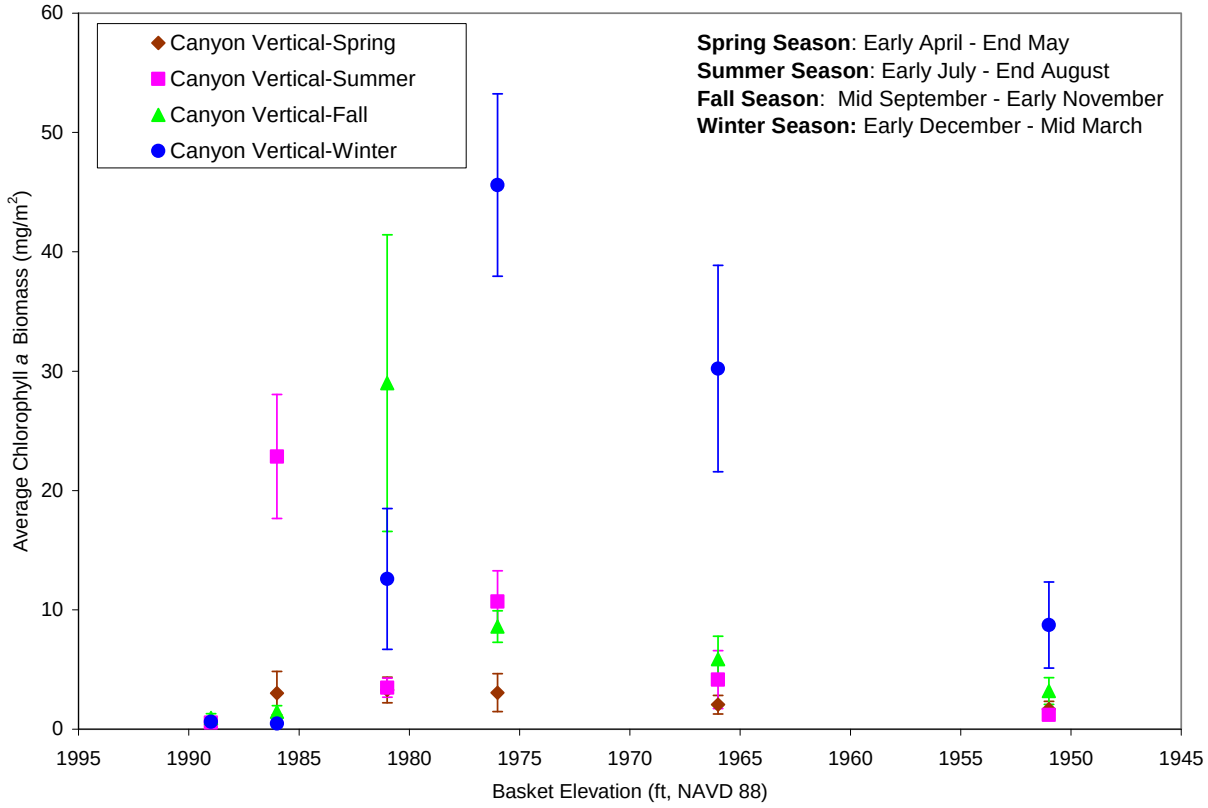


**Figure 6.1-4.** Average periphyton chlorophyll *a* for the Canyon Reach vertical site in Boundary Reservoir, 2007 and 2008.

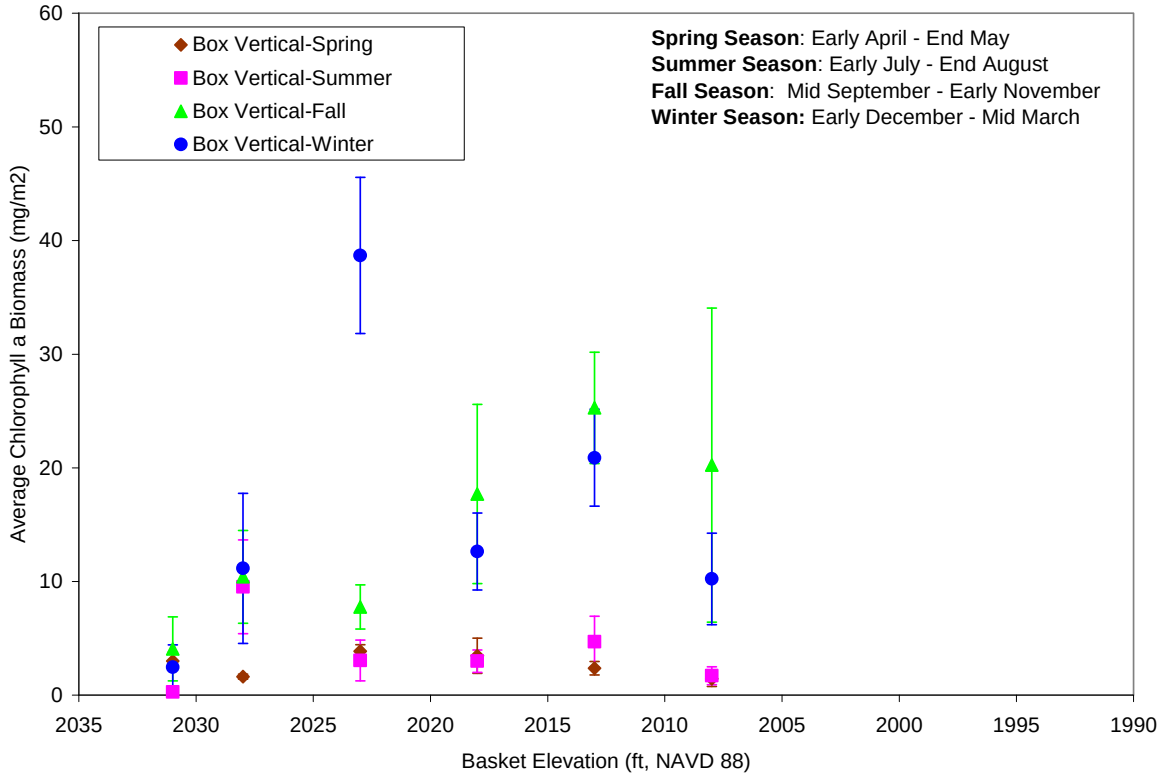


**Figure 6.1-5.** Average periphyton chlorophyll *a* for the vertical site in Box Canyon Reservoir, 2007 and 2008.

**Table 6.1-1.** Summary of average periphyton chlorophyll *a* (standard deviations) for the vertical treatment site in the Canyon Reach of Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Canyon Reach Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Canyon Vertical Average Periphyton Chlorophyll *a* ($mg/m^2$) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,989 (1,985) | 0[1] | 0.55 (0.21) | 0.93 (0.37) [1] | 0.62 (0.14) |
| 5 | 1,986 (1,982) | 3.02 (1.81) | 22.9 (5.19) | 1.45 (0.52) | 0.48 (0.18) |
| 10 | 1,981 (1,977) | 3.28 (1.07) | 3.48 (0.79) | 29.0 (12.42) | 12.6 (5.9) |
| 15 | 1,976 (1,972) | 3.05 (1.59) | 10.7 (2.57) | 8.60 (1.33) | 45.6 (7.64) |
| 20 | - | - | - | - | |
| 25 | 1,966 (1,962) | 2.06 (0.78) | 4.16 (2.43) | 5.86 (1.93) | 30.2 (8.64) |
| 40 | 1,951 (1,947) | 1.68 (0.65) | 1.19 (0.33) | 3.20 (1.12) | 8.73 (3.61) |

Notes:
1 The samples were retrieved dry.
2 Winter periphyton results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and calibration of HSI curves.

**Table 6.1-2.** Summary of average periphyton chlorophyll *a* (standard deviations) for the vertical treatment site in Box Canyon Reservoir, 2007 and 2008.

| Elevation Interval | Box Canyon Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Box Vertical Average Periphyton Chlorophyll *a* ($mg/m^2$) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 2,031 (2,027) | 3.00 (0.79) | 0.28 (0.13) [1] | 4.08 (2.81) | 2.46 (1.95) |
| 5 | 2,028 (2,024) | 1.62 (0.22) | 9.53 (4.13) | 10.4 (4.08) | 11.2 (6.61) |
| 10 | 2,023 (2,019) | 3.86 (0.58) | 3.05 (1.79) | 7.76 (1.94) | 38.7 (6.87) |
| 15 | 2,018 (2,014) | 3.47 (1.55) | 3.00 (0.99) | 17.7 (7.88) | 12.7 (3.38) |
| 20 | 2,013 (2,009) | 2.37 (0.59) | 4.71 (2.22) | 25.3 (4.90) | 20.9 (4.27) |
| 25 | 2,008 (2,004) | 1.44 (0.69) | 1.71 (0.78) | 20.3 (13.8) | 10.2 (4.02) |
| 40 | - | - | - | - | - |

Notes:
1 The samples were retrieved dry.
2 Winter periphyton results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and calibration of HSI curves.

### 6.1.2. Shoreline Treatment Sites

Figures 6.1-6 through 6.1-8 graphically present average periphyton chlorophyll *a* ($mg/m^2$) by elevation at each shoreline treatment site for samples collected in 2007 and 2008. Tables 6.1-3 through 6.1-5 summarize the average periphyton chlorophyll *a* found in shoreline treatment samples collected in the Canyon Reach, Metaline Reach, and Box Canyon Reservoir, respectively.

Average periphyton chlorophyll *a* at shoreline treatment sites ranged from 0.85 to 10.6 $mg/m^2$ in the Canyon Reach, 0.68 to 29.7 $mg/m^2$ in the Metaline Reach, and 0.81 to 15.3 $mg/m^2$ in Box Canyon Reservoir. These ranges disregard baskets that were dry and winter concentrations. The high chlorophyll *a* concentrations during the winter study period were attributed to the longer exposure time and are not comparable to results from the rest of the study period. Winter results were not used in the calibration of the periphyton HSI curves and are not discussed in detail below. In addition, the baskets in the Box Canyon shoreline treatment during the summer and fall were covered by aquatic macrophytes. This potential bias was taken into account in the development of the final periphyton HSI curves.

At the shoreline treatment site in the Canyon Reach of Boundary Reservoir, average periphyton chlorophyll *a* in the spring was very low and ranged from 0.85 to 2.89 $mg/m^2$ (Figure 6.1-6). The spring maximum of 2.89 $mg/m^2$ occurred at the 10 foot elevation interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]), and was the only basket to have over 1 $mg/m^2$ of chlorophyll *a*. Baskets placed at the 2 and 5 foot elevation intervals were dry at the time of spring retrieval. Average periphyton chlorophyll *a* concentrations were higher in the summer and fall seasons, (1.11 to 10.6 and 1.41 to 4.72 mg /m2, respectively) but were not as high as concentrations at the vertical treatment site in the Canyon Reach (Figure 6.1-6). Although, periphyton chlorophyll *a*

was low at the Canyon Reach shoreline treatment site, chlorophyll *a* did follow a decreasing trend with increasing depth during all seasons.

The Metaline Reach shoreline treatment site had markedly higher periphyton chlorophyll *a* than the Canyon Reach. Average periphyton chlorophyll *a* in the spring was the lowest of the three seasons and ranged from 0.68 to 5.46 mg/m$^2$, with a maximum at the 10 foot elevation interval (1,987.58 feet NAVD 88 [1,983.58 feet NGVD 29]). Summer periphyton chlorophyll *a* at the shoreline site in Metaline Reach ranged from 3.38 to 11.2 mg/m$^2$ and fall periphyton chlorophyll *a* ranged from 1.34 to 29.7 mg/m$^2$ (Figure 6.1-7). Maximum periphyton chlorophyll *a* occurred at the 15 foot elevation intervals (1,982.58 feet NAVD 88 [1,978.58 feet NGVD 29]) and the 10 foot elevation interval (1,987.58 feet NAVD 88 [1,983.58 feet NGVD 29]), respectively. During the summer season baskets at the 2 and 5 foot elevation intervals were dry at retrieval, which could be the reason for the shift in maximum chlorophyll *a*. From the maximum, there was a decreasing trend observed for periphyton chlorophyll *a* with increasing depth during the spring and summer seasons in the Metaline Reach. This trend was not observed during the fall season, similar to the vertical site in Box Canyon Reservoir.

Average periphyton chlorophyll *a* at the shoreline treatment site in Box Canyon Reservoir ranged from 0.95 to 3.65 mg/m$^2$ in the spring, from 0.81 to 12.8 mg/m$^2$ in the summer, and from 1.14 to 15.3 mg/m$^2$ in the fall (Figure 6.1-8). Spring periphyton chlorophyll *a* was the lowest of the three seasons. Similar to what was observed at the site in the Metaline Reach, maximum periphyton chlorophyll *a* occurred in the fall at the 25 foot elevation interval. During spring and summer, periphyton chlorophyll *a* at the shoreline treatment site in Box Canyon Reservoir followed a decreasing trend with increasing depth. This was not true during the fall season.

Overall periphyton chlorophyll *a* at the shoreline treatment sites in the Metaline Reach and Box Canyon Reservoir were higher than concentrations observed in the Canyon Reach. At all shoreline treatment sites periphyton chlorophyll *a* was the higher and more variable during the fall. This was also the case at the vertical treatment sites. All periphyton chlorophyll *a* data for shoreline treatment sites is available in spreadsheet form upon request.

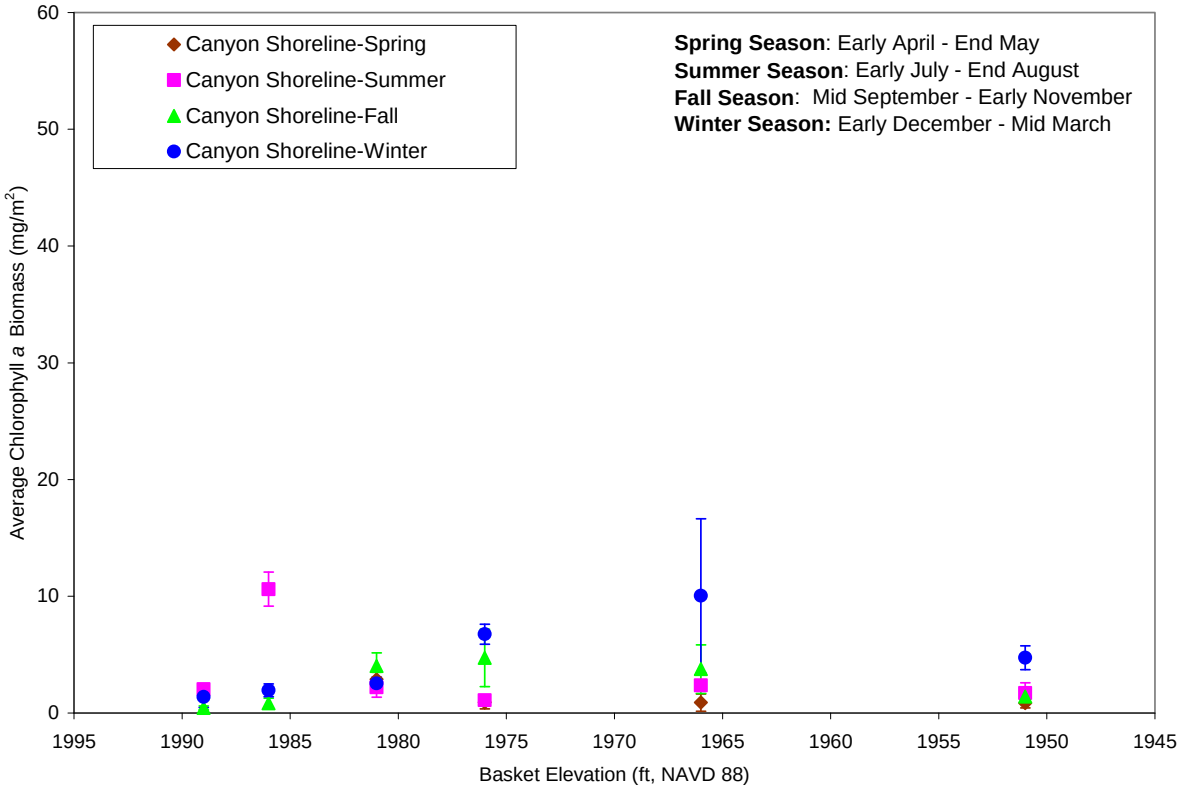


**Figure 6.1-6.** Average periphyton chlorophyll *a* for the Canyon shoreline site in Boundary Reservoir, 2007 and 2008.

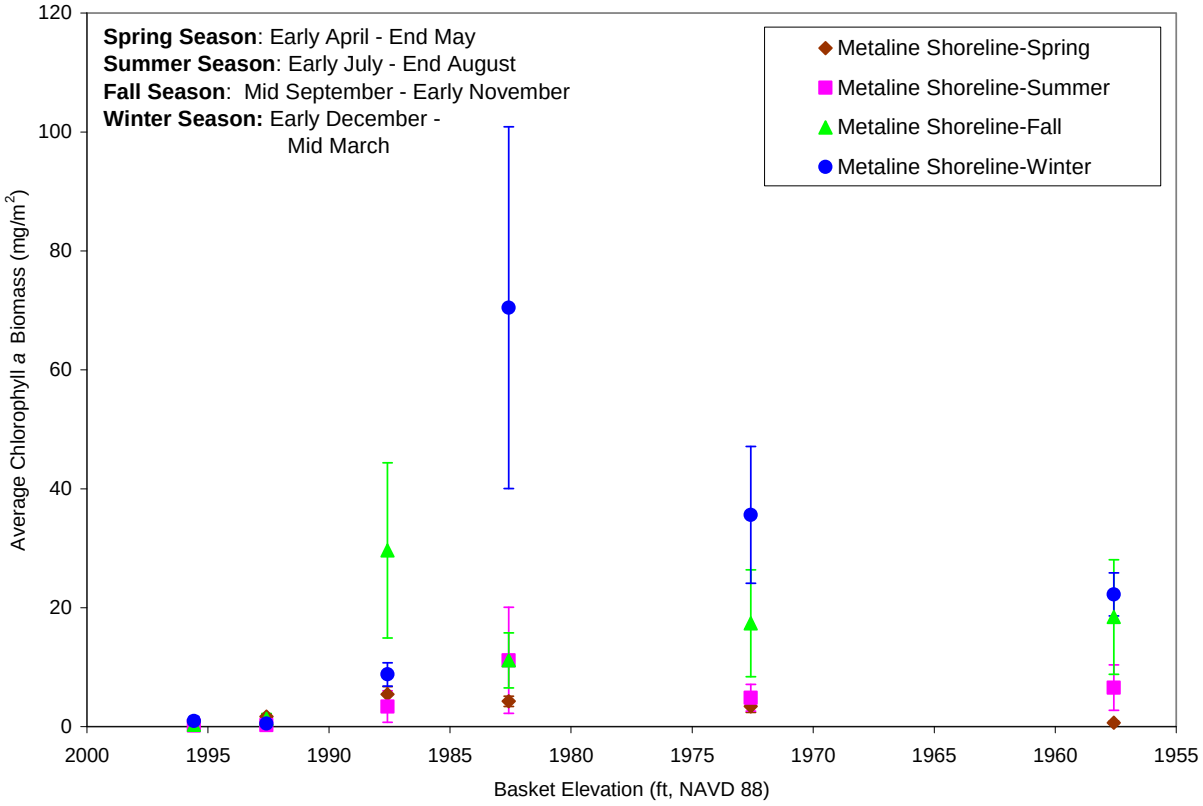


**Figure 6.1-7.** Average periphyton chlorophyll *a* for the Metaline shoreline site in Boundary Reservoir, 2007 and 2008.

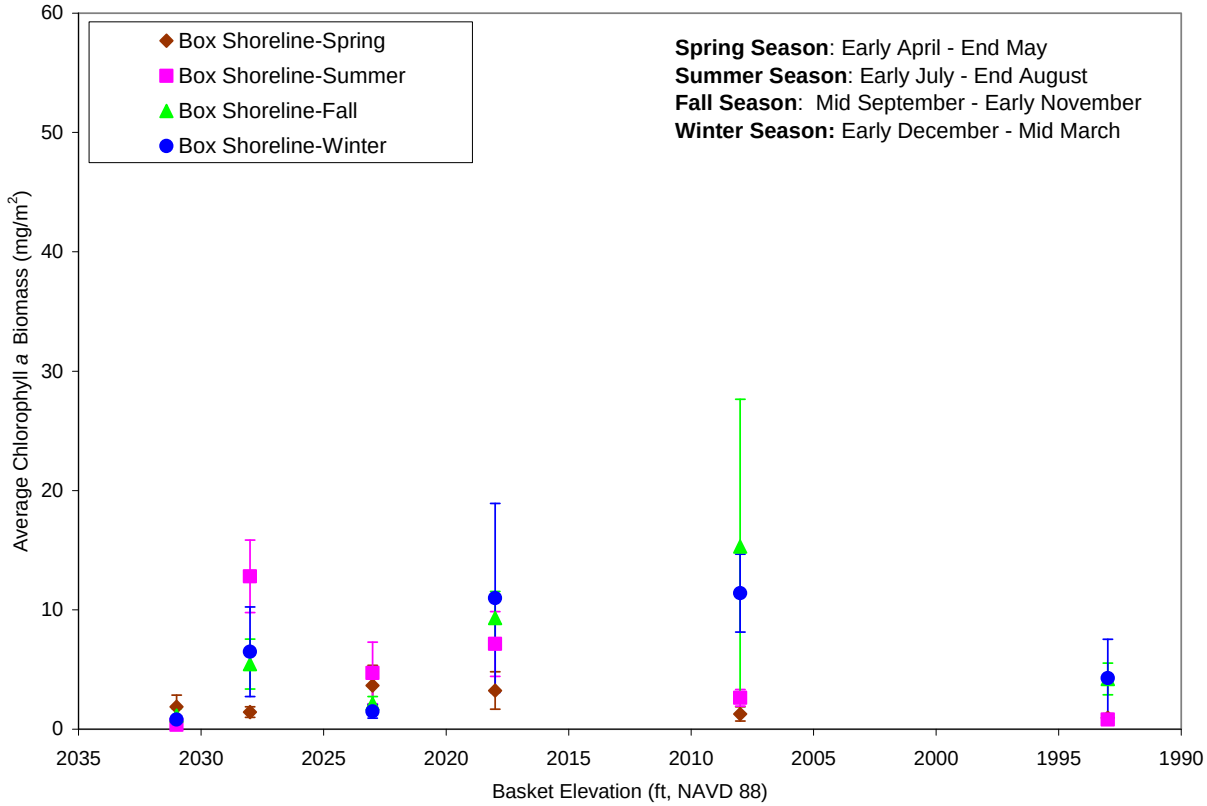


**Figure 6.1-8.** Average periphyton chlorophyll *a* for the shoreline site in Box Canyon Reservoir, 2007 and 2008.

**Table 6.1-3.** Summary of average periphyton chlorophyll *a* (standard deviations) for the Canyon shoreline treatment site in Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Canyon Reach Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Canyon Shoreline Average Periphyton Chlorophyll *a* ($mg/m^2$) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,989 (1,985) | -[1] | 2.05 (0.32) | 0.45 (0.16) [1] | 1.37 (0.92) [1] |
| 5 | 1,986 (1,982) | -[1] | 10.6 (1.46) | 0.82 (0.45) [1] | 1.95 (0.55) [1] |
| 10 | 1,981 (1,977) | 2.89 (0.59) | 2.20 (0.85) | 4.02 (1.12) | 2.54 (0.53) |
| 15 | 1,976 (1,972) | 0.91 (0.56) | 1.11 (0.30) | 4.72 (2.46) | 6.76 (0.85) |
| 20 | - | - | - | - | |
| 25 | 1,966 (1,962) | 0.89 (0.75) | 2.37 (0.45) | 3.76 (2.09) | 10.1 (6.57) |
| 40 | 1,951 (1,947) | 0.85 (0.41) | 1.71 (0.88) | 1.41 (0.34) | 4.74 (1.02) |

Notes:
1 The samples were retrieved dry.
2 Winter periphyton results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and calibration of HSI curves.

**Table 6.1-4.** Summary of average periphyton chlorophyll *a* (standard deviations) for the Metaline shoreline treatment site in Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Metaline Reach Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Metaline Shoreline Average Periphyton Chlorophyll *a* ($mg/m^2$) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,995.58 (1,991.58) | -[1] | 0.17 (0.05) [1] | 0.34 (0.26) [1] | 0.96 (0.77) [1] |
| 5 | 1,992.58 (1,988.58) | 1.70 (0.37) | 0.27 (0.07) [1] | 1.34 (0.87) | 0.51 (0.43) [1] |
| 10 | 1,987.58 (1,983.58) | 5.46 (1.27) | 3.38 (2.65) | 29.7 (14.7) | 8.80 (1.97) |
| 15 | 1,982.58 (1,978.58) | 4.26 (0.88) | 11.2 (8.90) | 11.2 (4.63) | 70.5 (30.4) |
| 20 | - | - | - | - | - |
| 25 | 1,972.58 (1,968.58) | 3.44 (1.05) | 4.86 (2.24) | 17.4 (8.99) | 35.6 (11.5) |
| 40 | 1,957.58 (1,953.58) | 0.68 (0.28) | 6.57 (3.82) | 18.4 (9.63) | 22.3 (3.60) |

Notes:
1 The samples were retrieved dry.
2 Winter periphyton results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and calibration of HSI curves.

**Table 6.1-5.** Summary of average periphyton chlorophyll *a* (standard deviations) for the shoreline treatment site in Box Canyon Reservoir, 2007 and 2008.

| Elevation Interval | Box Canyon Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Box Vertical Shoreline Periphyton Chlorophyll *a* ($mg/m^2$) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 2,031 (2,027) | 1.88 (0.96) | 0.38 (0.33) [1] | 1.14 (0.57) | 0.81 (0.31) [1] |
| 5 | 2,028 (2,024) | 1.43 (0.43) | 12.8 (3.03) | 5.46 (2.10) | 6.49 (3.75) |
| 10 | 2,023 (2,019) | 3.65 (1.70) | 4.71 (2.58) | 2.15 (0.58) | 1.50 (0.57) |
| 15 | 2,018 (2,014) | 3.24 (1.57) | 7.14 (2.71) | 9.32 (2.21) | 10.9 (7.92) |
| 20 | 2,013 (2,009) | - | - | - | - |
| 25 | 2,008 (2,004) | 1.28 (0.59) | 2.62 (0.70) | 15.3 (12.3) | 11.4 (3.26) |
| 40 | 1,993 (1,989) | 0.95 (0.36) | 0.81 (0.25) | 4.21 (1.33) | 4.28 (3.24) |

Notes:
1 The samples were retrieved dry.
2 Winter periphyton results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and calibration of HSI curves.

## 6.2. Periphyton Colonization Rates

Colonization baskets were deployed in Box Canyon Reservoir beginning July 6, 2007, and ending August 28, 2007, in order to determine summer periphyton colonization rates in a low water fluctuation area. Hard substrate baskets were deployed at time intervals of 8, 6, 4, and 2 weeks, 1 week, and 3 days. Winter colonization baskets were deployed beginning December 5, 2007, and ending March 13, 2008. Winter colonization samples were to be retrieved initially

February 1, 2008 but were not retrieved until March 2008 due to ice cover and reservoir inaccessibility. Due to reservoir and weather conditions winter colonization samples were deployed at time intervals of 14, 12, 10, 8, and 1 weeks, and 3 days and results from the winter colonization field work were not used in the calibration of periphyton HSI curves. Winter colonization data is not comparable to data collected in the summer and therefore no seasonal analysis was completed. Summer and winter colonization results are presented below separately.

Average summer periphyton chlorophyll *a* collected from colonization baskets in Box Canyon Reservoir are shown in Figure 6.2-1 and summarized in Table 6.2-1. Average summer periphyton colonization rates were calculated by depth and are presented in Figure 5.2-2. Winter colonization results are show in Figure 6.2-3 and summarized in Table 6.2-2, although these colonization are not comparable to the summer results. Average winter periphyton colonization rates were calculated by depth and are presented in Figure 5.2-4.

Average summer periphyton chlorophyll *a* collected from colonization baskets ranged from 0.80 to 17.02 mg/m$^2$ at all elevations (5, 15, and 25 foot elevation intervals). The highest periphyton chlorophyll *a* was observed at the 5 foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]) and after 42 days (6 weeks) of incubation. The lowest periphyton chlorophyll *a* was seen at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]) after only 3 days of incubation (Figure 6.2-1).

Summer periphyton colonization rates varied from 0.24 to 0.55 mg/m$^2$-day for baskets at the 5 foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]), 0.11to 0.35 mg/m$^2$-day for baskets at the 15 foot elevation interval (2,018 feet NAVD 88 [2,014 feet NGVD 29]), and 0.04 to 0.27 mg/m$^2$-day for baskets at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]). There was a decrease in periphyton colonization at Day 28 (Table 6.2-1). This decrease in periphyton colonization does not appear to be related to water level fluctuation (see Figure 6.1-1) and is more likely related to localize environmental conditions (i.e. weather, light, and nutrient availability). Average summer colonization rates were 0.38, 0.23, and 0.18 mg/m$^2$-day for baskets at 5, 15, and 25 foot elevation intervals, respectively. Overall the average summer periphyton colonization for hard substrate in Box Canyon Reservoir was determined to be 0.26 mg/m$^2$-day (Figure 6.2-2).

Average winter periphyton chlorophyll *a* collected from colonization baskets ranged from 1.64 to 53.3 mg/m$^2$ at all elevations (5, 15, and 25 foot elevation intervals). The highest periphyton chlorophyll *a* from winter colonization baskets was observed at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]) after 83 days (12 weeks) of exposure. The lowest periphyton chlorophyll *a* was also observed at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]) after only 3 days of exposure (Figure 6.2-3).

Winter periphyton colonization rates varied from 0.09 to 0.68 mg/m$^2$-day for baskets at the 5 foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]), 0.06 to 1.05 mg/m$^2$-day for baskets at the 15 foot elevation interval (2,018 feet NAVD 88 [2,014 feet NGVD 29]), and 0.20 to 0.64 mg/m$^2$-day for baskets at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]) (Table 6.2-2). There was a decrease in periphyton colonization at the 5 foot and 15 foot elevation intervals (2,028 and 2,018 feet NAVD 88 [2,024 and 2,014 feet NGVD 29]) after

69 days of exposure and a decrease in periphyton colonization at the 25 foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]) after 83 days of exposure (Figure 6.3-3). Periphyton colonization steadily increased at all elevation intervals from 0 to 55 days of exposure, which was the exposure time during the summer. Overall the average winter periphyton colonization rate for hard substrate in Box Canyon Reservoir was determined to be 0.41 mg/m$^2$-day (Figure 6.2-4). This rate is almost double the summer colonization rate which corresponds to the almost doubling of exposure time during the winter. Winter periphyton colonization data was not used in the calibration of the duration of inundation HSI curve.

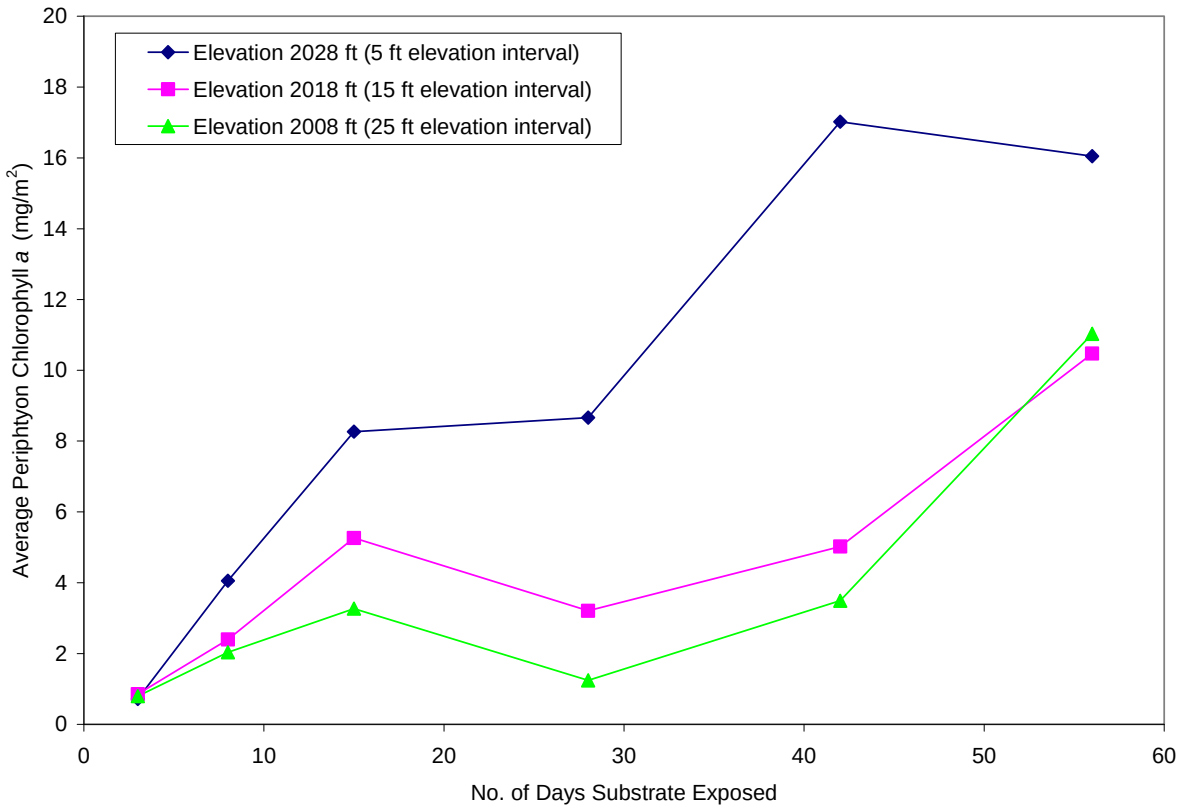


**Figure 6.2-1.** Average summer periphyton chlorophyll *a* collected at elevation intervals 5, 15, and 25 feet in Box Canyon reservoir after various days of incubation.

**Table 6.2-1.** Average summer periphyton chlorophyll *a* and colonization rates per elevation, elevation interval, and number of days incubated in Box Canyon Reservoir.

| Date Retrieved | No. of Days Exposed | Elevation Interval | Elevation in ft, NAVD 88 (ft, NGVD 29) | Average Periphyton Chlorophyll *a* ($mg/m^2$) | Periphyton Colonization Rate ($mg/m^2$-day) |
|---|---|---|---|---|---|
| 8/31/07 | 56 | 5 | 2,028 (2,024) | 16.05 | 0.29 |
| | | 15 | 2,018 (2,014) | 10.47 | 0.19 |
| | | 25 | 2,008 (2,004) | 11.03 | 0.20 |
| | 42 | 5 | 2,028 (2,024) | 17.02 | 0.41 |
| | | 15 | 2,018 (2,014) | 5.02 | 0.12 |
| | | 25 | 2,008 (2,004) | 3.50 | 0.08 |
| | 28 | 5 | 2,028 (2,024) | 8.67 | 0.31 |
| | | 15 | 2,018 (2,014) | 3.21 | 0.11 |
| | | 25 | 2,008 (2,004) | 1.25 | 0.04 |
| | 15 | 5 | 2,028 (2,024) | 8.27 | 0.55 |
| | | 15 | 2,018 (2,014) | 5.26 | 0.35 |
| | | 25 | 2,008 (2,004) | 3.27 | 0.22 |
| | 8 | 5 | 2,028 (2,024) | 4.06 | 0.51 |
| | | 15 | 2,018 (2,014) | 2.40 | 0.30 |
| | | 25 | 2,008 (2,004) | 2.04 | 0.26 |
| | 3 | 5 | 2,028 (2,024) | 0.72 | 0.24 |
| | | 15 | 2,018 (2,014) | 0.85 | 0.28 |
| | | 25 | 2,008 (2,004) | 0.80 | 0.27 |

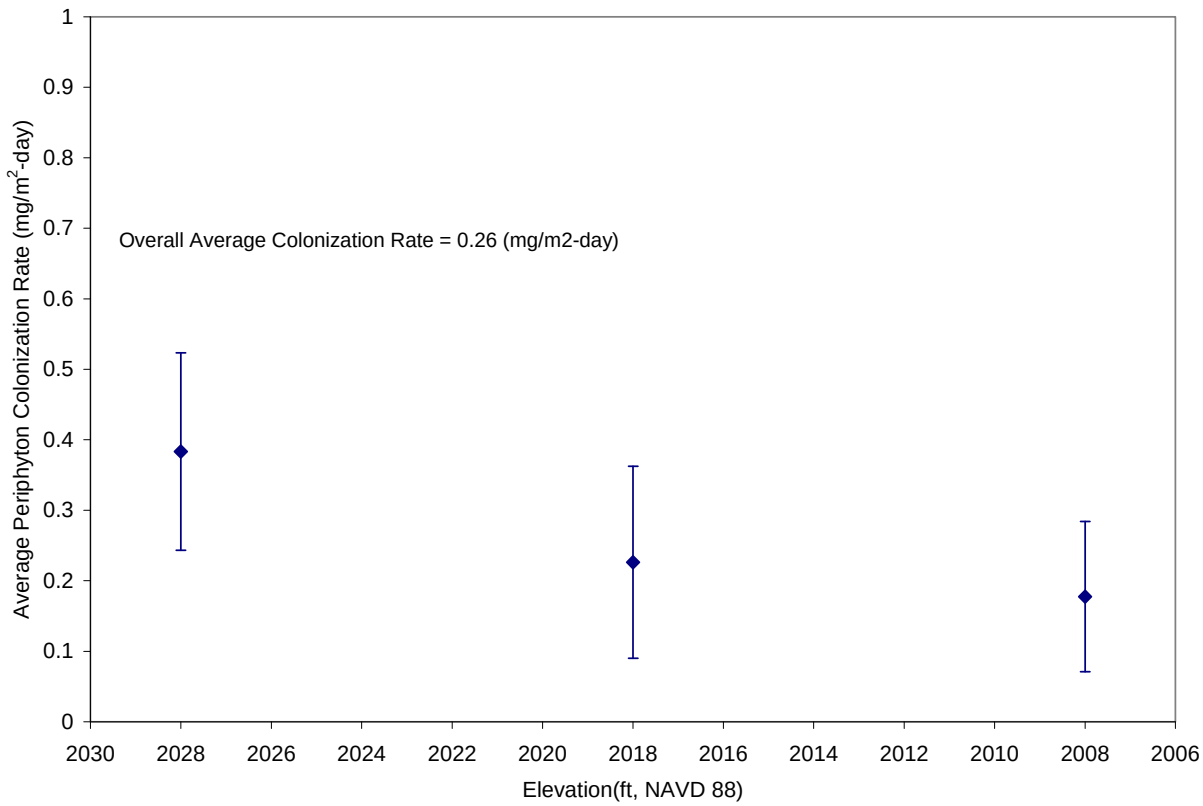


**Figure 6.2-2.** Average summer periphyton colonization rate, 2007.

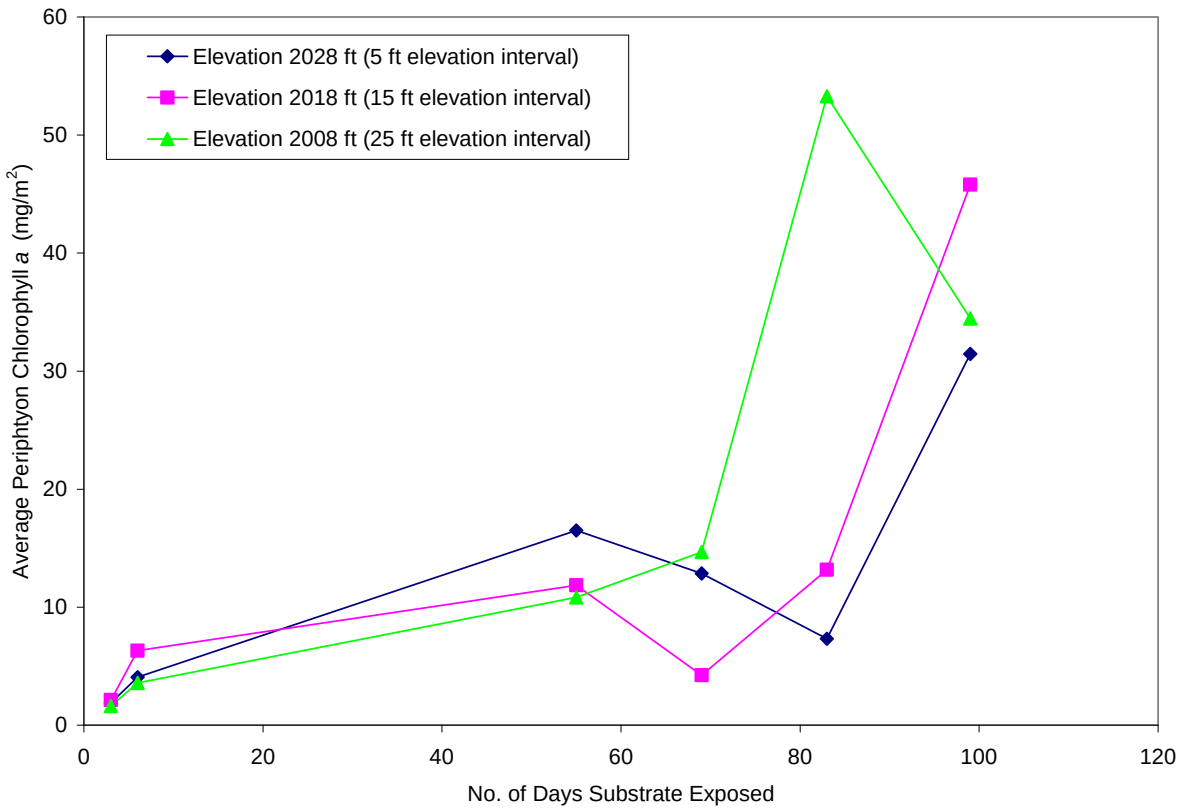


**Figure 6.2-3.** Average winter periphyton chlorophyll *a* collected at elevation intervals 5, 15, and 25 feet in Box Canyon Reservoir after various days of incubation.

**Table 6.2-2.** Average winter periphyton chlorophyll *a* and colonization rates per elevation, elevation interval, and number of days incubated in Box Canyon Reservoir.

| Date Pulled | No. of Days Exposed | Elevation Interval | Elevation in ft, NAVD 88 (ft, NGVD 29) | Average Periphyton Biomass (mg/m$^2$) | Periphyton Colonization Rate (mg/m$^2$-day) |
|---|---|---|---|---|---|
| 3/13/08 | 99 | 5 | 2,028 (2,024) | 31.46 | 0.32 |
| | | 15 | 2,018 (2,014) | 45.81 | 0.46 |
| | | 25 | 2,008 (2,004) | 34.46 | 0.35 |
| | 83 | 5 | 2,028 (2,024) | 7.31 | 0.09 |
| | | 15 | 2,018 (2,014) | 13.18 | 0.16 |
| | | 25 | 2,008 (2,004) | 53.30 | 0.64 |
| | 69 | 5 | 2,028 (2,024) | 12.86 | 0.19 |
| | | 15 | 2,018 (2,014) | 4.23 | 0.06 |
| | | 25 | 2,008 (2,004) | 14.68 | 0.21 |
| | 55 | 5 | 2,028 (2,024) | 16.49 | 0.30 |
| | | 15 | 2,018 (2,014) | 11.85 | 0.22 |
| | | 25 | 2,008 (2,004) | 10.83 | 0.20 |
| | 6 | 5 | 2,028 (2,024) | 4.07 | 0.68 |
| | | 15 | 2,018 (2,014) | 6.32 | 1.05 |
| | | 25 | 2,008 (2,004) | 3.59 | 0.60 |
| | 3 | 5 | 2,028 (2,024) | 1.90 | 0.63 |
| | | 15 | 2,018 (2,014) | 2.14 | 0.71 |
| | | 25 | 2,008 (2,004) | 1.64 | 0.55 |

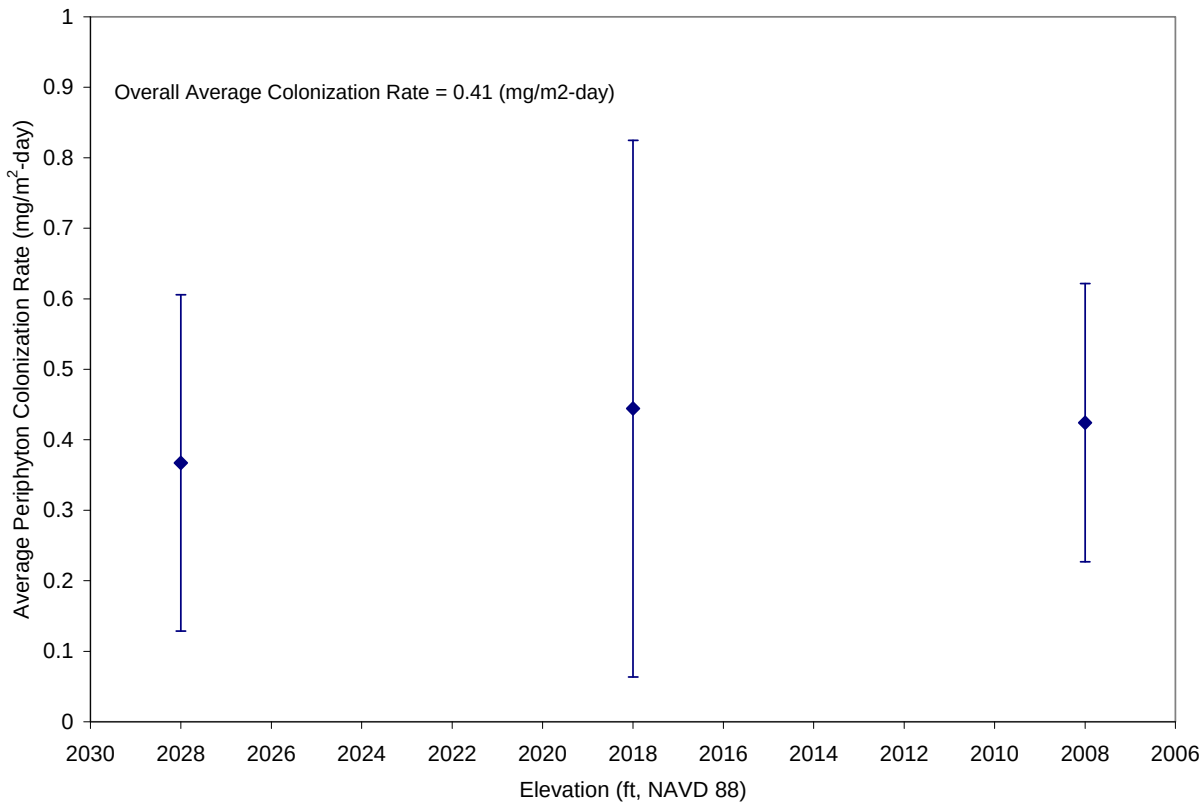


**Figure 6.2-4.** Average winter periphyton colonization rate, 2007 and 2008.

## 6.3. Periphyton Comparison Study

In the spring of 2008, a comparison study between periphyton growth on artificial and natural substrate was conducted. This additional field work was conducted to determine how artificial substrate versus natural substrate influences colonization of periphyton communities in Boundary Reservoir. Two sets of artificial substrate baskets were placed along the bottom of the reservoir at 17- and 25-foot elevation intervals for a four week exposure time. One set of baskets contained a set volume of rocks, identical to baskets that were used in the 2007 hard substrate periphyton monitoring (VOLUME). The other set of baskets contained a single layer of rock on the bottom of the basket to represent what would be sampled from the natural substrate in the reservoir (SURFACE). Natural rock substrate was sampled just upstream of the baskets from a cleaned one-square meter area. The comparison study was conducted at the shoreline treatment sites in the Canyon and Metaline Reaches of Boundary Reservoir.

Figures 6.3-1 and 6.3-2 graphically present the average periphyton chlorophyll *a* found in artificial and natural substrates in the Canyon and Metaline Reaches, respectively, for the spring of 2008. Table 6.3-1 summarizes periphyton chlorophyll *a* found in artificial and natural substrates at the shoreline treatment sites in Boundary Reservoir.

Average periphyton chlorophyll *a* on artificial substrate in the Canyon Reach ranged from 0.75 to 1.67 mg/m$^2$. There was little difference between periphyton chlorophyll *a* between the two elevation intervals and very little difference between the volume and surface samples (Figure 6.3-1). Average periphyton chlorophyll *a* found on natural substrate in the Canyon Reach was significantly higher and than chlorophyll *a* found on artificial substrate. Natural substrate periphyton chlorophyll *a* ranged from 10.6 to 12.1 mg/m$^2$ and had more variation than the artificial substrate in the Canyon Reach (Figure 6.3-1). There was little difference in natural substrate periphyton chlorophyll *a* between the two elevation intervals.

Average periphyton chlorophyll *a* on artificial substrate at the shoreline treatment site in the Metaline Reach ranged 1.72 to 5.98 mg/m$^2$ (Figure 6.3-2). Similar to the Canyon Reach, there was little difference in periphyton chlorophyll *a* between the surface and volume artificial substrate baskets. Average periphyton chlorophyll *a* on natural substrate in the Metaline Reach ranged from 18.0 to 43.7 mg/m$^2$, which was significantly higher than chlorophyll *a* observed on artificial substrate in the Metaline Reach. For all three sample types, (natural, surface, and volume) there was a difference in periphyton chlorophyll *a* between the two elevation intervals. The 25 foot elevation interval (1,965.5 feet NAVD 88 [1,961.5 feet NGVD 29]) had higher periphyton chlorophyll *a* than the 17 foot elevation interval (1,973 feet NAVD 88 [1,969 feet NGVD 29]). This could be due to the 25 foot elevation interval (1,965.5 feet NAVD 88 [1,961.5 feet NGVD 29]) samples having an extra week of exposure time, but if so, than a difference in chlorophyll *a* at depth would have been seen in the Canyon Reach as well. More likely this difference in chlorophyll *a* at depth in the Metaline Reach is a reflection of conditions at that treatment site, such as velocity that may have provided more micro-nutrient exposure at differing depths.

Overall, periphyton chlorophyll *a* was higher in the Metaline Reach of Boundary Reservoir than in the Canyon Reach. This was also observed during the 2007 hard substrate monitoring (see Section 6.1). Average periphyton chlorophyll *a* found in the volume artificial substrate samples, for both the Canyon and Metaline Reaches, were similar to chlorophyll *a* concentrations observed at these sites in the spring of 2007. This similarity verifies the procedures used during the comparison study.

Periphyton chlorophyll *a* observed in natural substrate at both sites during the comparison study were significantly higher than chlorophyll *a* observed in the artificial substrate samplers. This contradicts the initial hypothesis that the influence of velocity on periphyton growth was being under expressed by the geometry of the baskets, or that the baskets were creating favorable growing environments. However, these results (higher chlorophyll *a* in natural substrate vs. artificial substrate) do indicate that the artificial samplers were influencing the growth of periphyton and perhaps hindering or suppressing growth. This was taken into account during the calibration process of the periphyton HSI velocity curve.

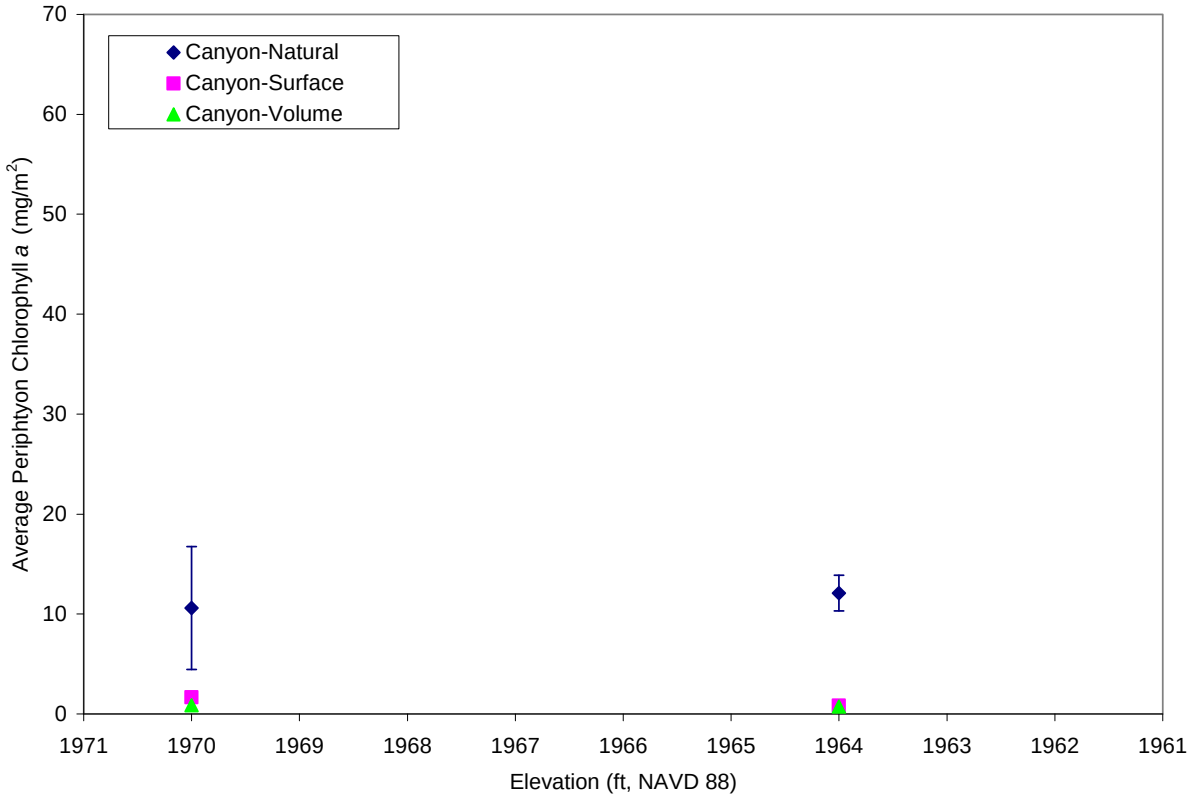


**Figure 6.3-1.** Average periphyton chlorophyll *a* found artificial and natural substrates at the shoreline treatment site of the Canyon Reach of Boundary Reservoir, spring 2008.

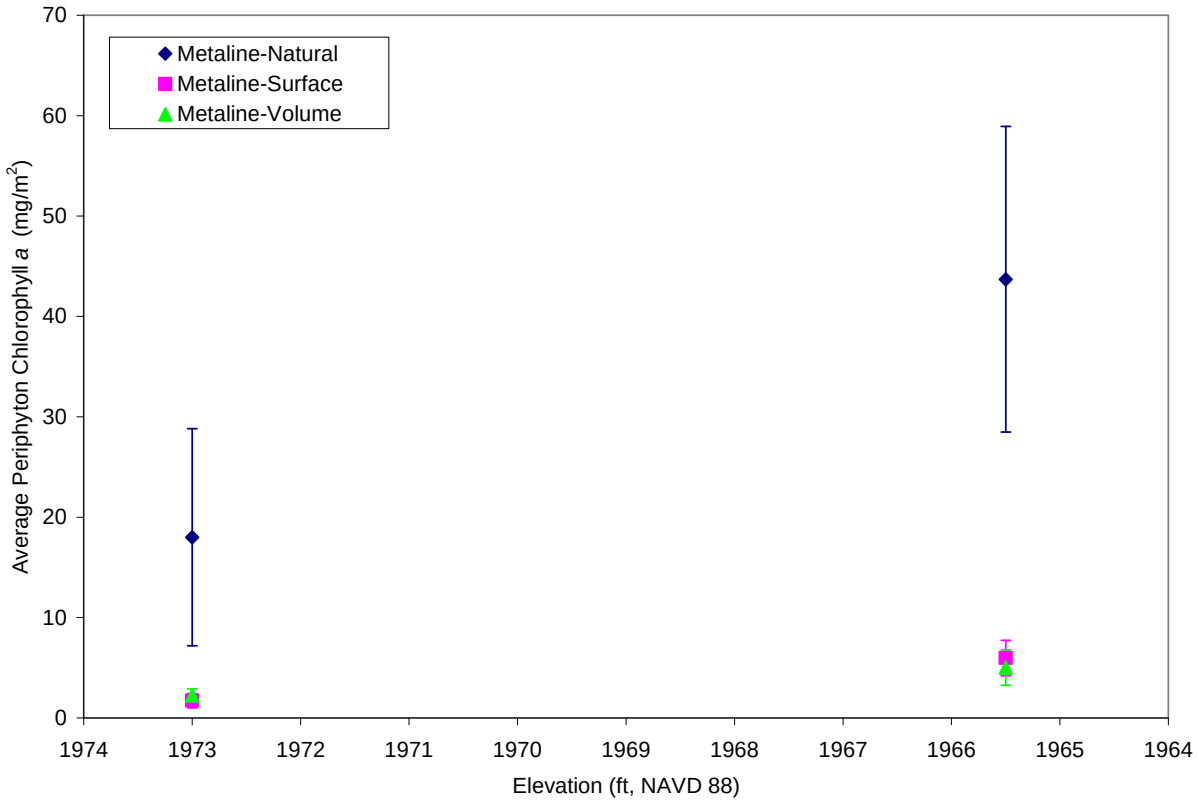


**Figure 6.3-2.** Average periphyton chlorophyll *a* found in artificial and natural substrates at the shoreline treatment site in the Metaline Reach of Boundary Reservoir, spring 2008.

**Table 6.3-1.** Average periphyton chlorophyll *a* (standard deviations) found in artificial and natural substrates in May 2008 in Boundary Reservoir.

| Date | Depth | Elevation ft, NAVD 88 (ft, NGVD 29) | Average Periphyton chlorophyll *a* (mg/m$^2$) (STDEV) | | | Elevation ft, NAVD 88 (ft, NGVD 29) | Average Periphyton chlorophyll *a* (mg/m$^2$) (STDEV) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Canyon Natural | Canyon Surface | Canyon Volume | | Metaline Natural | Metaline Surface | Metaline Volume |
| May-08 | 17 | 1,970 (1,966) | 10.6 (6.14) | 1.67 (0.19) | 0.87 (0.38) | 1,973 (1,969) | 18.0 (10.8) | 1.72 (0.71) | 2.26 (0.65) |
| | 25 | 1,964 (1,960) | 12.1 (1.78) | 0.84 (0.15) | 0.75 (0.26) | 1,965.5 (1961.5) | 43.7 (15.2) | 5.98 (1.76) | 5.02 (1.77) |

## 7 FINAL PERIPHYTON HSI CURVES

This section details the process that was used to calibrate and finalize the periphyton HSI curves for Boundary Reservoir. The final curves for periphyton are also presented in this section.

## 7.1. Calibration of Periphyton HSI Curves

Once all periphyton monitoring data were collected, field data along with results from the HRM were used to further refine and validate HSI curves for depth, velocity, substrate, and duration of inundation and dewatering. The HRM provided information concerning site-specific water surface elevations during the sampling period so the depth of each sample and the duration of inundation and dewatering were determined. The HRM also provided information on the water velocity at each treatment site. Using the information provided by the HRM, the calculated depth and duration of inundation and dewatering of each sample, the average periphyton chlorophyll *a* at each treatment site, and the type of substrate used during the experiment, the literature-based HSI curves were refined and validated for Boundary Reservoir.

### 7.1.1. Depth

Using results from the HRM, the water surface elevations at each hard substrate treatment site over the course of each deployment were used to calculate the average depth of water at each sample over time. Average depth of each sample was calculated by taking the fixed elevation of each sample basket and subtracting it from the water surface elevation produced by the HRM at that specific cross section at each 15-minute interval during the deployment period. The sample depths for each 15-minute interval were averaged over the length of the deployment period to determine the average depth that each specific sample experienced. These average depths were plotted against corresponding average periphyton chlorophyll *a* concentrations in order to determine which depths were best suitable for periphyton growth in Boundary Reservoir. Figures 7.1-1 and 7.1-2 show average sample depth vs. average periphyton chlorophyll *a* concentration by reach and for the entire reservoir. All hard substrate periphyton data, except for winter data, was plotted in Figures 7.1-1 and 7.1-2. Colonization and data from the comparison study was not included.

A statistical program was used to determine the curve that best-fit the depth vs. periphyton chlorophyll *a* data. These curves are also shown in Figure 7.1-1 and 7.1-2. Periphyton suitability values for depth were determined from these best-fit curves and an observed depth HSI curve was created for periphyton in Boundary Reservoir. Figure 7.1-3 shows the provisional suitability curve for depth compared to the observed suitability curve for depth.

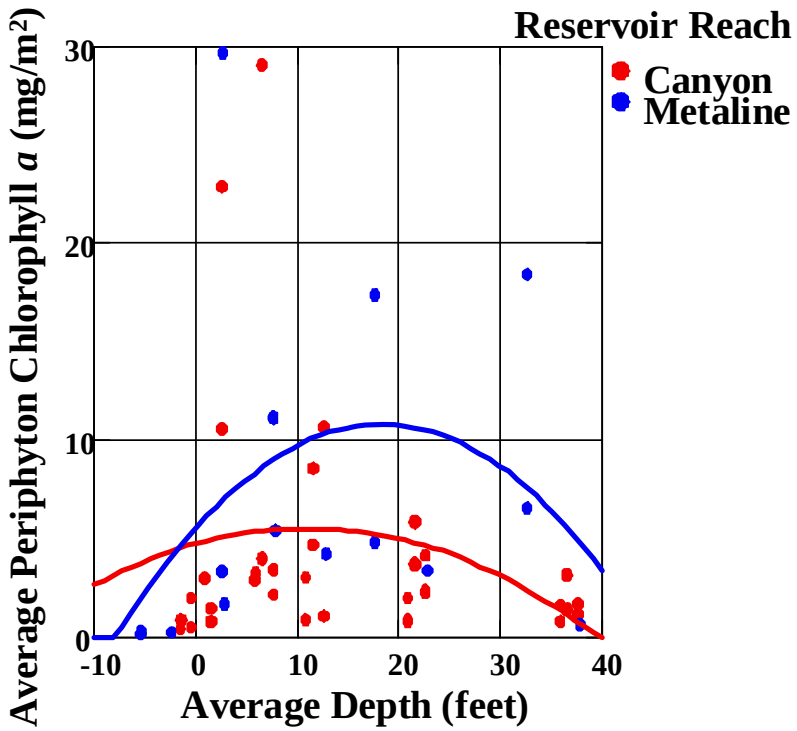


**Figure 7.1-1.** Average sample depth vs. average periphyton chlorophyll *a* for both the Canyon and Metaline Reach in Boundary Reservoir during spring, summer, and fall 2007.

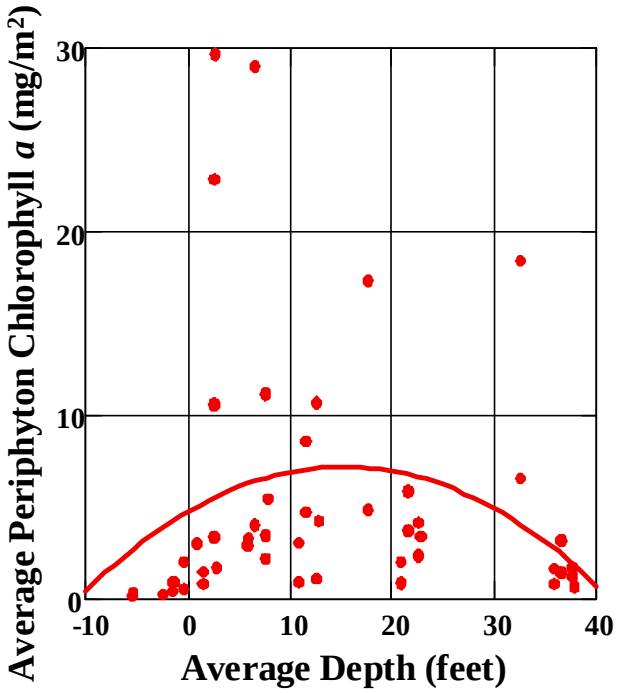


**Figure 7.1-2.** Average sample depth vs. average periphyton chlorophyll *a* for Boundary Reservoir during spring, summer, and fall 2007.

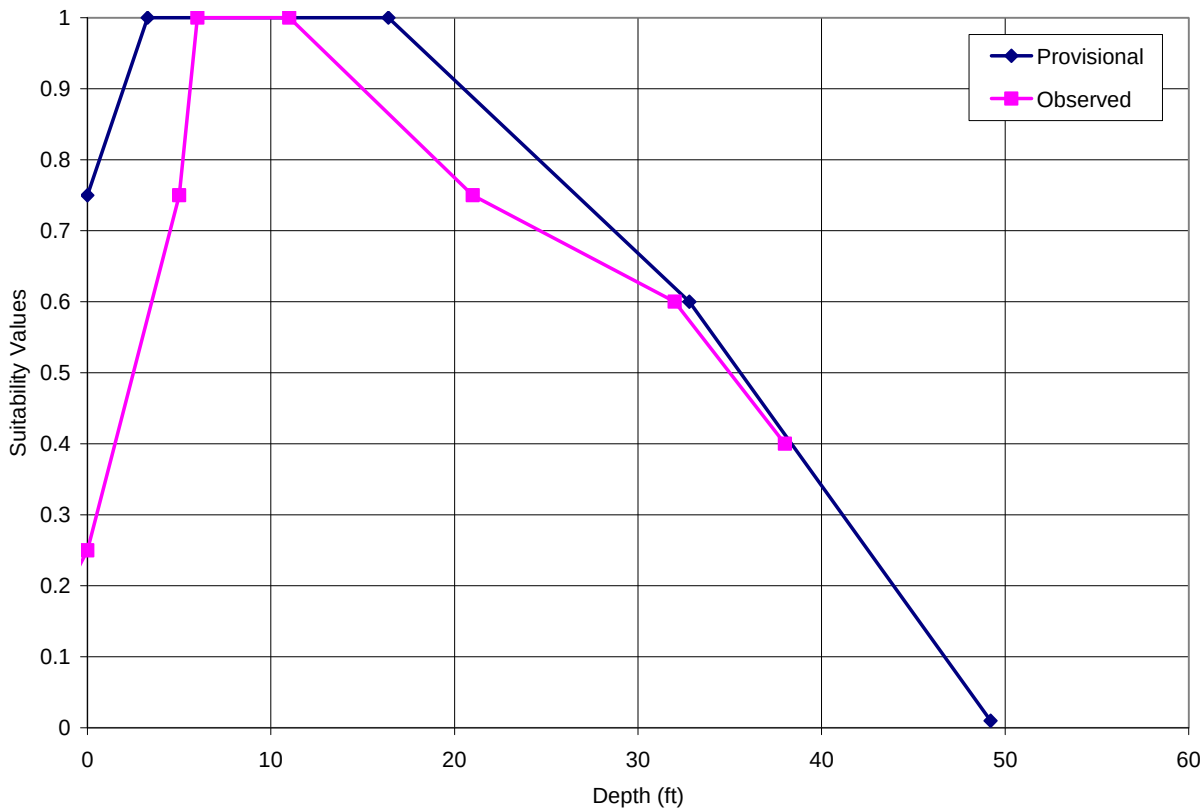


**Figure 7.1-3.** Provisional depth suitability curve for periphyton compared to observed depth suitability curve for periphyton in Boundary Reservoir.

### 7.1.2. Velocity

The HRM provided estimates of water velocities at each hard substrate treatment site. Water velocities obtained from the HRM were in 15-min increments for each deployment period, spring, summer, and fall. Winter periphyton results were not used in the calibration of the velocity suitability curve because results were skewed due to a longer exposure time. Average water velocities were calculated for each treatment site location and not for each individual sample. This was because the HRM could not determine the water velocity at specific elevations but could only provide water velocities for a specific reservoir location and time. Due to this model limitation, periphyton chlorophyll *a* concentrations for spring, summer, and fall at each treatment site were assigned a corresponding an average water velocity from the HRM. These average water velocities were plotted against corresponding periphyton chlorophyll *a* concentrations to determine the range of water velocities in Boundary Reservoir that were most suitable for periphyton growth. Figure 7.1-4 shows average water velocities vs. average periphyton chlorophyll *a* for spring, summer, and fall in Boundary Reservoir. Similar to depth, a statistical program was used to determine the curve that best-fit the relationship between average water velocity and periphyton chlorophyll *a*. This curve is also shown in Figure 7.1-4.

Periphyton suitability values for water velocity were determined from these best-fit curves and an observed velocity HSI curve was created for periphyton in Boundary Reservoir. Figure 7.1-5 shows the provisional suitability curve for velocity compared to the observed suitability curve for velocity. Note that the observed low velocities within Boundary Reservoir at the basket sites resulted in a curve that is limited in response range and therefore may have created a bias toward low velocity when compared to the provisional curve based on literature.

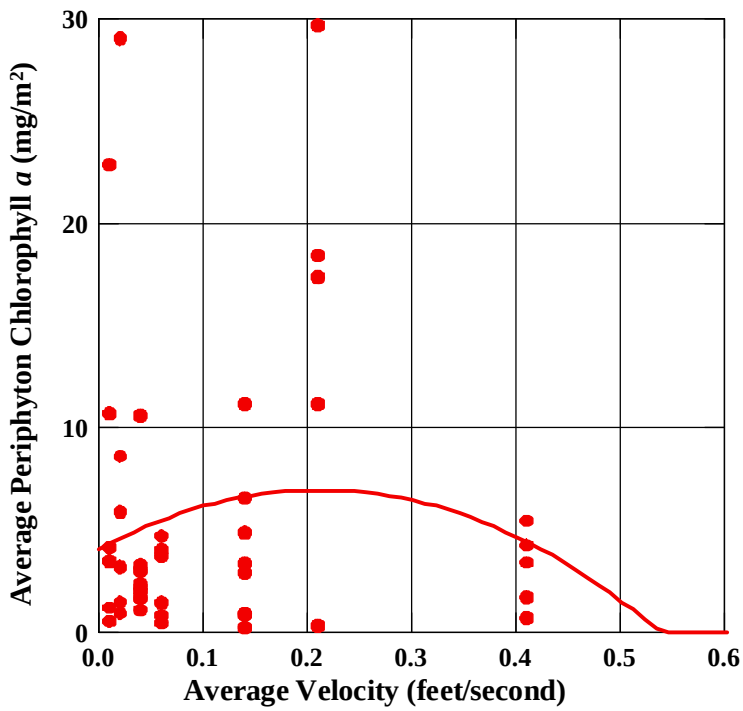


**Figure 7.1-4.** Average water velocity vs. average periphyton chlorophyll *a* in Boundary Reservoir during spring, summer, and fall 2007.

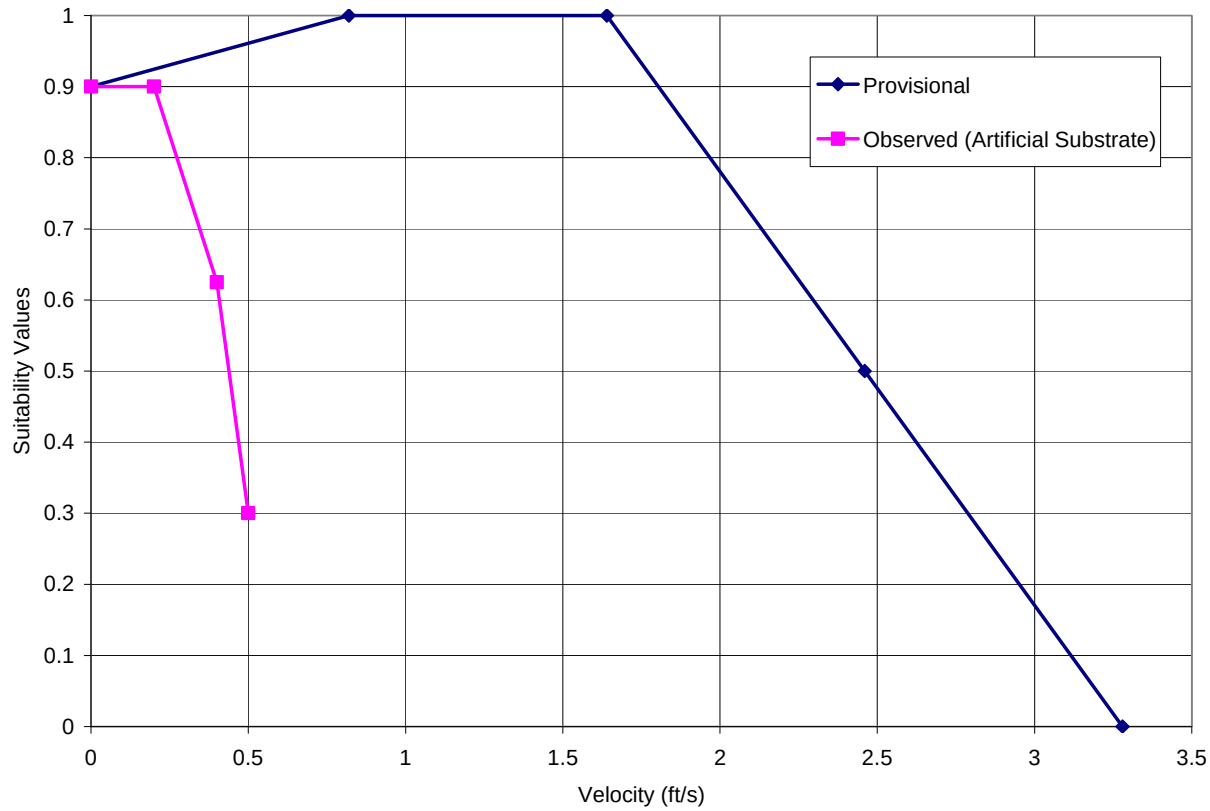


**Figure 7.1-5.** Provisional velocity suitability curve for periphyton compared to observed velocity suitability for periphyton in Boundary Reservoir.

### 7.1.3. Substrate

No further calibration of the substrate provisional suitability curve was necessary for periphyton in Boundary Reservoir. Hard substrate was the only substrate sampled during field monitoring and was assumed to be the best suitable substrate for periphyton growth in Boundary Reservoir.

### 7.1.4. Duration of Dewatering

The HRM provided information for the duration of dewatering at each treatment site for each deployment period. For each sample, the time of dewatering was calculated on an hourly basis from the water surface elevation generated by the HRM with respect to the fixed elevation of each sample. An average of the hours of dewatering for each sample was calculated to determine the average duration of dewatering each sample experienced for each deployment period, spring, summer, and fall. Depending on the treatment site and season, samples at elevation intervals 2, 5, 10, and 15 feet were dewatered for some length of time. The average duration of dewatering, in hours, was plotted against corresponding average periphyton chlorophyll *a* concentrations for only those samples that experience dewatering during the spring, summer, and fall deployment periods (Figure 7.1-6) in order to determine suitability

values for duration of dewatering. Samples that experienced no dewatering during these deployment periods were not plotted in Figure 7.1-6. A statistical program was used to determine the curve that best-fit the relationship between average duration of dewatering and average periphyton chlorophyll *a* (Figure 7.1-6). Duration of dewatering suitability values for periphyton growth in Boundary Reservoir were determined from this curve and were compared to provisional suitability values in Figure 7.1-7.

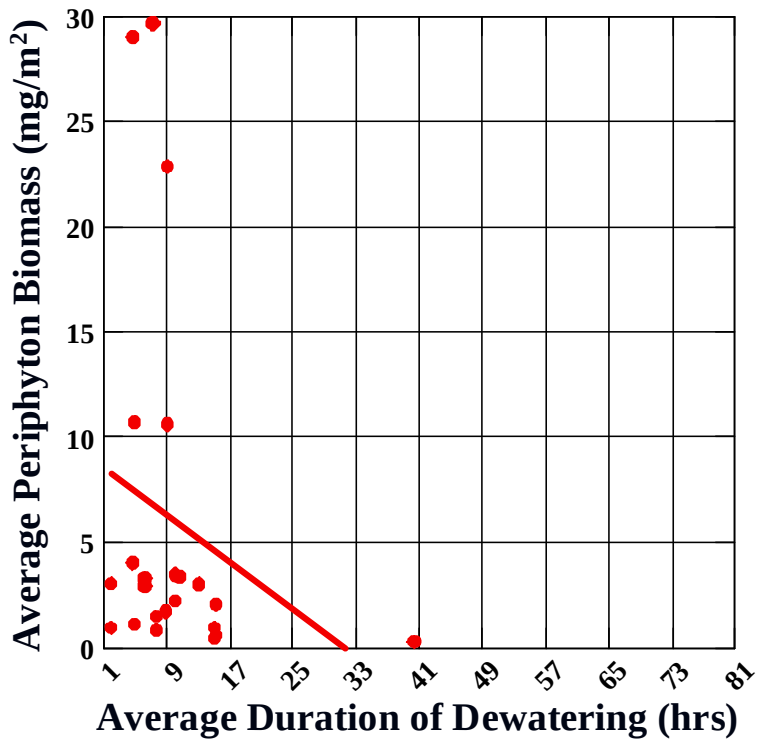


**Figure 7.1-6.** Average duration of dewatering vs. average periphyton chlorophyll *a* concentrations in Boundary Reservoir during spring, summer, and fall 2007.

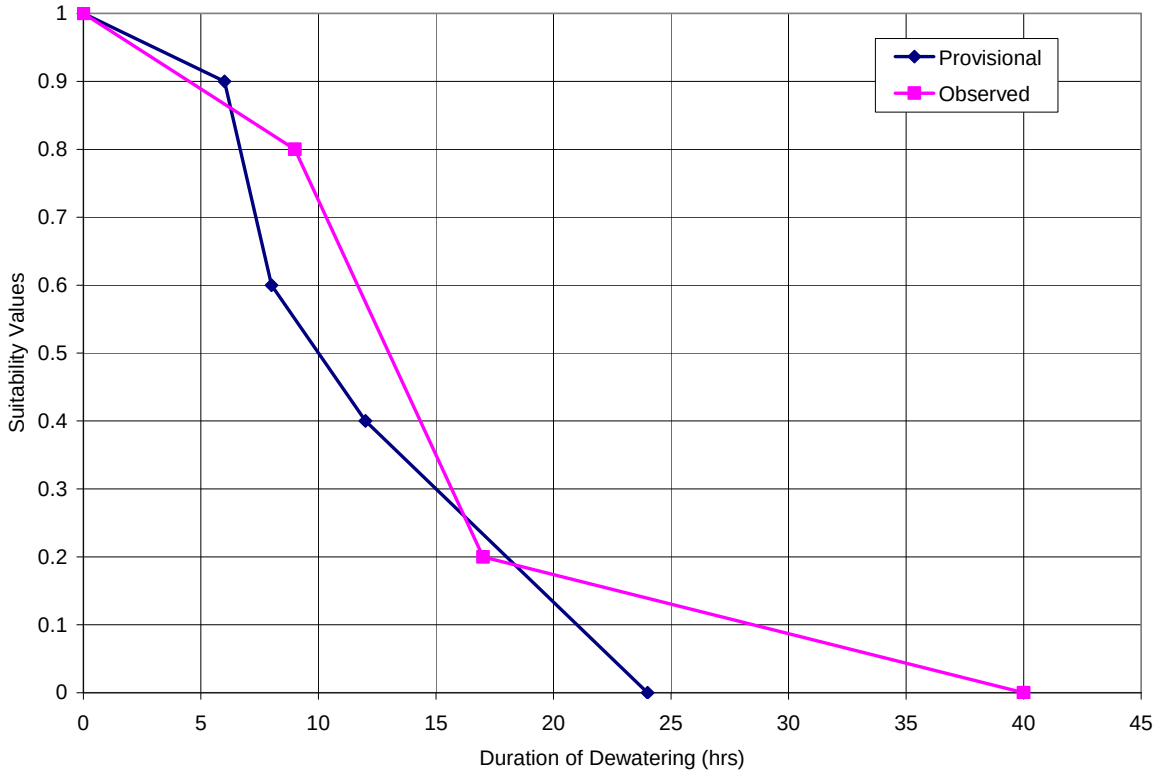


**Figure 7.1-7.** Provisional duration of dewatering suitability values compared to observed duration of dewatering suitability values for periphyton in Boundary Reservoir.

### 7.1.5. Duration of Inundation

Summer colonization periphyton data, collected in Box Canyon Reservoir, was used in the calibration of the duration of inundation suitability curve. The duration of inundation for each sample was determined by the deployment date (or date baskets were set) and the retrieval date (or the date which periphyton samples were collected). Duration of inundation for summer colonization samples in Box Canyon Reservoir ranged from 3 days to 56 days (72 hours to 1344 hours). The duration of inundation, in days, was plotted against the corresponding average periphyton chlorophyll *a* concentration for all summer colonization samples (Figure 7.1-8). This plot was created in order to determine the suitability values for duration of dewatering. A statistical program was used to determine the curve the best-fit the relationship between duration of inundation and average periphyton chlorophyll *a* (Figure 7.1-8). Duration of inundation suitability values were determined from this best-fit curve and are compared to provisional suitability values in Figure 7.1-9. Figure 7.1-9 shows the provisional duration of inundation suitability values for Boundary Reservoir and the observed suitability values for Box Canyon Reservoir. Slight modifications to the Box Canyon Reservoir suitability values were made to determine duration of inundation suitability values for periphyton in Boundary Reservoir (Section 7.2).

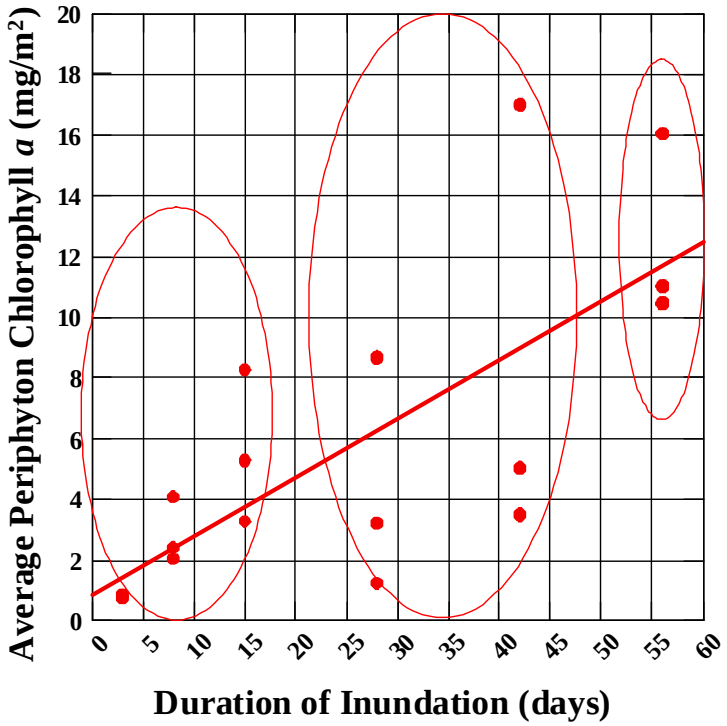


**Figure 7.1-8.** Duration of inundation vs. average periphyton chlorophyll *a* for summer 2007 in Box Canyon Reservoir.

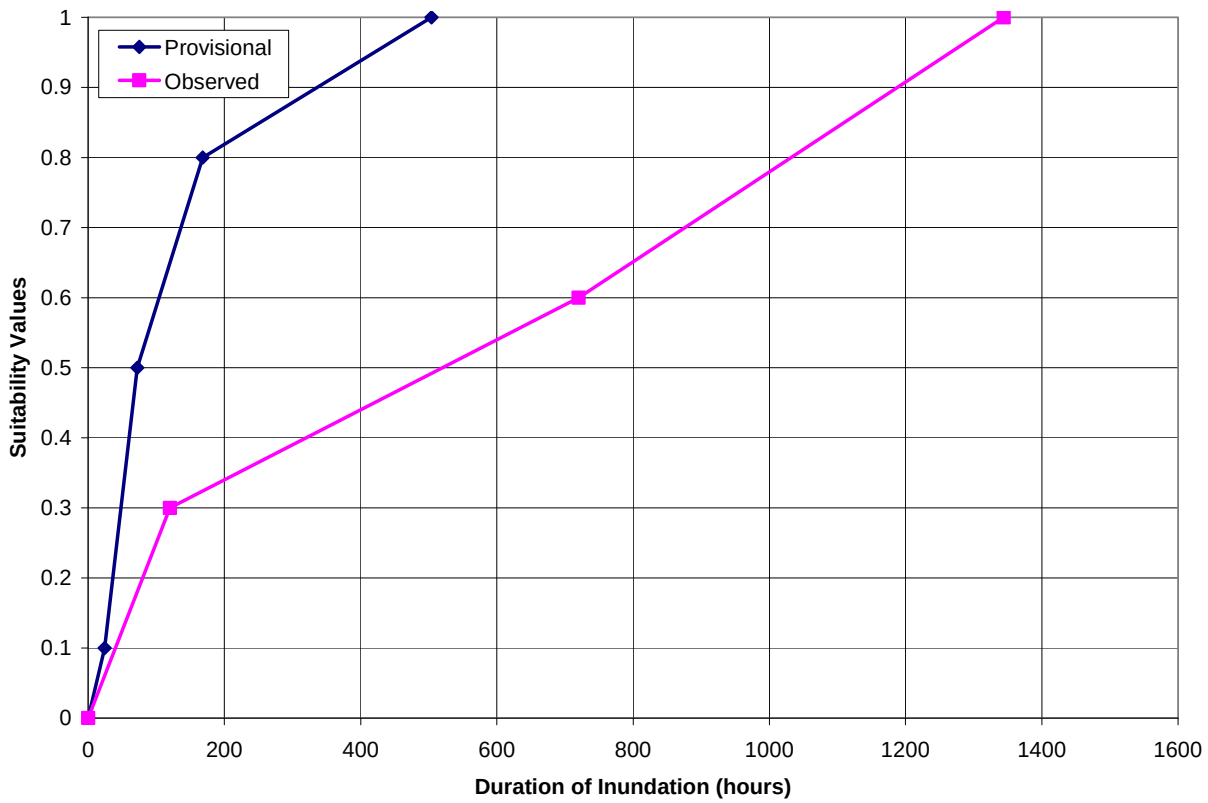


**Figure 7.1-9.** Provisional duration of inundation suitability values compared to observed duration of inundation suitability values for periphyton in Box Canyon Reservoir.

## 7.2. Final Periphyton HSI Curves

Development of the final periphyton HSI curves for the environmental gradients began with development of provisional curves, which were compared against response curves developed from field data (observed curves), and then finalized based on meetings and discussion with relicensing participants. The final curves are a combination of knowledge acquired through examination of the literature-based provisional curves and refinement through development of community response based on field measurements.

Discussion of refinements of the provisional curves based on comparison to observed (field data-based) curves were proposed to relicensing participants at three meetings: 1) Water Quality Workgroup meeting (July 15, 2008); 2) Fish and Aquatics Workgroup meeting (August 7, 2008); and 3) Fish and Aquatics Workgroup meeting (August 27, 2008). Further clarification was provided to Washington Department of Fish and Wildlife relicensing participants on how the substrate comparison study results were used to develop the final depth HSI curve (teleconference on September 5, 2008).

### 7.2.1. Depth

The periphyton biomass HSI curve reflected presence of measurable quantities over a slightly greater depth range of the reservoir than presented in the provisional curve. The original provisional curves were based on literature representing mostly non-regulated rivers and lakes. Results from the field data indicated that periphyton biomass occupies a similar range of optimal depths as described for a variety of locations in the literature.

Substrate comparison results were examined for similarity of periphyton biomass estimates: 1) on natural versus artificial substrates, and 2) for identifiable biomass response to an environmental gradient like depth. Results of periphyton collection in the reservoir indicated that natural substrate produced higher biomass estimates than artificial substrate estimates (Figure 6.3-1 and Figure 6.3-2). Identifiable response to the depth gradient using periphyton biomass estimates was identified at sites in both the Canyon and Metaline Reach, but variability in observations was higher from natural substrate collections.

The final depth suitability curve (Figure 7.2-1) reflected the provisional curve except for a narrower optimal depth range (Suitability Value = 1.0). The final curve was a combination of characteristics between the provisional curve and the proposed curve based on field observations.

The final depth HSI curve for periphyton was revised in January 2009 (presented to Relicensing Participants at the January 28, 2009, Fish and Aquatics Workgroup meeting). These revisions to the HSI curve were necessary in order to separate the effect of depth from the duration of dewatering scores that estimate the weighted useable area for periphyton on hourly time intervals and from each transect with the Mainstem Aquatic Habitat Model. Final revisions to the depth HSI curve including assigning a suitability value of 0 when depth is 0 feet (Figure 7.2-2). This HSI score differs from the final depth curve that was co-developed with relicensing participants where a suitability value of 0.25 was assigned when depth was 0 feet (Figure 7.2-1). Both depth and duration of dewatering contribute HSI scores that describe availability of aquatic habitat. This relationship between the two variables used in generating suitability scores through the Mainstem Aquatic Habitat Model needed to be separated so that effects of each variable were independent of the other. The revised final periphyton suitability values for depth are presented in Table 7.2-1, and the revised final HSI curve is presented in Figure 7.2-2.

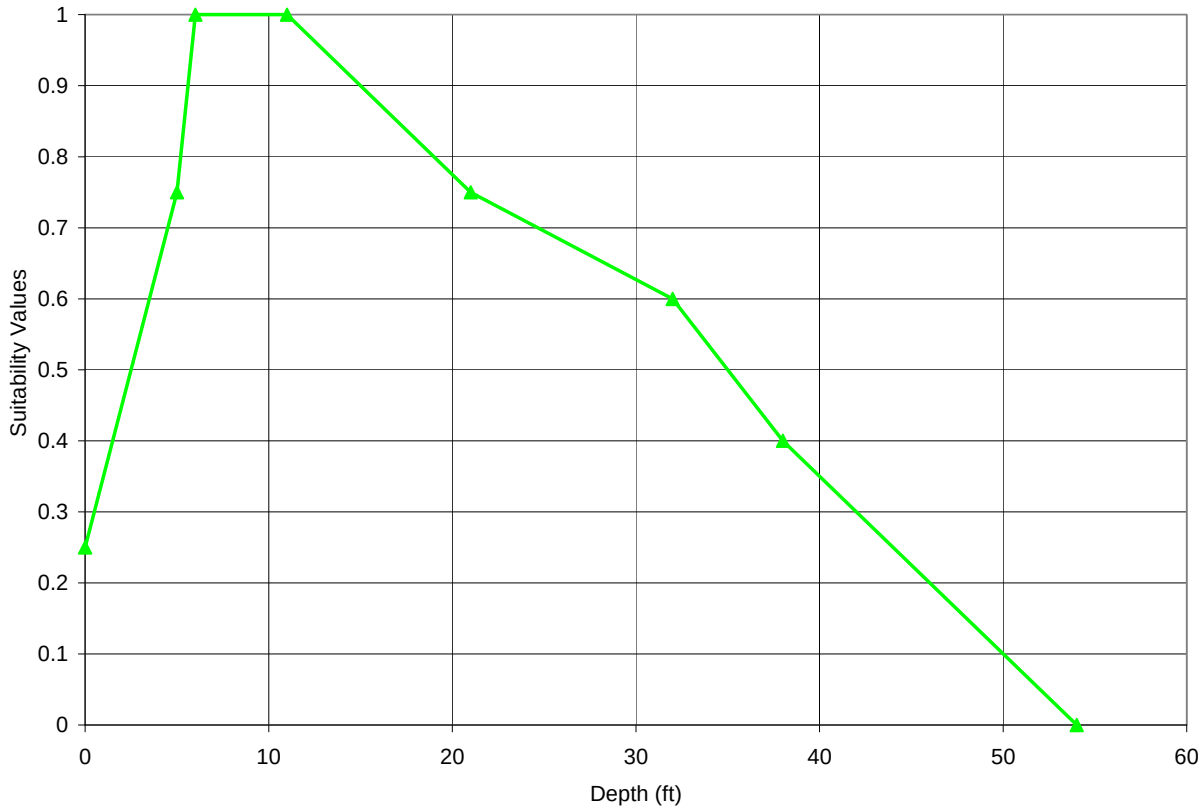


**Figure 7.2-1.** Final depth suitability curve for periphyton in Boundary Reservoir.

**Table 7.2-1.** Revised final depth suitability values for periphyton in Boundary Reservoir.

| Depth (ft) | Final Suitability Values |
|---|---|
| 0 | 0.0 |
| 0.1 | 0.25 |
| 5 | 0.75 |
| 6 | 1.0 |
| 11 | 1.0 |
| 21 | 0.75 |
| 32 | 0.6 |
| 38 | 0.4 |
| 54 | 0 |

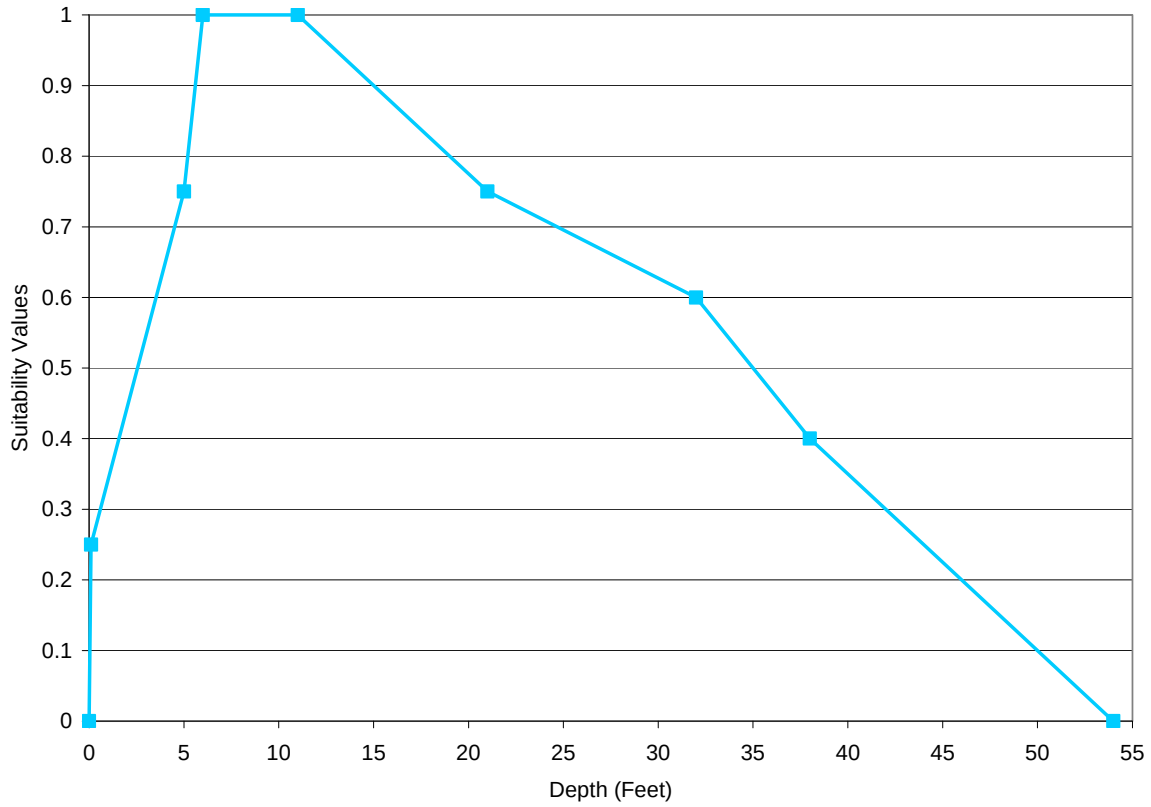


**Figure 7.2-2.** Revised final depth suitability curve for periphyton in Boundary Reservoir (revisions approved by relicensing participants at the January 28, 2009, Fish and Aquatics Workgroup meeting).

### 7.2.2. Velocity

Velocities were estimated from the Hydraulic Routing Model for each location where periphyton biomass was collected. The range of results represented only a fraction of the range reported for suitability scores determined from a review of the literature. The decision was made to use the suitability scores suggested from the provisional, literature-based HSI curve for velocity (Figure 7.2-3). Table 7.2-2 summarizes the final velocity suitability values for periphyton.

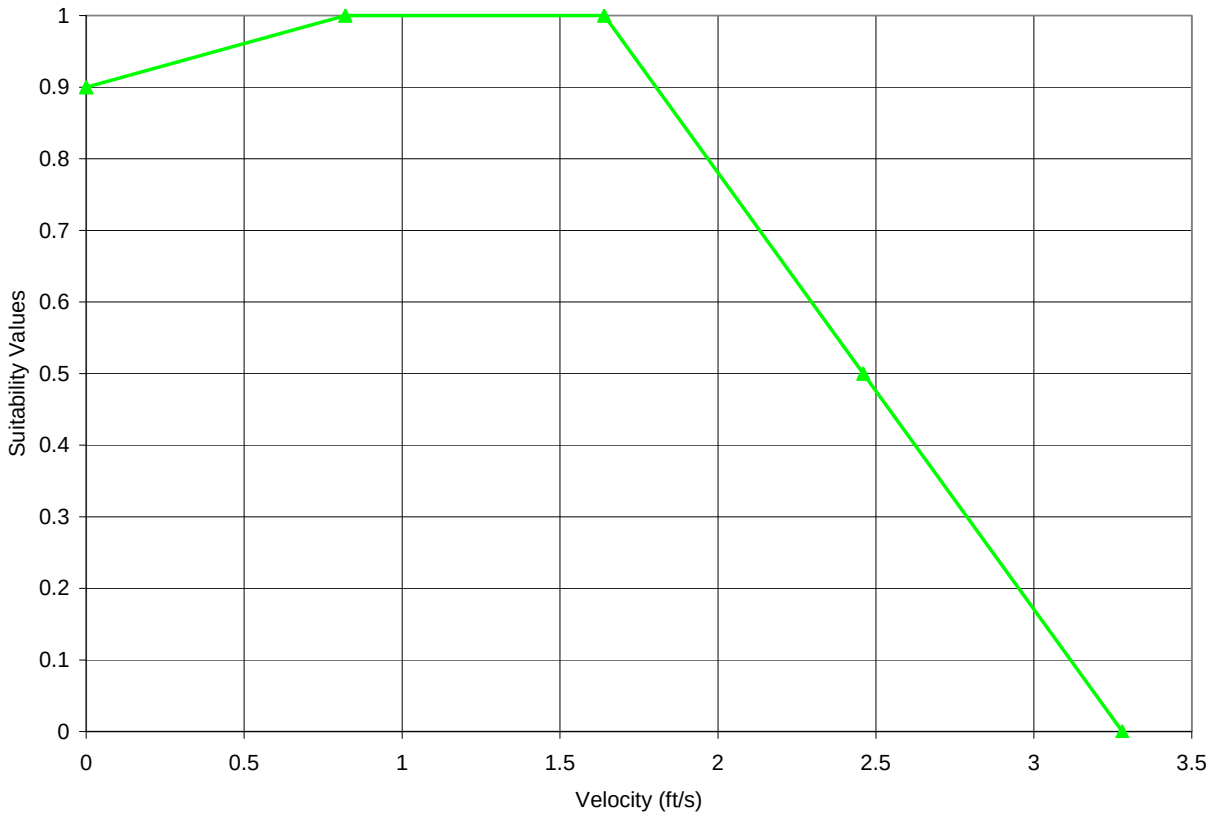


**Figure 7.2-3.** Final velocity suitability curve for periphyton in Boundary Reservoir.

**Table 7.2-2.** Final velocity suitability values for periphyton in Boundary Reservoir.

| Velocity (fps) | Final Suitability Values |
|---|---|
| 0 | 0.9 |
| 0.82 | 1.0 |
| 1.64 | 1.0 |
| 2.46 | 0.5 |
| 3.28 | 0 |

### 7.2.3. Substrate

Periphyton (attached algae) colonies show optimal growth on hard substrates (Figure 7.2-4). Incidental colonies of attached algae can break away from hard substrate and be found temporarily residing on soft substrate, but do not produce long-lived and viable colonies because of the shifting soft substrates. The final suitability curve was adopted directly from the provisional curve. Table 7.2-3 summarizes the final substrate suitability values for periphyton.

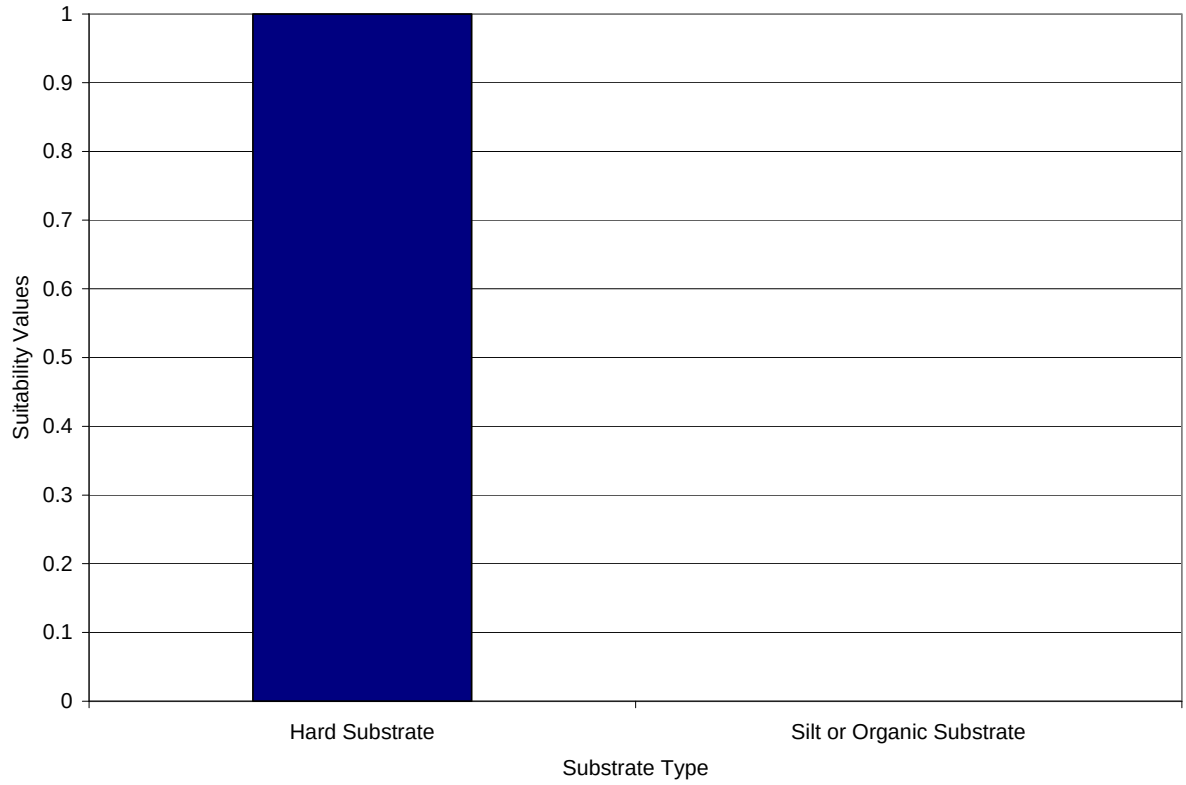


**Figure 7.2-4.** Final substrate suitability curve for periphyton in Boundary Reservoir.

**Table 7.2-3.** Final substrate suitability values for periphyton in Boundary Reservoir.

| Substrate | Final Suitability Values |
|---|---|
| Hard Substrate | 1.0 |
| Silt or Organic Substrate | 0 |

### 7.2.4. Duration of Dewatering

The provisional HSI curve displayed a gradual periphyton biomass response to increased time of dewatering, and field observations generally agreed with the literature-based curve. Periphyton growth was severely limited beyond seventeen hours with only a single sample showing any measurable biomass beyond this dewatering time interval (Figure 7.1-6). Field observations showed that a duration of dewatering interval greater than 17 hours resulted in no measurable periphyton biomass and so the maximum duration of dewatering endpoint was adopted from the provisional curve. The final curve represents these field observations and modifications (Figure 7.2-5). Table 7.2-4 summarizes the final duration of dewatering suitability values for periphyton**.**

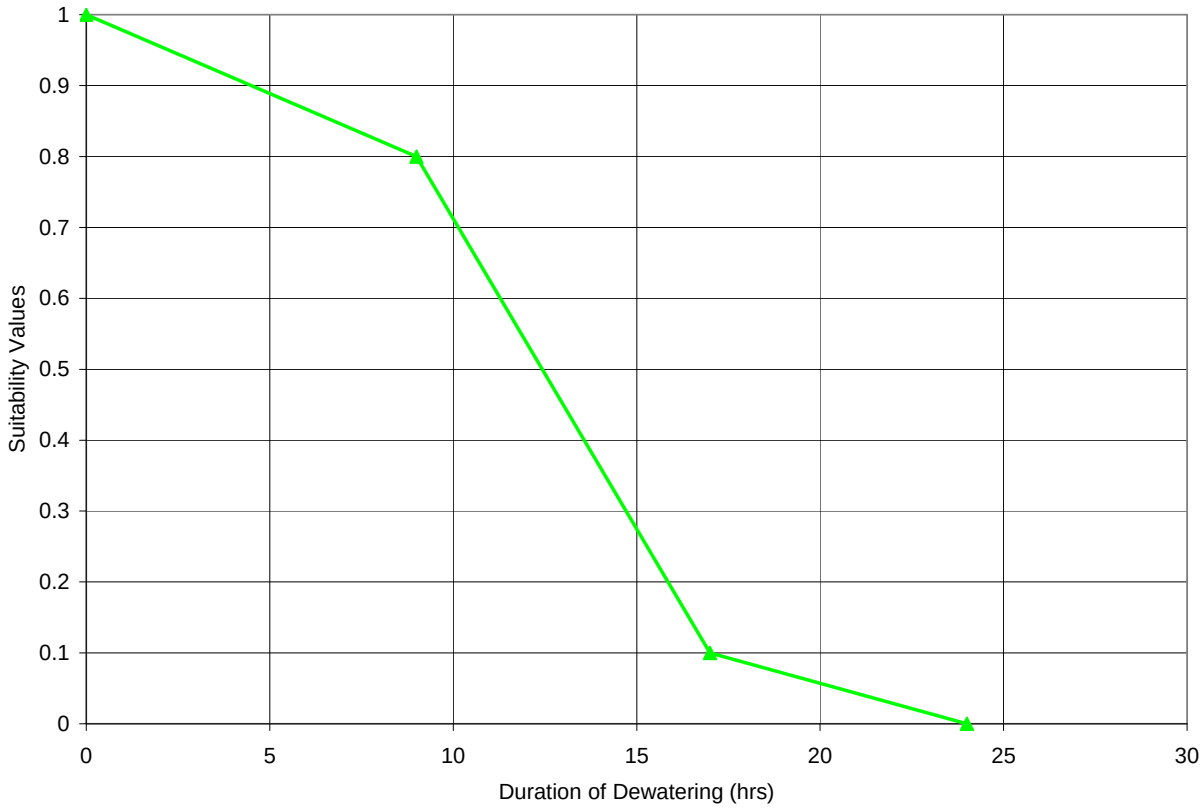


**Figure 7.2-5.** Final duration of dewatering suitability curve for periphyton in Boundary Reservoir.

**Table 7.2-4.** Final duration of dewatering suitability values for periphyton in Boundary Reservoir.

| Duration of Dewatering (hrs) | Final Suitability Values |
|---|---|
| 0 | 1.0 |
| 9 | 0.8 |
| 17 | 0.1 |
| 24 | 0 |

### 7.2.5. Duration of Inundation

The duration of inundation (hours) suitability curve was modified from the literature-based, provisional curve from field observations (Figure 7.1-8). Field observations for periphyton biomass estimates showed distinct increases in biomass as duration of inundation intervals increased from 15, 42, and 56 days (360, 1008, and to 1344 hours). The field results for periphyton biomass response to duration of inundation produced a suitability curve different from the provisional curve (July 15, 2008, Water Quality Workgroup Meeting). The duration of inundation interval between 5 and 30 days (120 to 720 hours) reflected field observations showing periphyton biomass did not change substantially until a period after 1,680 hours (or 70

days). The final curve represents a compromise between the observed field results and the provisional, literature-based suitability curve (Figure 7.2-6). The shape of the final curve maintains the general shape of the provisional suitability curve, but reflects a lower expected biomass over longer duration of inundation intervals. Table 7.2-5 summarizes the final duration of inundation suitability values for periphyton.

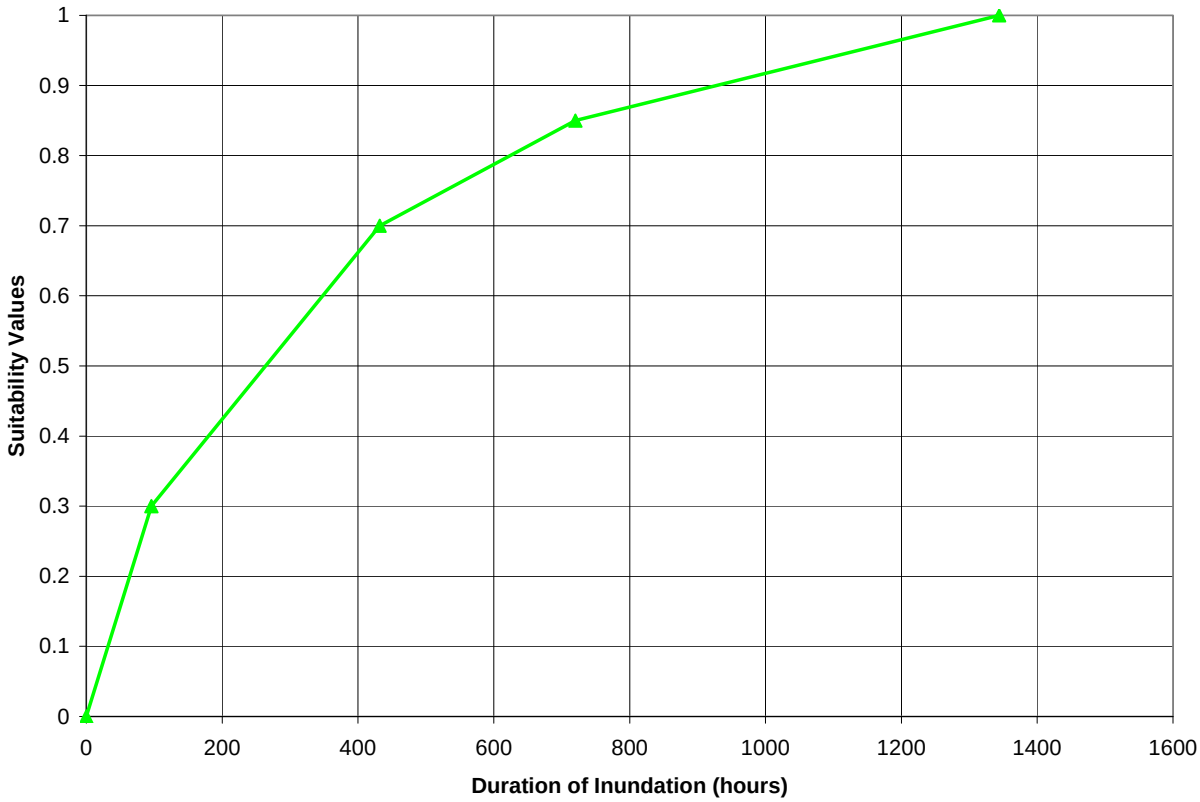


**Figure 7.2-6.** Final duration of inundation suitability curve for periphyton in Boundary Reservoir.

**Table 7.2-5.** Final duration of inundation suitability values for periphyton in Boundary Reservoir.

| Duration of Inundation (hours) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 96 | 0.3 |
| 432 | 0.7 |
| 720 | 0.85 |
| 1,344 | 1.0 |

# 8 MODEL RESULTS

The final periphyton HSI curves were used in the Mainstem Aquatic Habitat Model to determine the weighted usable area (WUA) available for periphyton in Boundary Reservoir. The Mainstem Aquatic Habitat Model was run for three water years: a wet year (1997), a dry year (2001) and an average year (2002). An example of model output for periphyton WUA for the Upper Reservoir Reach in a dry year is presented in Figure 8.1-1. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for periphyton on the y-axis. Table 8.1-1 is an example of tabular model output for periphyton WUA. Complete models results and discussion of periphyton WUA can be found in Section 5.7 of the Study 7 Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009b). A more detailed discussion of periphyton production can be found in the Study 11 Final Report (SCL 2009a).

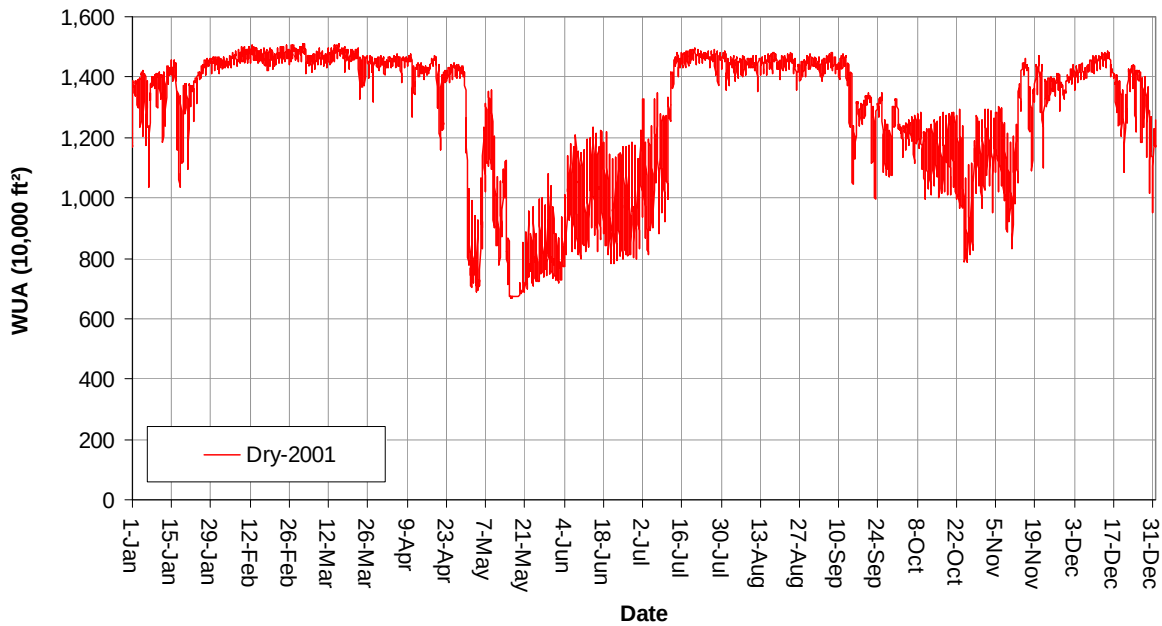


**Figure 8.1-1.** Habitat WUA for periphyton in the Upper Reservoir Reach of Boundary Reservoir, determined by the Mainstem Aquatic Habitat Model, for a dry water year (2001).

**Table 8.1-1.** Summary of monthly periphyton WUA (10,000 sq. ft) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | Max | Min | Stdev. | Avg. | Max | Min | Stdev. | Avg. | Max | Min | Stdev. |
| January | 1,066 | 1,460 | 553 | 219.5 | 1,367 | 1,468 | 1,034 | 85.6 | 1,196 | 1,469 | 709 | 198.3 |
| February | 1,081 | 1,411 | 810 | 127.1 | 1,468 | 1,507 | 1,421 | 17.7 | 1,202 | 1,401 | 901 | 110.9 |
| March | 814 | 1,287 | 458 | 231.7 | 1,463 | 1,512 | 1,320 | 27.5 | 1,102 | 1,356 | 749 | 151.1 |
| April | 611 | 870 | 346 | 144.3 | 1,408 | 1,476 | 776 | 99.0 | 831 | 1,334 | 431 | 283.1 |
| May | 409 | 426 | 360 | 11.7 | 856 | 1,357 | 670 | 171.3 | 617 | 1,080 | 301 | 196.9 |
| June | 478 | 622 | 351 | 74.7 | 950 | 1,232 | 720 | 124.6 | 369 | 407 | 315 | 25.5 |
| July | 776 | 1,305 | 460 | 221.5 | 1,336 | 1,496 | 813 | 188.2 | 794 | 1,392 | 346 | 248.9 |
| August | 1,136 | 1,509 | 808 | 166.1 | 1,444 | 1,482 | 1,353 | 22.3 | 1,378 | 1,473 | 1,081 | 84.5 |
| September | 1,142 | 1,363 | 914 | 101.8 | 1,330 | 1,480 | 994 | 119.4 | 1,433 | 1,495 | 1,205 | 44.1 |
| October | 971 | 1,266 | 784 | 114.8 | 1,134 | 1,292 | 788 | 115.1 | 1,305 | 1,478 | 980 | 95.6 |
| November | 1,011 | 1,389 | 775 | 137.6 | 1,268 | 1,472 | 833 | 144.8 | 1,338 | 1,455 | 950 | 95.9 |
| December | 1,162 | 1,435 | 826 | 134.6 | 1,373 | 1,487 | 949 | 100.4 | 1,251 | 1,452 | 892 | 145.8 |

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# Appendix 8: Mainstem Aquatic Habitat Modeling Study Benthic Macroinvertebrate Habitat Suitability Index (HSI) Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

# *Study 7: Mainstem Aquatic Habitat Modeling Study*

# *Appendix 8*

# *Benthic Macroinvertebrate Habitat Suitability Index (HSI) Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Tetra Tech**

**March 2009**

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# Study 7 Appendix 8
# Benthic Macroinvertebrate HSI Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

The Mainstem Aquatic Habitat Modeling: Benthic Macroinvertebrate (BMI) HSI was conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007 and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This final report describes all field efforts and analyses for 2007 and 2008 of the Mainstem Aquatic Habitat Modeling: BMI Monitoring.

### 1.1. Study Background

A Habitat Suitability Index (HSI) was developed to describe the response of BMI to various reservoir management scenarios, for use in the Boundary Reservoir mainstem aquatic habitat model. Specifically, the scenarios including cyclic inundation and dewatering that may change physical parameters that BMI are exposed to, such as, depth, water velocity, substrate, etc. An HSI is a model for calculating the habitat suitability of an area for a single species or assemblage of species. A set of variables that represent the life requisites for the species (e.g., percent cover, water depth, water quality) is combined into a mathematical habitat model. The variables are then measured in the field and their corresponding index values are inserted into the model to produce a score that describes existing habitat suitability. The value is an index score between 0 and 1. The mathematical model used for developing HSI curves for BMI was based upon literature addressing the species' habitat requirements and preferences.

Because BMI communities are comprised of numerous taxa that vary independently from the five variables under study (depth, velocity, substrate, duration of dewatering, and duration of inundation); the HSI for the Project is not specific to any individual species, but was developed for the BMI community as a whole.

BMI are organisms that live on the bottom of a river or lake, or on substrates attached to the bottom such as logs or plants. The BMI community in a water body is an assemblage of organisms, large enough to be seen by the unaided eye, that are involved in the recycling of nutrients and the decomposition of organic materials such as leaves, and thus facilitate the transfer of energy from organic matter resources to fish and other larger organisms (Hershey and Lamberti 2001; Hauer and Resh 1996; Reice and Wohlenberg 1993; Klemm et al. 1990).

The littoral habitat of lakes, reservoirs, and large rivers is the bottom area along the shoreline where the level of light penetration is sufficient for photosynthesis (Wright and Szluha 1980; Wetzel 2001). This area usually supports larger and more diverse populations of periphyton and BMI than deeper water habitats (Wright and Szluha 1980; Ward 1992; Thorp and Covich 2001;

Wetzel 2001). The vegetation and substrate heterogeneity of the littoral habitat provide an abundance of microhabitats supplying food and shelter, which, in turn, enhances invertebrate production (Wright and Szluha 1980; Gerritsen et al. 1998).

The varial zone in reservoirs is defined as the area between the high and low water surface elevations over a defined time period due to natural or artificial fluctuations in pool water surface elevation or flow. If the magnitude and duration of water surface elevation fluctuations is low, the varial zone can be highly productive. However, as the magnitude and duration of water surface elevation fluctuations increase, the abundance and diversity of periphyton in the varial zone is reduced (Fisher and LaVoy 1972; Ward 1992).

Several studies have reported that load-following flow releases associated with hydropower production can substantially reduce the species diversity and abundance of periphyton and BMI both above and below hydropower projects (Brusven et al. 1974; Gislason 1985; Perry and Perry 1986; Troelstrup and Hergenrader 1990; Blinn et al. 1995; DeVries et al. 2001; Grzybkowska and Dukowska 2002) and within reservoirs subject to drawdown (Fillion 1967; Paterson and Fernando 1969; Kaster and Jacobi 1978; May et al. 1988; Chisholm et al. 1989; Furey et al. 2006).

Fisher and LaVoy (1972) examined BMI communities along a sand/gravel bar below a hydroelectric dam on the Connecticut River in Massachusetts. Fluctuations of approximately 3.3 feet at the bar completely submerged the bar during high flows, and exposed it during low flows. Four zones were established along a transect running from high (Zone 1, exposed 70 percent of the summer) to low (Zone 4, constantly submerged) water marks. Results indicated reduced diversity, biomass, densities, and taxa richness in Zones 1 and 2. Metric values and community compositions of Zone 4 did not differ significantly from Zone 3, which was exposed for 13 percent of the summer, suggesting that the benthic community established at those levels was adapted to brief exposure periods.

Blinn et al. (1995) determined that discharge fluctuations during the summer and winter influenced the benthic community in the Colorado River downstream of Glen Canyon Dam, Arizona. The annual mean biomass of BMI in a continuously inundated section of the channel was more than four times the biomass of BMI in the proximal varial zone. Gislason (1985) concluded that the effects of power peaking adversely influenced insect density along the margins of the Skagit River in Washington. Under fluctuating flows, insect density increased in the direction from shallow to deep water, and density decreased with increasing number of hours of dewatering prior to sampling. Diversity appeared to increase with water depth, and decrease with increased duration of dewatering.

## 1.2. Study Description

The BMI HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional HSI, 2) collection of site-specific field data, 3) calibration of the literature-based HSI curves using field data, and 4) finalization of the BMI HSI for Boundary Reservoir. Field data generation included BMI data collected at several elevation intervals and cross-sectional data collection that included depth, velocity, and substrate measurements. Site-specific BMI monitoring consisted of four different components: artificial substrate sampling on

hard substrate surfaces, BMI sampling in soft substrate, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

The artificial substrates for BMI sampling consisted of small heavy gauge wire baskets containing rocks with intermediate diameters ranging from 1 to 3 inches. The rocks used for artificial substrate were preconditioned prior to deployment by being placed for 4 weeks in Boundary Reservoir and then air-dried so that they would mimic conditions present on native substrate. Where possible, BMI sampling sites were located along mainstem habitat transects measured for the Mainstem Aquatic Habitat Model. The sampling design included three treatments representing the range of depths and inundation/exposure periods and frequencies likely to occur under various operations scenarios. The three treatments included relatively large pool surface elevation fluctuations, moderate pool surface elevation fluctuations, and small pool surface elevation fluctuations. Each site was sampled using fixed sampling units placed along the channel bed at specific elevations.

The artificial substrate rock baskets were installed along the shorelines and on vertical faces in Boundary and Box Canyon reservoirs, with units deployed at elevations that corresponded with the range from full pool to the euphotic depth under maximum expected reservoir drawdown for the sample period. The sampling units were located at fixed elevations, so some units were dewatered and inundated repeatedly, thereby describing the response of organisms to fluctuating reservoir water surface elevations at that site. Sampling was conducted at a site below Metaline Falls and in the Canyon Reach to describe the response of BMI to the effects of pool surface elevation fluctuations in the Canyon reach. Artificial substrate sampling was also conducted at a site in the Metaline Reach and sites in Box Canyon Reservoir to describe the response to a smaller range of pool surface elevation fluctuations.

The BMI artificial substrate sampling was conducted during spring, summer, and fall for 8-week periods. Winter BMI sampling was conducted over a 14-week period instead of an 8-week period because baskets could not be retrieved due to reservoir ice cover and winter conditions. BMI artificial substrate baskets were deployed during April 2–6, July 6–9, September 11–14, and December 4–7, 2007. The baskets were retrieved 8 weeks later during, May 29–June 1, September 1–6, and November 5–10, 2007 and 14 weeks later for the winter samples during March 10-13, 2008.

BMI sampling in soft substrates was conducted within Boundary and Box Canyon Reservoirs at three treatment locations representing the range of depths and inundation/exposure periods likely to occur for operations scenarios, similar to hard substrate sampling. Soft substrate samples were collected in Boundary Reservoir below Metaline Falls in the Canyon Reach, above Metaline Falls in the Metaline Reach, and within Box Canyon Reservoir. Soft substrate sampling was conducted during the same time as hard substrate sampling.

The third component of the study included the determination of seasonal BMI colonization rates within the reservoir. For the summer period, sets of three preconditioned artificial substrates were deployed incrementally for set periods of colonization time (e.g., 8, 6, 4, 2, 1 and less than one weeks) and then pulled simultaneously at the conclusion of the colonization period. For the winter period, sets of three preconditioned artificial substrates were deployed at 14, 12, 10, 8, 1

and less than one weeks. This schedule was different than the summer colonization period due to reservoir ice cover and inaccessibility of sample sites. Artificial substrate baskets were deployed at three depths at a fixed site along the shoreline of Box Canyon Reservoir at an elevation within the euphotic zone where they remained wetted throughout the incubation period. Results from the summer colonization study were used for BMI HSI development and calibration.

An additional comparison study between artificial and natural substrate was conducted during the spring of 2008. Results from the 2007 sampling effort showed that the taxonomic group *Hydra* sp. accounted for a large portion of the BMI biomass in some samples. One possible explanation for this was that the sampling baskets were creating an artificial environment that influenced natural velocity patterns, and this condition affected both community structure and biomass estimates of BMI. Increased biomass resulting from the presence of *Hydra* sp. may have been influenced by the reduction in water velocity caused by the baskets themselves that would not occur over natural substrates. The combination of reduced velocity and reductions in turbulent flow within artificial substrate spaces provided an opportunity for the pelagic *Hydra* sp. to attach and reside in a low-disturbance environment. A comparison of biomass from natural versus artificial substrate collection methods was proposed to determine whether other factors influenced results between the two collection methods. Results from this comparison study were also used in the calibration of HSI curves and to test the hypothesis that the artificial sampling baskets were influencing the colonization of *Hydra* sp. and biasing the BMI biomass.

## 2 STUDY OBJECTIVES

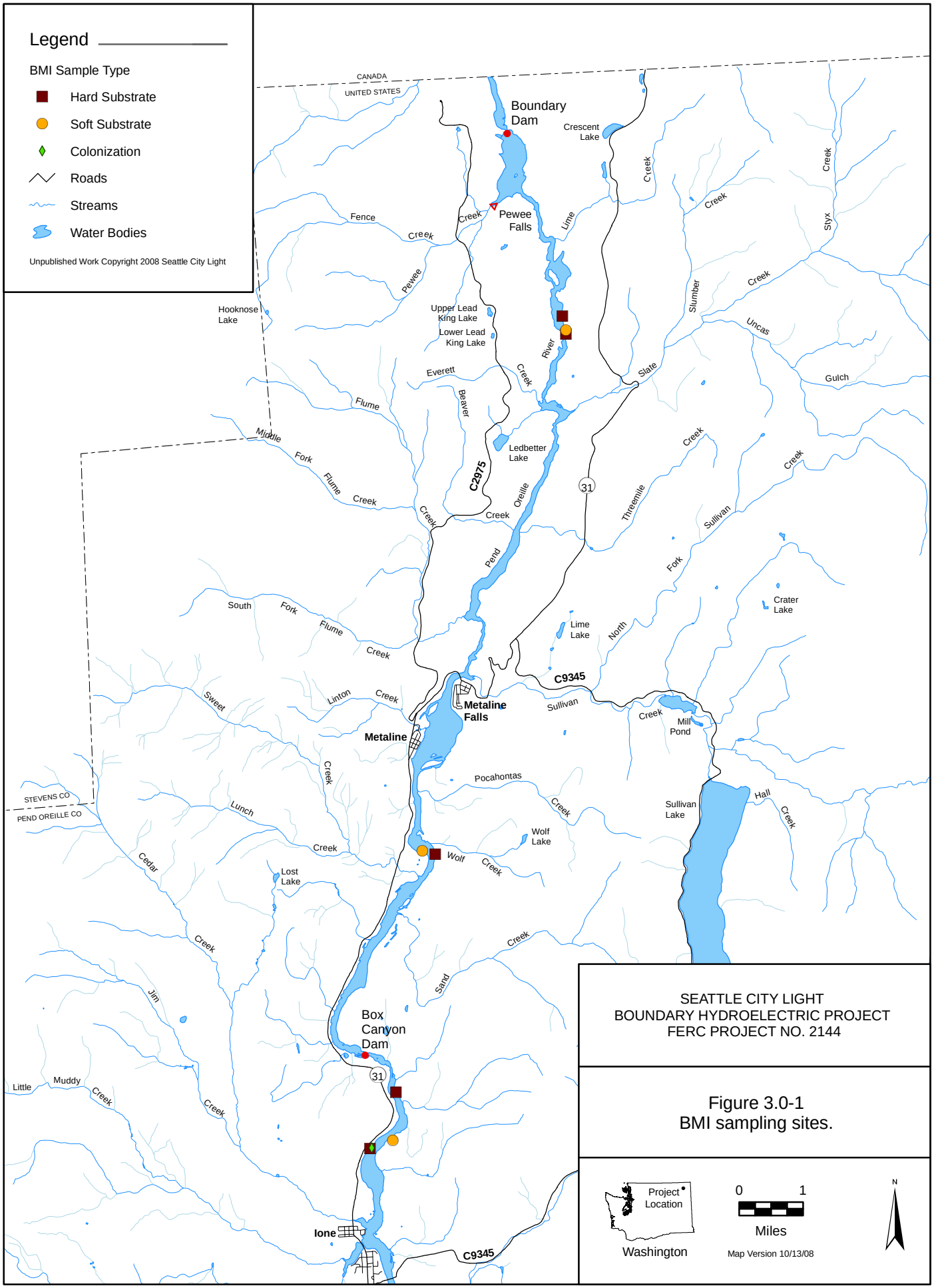
The primary objective of this study was to develop a BMI HSI to help assess the effects of operations scenarios on aquatic productivity. The BMI HSI was used in the Mainstem Aquatic Habitat Model, which integrated hydraulic modeling, reservoir bathymetry, and biological information on the distribution, timing, abundance, and suitability of habitat within Boundary Reservoir. This study included the following seven primary elements necessary to develop an accurate and comprehensive HSI:

- Literature-based BMI HSI curves
- Sampling of BMI communities on hard substrate
- Sampling of BMI communities in soft substrate
- Determination of BMI colonization rates on hard substrate
- Comparison of BMI communities between artificial and natural hard substrate
- Calibration of BMI HSI curves
- Finalization of BMI HSI curves.

## 3 STUDY AREA

The Project is located in northeastern Washington State, in Pend Oreille County. Pend Oreille County is bordered by British Columbia, Canada, to the north and Idaho to the east. Boundary Dam is located approximately 100 miles north of Spokane, near the town of Metaline Falls. The study area for this study encompassed the Canyon and Upper Reservoir Reaches of Boundary Reservoir and Box Canyon Reservoir (see Section 3.0 of the main body for Project Reach

definitions). Hard and soft substrate sampling was conducted in all three areas, while the colonization study was limited to Box Canyon Reservoir. Box Canyon was utilized as a sample site for this study to represent a smaller range of pool surface elevation fluctuations. The Box Canyon Project usually operates as a typical run-of-river project with approximately equal incoming and outgoing flows. In contrast, Boundary Project operations result in daily fluctuations in pool elevations due to differences in incoming and outgoing flows. In order to more fully validate the BMI HSI with site specific information, sampling needed to occur under pool conditions with both high and low levels of water surface fluctuation. BMI sample site locations are shown in Figure 3.0-1.

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FERC PROJECT NO. 2144

Figure 3.0-1
BMI sampling sites.

# 4 METHODS

This section describes the methods used in the BMI HSI development for Boundary Reservoir. The BMI HSI development for Boundary Reservoir consisted of four components: 1) creation of a literature-based provisional BMI HSI, 2) field data collection, 3) calibration of the provisional HSI, and 4) finalization of the BMI HSI for Boundary Reservoir. Field data collection included site-specific BMI monitoring of four different components: artificial substrate sampling on hard substrate, BMI sampling in soft substrate, determination of seasonal colonization rates, and a comparison study between artificial and natural substrate.

## 4.1. Literature-Based Provisional BMI HSI

The Project BMI model combined a standard composite Habitat Suitability Curve (HSC) value of depth, velocity, and substrate, modified by a composite HSI reflecting the duration of prior inundation and dewatering (Table 4.1-1). The model was designed to integrate the HSC and HSI values to develop a Composite Suitability Index (CSI) for each cell within a mainstem habitat transect using hourly time steps. The HSC value captured the specific habitat conditions present at a given cell during a given hourly time step while the HSI value captured the relative level of suitability of those conditions to support biomass of BMI by incorporating the influence of duration of inundation and dewatering on BMI biomass levels.

**Table 4.1-1.** Project benthic macroinvertebrate (BMI) model.

| **Benthic Macroinvertebrate Composite Suitability Index** | $\mathbf{CSI_{BMI} = HSC_i * HSI_i}$ |
|---|---|
| Benthic Macroinvertebrate HSC | $HSC_i = Di * Vo_i * S_i$ |
| Benthic Macroinvertebrate HSI | $HSI_i = f(DI_i, DD_i)$ [1] |
| BMI Variables | $D_i$ = Depth<br>$Vo_i$ = Velocity<br>$S_i$ = Substrate<br>$DI_i$ = Duration of Inundation<br>$DD_i$ = Duration of Dewatering |

Note:

1 See Study 7: Mainstem Aquatic Habitat Model, Varial Zone Analysis PowerPoint presentation (posted on SCL's website as part of the July 24, 2007 meeting materials) for details on integrating inundation and dewatering factors.

The methods used to determine provisional values for each of the five variables are described in the next paragraphs, and the results from literature review are described in further detail in Section 5.

The most common method of calculating weighted usable area values in PHABSIM studies is a multiplicative aggregation given by:

$$HSC_i = D_i * Vo_i * S_i$$

Where:

HSCi = composite habitat suitability of cell i

$D_i$ = suitability associated with depth in cell i
$Vo_i$ = suitability associated with velocity in cell i
$S_i$ = suitability associated with substrate in cell i

Using a multiplicative aggregation, if any of the variables results in a score of zero, the composite value will become zero and the habitat would be rated as unsuitable for use for that time step. This composite HSC approach was used for the Boundary BMI model to calculate the suitability of a cell to support BMI at a given hour. However, the value of a cell for use by BMI was also affected by the length of time that the cell had been inundated. Cells that were inundated for several weeks or more typically supported a higher BMI biomass than cells were newly inundated. Cells that were dewatered for even a period of hours had a lower BMI biomass than cells that were not dewatered. Frequent cycles of dewatering and inundation affected BMI productivity in a cell regardless of its suitability as defined by depth, velocity, and substrate.

In order to evaluate the effects of pool water surface elevation fluctuations on BMI productivity, the prior inundation history of the cell was tracked using hourly time steps. As the duration of continuous inundation increased, the BMI biomass was assumed to increase up to a maximum suitability of 1.0. The rate of BMI increase was determined from a Duration of Inundation (DI) HSI. While BMI biomass in a cell increased as the duration of continuous inundation increased, dewatering of the cell reduced BMI biomass through emigration or mortality. The rate of BMI decrease in response to dewatering was determined from a Duration of Dewatering (DD) HSI that decays the index value from a maximum suitability of 1.0 to a suitability of zero.

The pattern of prior inundation and dewatering determined the relative status of a cell at a given time step as indicated by an HSI value between 1.0 and zero (see Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, Varial Zone Analysis PowerPoint presentation [posted on SCL's website as part of the July 24, 2008 meeting materials] for details on integrating inundation and dewatering). An integrated HSI value of less than 1.0 indicated that the prior history of inundation and dewatering reduced BMI production in that cell at the specific time step. The HSI value and the HSC value were multiplied to determine a composite suitability index for that cell at the given hour.

## 4.2. Field Data Collection

BMI site-specific monitoring initially consisted of three different components: 1) artificial substrate sampling on hard substrate surfaces; 2) sampling of soft substrates; and 3) determination of seasonal colonization rates. Hard and soft substrate sampling was conducted in Boundary and Box Canyon reservoirs and the colonization study was limited to Box Canyon Reservoir. Samples were collected at fixed locations at six predetermined elevation intervals.

During the initial deployment, an underwater video camera was used to verify the type of substrate at each sampling site.

In addition, a fourth component was added in 2008 involving a sampling substrate comparison study that was completed at two sites from the original locations sampled in 2007 (Figure 3.0-1). Results from the 2007 sampling effort showed the taxonomic group *Hydra* sp. accounted for a large portion of the biomass in some samples. One possible explanation was that the sampling baskets were creating an artificial environment that influenced natural velocity patterns, and this condition affected both community structure and biomass estimates of BMI. Increased biomass resulting from the presence of *Hydra* sp. may have been influenced by the reduction in water velocity that would not occur over natural substrates. The combination of reduced velocity and reductions in turbulent flow within artificial substrate spaces was thought to have provided an opportunity for the pelagic *Hydra* sp. to attach and reside in a low-disturbance environment. A comparison of biomass from natural versus artificial substrate collection methods was proposed to determine whether these and other factors influenced results between the two collection methods.

### 4.2.1. Hard Substrate BMI Monitoring

Sampling of artificial hard substrate was conducted at two types of sites; shoreline sites, in which the sampling units were placed at pre-determined elevation intervals along the bottom of the reservoir, and vertical sites that allowed the units to be suspended at various predetermined elevation intervals within the water column. The elevation intervals specified for hard substrate sampling were 2 feet, 5 feet, 10 feet, 15 feet, 25 feet, and 40 feet, and the specific elevations were established as measured below the full pool elevation observed during the first deployment event. These elevations were maintained throughout all sampling seasons during the study. The elevation intervals at which samples were placed were chosen to represent a range of inundation and exposure periods resulting from various operations that included large, moderate, and small levels of water surface elevation fluctuation found in lower Boundary Reservoir, upper Boundary Reservoir, and Box Canyon Reservoir, respectively.

In order to facilitate the sampling of BMI at predetermined elevations, a zero elevation level was established in the field during the first deployment event. This allowed for the baskets to be placed at the various elevation intervals in reference to that zero level. The zero mark, or water surface elevation at the time of the initial deployment, was determined by noting the surface elevation at the date and time of the initial basket deployments. During later deployments, the vertical distance from the zero mark to the water surface was used as the “offset” for the deployment elevation intervals at each location. This level was marked in the field with orange paint to allow for easy relocation during later deployments. The date and time information was used in conjunction with water elevation records from Boundary Dam and Box Canyon Dam to determine the zero level elevation at the time of initial deployment, and the periods of dewatering and inundation for each sample during each deployment.

During 2007, a total of four hard substrate sampling unit deployments were conducted and three retrievals were completed. A fourth retrieval event was conducted during the first quarter of 2008. The hard substrate sampling schedule is shown in Table 4.2-1. All hard substrate samples (shoreline and vertical sites) were retrieved 8 weeks following deployment, with the exception of

the winter sample that was deployed in December of 2007. Winter weather conditions and ice on the reservoir prevented the retrieval of those samples at the 8-week interval. The samples were collected at the earliest possible time that allowed field staff to safely operate, which was 14 weeks after deployment. Each sampling event, or retrieval, required the processing of 54 hard substrate samples at the shoreline sites and 36 at the vertical sites, for a total of 90 samples per event, or 320 hard substrate samples taken during the 2007-2008 field season.

At each vertical site in Boundary and Box Canyon reservoirs, two expansion bolts with hangers were installed the cliff face using a rock hammer. Ropes were attached to suspend the artificial substrate baskets at the correct elevations. Shoreline sites included a large tree as the anchor point for the attachment line to the sampling units. The ropes for each shoreline site were left relatively loose to prevent dragging and buried under the sediment and existing vegetation as much as possible to reduce visibility. Non-buoyant line was used to insure the rope remained on the bottom of the reservoir at the shoreline sites and did not float to the surface to prevent interference with boats and other reservoir uses.

**Table 4.2-1.** Sampling schedule (2007 and 2008) for benthic communities on hard substrate (vertical and shoreline) in Boundary and Box Canyon Reservoirs.

| Sampling Event | Date |
|---|---|
| Deployment of hard substrate sampling units | April 1 – April 4, 2007 |
| Retrieval of hard substrate sampling units | May 29 – June 1, 2007 |
| Deployment of hard substrate sampling units | July 5 – July 9, 2007 |
| Retrieval of hard substrate sampling units | August 30 – September 1, 2007 |
| Deployment of hard substrate sampling units | September 17 – September 19, 2007 |
| Retrieval of hard substrate sampling units | November 5 – November 8, 2007 |
| Deployment of hard substrate sampling units | December 4 – December 7, 2007 |
| Retrieval of hard substrate sampling units | March 11 – March 13, 2008 |

The sampling units used for hard substrate sampling consisted of 3 cylindrical heavy gauge wire mesh baskets, each containing a fixed volume of 1- to 3-inch diameter rocks, attached to a base frame using zip ties. The volume of the rocks in each basket was 622 cubic inches (16.4 cubic centimeters). Each frame was fitted with a rope bridal, connecting to all four corners of the base, to ensure that the unit was lowered and raised in a horizontal alignment. The rocks used for artificial substrate were preconditioned in Boundary Reservoir for 4 weeks prior to deployment and then completely air-dried to remove any growth or material on the rocks. The hard substrate sampling units were assembled onsite and were reused for each deployment.

Sampling units were deployed at each of the six predetermined elevation intervals at every vertical and shoreline site, with the exception of the vertical site in Box Canyon Reservoir. A 40-foot vertical face could not be found in Box Canyon Reservoir due to lack of deep vertical face habitat; therefore, samples were placed at 2-, 5-, 10-, 15-, 20-, and 25-foot elevation intervals at this location. By placing a sampling unit at the 20-foot interval, rather than

replicating one of the other elevations to obtain six sampling intervals, the results better reflected the natural variability in BMI response to depth in Box Canyon.

The following methods were used for retrieving hard substrate samples:

a. For vertical sites, the anchor line was released and attached to a davit and winch combination on the boat. The sampling unit was slowly raised to an elevation just below the water surface. For shoreline sampling sites the anchor line was released from the shore anchor. The boat was then positioned over the location of the sampling unit and the unit was slowly raised just below the water surface to minimize disturbance of the sample.
b. When the sampling unit was near the surface, the zip ties were cut from the first basket to separate it from the frame and a mesh bag was slipped over a basket. The bag and basket were then lifted out of the water and secured to prevent escape of invertebrates during sample retrieval. This procedure was followed for the remaining two baskets on the sampling unit.

Samples were processed for one elevation interval at a time and all sample processing occurred on the boat. The following steps were conducted during sample processing for vertical and shoreline sites:

a. The mesh bag containing the rock basket was placed into a plastic tub. The mesh bag was opened and the remaining zip ties cut to open the basket enclosure. While in a horizontal position, a flat rock was chosen from the basket for periphyton analysis. The remaining rocks were then placed into the bucket for BMI processing. Upon completion of periphyton analysis, the rock was placed back into its respective basket to ensure that the volume of artificial substrate was not altered.
b. The mesh bag and basket were carefully inspected to ensure that no BMI remained. Each rock was sprayed with water and scrubbed into the plastic tub to remove all BMI from the rock surface.
c. The resulting slurry was passed through a 500-micron sieve to collect all BMI and the sample was then transferred into a sample bottle containing preservative.

Once all samples were collected, the sample bottles were sealed and packaged in coolers and shipped to the laboratory for analysis.

### 4.2.2. Soft Substrate BMI Monitoring

In addition to hard substrate, this study evaluated BMI populations in soft substrate within Boundary Dam Reservoir and Box Canyon Reservoir. Sediment samples were collected at predetermined elevation intervals within each of the reservoirs, including 2 feet, 5 feet, 10 feet, 15 feet, 25 feet, and 40 feet, with the exception of the upper Boundary Reservoir. The same procedures to establish the zero point elevation for the hard substrate samples were also used for the soft substrate samples. Prior to collecting soft substrate samples, the zero mark was located at the vertical hard substrate site to determine any variation in elevation and account for it in sample collection of soft substrate. Soft sediment could not be found within the upper Boundary Reservoir at the 40-foot elevation interval; therefore, samples were only taken at the other five elevation intervals. Unlike the hard substrate sites, no anchors or sampling units were left in

place for soft substrate sampling, so no disturbance of the sampler was expected by the curious recreationalists on the reservoir.

During 2007, a total of three soft sediment sampling events were completed and a fourth sampling event was conducted in March of 2008 (Table 4.2-2). Each sampling event included the collection of 51 soft sediment samples, for a total of 204 soft substrate samples taken in 2007 and 2008.

**Table 4.2-2.** Sampling schedule for benthic communities on soft substrate in Boundary and Box Canyon reservoirs.

| Sampling Event | Date |
|---|---|
| Collection of soft substrate samples | May 15 – May 18, 2007 |
| Collection of soft substrate samples | August 28 – August 31, 2007 |
| Collection of soft substrate samples | November 8 – November 10, 2007 |
| Collection of soft substrate samples | March 10 – March 12, 2008 |

Soft substrate sampling equipment included a petite Ponar grab with a volume capacity of approximately 2.4 liters, a hydraulic winch and davit, and 500-micron sieve buckets. Samples were collected in 1-liter Nalgene sample bottles and were labeled in triplicate.

The following methods were used to collect soft substrate samples:

a. The Ponar grab was lowered over the side of the boat on a davit and hydraulic winch. Once the Ponar grab was trigged and collected a sample, it was raised onto the boat, and deposited into a plastic tub.

b. The sediment grab was passed through a 500-micron sieve bucket and the resulting sample was then transferred into a sample bottle containing preservative.

Once all samples were collected, the bottles were packaged in coolers and shipped to the laboratory for analysis.

One minor variance from the RSP involved sampling for soft substrate in the Metaline reach, which was affected by velocity conditions at the sample site. After the first collection event in spring of 2007, velocity conditions at the 40-foot depth prevented the collection of a viable soft sediment sample either because the soft sediment had been washed away, or because the sediment was washed out of the petite ponar during retrieval. Repeated sampling in the area of the sample site did not produce a viable sample. Rather than change the location of the sample (which would have changed the physical habitat data analysis point), the 40-foot depth sample was not collected at this location in later sampling events at this location. Although all samples are considered valuable in this study, initial literature review suggested that while BMI may be found at 40 feet and deeper, the most suitable habitat is found at shallower depths. As such, the removal of the 40-foot depth seasonal samples from this location did not influence analytical results for BMI in a system of moderate pool fluctuation, such as the Metaline Reach in Boundary Reservoir.

### 4.2.3. BMI Colonization Monitoring

Colonization samples were collected utilizing the same sampling unit design as the hard substrate samples. All colonization samples were deployed in one location within Box Canyon Reservoir at elevation intervals of 5, 15, and 25 feet from a zero mark elevation established and marked during the first deployment. The sampling units were deployed on a specific schedule to evaluate the level of colonization that occurred within a given timeframe. The first set of baskets was deployed approximately 8 weeks prior to the first collection date, with the last set placed only 3 days prior to retrieval. Table 4.2-3 lists the deployment and retrieval dates for all sampling events that occurred in 2007 and 2008. The same deployment and retrieval procedures were used for the colonization samples as for the hard substrate shoreline samples.

**Table 4.2-3.** Sampling schedule for benthic colonization in Box Canyon Reservoir.

| Sampling Event | Date | Duration (days) |
|---|---|---|
| Colonization deployment | July 6, 2007 | 56 |
| Colonization deployment | July 20, 2007 | 42 |
| Colonization deployment | August 3, 2007 | 28 |
| Colonization deployment | August 16, 2007 | 14 |
| Colonization deployment | August 23, 2007 | 7 |
| Colonization deployment | August 28, 2007 | 3 |
| Colonization retrieval | August 31, 2007 | Retrieval of all samples |
| Colonization deployment | December 5, 2007 | 99 |
| Colonization deployment | December 21, 2007 | 83 |
| Colonization deployment | January 4, 2008 | 69 |
| Colonization deployment | January 18, 2008 | 55 |
| Colonization deployment | March 7, 2008 | 7 |
| Colonization deployment | March 10, 2008 | 3 |
| Colonization retrieval | March 13, 2008 | Retrieval of all samples |

During 2007, eight colonization deployments and one retrieval event were conducted. Four additional colonization deployments and one retrieval event were conducted in the first quarter of 2008. Each retrieval event required the processing of 54 BMI samples, for a total of 108 samples collected during the 2007-2008 sampling effort.

### 4.2.4. BMI Comparison Study

An additional element of this study was initiated in 2008 to determine whether the artificial substrate influenced colonization of BMI communities when compared to natural substrate. This comparison study included two sets of samples deployed by divers in the spring to evaluate colonization response of biological communities on natural substrate versus rock within mesh baskets. The colonization intervals were originally planned for an 8-week and 4-week exposure (at both 17-foot and 25-foot elevation intervals) at two locations in Boundary Reservoir.

#### 4.2.4.1. Artificial Substrate

Sampling of artificial hard substrate was completed at two sampling locations along the shoreline. Two sets of sampling units were placed along the bottom of the reservoir at each of 17- and 25-foot elevation intervals. The artificial sampling units were the same design and construction as those used in the hard substrate sampling efforts. The volume of rocks used in one of the artificial substrate samplers was the same as the standard volume used for the other hard substrate sampling throughout the study. The other set of baskets per elevation interval contained a single layer of rocks within the basket that simulated a surface area equal to the natural substrate sampled. Two different depths and sites were included in the comparison study to examine consistency in the biological response between the treatments.

Originally, first set of baskets deployed was intended to have an exposure period of 8 weeks prior to collection, and a second deployment of baskets was planned to have an exposure period of 4 weeks prior to retrieval. The original plan for deployment and retrieval of basket sets is described in Table 4.2-4. However, following initial deployment of the first set of baskets, actual measured flows in May and projected June water flows exceeded the safe threshold for diving and retrieval of the first set of baskets and deployment of the second set of baskets, so all baskets were successfully retrieved 4 weeks after the first deployment. The actual deployment and retrieval dates are reported in Table 4.2-5.

Although 8-week colonization interval samples were not collected for BMI communities, the 4-week exposure time for both depths ensured uniform results. The relationship between the production on the natural substrate and the artificial substrate was maintained regardless of exposure time, and adjustments to the HSI curves were possible based on data collected from this study. The rocks from basket sets were processed for BMI following the same procedures used in the hard substrate sampling efforts.

**Table 4.2-4.** Proposed sampling schedule for the comparison study.

| Event | Date |
|---|---|
| Spring deployment/natural substrate preparation – 25 ft (for the 8-week samples) | April 7–9, 2008 |
| Spring deployment/natural substrate preparation – 17 ft (for the 8-week samples) | April 17–19, 2008 |
| Planned spring deployment/natural substrate preparation – 25 ft and 17 ft (for the 4-week samples) | May 5–8, 2008 |
| Planned first collection of samples (4-week 17 ft and 25 ft, 8-week 25 ft) | June 1–4, 2008 |
| Second collection of samples (8-week 17 ft) | June 16–18, 2008 |
| Send samples to lab | June 18, 2008 |

**Table 4.2-5.** Actual sampling schedule for the comparison study.

| Event | Date |
|---|---|
| Spring deployment/natural substrate preparation – 25 ft and 17 ft (4-week samples) | April 8, 2008 |
| Collection of samples (4-week 17 ft and 25 ft) | May 8, 2008 |
| Send samples to lab | May 9, 2008 |

#### *4.2.4.2. Natural Rock Substrate*

In addition to artificial substrate, natural rock substrate was sampled at each of the two locations. Prior to deployment of the rock baskets, a set area (1.0 square meter) of natural rock was cleaned by a diver and marked for relocation. This area was located just upstream of where the rock baskets were placed at each site. A diver collected rocks from within the previously defined area (using a surface area measurement device that kept the surface area the same size as the artificial sampler) and placed them into 500-micron mesh bags. The rocks were then processed for BMI by following the same procedures used in the hard substrate sampling efforts.

#### *4.2.4.3. Statistical Analysis*

Data from each site were collected from two different artificial substrate samplers and from natural substrate at two depths (17 feet and 25 feet). Statistical evaluations at the two depths and from three substrate collection types were analyzed for a potential influence from substrate collection type or depth on BMI biomass. The purpose for this comparison was to determine if results from artificial substrates used in earlier sampling efforts were influenced by artificially created velocity conditions.

Statistical comparisons of depth and substrate types were conducted using parametric analysis of variance (ANOVA) evaluation methods. Each data set generated for biomass estimates was transformed as needed to meet the normal distribution requirements for parametric statistical tests.

#### *4.2.4.4. Effect of Artificial vs. Natural Substrate and Depth on Results*

Biological samples describing properties of BMI can be highly variable depending on their response to multiple environmental gradients. Properties of this variability in the biological response (e.g., dry biomass estimates) were evaluated using ANOVA and testing for influences from artificial vs. natural substrates and from depth of deployment. Depth and substrate type influences on biological response (dry biomass estimates) were tested for, as well as any interaction between these two effects. An interaction is defined as a biological response (BMI) collected with both artificial and natural substrate samples that did not respond consistently with a change in depth. Significant interactions between the two variables (e.g., artificial vs. natural substrates and depth) indicate an influence on results from one (e.g., artificial vs. natural substrates) that is mediated by the other variable (e.g., depth).

BMI biomass was estimated with *Hydra* sp. and without *Hydra* sp. for each of the substrate collection devices and at both depths. Previous collection of biological information analyzed the effect of inclusion and exclusion of *Hydra* sp. on interpretation of response to environmental gradients. Each of the ANOVA models used BMI data sets that included *Hydra* sp. and excluded *Hydra* sp. and examined the consistency of response between the two data sets and the biotic response to changes in substrate sampling method and depth.

#### *4.2.4.5. Influence of Results on Developing HSI Curves*

The initial assumption for use of the artificial substrates in characterizing dry biomass (BMI) as a biological response to environmental gradients was that estimates are representative of: 1) results that would be collected from natural substrates and 2) that direction of response (e.g., increased or decreased dry biomass) would be consistent with the direction found from natural substrate. This assumption was further tested by partitioning data into reach responses and by depths of collection.

Statistical testing addressed the potential for differential biological response at locations in the Canyon and Metaline reaches of Boundary Reservoir. These results determined whether HSI curves should be developed for each of these two reaches in the reservoir, or if the response from BMI communities to depth was consistent throughout the reservoir. Because this test used an environmental variable consistently used throughout the study area (i.e., depth), the statistical test evaluated a zone effect (i.e., Canyon vs. Metaline).

A set of graphical presentations was developed for each of the analyses to determine the direction of the response in each of the artificial vs. natural substrates to depth intervals. These results evaluated the level of colonization on the substrates (e.g., dry biomass accumulated during deployment) and the influence of the biological signal from the depth gradient on each of the artificial vs. natural substrates. Results from this evaluation were used to determine how well the use of previous artificial substrate results reflected natural substrate responses.

## 4.3. Calibration of BMI HSI Curves

Following the literature review and development of literature-based (provisional) habitat suitability curves, a histogram or line graph for each of the habitat parameters researched was developed. Histograms and line graphs were also created from the site-specific field results in order to develop observed curves to compare to the provisional curves from the literature. Site-specific data for velocity was not collected as part of this study, but was estimated from the Hydraulic Routing Model (HRM). The observed histograms and line graphs were compared with the literature-based (provisional) HSI curves to validate the applicability of the literature-based HSI curve used for aquatic habitat modeling.

## 4.4. Finalization of BMI HSI Curves

The HSI curves for each benthic metric were reviewed by a panel of relicensing participants and regional experts. Panel members reviewed the provisional literature-based curves, along with the site-specific data (observed curves) to develop the final set of HSI curves. The panel consisted of relicensing participants and regional experts (agency, tribal, industry, and university

researchers). The final benthic HSI curves were used in the aquatic habitat modeling study to predict Project operations effects based on several environmental gradients.

# 5 LITERATURE RESULTS

Suitability curves are graphical relationships between physical habitat components and an index of biological response scaled between 0 and 1.0, with 1.0 representing the maximum habitat suitability. Based on an extensive literature review, numerous suitability curves for individual species, genus, insect order, and functional groups of BMI were found. These studies documented general BMI HSC for lotic environments, but these curves did not apply directly to conditions in the Boundary reservoir. Existing work on BMI suitability curves focused on a few, select benthic macroinvertebrate taxa. The focus of this BMI model was to determine the response of the benthic macroinvertebrate community to stressors in the environment. As such, the HSC and HSI curves provided here focus on the suitability for macroinvertebrates as a group based, in part, on information from literature as well as professional experience and judgment. Plots of existing data sets, combined with professional judgment and other literature sources, were used to determine ranges of provisional suitability values for each of the five model variables. This section provides a summary of the information from literature sources and the provisional suitability curves.

## 5.1. Depth

Many factors, including temperature, dissolved oxygen, level of light penetration, organic and inorganic substrate, velocities, swimming ability, and biotic factors, influence the depth distribution of benthic macroinvertebrates (Merritt and Cummins 1984; Diggins and Thorp 1985; Ward 1992; Williams and Feltmate 1992; Thorp and Covich 2001). The majority of freshwater benthos exhibits a decline in densities and diversity with increasing depth (Diggins and Thorp 1985; Ward 1992; Thorp and Covich 2001). Ward (1992) found the greatest number of aquatic insect species at depths between 3.3 and 6.6 feet (1 and 2 m) in lentic environments, with the exception of a few Dipterans that have been found at depths exceeding 700 feet (213 m).

The littoral zone is described in the literature as the shallow region extending from the water's edge to a depth where light penetration to the bottom is no longer adequate for macrophyte growth (Merritt and Cummins 1984; Williams and Feltmate 1992). Deep water habitats refer to the area in Boundary Reservoir below the photosynthetic zone for algae. In deep water habitats, the number of aquatic insect species is limited, but abundance may be very high (Merritt and Cummins 1984).

In determining depth preferences for BMI, difficulties arose in that invertebrate production is not exclusively controlled by depth, but also varies with the type of system being sampled and water clarity. For example, in lentic environments, Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Coleoptera (beetles), and Dipterans (true flies) generally have a preference for shallow water habitats. In deep water habitats of oligotrophic lakes, the diversity of aquatic insect species may be high, while the density remains low (Williams and Feltmate 1992). In contrast, in deepwater habitats of eutrophic lakes, diversity may be low, but the density may be much higher than in oligotrophic lakes (Williams and Feltmate 1992).

In deep water habitats of most lakes, the most common benthos is chironomid larvae, a Dipteran taxon (Williams and Feltmate 1992). Chironomids were predicted to be one of the most abundant aquatic insect taxa in the Boundary Reservoir based on data from McLellan and O'Connor (2001) and Ashe and Scholz (1992). As a group, chironomids can be found in a variety of habitats. Chironomid peak suitability was determined to be around 1 foot (0.30 m) in the Salmon River, New York (Milhous 1990). In a study of a South Carolina lake, the peak density of Chironomidae was at nearly 8.2 feet (2.5 m) decreasing in very shallow water (less than 2.72 feet [0.83 m]), but remaining moderately abundant at a depth of 14.76 feet (4.5 m) (Diggins and Thorp 1985).

Studies that have developed depth suitability curves for BMI in lotic environments are numerous. All of these studies, however, are from systems with much shallower depths than occur in Boundary Reservoir, which limits their usefulness in assessing influence of deeper water on benthic invertebrate preference. For example, Jowett et al. (1991) studying four rivers in New Zealand, Gore et al. (2001) studying a range of streams from the southeastern U.S., and Jowett and Davey (2007) studying five rivers in New Zealand, found similarities in preferred depth for Ephemeroptera, demonstrating a suitability of 1.0 approximately at 1.6 feet (0.5 m). At depths greater than 2.3 feet (0.7 m) suitability declined for Ephemeroptera between 0.4 and 0.2. However, a suitability value of 0.0 never resulted for any depths greater than 0 foot (0 m) in any of the three studies. In a large Canadian lake, Ephemeroptera and Trichoptera were collected at depths of 39 and 49 feet (11.9 and 14.9 m), respectively (Adamstone 1924 as cited in Ward 1992).

In the studies by Gore et al. (2001) and Jowett and Davey (2007), which were conducted in systems that were shallower and more lotic than Boundary Reservoir, Trichoptera suitability curves differed markedly between the two studies for depth. Jowett and Davey (2007) found the Trichoptera taxa *Aoteapsyche* had peak suitability of 1.0 from about 0.0 to 1.6 feet (0.0 to 0.5 m), falling to a suitability of approximately 0.2 at depths greater than 4.3 feet (1.3 m). Gore et al. (2001) presents results for Trichoptera illustrating a 0.0 suitability at 0.0 foot (0.0 m) and a peak suitability of 1.0 between 1.3 and 3.1 feet (0.4 to 0.95 m). As noted above, even the relatively large Sacramento River would have depth ranges much less than what occur in Boundary Reservoir, limiting its applicability for evaluating effects of deep water on BMI suitability.

Sampling from a range of streams in the southeastern U.S., Gore et al. (2001) demonstrated Plecoptera suitability was between 0.0 and 0.4 at depths between 0 and 0.3 foot (0 and 0.1 m), a peak suitability of 1.0 at depths between 1.3 and 2.5 feet (0.4 and 0.75 m), and a decline in suitability between 0.6 and 0.3 at depths ranging from 2.8 and 3.1 feet (0.85 and 0.95 m). In Lake Tahoe, Nevada, adults of the Plecopteran *Capnia tahoensis* have been found on submerged plants at depths between 197 and 263 feet (60 and 89 m) (Jewett 1963 as cited in Williams and Feltmate 1992). Evaluating depth suitability for total macroinvertebrates in the Sacramento River, California, Gard (2006) found a peak suitability at 2.0 feet (0.6 m), and minimum suitability at both 0.0 and 4.3 feet (0.0 and 1.3 m) deep (Figure 5.1-1).

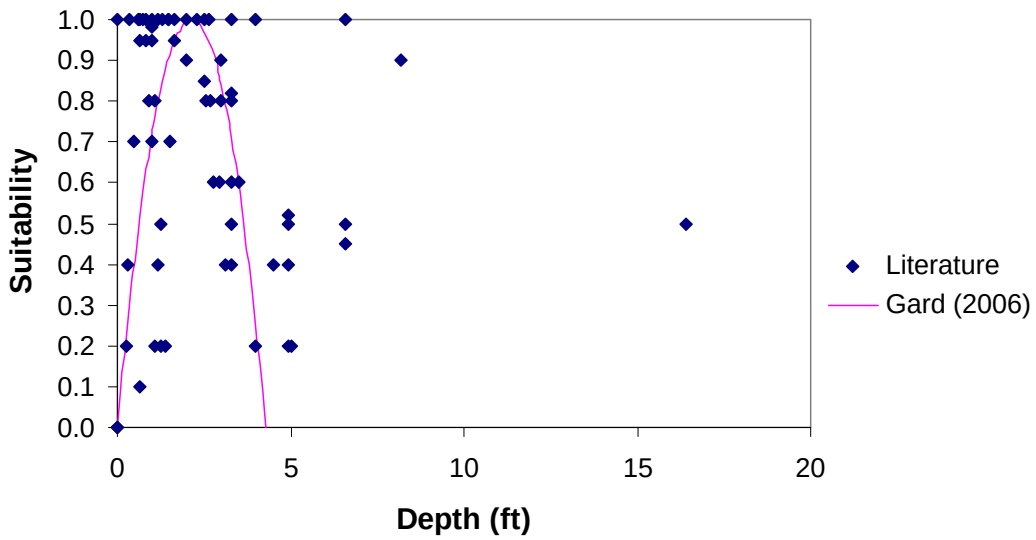


**Figure 5.1-1.** Habitat suitability curve data of depth for total BMI produced from suitability curves developed by Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007). Gard (2006) suitability curve was developed directly from data provided in report.

As described in Section 4 of this report, the data from existing BMI suitability curves, an extensive literature review, and professional judgment were used to develop depth ranges and provisional suitability values (Table 5.1-1 and Figure 5.1-2). BMI biomass below 50 feet was insignificant relative to the biomass that occurs in the varial zone above 50 feet within the reservoir. Therefore, the HSI was assigned a zero value as measurement of BMI. Further calibration of the provisional values was performed with data collected in the field evaluating the differences in BMI biomass at varying water depths.

**Table 5.1-1.** Depth ranges and provisional suitability values for BMI.

| Depth in feet | Provisional Suitability Values |
|---|---|
| 0 | 0.0 |
| 0.3 | 0.2 |
| 0.5 | 0.4 |
| 3.0 | 0.7 |
| 10 | 1.0 |
| 15 | 1.0 |
| 20 | 0.6 |
| 40 | 0.3 |
| >50 | 0 |

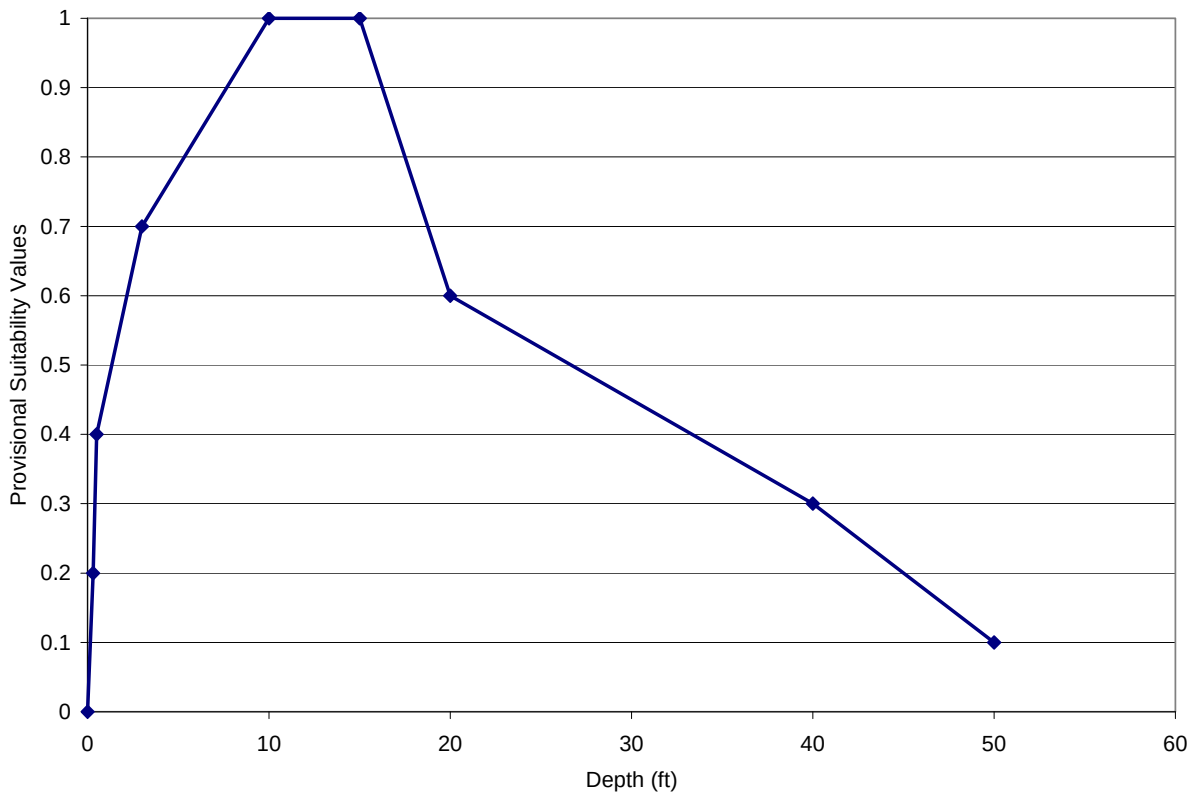


**Figure 5.1-2.** Provisional depth suitability curve for BMI. Maximum depth for presence of BMI exceeds 60 feet.

## 5.2. Velocity

Aquatic insects select microhabitat space within an optimal range of velocities (Keup 1988). A change in hydrologic conditions that alters localized velocities influences the useable area for BMI (Gore et al. 2001). Although BMI are not velocity-specific, high faunal diversity has been shown at velocities between 2.46 and 4.10 feet per second [fps] (0.75 and 1.25 meters per second [m/s]) at depths between 0.66 and 1.31 feet (0.2 and 0.4 m) (Gore 1978; Williams and Feltmate 1992) in the Tongue River, Montana. In the littoral zone, velocity and water movement characteristics are important mechanisms that regulate community development, feeding, growth, and reproduction of aquatic insects (Wetzel 2001). The majority of studies found during the literature review were focused on velocity suitability curves specific to groups of BMI in lotic environments.

Jowett et al. (1991) and Jowett and Davey (2007) developed suitability curves for the Ephemeroptera genus *Deleatidium* and found the peak velocity suitability for the genus to be approximately 3.28 to 4.92 fps (1.0 to 1.5 m/s). In addition, the suitability index was greater than 0.3 for all velocities between 0 and 5.25 fps (0 and 1.6 m/s) (Jowett et al. 1991, Jowett and Davey 2007). In contrast, Gore et al. (2001) studied many streams throughout the southeastern

U.S., and found Ephemeroptera to have peak suitability between 0.3 to 0.98 fps (0.1 to 0.3 m/s), with the suitability index ranging from 0.5 at 0 fps (0 m/s) to 0.0 at 2.95 fps (0.9 m/s).

In studies by Gore et al. (2001) and Jowett and Davey (2007), suitability for Trichoptera was near 0.0 when velocities were at 0 fps (0 m/s). However, Jowett and Davey (2007) determined peak suitability for the Trichoptera genus *Aoteapsyche* to be at velocities greater than 4.92 fps (1.5 m/s), while Gore et al. (2001) found a suitability of 0.0 for velocities at 2.95 fps (0.9 m/s).

Evaluating velocity suitability for total macroinvertebrates in the Sacramento River, California, Gard (2006) found a peak suitability at 2.2 fps (0.67 m/s) and minimum suitability at 0.0 and 5.0 fps (0.0 and 1.52 m/s) (Figure 5.1-3).

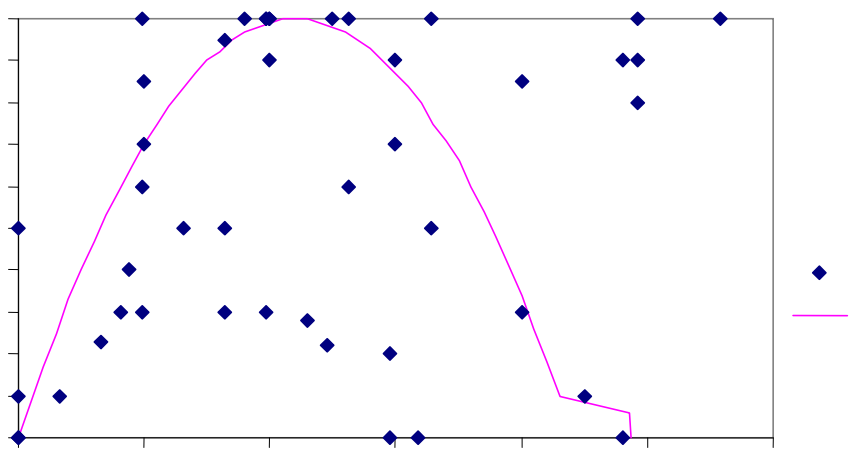

**Figure 5.1-3.** Habitat suitability curve data of velocity for total BMI produced from suitability curves developed by Gore and Judy (1981), Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007). Gard (2006) suitability curve was developed directly from data provided in report.

As described in Section 4 of this report, an extensive literature review, and professional judgment were used to develop velocity ranges and provisional suitability values (Table 5.1-2 and Figure 5.1-4).

**Table 5.1-2.** Velocity ranges and provisional suitability values for benthic macroinvertebrates (BMI).

| Velocity in feet per second | Provisional Suitability Values |
|---|---|
| 0 | 0.6 |
| 0.12 | 0.8 |
| 1.4 | 1.0 |
| 2.6 | 1.0 |
| 3.8 | 0.6 |
| 5 | 0.3 |
| 8 | 0.1 |
| 20 | 0.0 |

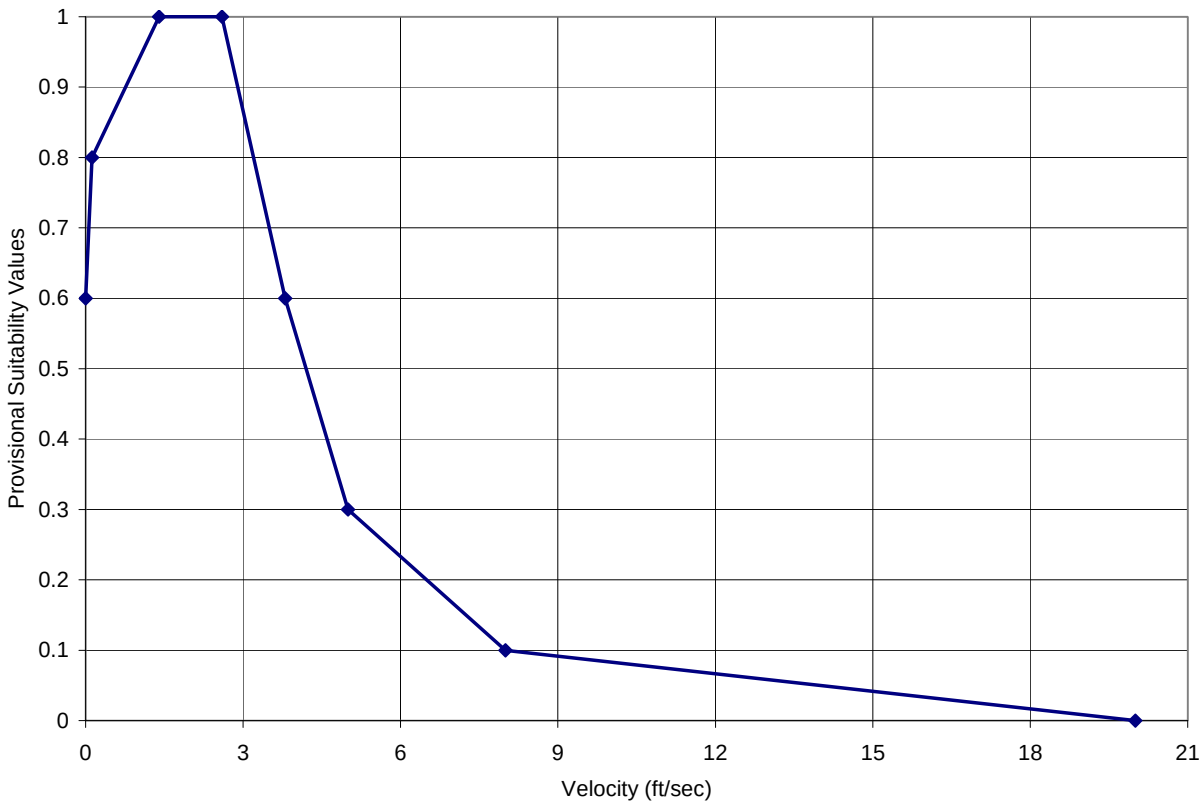


**Figure 5.1-4.** Provisional velocity suitability curve for BMI.

## 5.3. Substrate

Substrate type has been shown to be a major determinate in the distribution and abundance of aquatic insects (Minshall 1984 as cited in Ward 1992). In general, aquatic insect species exhibit distinct preferences for specific substrate types; however, very few are restricted to a single specific type (Ward 1992). At the order level, preferences are extremely variable and cannot be

limited to one substrate type. For example, Ward (1992) provides detailed information on categories of benthic insects based on substrate type, documenting that different species within Ephemeroptera and Diptera each prefer hydrophytes, wood, stones, gravel, sand, and mud, such that there is not a primary preference for the order, much less for all macroinvertebrates. In the littoral zone, aquatic invertebrate biomass and diversity are generally greater when aquatic macrophytes are present when compared to areas without macrophytes at the same location in both lentic and lotic habitats (Merritt and Cummins 1984). In a study on how reservoir-release-flows influence distribution and abundance of BMI, Brusven (1984) recorded the highest mean insect densities from large cobble substrates, and the lowest from sand. Although the examples from Ward (1992) and Brusven (1984) provide BMI and substrate generalities, the reviewed literature mostly presented studies on individual species.

Descriptions of individual taxon preferences for substrate types are numerous in the literature. The sediment size and the density and diversity of aquatic vegetation have been presented as the most important factors affecting benthic species distribution (Diggins and Thorp 1985). For example, Williams and Feltmate (1992) state that chironomid larvae show preferences for specific substrate types based on species, with some preferring hard rock surfaces and gravel, and others preferring sand and silt. In studying Par Pond in the Savannah River, Diggins and Thorp (1985) indicate that large variations in Chironomidae composition were associated with significant changes in sediment particle size with depth. Milhous (1990) determined chironomid larvae preference to be in gravel substrate (0.08 to 2.52 inches [2 to 64 millimeters]) of the Salmon River, New York. In a study of littoral habitat in nine New Zealand lakes, chironomid larvae abundance was found to correlate inversely with substrate size, with the finest substrate (sand) having the highest abundance and gravel the lowest abundance (Weatherhead and James 2001).

Substrate, macrophyte biomass, and detritus were the most important factors controlling BMI abundance and distribution in the littoral zone of nine New Zealand lakes (Weatherhead and James 2001). Specifically, Ephemeroptera demonstrated preferences for coarse gravel and cobble substrate; *Potamopyrgus antipodarum*, a New Zealand snail, preferred macrophytes, and oligochaetes and chironomids were associated with fine, detritus-rich sediments (Weatherhead and James 2001). In a study of streams across New Zealand, *Potamopyrgus antipodarum* showed the greatest accumulation in the crevices between gravels and pebbles, and less accumulation between cobbles (Holomuzki and Biggs 1999).

Suitability curves from lotic environments regarding BMI and substrate are numerous in the literature. Gore et al. (2001) found that Ephemeroptera exhibited a peak preference for cobble substrate in a study from a range of streams from the southeastern U.S. These results were confirmed in two studies of rivers in New Zealand (Jowett et al. 1991; Jowett and Davey 2007). Weatherhead and James (2001) found that Ephemeroptera abundance was greatest in gravel and cobble substrate and lowest in fine sediment in the littoral habitat of nine New Zealand lakes. Based on suitability curves for Trichoptera from the southeastern U.S. (Gore et al. 2001) and five New Zealand rivers (Jowett and Davey 2007), peak suitability is found in large cobble or boulder substrate. Peak suitability for Plecoptera was similar to that of Ephemeroptera and Trichoptera for a range of streams from the southeastern U.S. (Gore et al. 2001), occurring in large cobble or boulder substrate. Oligochaete abundance was also found to correlate inversely with substrate

size, with the finest substrate (sand) having the highest abundance and gravel the lowest (Weatherhead and James 2001).

Milhous (1990) developed suitability curves for total benthic biomass (ash-free dry weight) and determined substrate preference to be highest in boulders (9.8 and 157.5 in [250 and 4,000 mm]) in relation to a depth preference of 1 foot (0.30 m), and a velocity preference of 2 fps (0.6 m/s) for the Salmon River, New York. Gard (2006) developed suitability curves for total macroinvertebrates from the Sacramento River, California, and found that large cobble had a maximum suitability of 1.0, and all other sizes, from fines to bedrock, had a suitability of approximately 0.3 (Gard 2006) (Figure 5.1-5).

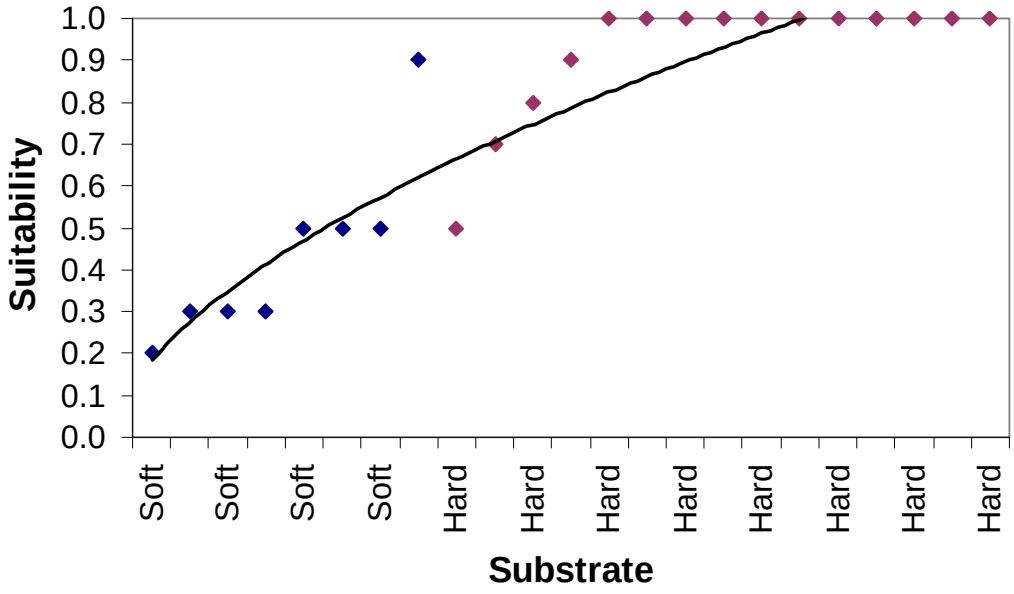


**Figure 5.1-5.** Habitat suitability curve data of substrate for total BMI produced from suitability curves developed by Gore and Judy (1981), Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007).

As described in Section 4, the data from BMI suitability curves, an extensive literature search, and professional judgment were used to develop substrate types and provisional suitability values (Table 5.1-3 and Figure 5.1-6). Further calibration of the provisional values was conducted with data collected in the field evaluating the differences in BMI biomass on artificial substrates.

**Table 5.1-3.** Substrate types and provisional suitability values for BMI.

| Substrate Types | Provisional Suitability Values |
|---|---|
| Soft Substrates (Sand, Silt or Organic Material) | 0.4 |
| Macrophytes | 0.6 |
| Gravels, Cobbles, and Boulders | 1.0 |
| Bedrock | 0.2 |

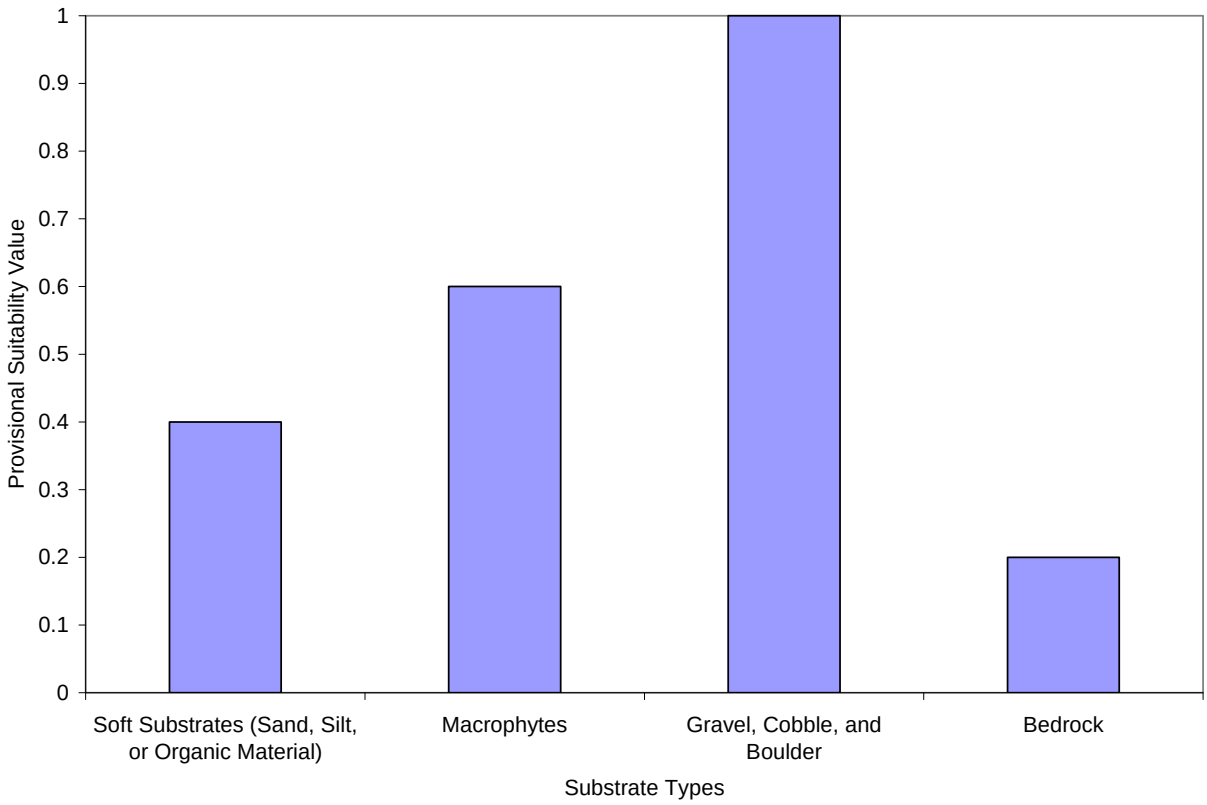


**Figure 5.1-6.** Provisional substrate suitability curve for BMI.

## 5.4. Duration of Dewatering

Water surface elevation fluctuations in reservoirs affect the littoral zone, where most benthic macroinvertebrates live (Ward 1992) and, therefore, can substantially affect the habitat and survival of those benthic communities (Wetzel 2001). The success of benthic fauna in littoral zones that become exposed during dewatering events depends on a wide range of factors, including duration and season of dewatering, the ability of benthos to retreat with receding water surface elevations, their survival in areas exposed to air or ice cover, and their ability to recolonize areas after refilling (Kaster and Jacobi 1978). Additionally, Furey et al. (2006) indicated that indirect effects of drawdown include sediment erosion along shorelines, reduction

in food resources, and overall changes that result in less suitable habitat for benthos. Most available literature information summarized in this section is from reservoirs undergoing seasonal drawdown without large daily decreases and increases in water surface elevations.

Macroinvertebrate communities are directly affected by exposure and desiccation following dewatering events in reservoirs (Ploskey 1986). Fisher and LaVoy (1972) found that benthic invertebrate communities of periodically exposed areas were lower in density and diversity than communities in continuously inundated areas. Stark and Bennett (2001) also found that as the duration of benthic macroinvertebrates exposure increased, density, biomass, and community structure were reduced. Grimas (1962) revealed a 70 percent density reduction of benthic fauna following drawdown in Lake Blasjon, Sweden. Kaster and Jacobi (1978) found areas of constant inundation supported greater numbers and biomass of benthos than those exposed to air. But they found some invertebrates survived exposure for several weeks in soft substrate, with exposed area abundance not falling to zero until exposed for 35 days based on weekly sample intervals. This was in a seasonal, not daily, fluctuating reservoir (i.e., most areas once exposed were dewatered for months, not hours or days). Other studies have shown (Turner 1980; Ward 1992) that while diversity may decrease, total density of benthos may increase following water surface elevation fluctuations and refilling, with higher numbers of certain species of oligochaetes and chironomids specifically. These documents summarized information from varied studies including those with 7 to 15 feet (2 to 4.5 m) in fluctuations, which were seasonal not daily changes. Dramatic density increases in disturbed habitats are common where taxa with high tolerances to a variety of environmental extremes can rapidly colonize and become dominant.

Duration of dewatering plays a significant role in survival of macroinvertebrates in exposure zones of reservoirs. As cited in Stark and Bennett (2001), the density and biomass of most benthic macroinvertebrates decreased as a result of water fluctuations; however, some invertebrates, including nymphs of the Plecoptera genus *Alloperla* sp., were able to tolerate brief periods of exposure without significant change. In their study, Stark and Bennett (2001) revealed that substrates exposed from 1 to 24 hours showed an average 59 percent decrease in total invertebrate density and a 65 percent reduction in invertebrate biomass. Blinn et al. (1995) conducted a study showing a 90 percent reduction in macroinvertebrate mass after a 12-hour daytime exposure event. In contrast, Furey et al. (2006) suggests that reservoirs operating under regular seasonal drawdown regimes may be capable of supporting macroinvertebrate densities and biomass that are equal to or greater than those in natural systems with similar biological and chemical conditions. This occurs only under circumstances where community taxa become dominant and can tolerate some regularity in appearance and disappearance of water. Furey et al. (2006) examined benthic communities in soft substrate within and below normal seasonal drawdown depths in a storage reservoir that did not undergo daily fluctuations, dissimilar to existing Project operations. The sample depths examined had been covered by water for several months prior to sampling, except for one site that was dewatered during the study.

Although duration of exposure is crucial in the survival of benthos during drawdown, there appears to be considerable differences among different species of benthic macroinvertebrates in their level of exposure tolerance as well (Brusven et al. 1974). In a study conducted by Brusven et al. (1974), Ephemeroptera appeared to be intolerant to short-term exposure, with high mortality after 24 to

48 hours. When temperatures were cool, survival was relatively high for Lepidoptera, Trichoptera, and Diptera at 24 to 48 hours (Brusven et al. 1974). Alternatively, the chironomid Dipterans showed very little mortality in the 24-hour exposure period, and even demonstrated survival after 96 and 120 hours of exposure (Brusven et al. 1974). Brusven et al. (1974) also noted that as air temperature increased to 85˚F, mortality of all insects listed increased substantially. Turner (1980) supported these findings and found that certain benthos, including many chironomid species, were able to withstand exposure of 50 to 85 days under winter drawdown conditions. Kaster and Jacobi (1978) suggested that some species of chironomids and oligochaetes are capable of withstanding those longer periods of desiccation due to their ability to burrow deeper into the substrate than other macroinvertebrates. It is not clear at this time whether the chironomids present in the Boundary Reservoir are the species that can withstand extended desiccation. Results from field data collection can provide information to address this issue.

Available literature presents a variety of findings in relation to the effects of dewatering on benthic macroinvertebrates. The literature suggests that many factors affect the ability of benthos to survive fluctuations in water surface elevations, including duration of dewatering. It appears that whereas certain species of macroinvertebrates express greater tolerance to exposure than others, macroinvertebrates generally experience desiccation and increased mortality with increased duration of exposure (Kaster and Jacobi 1978; Turner 1980; Furey et al. 2006; Stark and Bennett 2001). The information from the literature and professional judgment were used to develop the provisional suitability values identified in Table 5.1-4 and Figure 5.1-7.

**Table 5.1-4.** Duration of dewatering provisional suitability values for BMI.

| Duration of Dewatering | Provisional Suitability Values |
|---|---|
| No dewatering (0 hours) | 1.0 |
| 6 hours | 0.6 |
| 12 hours | 0.4 |
| 24 hours | 0.2 |
| 48 hours | 0.1 |
| 96 hours | 0.05 |
| 720 hours | 0.0 |

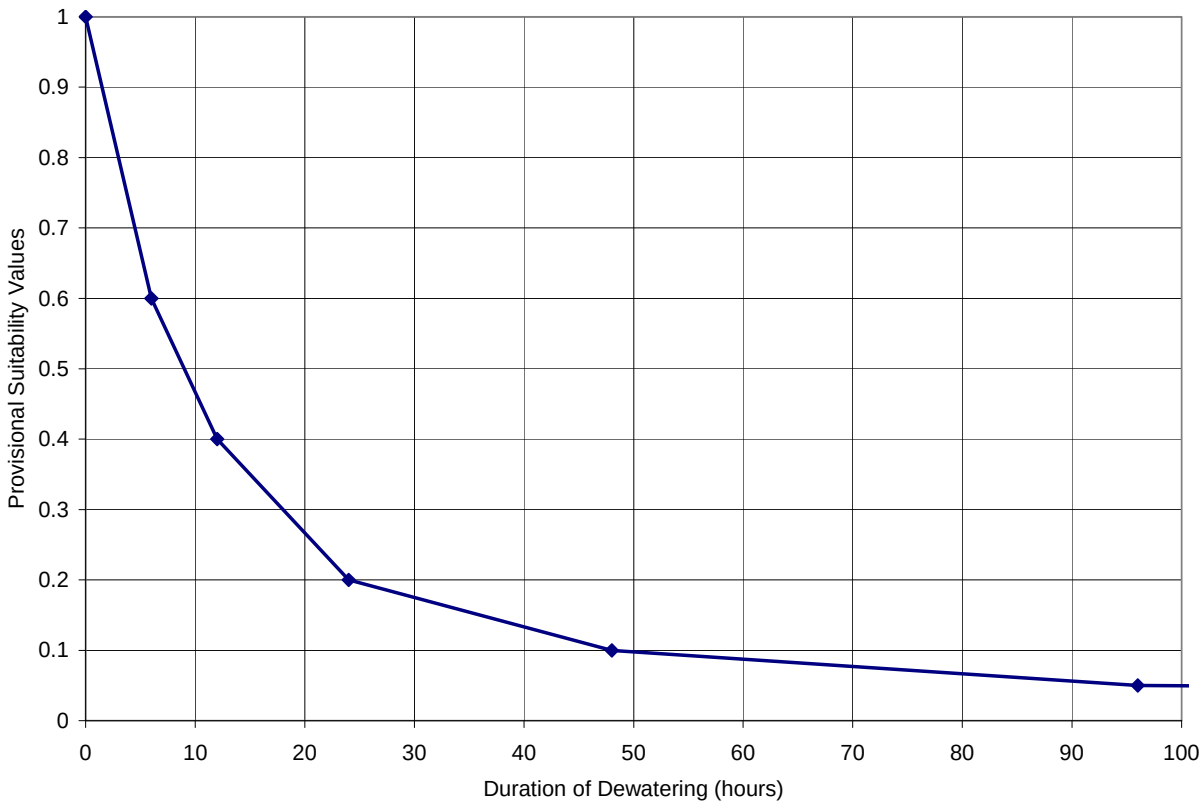


**Figure 5.1-7.** Provisional duration of dewatering suitability curve for BMI.

## 5.5. Duration of Inundation

Colonization of habitats by invertebrates is the process of organisms moving into and establishing in new habitats or re-establishing in previously occupied habitats (also called recolonization) (Smock 1996). Rates of colonization are affected by factors external to an organism, such as diel pattern, water temperature, fluctuation in water surface elevations, and season, as well as internal factors, such as breeding season or food requirements (Williams and Feltmate 1992). Many studies have shown rapid recolonization of disturbed areas, including areas dewatered by drought or water fluctuations (Gersich and Brusven 1981; Blinn et al. 1995; Miller and Gollady 1996), but the rate of colonization differs by species, season, habitat, and distance from colonizing sources (Gore 1982 as cited in Smock 1996; Blinn et al. 1995; R.L.&L. Environmental Services 2000; Collier and Quinn 2003). Substrate size also plays a role in the rate of colonization and the type of invertebrates that will recolonize a habitat following disturbance (Wise and Molles 1979 as cited in Smock 1996).

Colonization can occur via downstream movement, upstream movement, movement from the subsurface, or hyporheic zone, and aerial movement by adults (Smock 1996). Downstream drift is the most common colonization vector, and Townsend and Hildrew (1976 as cited in Williams and Feltmate 1992) found that 82 percent of colonization of denuded habitat in streams was

instigated by drifting invertebrates. Benthic invertebrates can also move along the sediment both downstream and upstream, but the distance of these movements is limited. Williams and Feltmate (1992) cite colonization of new habitats from the hyporheic zone, and Sedell et al. (1990 as cited in Smock 1996) note that the hyporheic zone provides important refuge for invertebrates during dewatering of the surface sediments. Aerial adults laying eggs at a site is dependent upon habitat conditions, oviposition requirements, and season (Smock 1996; Anderson and Wallace 1984).

Actual rates of colonization are quite varied throughout the literature, but general trends are present and have been used as the basis for the ratings for this component of the HSI model. For the major taxonomic groups, Collier and Quinn (2003) note that the colonization times follow the order Diptera<Ephemeroptera<Trichoptera<Plecoptera (Niemi et al. 1990 as cited in Collier and Quinn 2003) due to generation time, life history patterns, and likelihood of drift. Rosenberg and Resh (1982 as cited in R.L.&L. Environmental Services 2000) found that from 35 investigations of recolonization, times ranged from 3 to 49 days. Gersich and Brusven (1981) found recovery times on the Clearwater River in Idaho to be 47 days for unregulated systems and 66 days for regulated systems. R.L.&L. Environmental Services (2000) selected 50 days for its model estimate for recovery time for invertebrates affected by changes in water surface elevations for a hydroelectric facility, while Ciborowski and Clifford (1984) identified 46 days as the time needed for full recovery.

In a dry prairie environment, Miller and Gollady (1996) found that 85 percent of original invertebrate density was recovered in 67 days, and by 90 days, 90 percent of the density had recovered. Within 4 days after rewetting, 21 taxa were observed, but these were mostly Dipterans (Miller and Gollady 1996). McCabe and Gotelli (2000) identify 8 to 30 days as the time for full recovery following removal of invertebrates from artificial substrate. Negishi and Richardson (2006) found full recovery following flooding after 52 days, 75 percent recovery after 27 days, and 30 percent recovery after 14 days. Hauer and Stanford (1997 as cited in R.L.&L. Environmental Services 2000) stated that invertebrates require several weeks to months to recolonize dewatered substrates. Collier and Quinn (2003) predicted recovery times of 150 days in a forested system and 720 days in a stream in an agricultural setting. Conversely, on the Colorado River, Blinn et al. (1995) found gastropods colonizing cobbles within 1 day, followed by chironomids, and that cobbles were repopulated within 5 days. However, Blinn et al. (1995) noted that full recovery took about 120 days. In keeping with the information provided in the above sources and noting that establishment by early colonizers may begin immediately upon dewatering; the suitability values in Table 5.1-5 and Figure 5.1-8 are proposed for use to assess the affect of rate of colonization as part of the HSI model. For modeling purposes the rate of recolonization is considered a function of the duration of water inundation. Further calibration of the provisional values will be supported with data collected in the field evaluating the differences in BMI colonization rates on artificial substrates.

**Table 5.1-5.** Duration of inundation provisional suitability values for BMI.

| Duration of Inundation | Provisional Suitability Values |
|---|---|
| No inundation (0 hours) | 0.0 |
| 24 hours | 0.1 |
| 96 hours | 0.4 |
| 168 hours | 0.6 |
| 360 hours | 0.8 |
| 1,080 hours | 1.0 |
| 8,760 hours | 1.0 |

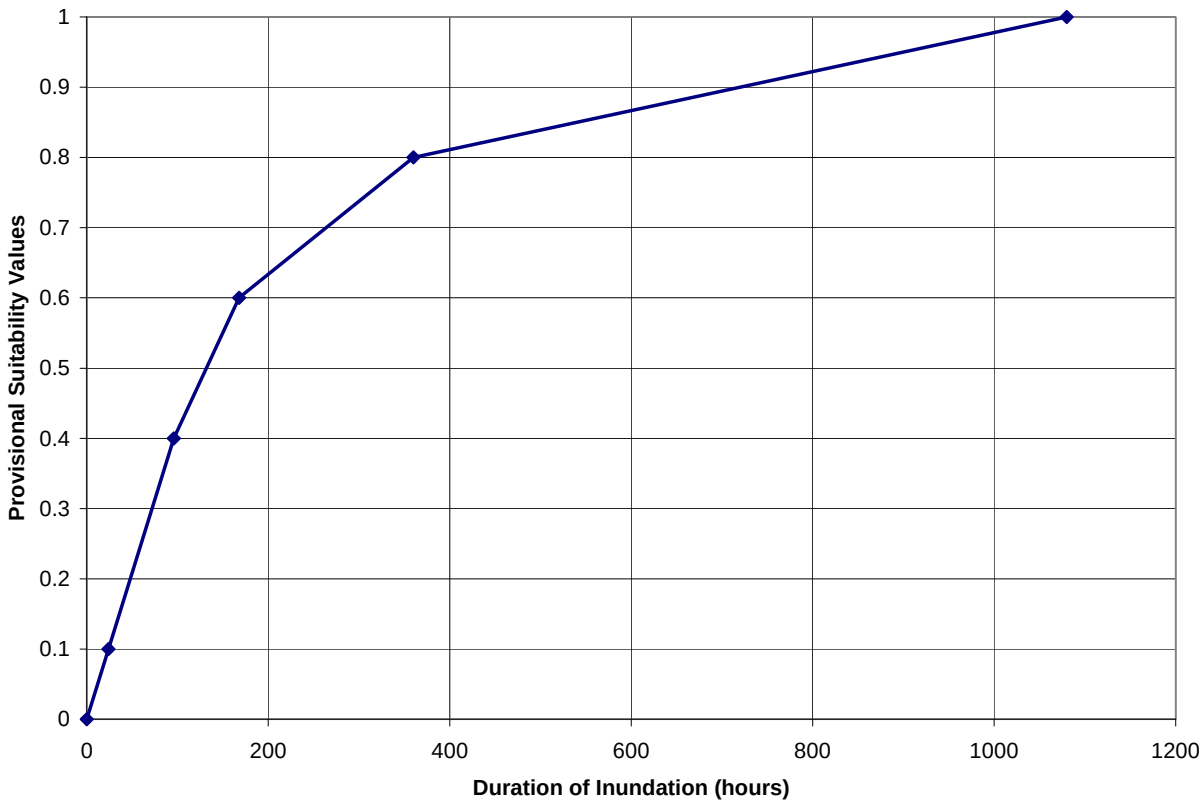


**Figure 5.1-8.** Provisional duration of inundation suitability curve for BMI.

## 6 FIELD DATA RESULTS

This section presents the results and analyses of BMI data collected during 2007 and 2008. All BMI data were evaluated to address the objectives of the study and are presented below. Site-specific BMI data are presented below by treatment site, elevation, and season.

## 6.1. BMI Communities on Hard Substrate

The BMI community was characterized using an artificial substrate that consisted of pre-cleaned rocks collected from the reservoir, placed in a heavy gauge wire mesh basket, and then deployed at incremental elevation intervals at locations within the reservoir. The purpose of using artificial substrates was to maintain uniformity in collection effort at discrete elevations along three environmental gradients (e.g., depth, velocity, and substrate) and under various reservoir conditions (e.g., inundated and dewatered with high, moderate, and low frequency). Data generated from these artificial substrates reflecting exposure to varying site-specific environmental conditions were used to suggest modifications to the provisional HSI curves. The modifications were only proposed in construction of the final HSI curves if: 1) field observations represented the range of environmental conditions known to exist in the natural environment, and 2) results showed strong variation from the provisional curves prepared from literature-based data.

Figures 6.1-1 through 6.1-3 show the basket elevations in Box Canyon and Boundary Reservoirs, respectively, in comparison to water surface fluctuations during the sample period. The fluctuation zone in Box Canyon Reservoir was much smaller than the fluctuation zones seen in both the Metaline and Canyon Reaches in Boundary Reservoir. As per the experimental design, the highest fluctuation zone was located in the Canyon Reach of Boundary Reservoir. The Metaline Reach of Boundary Reservoir had a moderate level of fluctuation and Box Canyon Reservoir had the lowest level of fluctuation in water surface elevation.

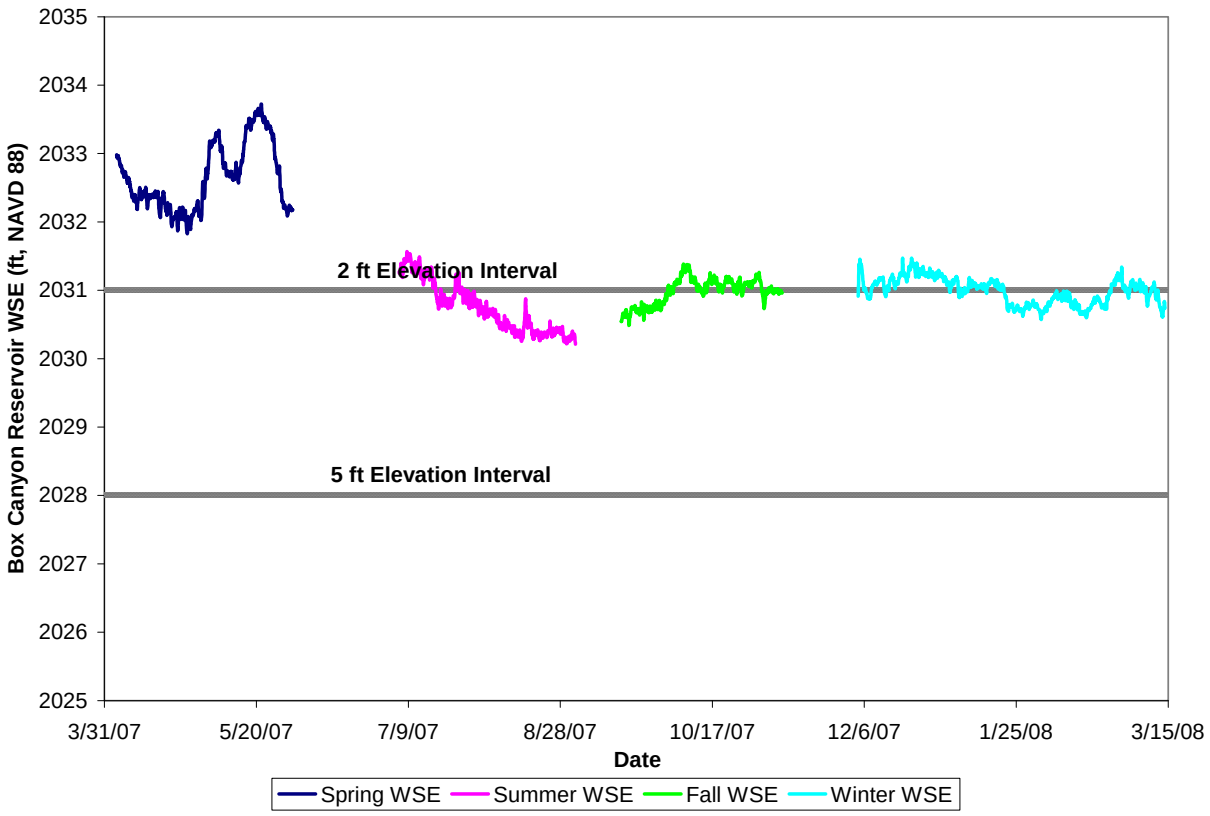


**Figure 6.1-1.** Box Canyon Reservoir hourly water surface elevations compared to basket locations at shoreline and vertical treatment sites.

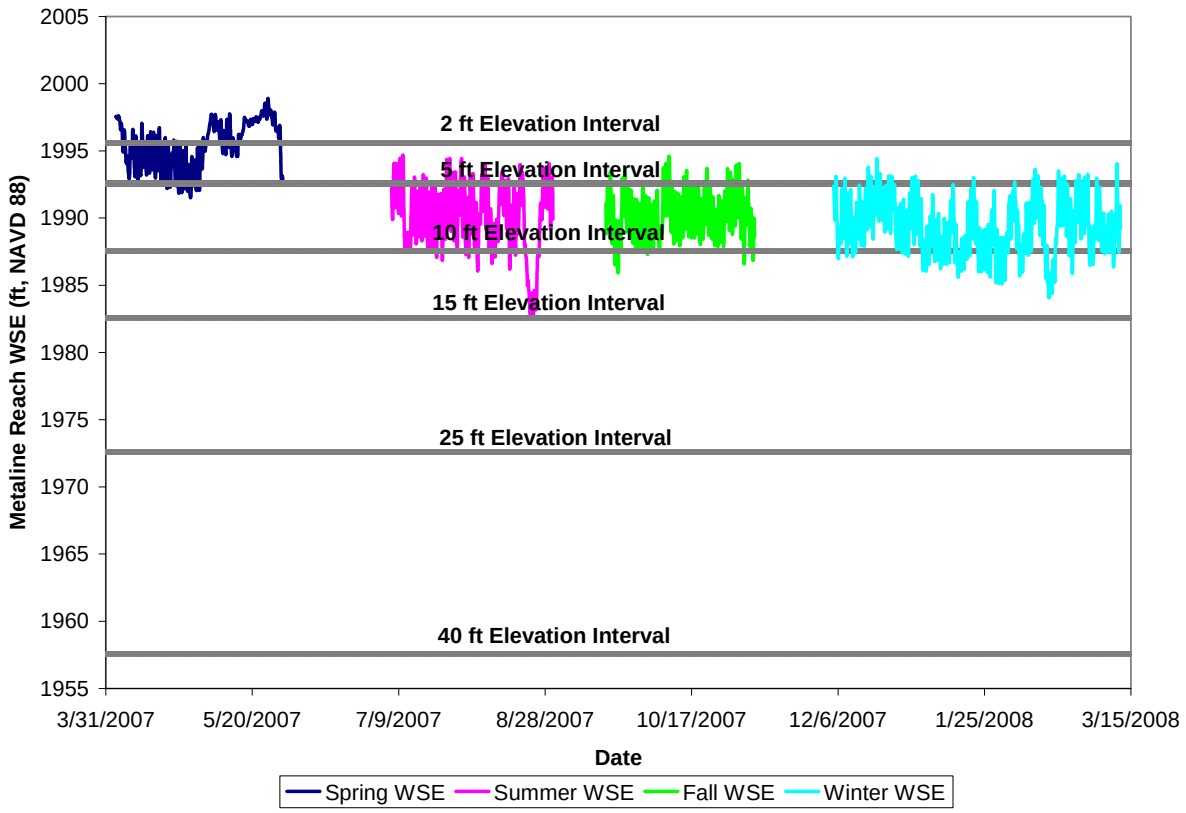


**Figure 6.1-2.** Metaline Reach (Boundary Reservoir) hourly water surface elevations compared to basket locations at the shoreline treatment site.

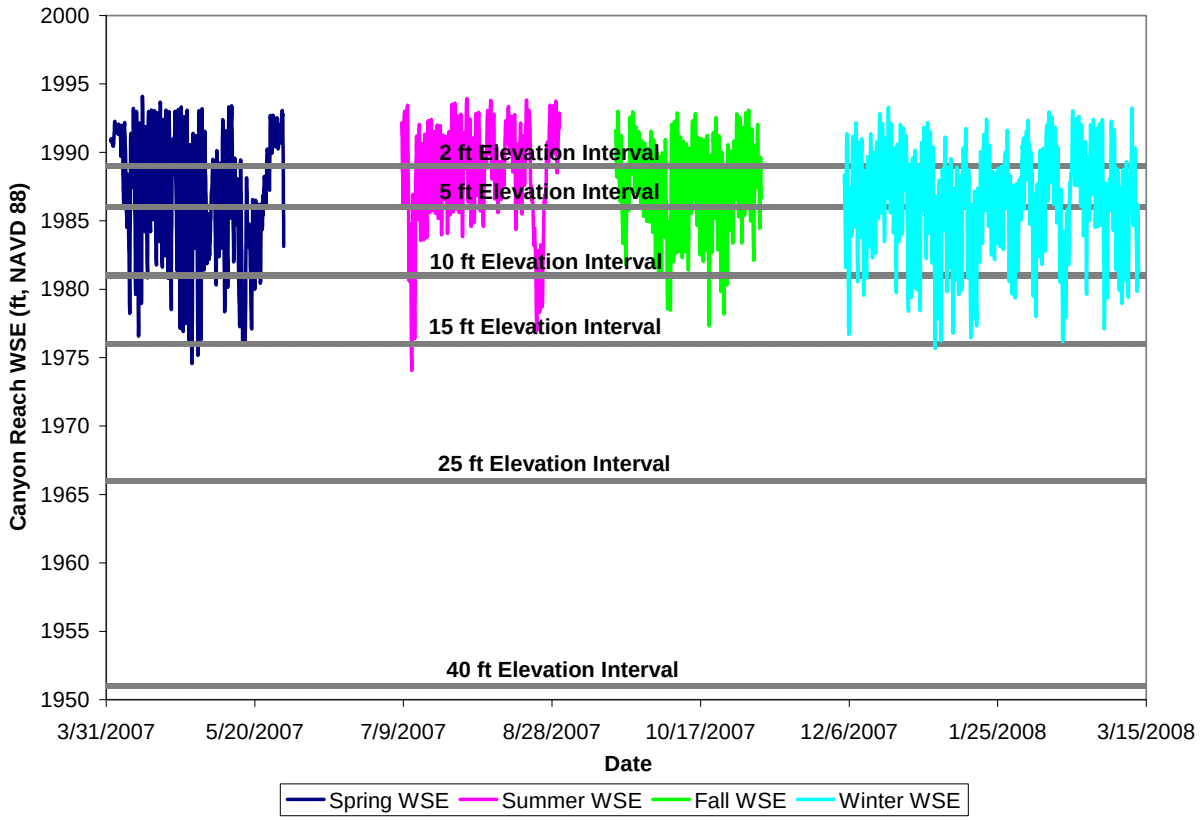


**Figure 6.1-3.** Canyon Reach (Boundary Reservoir) hourly water surface elevations compared to basket locations at shoreline and vertical treatment sites.

### 6.1.1. Vertical Treatment Sites

Figure 6.1-4 and Table 6.1-1 report the average BMI biomass (without *Hydra* sp.) in Canyon Reach vertical samples during all sampling seasons. The peak biomass during all seasons was observed at the 15-foot elevation interval (1,976 feet NAVD 88 [1,972 feet NGVD 29][1]), while the lowest production in Canyon Reach was observed at the 5-foot elevation interval (1,986 feet NAVD 88[ 1,982 feet NGVD 29]) during all seasons. Generally, biomass in Canyon Reach was lowest at all elevation intervals during the winter and highest at all elevation intervals, except at the 10-foot interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]), during the summer. Higher production occurred at the 10-foot elevation interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]) during the fall than in summer.

[1] SCL is in the process of converting all Project information from an older elevation datum (National Geodetic Vertical Datum of 1929 [NGVD 29]) to a more recent elevation datum (North American Vertical Datum of 1988 [NAVD 88]). As such, elevations are provided relative to both data throughout this document. The conversion factor between the old and new data is approximately 4 feet (e.g., the crest of the dam is 2,000 feet NGVD 29 and 2,004 feet NAVD 88).

Common taxa collected from vertical samples during spring, other than *Hydra*, were *Chironomidae* and *Ephemerella excrusians* in Canyon Reach. *Ephemerella excrusians* was the most common taxon found at all elevation intervals at Canyon Reach. The spring vertical samples also showed high numbers of *Simulium* at all elevation intervals except for the 2-foot interval (1,989 feet NAVD 88 [1,985 feet NGVD 29]).

Vertical samples collected from the Canyon Reach during the summer, was dominated by *Cladocera* at all elevation intervals except for 2 feet (1,989 feet, NAVD 88 [1,985 feet NGVD 29]), where *Porifera* dominated. *Polycentropous*, *Chironomidae*. *Hyalella*, *Gammarus*, and *Lymnaea* were also found to be among the most common taxa.

Fall collections of vertical samples from the Canyon Reach were dominated by, other than *Hydra* sp., *Oligochaeta*, *Gammarus*, and *Lymnaea spp.*. *Cladocera* was also commonly found at the 5-foot (1,986 feet NAVD 88), 10-foot (1,981 feet NAVD 88 [1,977 feet NGVD 29]), and 15-foot (1,976 feet NAVD 88 [1,972 feet NGVD 29]) elevation intervals. *Chironomidae* was prevalent in the Canyon Reach in the 25-foot and 40-foot (1,966 feet NAVD 88 [1,962 feet NGVD 29]) samples. The large-bodied *Valvata tricarinata* and Oligochaeta were the only taxa present at the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) elevation interval other than *Hydra*. Similarly, *Cheumatopsych*e and *Cladocera* were the only taxa found at the 5-foot elevation interval (1,986 feet NAVD 88 [1,982 feet NGVD 29]), other than *Hydra*.

The winter vertical samples collected in Canyon Reach had diminished diversity at the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) and the 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) elevation intervals, with only *Simulium* in the shallow depth, with addition of *Chironomidae* at the 5-foot depth interval. These two taxa were also found to be common at elevation intervals greater than 5 feet, in addition to *Gammarus*, *Nematoda*, *Oligochaeta*, and *Maccaffertium*.

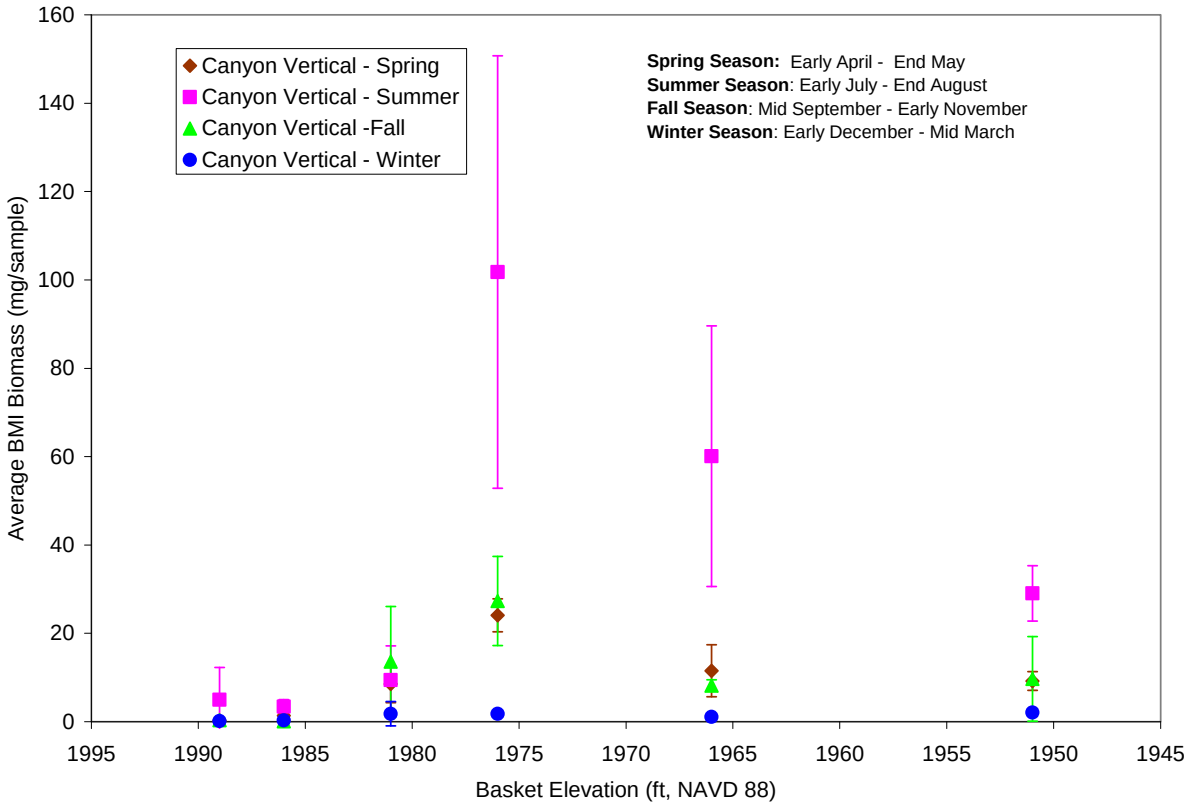


**Figure 6.1-4.** Average BMI biomass from the Canyon Reach vertical site in Boundary Reservoir 2007 and 2008.

**Table 6.1-1.** Summary of average BMI biomass (standard deviations) for the vertical site in the Canyon Reach, Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,989 (1,985) | 0.26 (0.44)[1] | 4.99 (7.27) | 0.34 (0.58)[1] | 0.14 (0.16)[1] |
| 5 | 1,986 (1,982) | 1.40 (0.08) | 3.44 (1.56) | 0.08 (0.14) | 0.30 (0.33)[1] |
| 10 | 1,981 (1,977) | 8.55 (4.21) | 9.45 (7.74) | 13.59 (12.51) | 1.80 (2.77) |
| 15 | 1,976 (1,972) | 24.09 (3.75) | 101.77 (48.93) | 27.32 (10.07) | 1.80 (0.52) |
| 25 | 1,966 (1,962) | 11.53 (5.89) | 60.11 (29.51) | 8.22 (1.27) | 1.10 (0.68) |
| 40 | 1,951 (1,947) | 9.21 (2.11) | 29.07 (6.26) | 9.70 (9.58) | 2.09 (0.88) |

Notes:
1 The samples were retrieved dry.
2 Winter BMI results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and validation of HSI curves.

Figure 6.1-5 and Table 6.1-2 illustrate the average BMI biomass (without *Hydra* sp.) in the Box Canyon vertical samples for each sampling season. The peak biomass during the spring and winter seasons was observed at the 2-foot elevation interval (2,031 feet NAVD 88 [2,027 feet NGVD 29]). In summer and fall, the peak biomass production in Box Canyon was observed at the 5-foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]). Generally, production appeared to be lowest during the spring and winter seasons, except at the 2-foot elevation interval (2,031 feet NAVD 88) [2,027 feet NGVD 29], where biomass was lowest during the summer season.

Spring vertical samples collected in Box Canyon were characterized by common taxa like *Chironomidae* and *Ephemerella excrusians*, including *Hydra* sp. *Ephemerella excrusians* was the prevalent at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]), 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]), and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation intervals. At the 2-foot elevation interval in Box Canyon, *Lynmaea spp*. was the most common taxon and *Chironomidae* was prevalent in the 20-foot (2,013 feet NAVD 88 [2,009 feet NGVD 29]) and 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) samples. Other common taxa found in the Box Canyon spring vertical samples included *Cheumatopsyche*, *Oligochaeta*, and *Coenagrion/Enallagma* (a large-bodied dragonfly).

The summer vertical hard substrate samples collected in Box Canyon showed *Lymnaea* as the most common taxon at the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) and 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) elevation intervals, while *Polycentropus* (a caseless caddisfly) was the most common taxon encountered at elevation intervals greater than 5 feet (2,028 feet NAVD 88 [2,024 feet NGVD 29]). Also commonly found in Box Canyon were *Chironomidae*, *Cheumatopsyche*, and *Helisoma anceps*.

The most common taxa, other than *Hydra* sp., collected in fall vertical samples were *Oligochaeta, Gammarus*, and *Lymnaea spp.* in Box Canyon. Chironomidae was prevalent at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]), 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]), and 20-foot (2,013 feet NAVD 88 [2,009 feet NGVD 29]) elevation intervals. The 10-foot (2,023 feet NAVD 88 [2,024 feet NGVD 29]) and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation intervals also showed *Polycentropus* and the 20-foot (2,013 feet NAVD 88 [2,009 feet NGVD 29]) and 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation intervals showed *Simulium* as prevalent.

The winter vertical samples collected in Box Canyon showed the most common taxa at the 2-foot elevation interval (2,031 feet NAVD 88 [2,027 feet NGVD 29]) to be *Ranatra*, along with *Gammarus* and *Lymnaea*. At elevation intervals greater than 2 feet (2,031 feet NAVD 88 [2,027 feet NGVD 29]), the most common taxa, other than *Hydra*, included *Gammarus, Lymnaea*, and *Chironomidae*. At the 20-foot elevation interval (2,013 feet NAVD 88 [2,009 feet NGVD 29]), *Nectopsyche* was also found to be abundant.

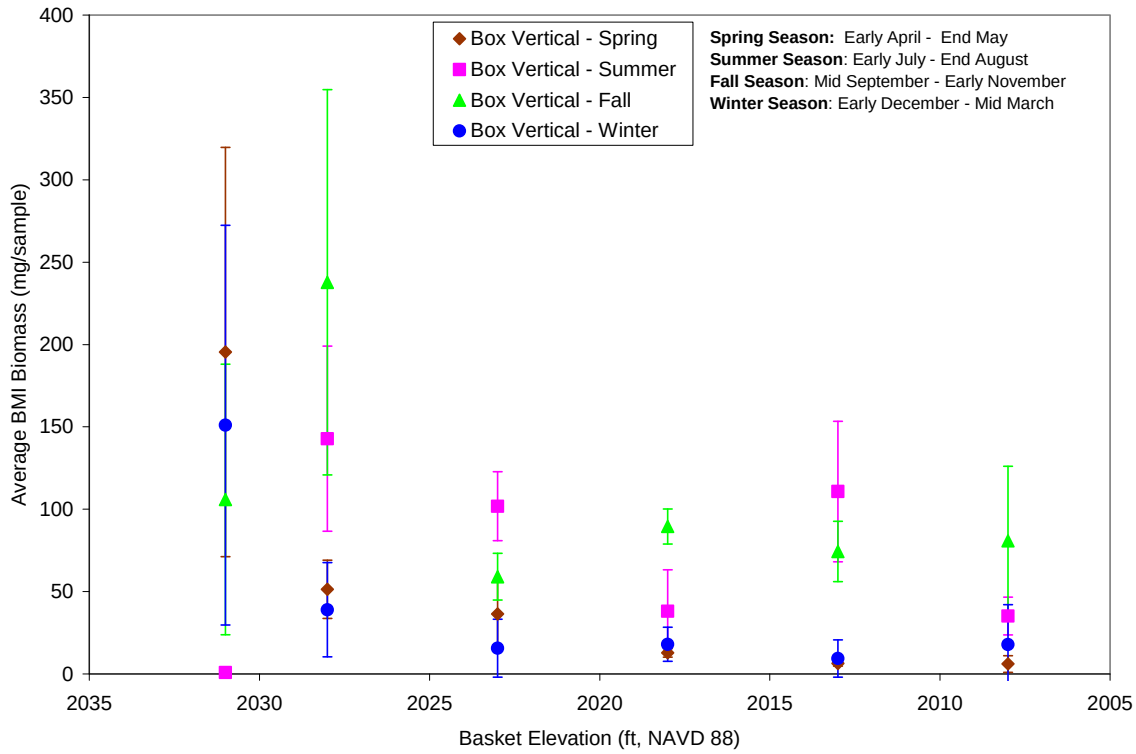


**Figure 6.1-5.** Average BMI biomass from the Box Canyon vertical site in Box Canyon Reservoir 2007 and2008.

**Table 6.1-2.** Summary of average BMI biomass (standard deviations in parentheses) for the vertical site in the Box Canyon Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft, NAVD 88 (ft, NGVD 20) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 2,031 (2,027) | 195.43 (124.2) | 0.81 (0.80)[1] | 105.95 (82.16)[1] | 151.05 (121.4)[1] |
| 5 | 2,028 (2,024) | 51.36 (17.7) | 142.82 (56.18) | 237.77 (116.89) | 38.98 (28.67) |
| 10 | 2,023 (2,019) | 36.48 (19.5) | 101.83 (20.86) | 59.05 (14.16) | 15.63 (17.59) |
| 15 | 2,018 (2,014) | 12.79 (2.61) | 38.03 (25.20) | 89.51 (10.64) | 17.93 (10.37) |
| 20 | 2,013 (2,009) | 6.39 (1.61) | 110.78 (42.67) | 74.31 (18.36) | 9.35 (11.30) |
| 25 | 2,008 (2,004) | 6.07 (5.06) | 35.20 (11.47) | 80.85 (45.20) | 17.87 (24.11) |

Notes:
1 The samples were retrieved dry.
2 Winter BMI results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and validation of HSI curves.

### 6.1.2. Shoreline Treatment Sites

Figure 6.1-6 and Table 6.1-3 illustrate the average BMI biomass (without *Hydra* sp.) in Canyon Reach shoreline samples during all sampling seasons. Peak biomass during the spring was observed at the 40-foot elevation interval (1,951 feet NAVD 88 [1,947 feet NGVD 29]), while it was at the 25-foot elevation interval (1,966 feet NAVD 88 [1,962 feet NGVD 29]) during the winter. In the summer and fall, peak production occurred at the 15-foot elevation interval (1,976 feet NAVD 88 [1,972 feet NGVD 29]). The lowest biomass produced during spring and winter was at the 10-foot interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]) and at the 2-foot interval (1,989 feet NAVD 88 [1,985 feet NGVD 29]) during summer. The lowest production during the winter season was seen from the 10-foot interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]) to the 2-foot interval (1,989 feet NAVD 88 [1,985 feet NGVD 29]). Generally across all seasons, biomass typically appeared to be higher at lower elevations and decreased significantly above the 10-foot elevation interval (1,981 feet NAVD 88 [1,977 feet NGVD 29]).

In the spring shoreline samples from Canyon Reach, no benthic macroinvertebrates were detected in the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) elevation interval. At the time of collection, the 2-foot elevation interval basket was exposed to the air, which may account for the lack of macroinvertebrates in the samples. At the other elevation intervals, the most common taxa, besides *Hydra*, were *Ephemerella excrusian*, *Lumbriculidae*, and *Caecidotea*. Other common taxa found included *Lymnaea auricularia*, *Physa*, *Gammarus*, and *Turbellaria*.

The summer shoreline samples collected in Canyon Reach showed that *Physa* (the environmentally tolerant snail) and *Polycentropus* were the most common taxa in the deeper samples. At shallower elevation intervals, *Cladocera*, *Hyalella*, and *Helisoma anceps* were found to be the most prevalent.

The fall shoreline samples from Canyon Reach showed *Cladocera* present in high numbers at all elevation intervals except 40 feet (1,951 feet NAVD 88 [1,947 feet NGVD 29]). *Physa* was one of the most common taxa found at intervals greater than 5 feet (1,986 feet NAVD 88 [1,982 feet NGVD 29]) and *Gammarus* was prevalent at elevation intervals greater than 10 feet (1,981 feet NAVD 88 [1,977 feet NGVD 29]). *Chironomidae* was one of the most common taxa encountered from the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) elevation interval to the 10-foot (1,981 feet NAVD 88 [1,977 feet NGVD 29]) elevation interval, and *Helisoma anceps* was only found to be abundant at the 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) elevation interval.

In the winter shoreline samples from Canyon Reach, no benthic macroinvertebrates were found at the 2-foot elevation interval (1,989 feet NAVD 88 [1,985 feet NGVD 29]) and only *Hydra* was found at the 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) and 10-foot (1,981 feet NAVD 88 [1,977 feet NGVD 29]) intervals. At the time of collection, the 2-foot (1,989 feet NAVD 88 [1,987 feet NGVD 29]) and 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) elevation interval baskets were exposed to the air, which may account for the lack of macroinvertebrates in the samples. *Gammarus* was found to be the most common taxa at the 15-foot (1,976 feet NAVD 88 [1,972 feet NGVD 29]) and 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) intervals, while *Physa* was prevalent at the 15-foot (1,976 feet NAVD 88 [1,972 feet NGVD 29]) and 25-foot (1,966 feet NAVD 88 [1,962 feet NGVD 29]) elevation intervals.

*Caecidotea* was common at elevation intervals greater than 10 ft and *Chironomidae* was common at the 25-foot (1,966 feet NAVD 88 [1,962 feet NGVD 29]) and 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) elevation intervals.

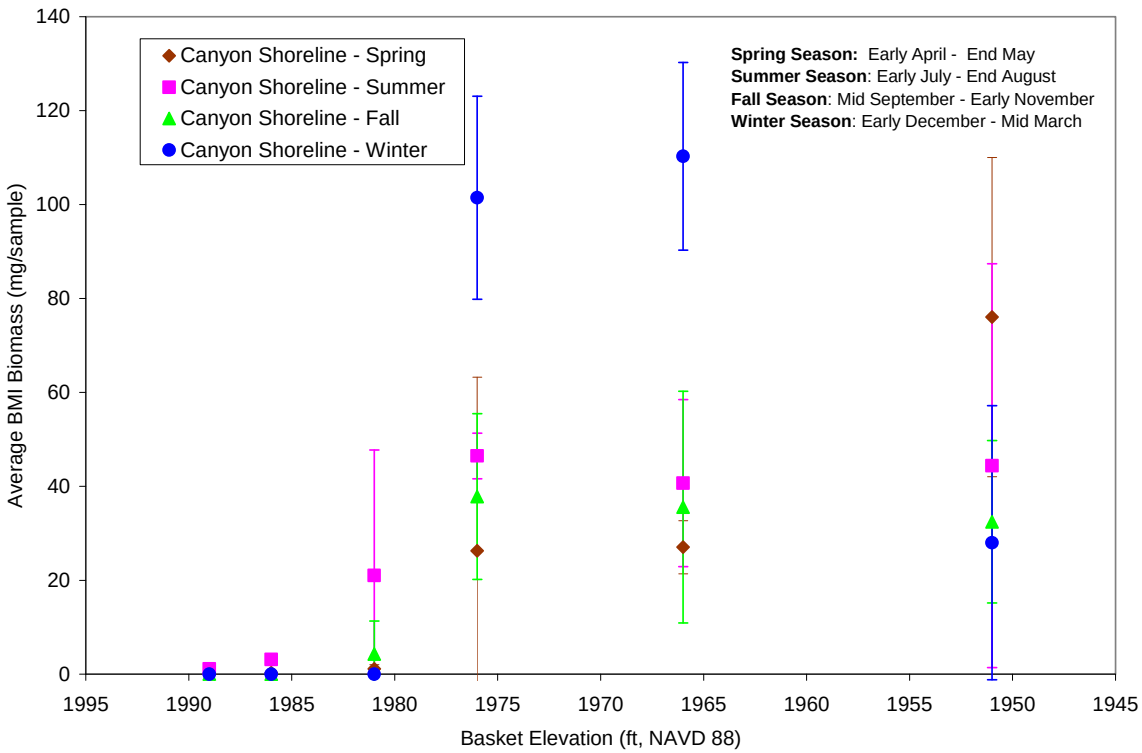


**Figure 6.1-6.** Average BMI biomass from the Canyon Reach shoreline site in Boundary Reservoir 2007 and 2008.

**Table 6.1-3.** Summary of average BMI biomass (standard deviations) for the shoreline site in the Canyon Reach, Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,989 (1,985) | 0.00 (0.00)[1] | 1.13 (0.83) | 0.04 (0.01)[1] | 0.00[1] |
| 5 | 1,986 (1,982) | 0.32 (0.40)[1] | 3.11 (1.14) | 0.01 (0.02)[1] | 0.00[1] |
| 10 | 1,981 (1,977) | 1.13 (0.87) | 21.01 (26.73) | 4.29 (7.03) | 0.00 |
| 15 | 1,976 (1,972) | 26.27 (36.99) | 46.47 (4.84) | 37.80 (17.66) | 101.45 |
| 25 | 1,966 (1,962) | 27.03 (5.66) | 40.67 (17.81) | 35.60 (24.67) | 110.29 |
| 40 | 1,951 (1,947) | 76.03 (33.96) | 44.39 (43.02) | 32.45 | 27.98 |

Notes:
1 The samples were retrieved dry.
2 Winter BMI results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and validation of HSI curves.

Figure 6.1-7 and Table 6.1-4 illustrate the average BMI biomass (without *Hydra* sp.) in the Metaline Reach shoreline samples during all sampling seasons. Peak biomass during summer and winter occurred at the 40-foot elevation interval (1,958 feet NAVD 88 [1,954 feet NGVD 29]), while during spring and fall, peak production was found at the 15-foot elevation interval (1,983 feet NAVD 88 [1,979 feet NGVD 29]). During winter, the lowest average biomass occurred at higher elevations between the 10-foot (1,988 feet NAVD 88 [1,984 feet NGVD 29]) and 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) elevation intervals. The lowest production during spring and summer occurred at the 5-foot interval (1,993 feet NAVD 88 [1,989 feet NGVD 29]), while the lowest biomass found during fall was at the 25-foot interval (1,973 feet NAVD 88 [1,969 feet NGVD 29]). In Metaline Reach, the lowest productivity at all elevation intervals appeared to occur during the winter season, while the highest productivity was generally found to be in the spring. At the 40-foot interval (1,958 feet NAVD 88 [1,954 feet NGVD 29]), however, the highest productivity was during summer.

In the spring shoreline samples from Metaline Reach, *Chrionomidae* was the only taxon found in the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) elevation intervals other than *Hydra*. At other elevation intervals, the most common taxa encountered, other than *Hydra*, were *Cheumatopsyche*, *Chironomidae*, and *Ephemerella excrusians*. *Oligochaeta* was also prevalent at the 10-foot elevation interval.

In the summer shoreline samples from Metaline Reach, *Cheumatopsyche* was very abundant at 40 ft (1,958 feet NAVD 88 [1,954 feet NGVD 29]), with *Ophiogomphus occidentis* and *Physa* also being common at elevation intervals of 15 ft (1,983 feet NAVD 88 [1,979 feet NGVD 29]) or greater. At shallower elevation intervals, *Cladocera*, *Lymnaea*, *Gammarus*, *Polycentropus*, *Chironomidae* were the most commonly encountered taxa. Also found to be abundant in Metaline Reach were *Cheumatopsyche* and *Hydropsyche*.

In the fall shoreline samples from Metaline Reach, no benthic macroinvertebrates were detected at the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) elevation intervals. At the time of collection, the 2-foot elevation interval basket was exposed to the air, which may account for the lack of macroinvertebrates in the samples. At all other elevation intervals in Metaline Reach, *Oligochaeta* was found to be among the most common taxa. *Lymnaea* was prevalent at elevation intervals greater than 5 ft (1,993 feet NAVD 88 [1,989 feet NGVD 29]), and *Hydropsyche* was common in the 15-foot (1,983 feet NAVD 88 [1,979 feet NGVD 29]) and 40-foot (1,958 feet NAVD 88 [1,954 feet NGVD 29]) elevation intervals. Other common taxa found in Metaline Reach included *Acari*, *Physa*, and *Cheumatopsyche*.

*Chironomidae* was found to be abundant at all elevation intervals in Metaline Reach winter shoreline samples. *Simulium* was commonly found in Metaline Reach at the 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]), 10-foot (1,988 feet NAVD 88 [1,984 feet NGVD 29]), 15-foot (1,983 feet NAVD 88 [1,979 feet NGVD 29]), and 40-foot (1,958 feet NAVD 88 [1,954 feet NGVD 29]) elevation intervals. Other common taxa found in the winter samples, besides *Hydra*, included *Lymnaea*, *Ceraclea*, *Oligochaeta*, and *Ophiogomphus occidentis*.

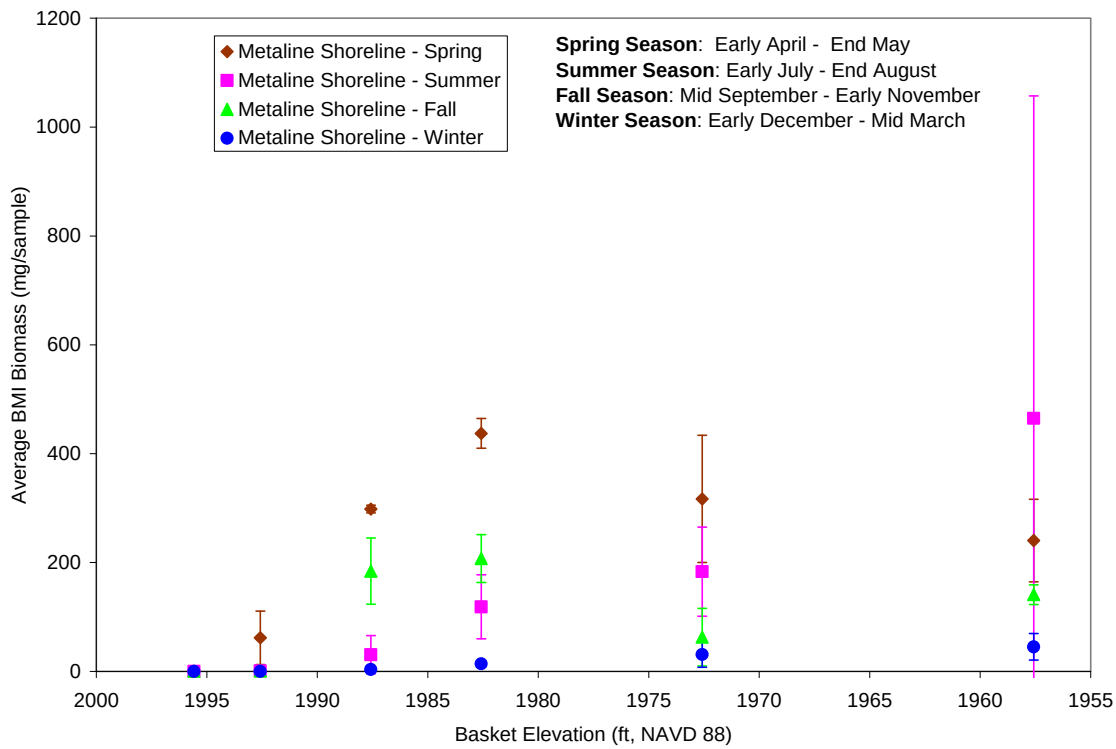


**Figure 6.1-7.** Average BMI biomass from the Metaline Reach shoreline site in Boundary Reservoir 2007 and 2008

**Table 6.1-4.** Summary of average BMI biomass (standard deviations) for the shoreline site in the Metaline Reach, Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 1,996 (1,992) | 0.03 (0.03)[1] | 0.07 (0.09)[1] | 0.31 (0.43)[1] | 0.01 (0.02)[1] |
| 5 | 1,993 (1,989) | 61.70 (48.97)[1] | 1.23 (2.10) | 0.73 (0.79)[1] | 0.08 (0.07)[1] |
| 10 | 1,988 (1,984) | 298.24 (7.11) | 30.87 (34.96) | 184.24 (60.87) | 3.70 (1.36) |
| 15 | 1,983 (1,979) | 437.35 (27.26) | 118.59 (58.69) | 207.29 (43.86) | 13.94 (5.08) |
| 25 | 1,973 (1,969) | 316.89 (116.88) | 183.44 (81.88) | 62.95 (52.97) | 31.20 (23.42) |
| 40 | 1,958 (1,954) | 240.41 (76.05) | 464.93 (592.35) | 140.98 (17.96) | 45.18 (24.52) |

Notes:
1 The samples were retrieved dry.
2 Winter BMI results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and validation of HSI curves.

Figure 6.1-8 and Table 6.1-5 illustrate the average BMI biomass (without *Hydra* sp.) in the Box Canyon shoreline samples during all sampling seasons. Biomass peaked during the summer at the 25-foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]), during the fall and

winter at the 15-foot interval (2,018 feet NAVD 88 [2,014 feet NGVD 29]), and during the spring at the 2-foot elevation interval (2,031 feet NAVD 88 [2,027 feet NGVD 29]). The lowest production observed during spring and fall was at the 40-foot elevation interval (1,993 feet NAVD 88 [1,989 feet NGVD 29]) and at the 2-foot elevation interval (2,031 feet NAVD 88 [2,027 feet NGVD 29]) during summer and winter. Biomass was generally lowest during the winter season at all elevation intervals.

The spring shoreline samples collected in Box Canyon revealed that *Ephemerella excrusian* was the most common taxon found at most elevation intervals, with the exception of the 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) and 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) intervals. At the 10-foot elevation interval (2,023 feet NAVD 88 [2,019 feet NGVD 29]), *Caecidotea* was most abundant, while *Ophiogomphus occidentis* was most common at the 25-foot elevation interval (2,008 feet NAVD 88 [2,004 feet NGVD 29]).

The summer shoreline samples collected in Box Canyon showed *Polycentropus* as the most abundant taxon from the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) to the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval, while *Cheumatopsyche* was most common in the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) and 40-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) intervals. Also commonly found in the Box Canyon Summer shoreline samples were *Chironomidae*, *Macromia magnifica*, *Porifera*, *Caecidotea*, and *Ophiogomphus occidentis*.

In the fall shoreline samples collected in Box Canyon, *Oligochaeta* was the most common taxon found at most elevation intervals, with the exception of the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) and 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) elevation intervals. At those elevation intervals, *Caecidotea* was most abundant. *Polycentropus* was commonly found at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]), 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]), and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation intervals, while *Porfiera* was only found to be prevalent at the 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) elevation interval. Other common taxa found in Box Canyon, other than *Hydra*, included *Chironomidae*, *Helisoma anceps*, and *Cladocera*.

In Box Canyon, the winter shoreline samples showed *Simulium* to be prevalent at elevation intervals greater than 10 ft (2,023 feet NAVD 88 [2,019 feet NGVD 29]), *Ceraclea* to be common in the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) and 40-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) intervals, and *Gammarus* in high numbers in the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation intervals. Other common taxa found in Box Canyon included *Hyalella*, *Nectopsyche*, and *Porifera*.

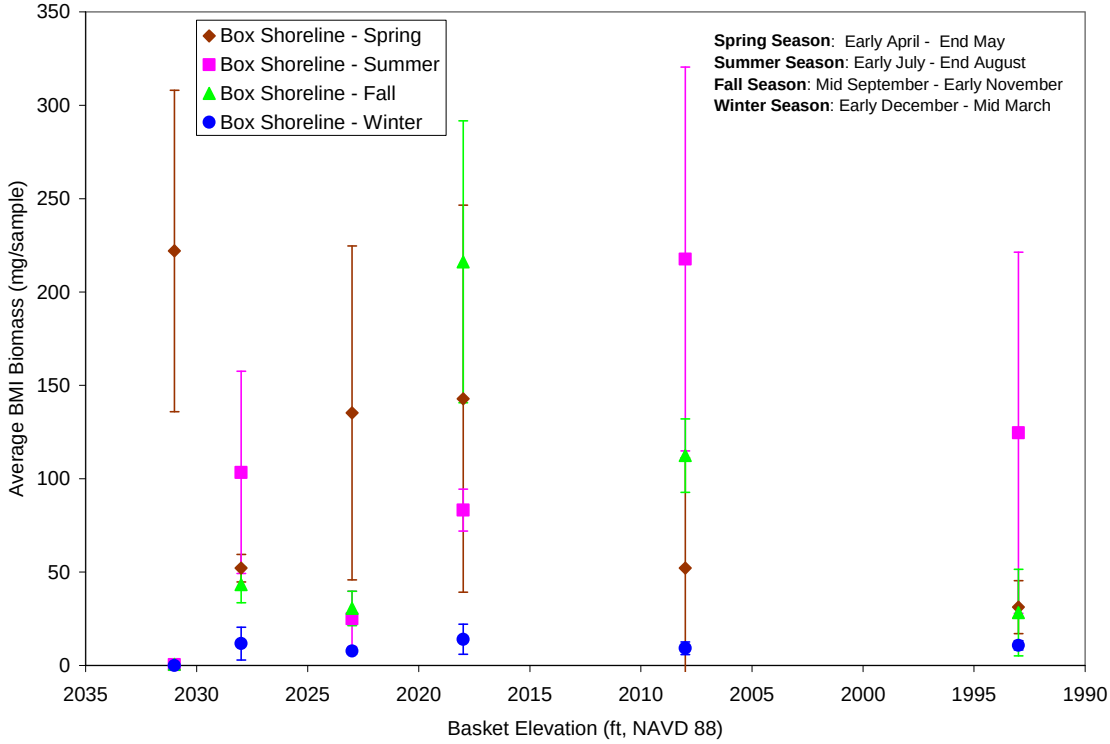


**Figure 6.1-8.** Average BMI biomass from the Box Canyon shoreline site in the Box Canyon Reservoir 2007 and 2008.

**Table 6.1-5.** Summary of average BMI biomass (standard deviations) for the shoreline site in the Box Canyon Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter[2] |
| 2 | 2,031 (2,027) | 222.00 (86.05) | 0.39 (0.46)[1] | 0.60 (0.48) [1] | 0.03 (0.05) [1] |
| 5 | 2,028 (2,024) | 52.14 (7.38) | 103.42 (52.21) | 43.29 (9.64) | 11.71 (8.82) |
| 10 | 2,023 (2,019) | 135.25 (89.44) | 24.98 (14.84) | 30.57 (9.19) | 7.79 (1.65) |
| 15 | 2,018 (2,014) | 142.87 (103.63) | 83.20 (11.17) | 216.14 (75.51) | 14.06 (8.06) |
| 25 | 2,008 (2,004) | 52.13 (58.98 | 217.65 (102.78) | 112.39 (19.70) | 9.23 (3.43) |
| 40 | 1,993 (1,989) | 31.23 (14.19) | 124.62 (96.68) | 28.34 (23.20) | 10.78 (2.52) |

Notes:
1 The samples were retrieved dry.
2 Winter BMI results are not comparable to other seasons due to the longer exposure time period. Winter results were disregarded from analysis and validation of HSI curves.

## 6.2. BMI Communities on Soft Substrate

Figure 6.2-1 and Table 6-2.1 illustrate the average BMI biomass (without *Hydra* sp.) in Canyon Reach soft substrate samples during all sampling seasons. Peak biomass in Canyon Reach was found to be at the 25-foot elevation interval (1,966 feet NAVD 88 [1,962 feet NGVD 29]) during all seasons, while the lowest production was at the 2-foot elevation interval (1,989 feet NAVD 88 [1,985 feet NGVD 29]) during all seasons. During winter, biomass was equally low at the 10-foot (1,981 feet NAVD 88 [1,977 feet NGVD 29]) and 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) intervals.

The spring soft substrate samples taken in Canyon Reach showed *Oligochaeta*, *Chironomidae*, and *Lumbriculidae* as the most common taxa at all elevation intervals, with the exception of the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) elevation interval. No benthic macroinvertebrates were found at the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) elevation interval sediment sample. Other common taxa in Canyon Reach included *Pisidium* and *Nematoda*.

The summer soft substrate samples showed *Oligochaeta* as one of the top three most abundant taxa in the Canyon Reach at all elevation intervals. *Chironomidae* was also found to be common at all elevation intervals, except for at the 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) interval. *Cladocera*, *Lymnaea*, *Nematoda*, *Erpobdellidae*, *Hyalella*, and *Sialis* were also abundant in the summer Canyon Reach soft substrate samples.

In the fall soft substrate samples from Canyon Reach, *Porifera* was the only taxa found at the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) interval and it was also one of the most common taxa at the 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]), 15-foot (1,976 feet NAVD 88 [1,972 feet NGVD 29]), and 25-foot (1,966 feet NAVD 88 [1,962 feet NGVD 29]) elevation intervals. *Lymnaea* was the only other taxon found at the 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) elevation intervals. *Oligochaeta* was the only taxon found at the 10-foot interval in Canyon Reach. *Chironomidae* was commonly found at elevation intervals greater than 10 ft (1,981 feet NAVD 88 [1,977 feet NGVD 29]) in Canyon Reach and *Nematoda* was only present in high numbers at the 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) elevation interval.

The winter soft substrate samples collected in Canyon Reach showed no benthic macroinvertebrates at the 10-foot (1,981 feet NAVD 88 [1,977 feet NGVD 29]) elevation intervals. *Oligochaeta* sas the only taxon identified at the 2-foot (1,989 feet NAVD 88 [1,985 feet NGVD 29]) and 5-foot (1,986 feet NAVD 88 [1,982 feet NGVD 29]) elevation intervals and it was also one of the most common taxa at the 15-foot (1,976 feet NAVD 88 [1,972 feet NGVD 29]), 25-foot (1,966 feet NAVD [1,962 feet NGVD 29]), and 40-foot (1,951 feet NAVD 88 [1,947 feet NGVD 29]) elevation intervals. Other common taxa found in the winter samples from Canyon Reach included *Sialis*, *Hyalella*, and *Porifera*.

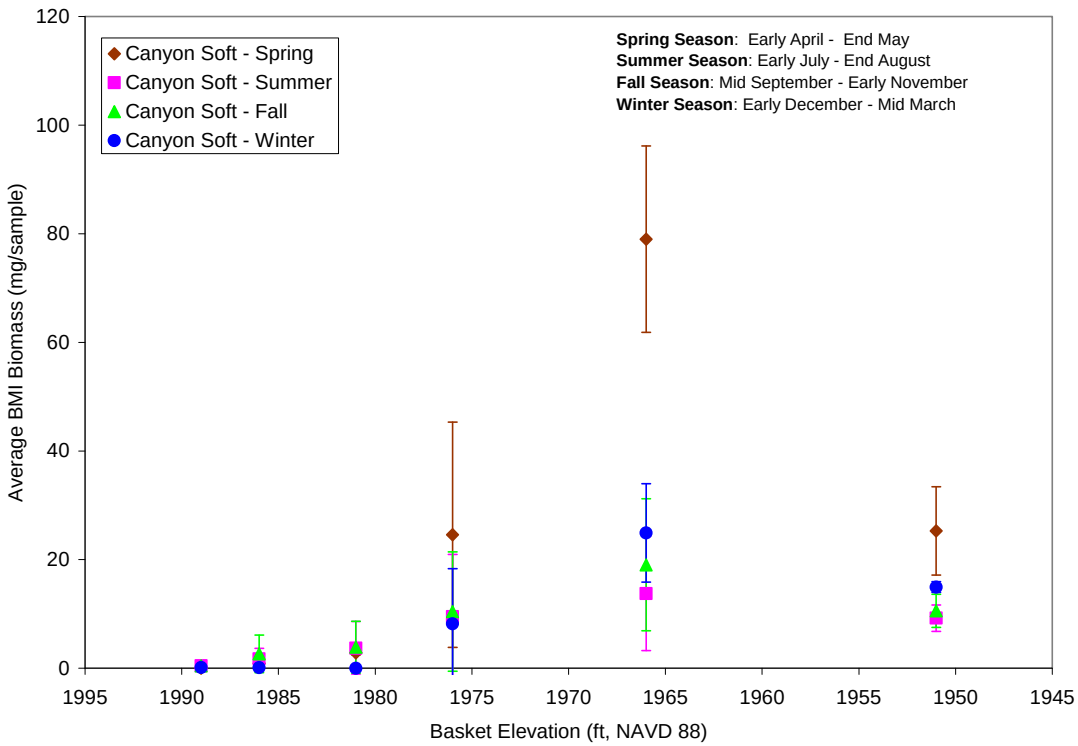


**Figure 6.2-1.** Average BMI biomass from the Canyon Reach soft sediment site in the Boundary Reservoir, 2007 and 2008.

**Table 6.2-1.** Summary of average BMI biomass (standard deviations) for the soft sediment treatment site in the Canyon Reach, Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter |
| 2 | 1,989 (1,985) | 0.00 (0.00)[1] | 0.44 (0.43) | 0.45 (0.43) | 0.14 (0.24)[1] |
| 5 | 1,986 (1,982) | 0.88 (0.21)[1] | 1.73 (1.92) | 2.65 (3.46) | 0.10 (0.16)[1] |
| 10 | 1,981 (1,977) | 2.82 (0.34)[1] | 3.69 (4.91) | 3.86 (4.76) | 0.00 (0.00) |
| 15 | 1,976 (1,972) | 24.60 (20.74) | 9.52 (11.44) | 10.42 (10.98) | 8.21 (10.12) |
| 25 | 1,966 (1,962) | 79.00 17.16) | 13.74 (10.51) | 19.05 (12.15) | 24.91 (9.04) |
| 40 | 1,951 (1,947) | 25.29 (8.12) | 9.22 (2.45) | 10.59 (3.05) | 14.94 (0.99) |

Note:
1 The samples were retrieved dry.

Figure 6.2-2 and Table 6.2-2 illustrate the average BMI biomass (without *Hydra* sp.) in the Metaline Reach soft substrate samples during all sampling seasons. Peak biomass was observed at the 2-foot elevation interval (1,996 feet NAVD 88 [1,992 feet NGVD 29]) in spring, the 10-foot elevation interval (1,988 feet NAVD 88 [1,984 feet NGVD 29]) in summer and fall, and at the 25-foot elevation interval (1,973 feet NAVD 88 [1,969 feet NGVD 29]) during winter. An

average biomass of zero was found for all seasons at the 40-foot (1,958 feet NAVD 88 [1,954 feet NGVD 29]) elevation interval, during spring at the 25-foot (1,973 feet NAVD 88 [1,969 feet NGVD 29]) interval, and during all seasons except for spring at the 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) and 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) intervals.

In the spring soft sediment samples collected in Metaline Reach, *Oligochaeta* as one of the three most common taxa at all elevation intervals except for the 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) inteval, where *Lymnaea* was most common, along with *Ceratopogoninae* and *Epitheca spinigera. Lumbriculidae, Acari, Chironomidae,Cheumatopsyche, Nematoda,* and *Ephemerella excrusians* were also among the most common taxa found.

In Metaline Reach, no benthic macroinvertebrates were found at the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]), 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]), or 40-foot elevation interval samples collected during the summer. At the time of collection, the water level in the Metaline Reach was low enough that the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) and 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) elevation intervals were above the water surface level, which may account for the lack of macroinvertebrates in those samples. The 10-foot (1,988 feet NAVD 88 [1,984 feet NGVD 29]), 15-foot (1983 feet NAVD 88 [1,979 feet NGVD 29]), and 25-foot (1,973 feet NAVD 88 [1,969 feet NGVD 29]) elevation interval samples showed *Chironomidae*, *Dubiraphia*, and *Hyalella* as common taxa, in addition to *Oligochaeta*.

In the fall soft substrate samples collected in Metaline Reach, *Nematoda* and *Oligochaeta* were the only two taxa identified at the 2-foot elevation interval (1,996 feet NAVD 88 [1,992 feet NGVD 29]) and *Oligochaeta* was the only taxon found at the 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) interval. At the time of collection, the water level in the Metaline Reach was low enough that the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) and 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) elevation intervals were above the water surface level, which may account for the low number of taxa in those samples. *Chironomidae* was found in abundance at the deeper elevation intervals of 10 feet (1,988 feet NAVD 88 [1,984 NGVD 29]), 15 feet (1,983 feet NAVD 88 [1,979 feet NGVD 29]), and 25 feet (1,973 feet NAVD 88 [1,969 feet NGVD 29]). Other common taxa found in Metaline Reach in the fall samples included *Ceratopogoninae, Hyalella*, and *Pisidium*.

In the winter soft substrate samples, no benthic macroinvertebrates were found at the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) and 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) elevation intervals in the Metaline Reach. At the time of collection, the water level in the Metaline Reach was low enough that the 2-foot (1,996 feet NAVD 88 [1,992 feet NGVD 29]) and 5-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) intervals were above the water surface level, which may account for the lack of macroinvertebrates in those samples. *Oligochaeta* and *Chironomidae* were among the most common taxa found at the 10-foot (1,988 feet NAVD 88 [1,984 feet NGVD 29]), 15-foot (1,983 feet NAVD 88 [1,979 feet NGVD 29]), and 25-foot (1,973 feet NAVD 88 [1,969 feet NGVD 29]) elevation intervals. *Lymnaea auricula* was prevalent at the 15-foot interval and *Caecidotea* was present in high numbers at the 25-foot (1,973 feet NAVD 88 [1,969 feet NGVD 29]) interval. *Dubiraphia* was also commonly found in

the Metaline Reach at the 10-foot elevation interval (1,988 feet NAVD 88 [1,984 feet NGVD 29]).

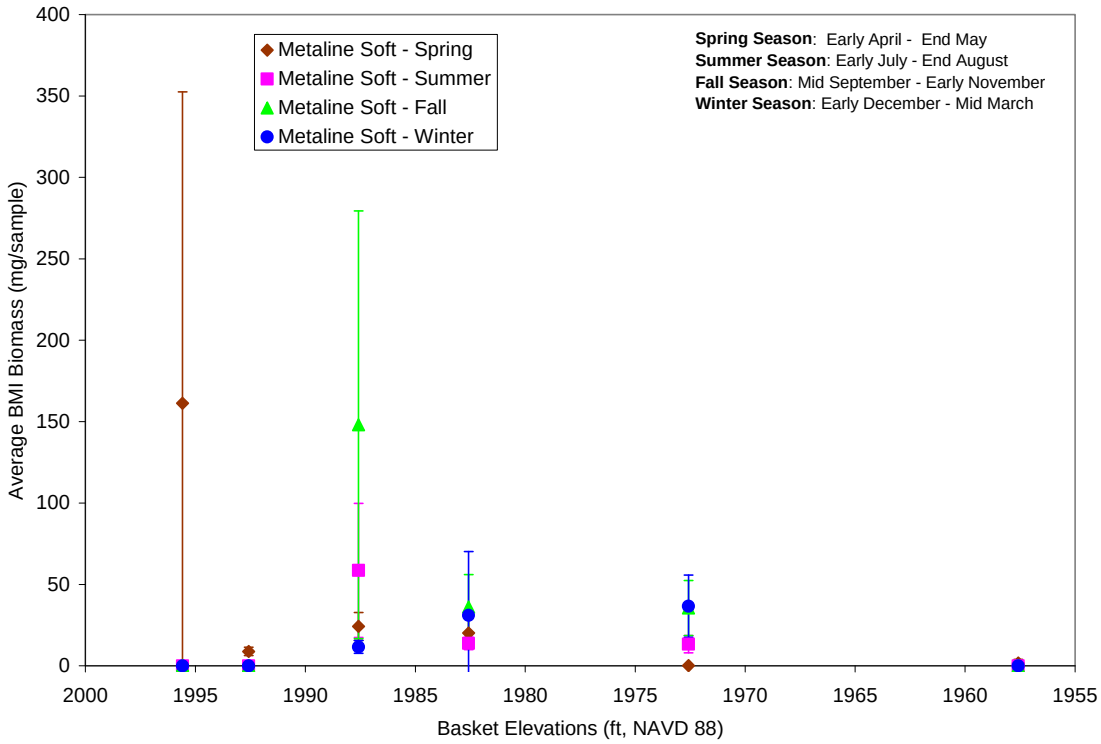


**Figure 6.2-2.** Average BMI biomass from the Metaline Reach soft sediment site in the Boundary Reservoir, 2007 and 2008.

**Table 6.2-2.** Summary of average BMI biomass (standard deviations) for the soft sediment treatment site in the Metaline Reach, Boundary Reservoir, 2007 and 2008.

| Elevation Interval | Basket Elevation ft NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter |
| 2 | 1,996 (1,992) | 161.20 (191.35)[1] | 0.00 (0.00)[1] | 0.25 (0.27)[1] | 0.00 (0.00)[1] |
| 5 | 1,993 (1,989) | 8.86 (2.51) | 0.00 (0.00)[1] | 0.13 (0.22)[1] | 0.00 (0.00)[1] |
| 10 | 1,988 (1,984) | 24.22 (8.61) | 58.59 (41.22) | 148.03 (131.31) | 11.59 (3.89) |
| 15 | 1,983 (1,979) | 20.09 (9.04) | 13.79 (3.80) | 36.09 (19.94) | 31.06 (39.17) |
| 25 | 1,973 (1,969) | 0.15 (0.13) | 13.28 (5.31) | 35.56 (16.91) | 36.66 (19.15) |
| 40 | 1,958 (1,954) | 1.74 (2.24) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) |

Note:
1 The samples were retrieved dry.

Figure 6.2-3 and Table 6.2-3 illustrate the average BMI biomass (without *Hydra* sp.) in the Box Canyon soft substrate samples during all sampling seasons. Biomass peaked during the summer and fall at an elevation interval of 10 feet (2,023 feet NAVD 88 [2,019 feet NGVD 29]) and during spring and winter at the 5 feet (2,028 feet NAVD 88 [2,024 feet NGVD 29]) interval. The lowest production during spring and winter was found at the 40-foot elevation interval (1,993 feet NAVD 88 [1,989 feet NGVD 29]), at the 5-foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]) during summer, and at the 2-foot elevation interval (2,031 feet NAVD 88 [2,027 feet NGVD 29]) during fall. Generally, biomass production appeared to be lowest during the summer season at all elevations except for the 40-foot elevation interval (1,993 feet NAVD 88 [1,989 feet NGVD 29]). Similarly, productivity was highest during the spring at all elevations except for the 40-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) and 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) elevation intervals.

In Box Canyon, the spring soft sediment samples showed *Chironomidae* among the most common taxon at all elevation intervals except for the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) and 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) intervals. At the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) elevation interval, *Oligochaeta* was the most common taxon, while *Lymnaea auricularia* was most prevalent at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) interval. Other common taxa in the Box Canyon spring soft substrate samples included *Hyalella*, *Lumbriculidae*, *Ephemerella excrusians*, *Caecidotea*, and *Gammarus* at shallower elevation intervals and *Nectophsyche* and *Nematoda* in the deeper samples.

The summer soft substrate samples showed *Oligochaeta* as one of the top three most abundant taxa in Box Canyon at all elevation intervals, except for at the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) interval. At the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) interval, only one taxon was present, which was *Dolichopodidae.* At the time of collection, a slightly lower water level in Box Canyon exposed the 2-foot (2,031 feet NAVD 88) [2,027 feet NGVD 29] elevation interval, which likely accounts for only one taxon being present in the samples. Other common taxa found in the Box Canyon samples included *Chironomidae, Dubiraphia*, *Hyalella*, *Harpacticoida*, *Physa*, and *Caecidotea*.

The fall soft substrate samples collected in Box Canyon showed *Oligochaeta* as one of the most common taxa and the only taxon found at the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) interval. *Chironomidae* and *Caenis* were also found to be prevalent in Box Canyon at the 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation intervals, while *Nematoda* was one of the most common taxa at the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) and 40-foot (1,993 feet NAVD 88 [1,989 feet NGVD 29]) intervals. *Porifera* was among the most common taxa at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) and 25-foot (2,008 feet NAVD 88 [2,008 feet NGVD 29]) elevation intervals and *Dubiraphia* was abundant at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) interval.

In the winter soft substrate samples collected in Box Canyon, *Chironomidae* was among the most common taxa at all elevation intervals, except for the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) interval. *Proifera* and *Dubiraphia* were the only two taxa identified at the 2-foot (2,031 feet NAVD 88 [2,027 feet NGVD 29]) elevation interval and *Dubiraphia* was also

prevalent at the 5-foot interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]). At the 10-foot (2,023 feet NAVD 88 [2,019 feet NGVD 29]) and 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) intervals, *Caecidotea* was one of the most common taxa and *Nectopsyche* was most abundant at the 25-foot (2,008 feet NAVD 88 [2,004 NGVD 29]) interval. Other common taxa found in Box Canyon included *Oligochaeta*, *Epitheca spinigera*, *Hyalella*, and *Ephemerella excrusians*.

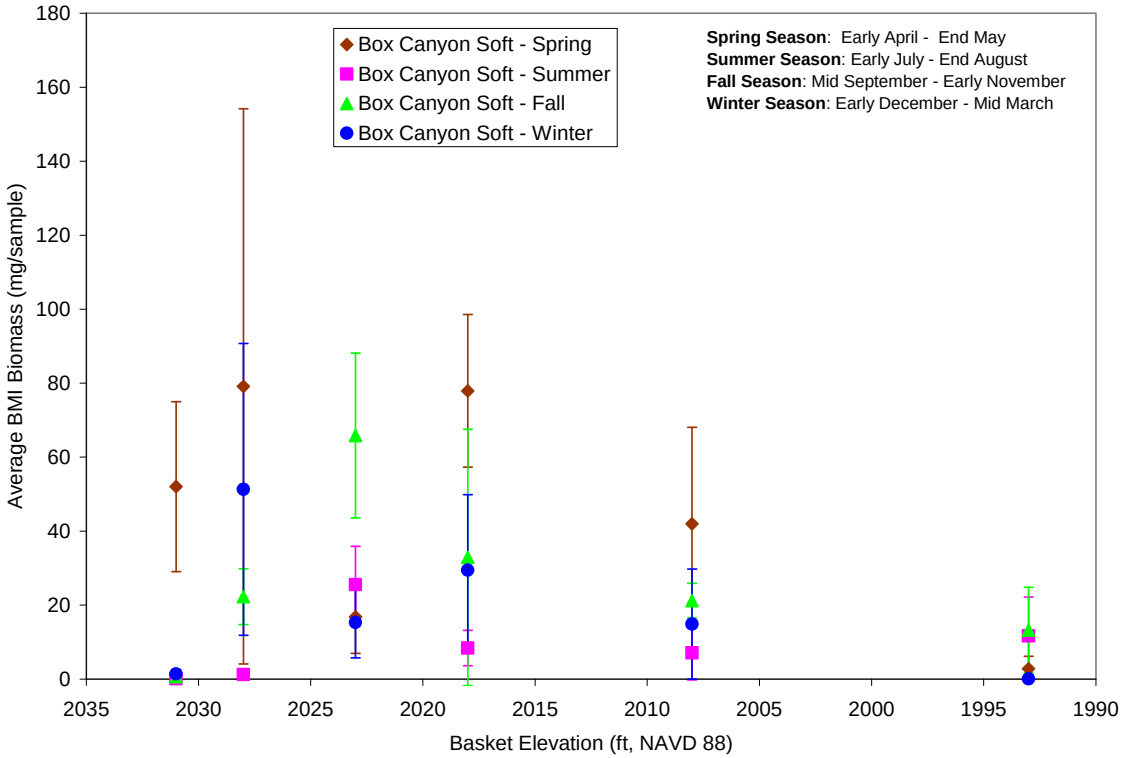


**Figure 6.2-3.** Average BMI biomass from the Box Canyon Reach soft sediment site in the Box Canyon Reservoir, 2007 and 2008.

**Table 6.2-3.** Summary of average BMI biomass (standard deviations) for the soft sediment treatment site in Box Canyon Reservoir, 2007 and 2008.

| Elevation Interval | Box Canyon Basket Elevation, ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) with (Standard Deviations) | | | |
|---|---|---|---|---|---|
| | | Spring | Summer | Fall | Winter |
| 2 | 2,031 (2,027) | 52.04 (22.95) | 0.06 (0.05)[1] | 0.60 (0.88) [1] | 1.37 (1.19) [1] |
| 5 | 2,028 (2,024) | 79.12 (75.05) | 1.24 (1.05) | 22.30 (7.56) | 51.29 (39.47) |
| 10 | 2,023 (2,019) | 16.80 (9.85) | 25.54 (10.35) | 65.86 (22.26) | 15.30 (9.55) |
| 15 | 2,018 (2,014) | 77.93 (20.66) | 8.40 (4.77) | 32.89 (34.66) | 29.45 (20.42) |
| 25 | 2,008 (2,004) | 41.95 (26.10) | 7.10 (7.33) | 21.19 (4.71) | 14.86 (14.88) |
| 40 | 1,993 (1,989) | 2.79 (3.37) | 11.66 (10.51) | 13.26 11.57) | 0.07 (0.09) |

Note:
1 The samples were retrieved dry.

## 6.3. BMI Colonization Rates

This section of the report describes results of BMI colonization sampling conducted in Box Canyon Reservoir. Sample collection was conducted in September 2007 and March 2008. The results from sampling are discussed below and are illustrated in Figures 6.3-1 through 6.3-4. Tables 6.3-1 and 6.3-2 contain numerical results from samples collected during specific time intervals and from three deployment elevations in 2007 and 2008.

Figure 6.3-1 illustrates the average biomass for the colonization samples collected during the summer 2007 season. The summer colonization samples reflect that at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) elevation interval, biomass generally increases with exposure time up to 28 days. After 28 days, biomass appears to decrease and then level off. At the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval, biomass initially increases in the first 7 days, and then slightly decreases with exposure between 7 and 14 days. With greater than 14 days of exposure, total biomass continually rises, with the greatest increase between 42 and 56 days of exposure. The 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval samples show an increasing trend at all exposure periods, with the most marked increases in the first 7 days and the period from 42 to 56 days. The rate of BMI colonization during the summer season is highest at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) elevation interval and lowest at the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval, although the variation between elevation intervals is fairly small (Figure 5.3-1). Table 6.3-1 provides the actual numerical results in terms of average biomass observed at each elevation interval for each exposure period.

**Table 6.3-1**. Average summer BMI biomass and colonization rates per elevation, elevation interval and number of days incubated in Box Canyon Reservoir.

| Date Retrieved | No. of Days Exposed | Elevation Interval | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) | BMI Colonization Rate (mg/sample-day) |
|---|---|---|---|---|---|
| 8/31/07 | 56 | 5 | 2,028 (2,024) | 131.41 | 2.35 |
| | | 15 | 2,018 (2,014) | 585.31 | 10.45 |
| | | 25 | 2,008 (2,004) | 678.44 | 12.12 |
| | 42 | 5 | 2,028 (2,024) | 118.08 | 2.81 |
| | | 15 | 2,018 (2,014) | 167.58 | 3.40 |
| | | 25 | 2,008 (2,004) | 214.12 | 5.10 |
| | 28 | 5 | 2,028 (2,024) | 234.65 | 8.38 |
| | | 15 | 2,018 (2,014) | 129.48 | 4.62 |
| | | 25 | 2,008 (2,004) | 190.03 | 6.79 |
| | 14 | 5 | 2,028 (2,024) | 103.77 | 7.41 |
| | | 15 | 2,018 (2,014) | 93.07 | 6.648 |
| | | 25 | 2,008 (2,004) | 120.45 | 8.60 |
| | 7 | 5 | 2,028 (2,024) | 111.99 | 16.00 |
| | | 15 | 2,018 (2,014) | 119.11 | 17.02 |
| | | 25 | 2,008 (2,004) | 96.77 | 13.82 |
| | 3 | 5 | 2,028 (2,024) | 2.92 | 0.97 |
| | | 15 | 2,018 (2,014) | 1.05 | 0.35 |
| | | 25 | 2,008 (2,004) | 8.80 | 2.93 |

Common taxa encountered in the summer colonization samples varied by elevation interval and duration of exposure. At the 5-foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]), *Cladocera*, *Hyalella*, *Turbellaria*, and *Oligochaeta* were most commonly found in samples that were exposed for less than 14 days. As exposure period increased, *Polycentropus*, *Chironomidae*, *Macromia magnifica*, *Cheumatopsyche*, *Cladocera*, and *Oligochaeta* became the more prevalent taxa. Samples placed at the 15-foot elevation interval (2,018 feet NAVD 88 [2,014 feet NGVD 29]) showed *Cladocera* as the dominant taxa in samples exposed for up to 14 days. As exposure time increased above 14 days, *Cheumatopsyche* became the most common taxa. *Oligochaeta* and *Hyalella* were found to be one of the top three most common taxa after just 3 days of exposure, but were not common in any of the other samples. Other common taxa found in samples exposed for greater than 3 days included *Helisoma anceps*, *Maccaffertium*, *Polycentropus*, and *Ophiogomphus occidentis*. Similar to the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval samples, the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval samples showed *Cladocera* as the most common taxa found during exposure periods of up to 14 days and *Cheumatopsyche* as the most prevalent taxa in samples exposed for longer periods. *Cladocera* remained one of the top three most common taxa in the 28-day sample and *Cheumatopsyche* was one of the top three in the 14-day sample. Other common taxa encountered at the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval were similar to those found at the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29])

interval, including *Hydropsyche*, *Ophiogomphus occidentis*, *Maccaffertium*, *Helisoma anceps*, and *Chironomidae*.

Average colonization rates across all exposure periods for the three elevation intervals are compared in Figure 6.3-2. The average rates did not differ significantly during the summer season.

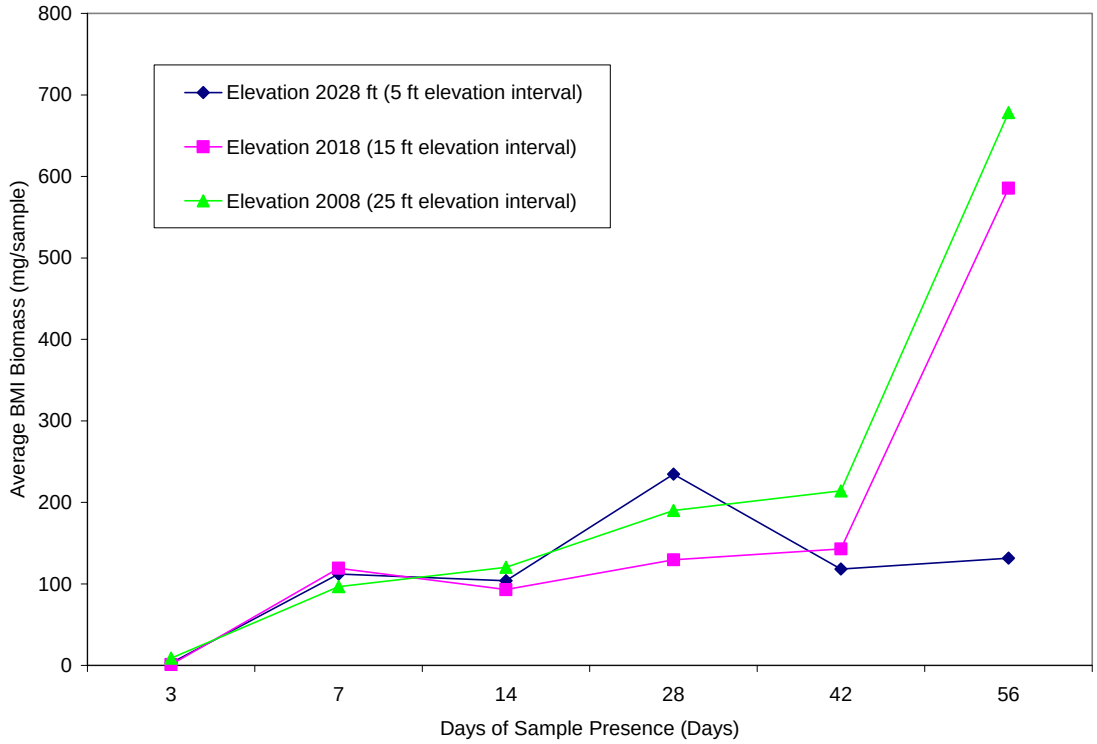


**Figure 6.3-1.** Colonization sampling, biomass without *Hydra* sp., summer 2007.

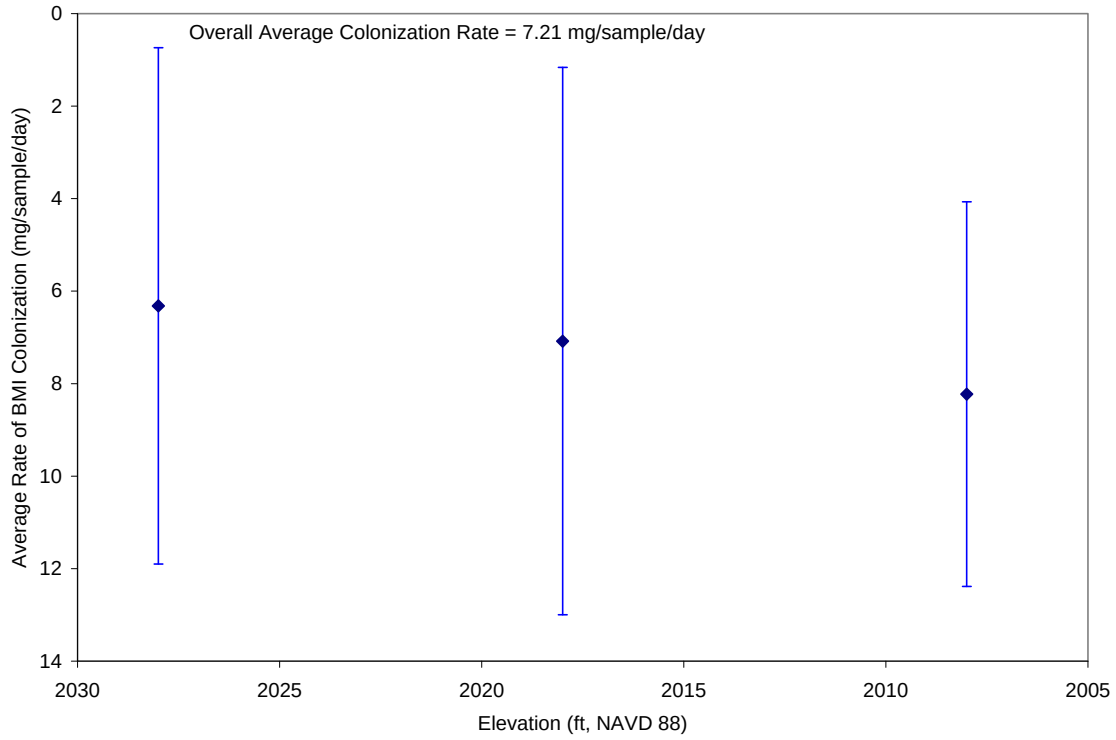


**Figure 6.3-2.** Average summer BMI colonization rates, 2007.

Figure 6.3-3 illustrates the average biomass for the colonization samples collected during the 2007-2008 winter season. At the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) elevation interval, the winter samples show that biomass increased with exposure time up to 55 days. After 55 days, biomass appeared to sharply decrease to 69 days, and then increase again from 69 to 99 days of exposure. At the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval, biomass slowly increased for the first 55 days, and then significantly increased from 55 to 69 days. Between 69 and 83 days, biomass appeared to sharply decrease, followed by another significant increase from 83 to 99 days. The 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval samples showed an increase in biomass in the first 3-7 days of exposure, followed by a slight decrease to 55 days. After 55 days, biomass increased again up to 83 days of exposure. Between 83 and 99 days, biomass began to slightly decrease. During the winter season, the rate of BMI colonization was highest at the 5-foot (2,028 feet NAVD 88 [2,024 feet NGVD 29]) elevation interval and lowest at the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval (Figure 5.3-3).

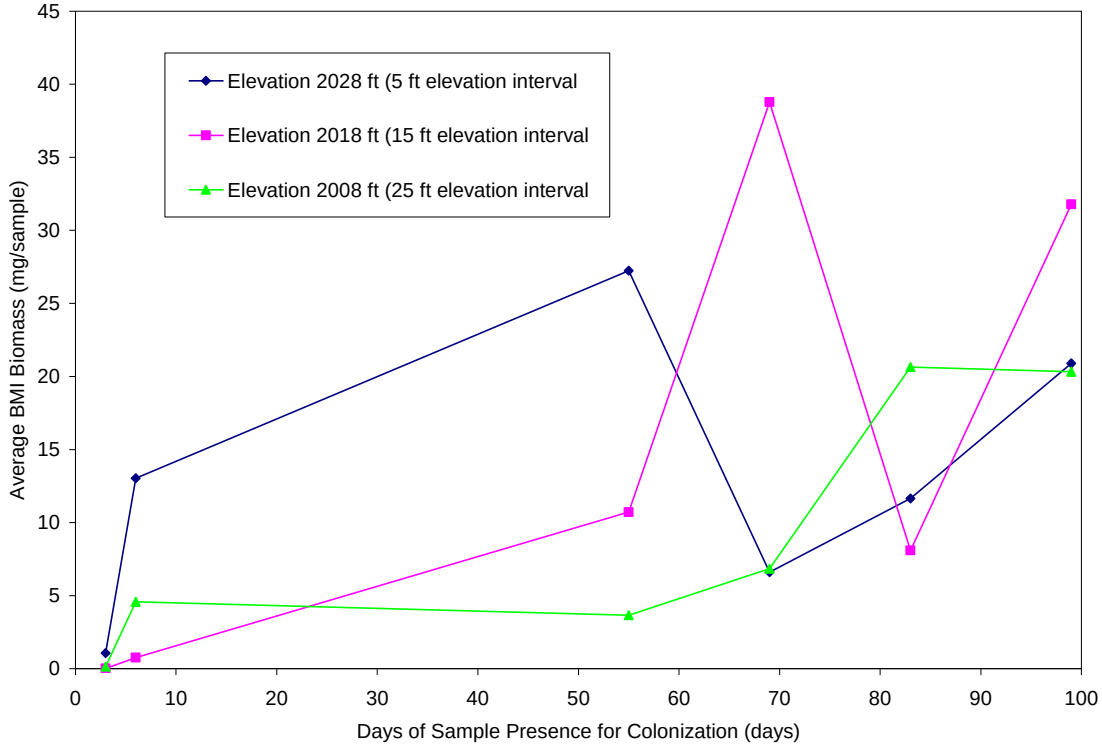


**Figure 6.3-3.** Colonization sampling, biomass without *Hydra* sp., winter 2007-2008.

The winter colonization samples showed slightly less variation in taxa diversity than the summer samples. At the 5-foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]), *Chironomidae* was the most common taxon encountered for all durations of exposure. *Oligochaeta* was also commonly found at the 5-foot elevation interval (2,028 feet NAVD 88 [2,024 feet NGVD 29]) during most periods of exposure, with the exception of the 55-day period. Samples placed at the 15-foot elevation interval (2,018 feet NAVD 88 [2,014 feet NGVD 29]) showed *Chironomidae* and *Oligochaeta* as the dominant taxa, other than *Hydra*, during all exposure periods, with the exception of the samples exposed for only 3 days. One taxon, *Simulium*, was found in the 3-day sample placed at the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval. *Simulium* was also prevalent in the 15-foot (2,018 feet NAVD 88 [2,014 feet NGVD 29]) elevation interval during all exposure periods except for those samples that were exposed for 7 days. *Chironomidae* and *Simulium* were found to be among the most common taxa in those samples placed at the 25-foot (2,008 feet NAVD 88 [2,004 feet NGVD 29]) elevation interval for all periods of duration. *Ceraclea* was commonly found in samples exposed up to 55 days, but no longer, and *Ephemerella excrusians* became prevalent in samples exposed for 69 days or more.

Table 6.3-2 shows the average BMI biomass for each colonization sample in Box Canyon Reservoir at three elevation intervals and across all exposure periods. The table also shows the rate of colonization for each interval and exposure period. Figure 6.3-4 illustrates the average colonization rates for each elevation interval across all exposure periods. The rates observed

during the winter season are much lower than those observed during the summer season. There is no significant difference between the colonization rates for any of the elevation intervals.

**Table 6.3-2.** Average winter BMI biomass and colonization rates per elevation, elevation interval, and number of days incubated in Box Canyon Reservoir.

| Date Pulled | No. of Days Exposed | Elevation Interval | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) | BMI Colonization Rate (mg/sample-day) |
|---|---|---|---|---|---|
| 3/13/08 | 99 | 5 | 2,028 (2,024) | 20.89 | 0.21 |
| | | 15 | 2,018 (2,014) | 31.79 | 0.32 |
| | | 25 | 2,008 (2,004) | 20.32 | 0.21 |
| | 83 | 5 | 2,028 (2,024) | 11.65 | 0.14 |
| | | 15 | 2,018 (2,014) | 8.10 | 0.10 |
| | | 25 | 2,008 (2,004) | 20.65 | 0.25 |
| | 69 | 5 | 2,028 (2,024) | 6.60 | 0.10 |
| | | 15 | 2,018 (2,014) | 38.78 | 0.56 |
| | | 25 | 2,008 (2,004) | 6.84 | 0.10 |
| | 55 | 5 | 2,028 (2,024) | 27.24 | 0.50 |
| | | 15 | 2,018 (2,014) | 10.72 | 0.19 |
| | | 25 | 2,008 (2,004) | 3.66 | 0.07 |
| | 6 | 5 | 2,028 (2,024) | 13.04 | 2.17 |
| | | 15 | 2,018 (2,014) | 0.76 | 0.13 |
| | | 25 | 2,008 (2,004) | 4.58 | 0.76 |
| | 3 | 5 | 2,028 (2,024) | 1.08 | 0.36 |
| | | 15 | 2,018 (2,014) | 0.02 | 0.01 |
| | | 25 | 2,008 (2,004) | 0.13 | 0.04 |

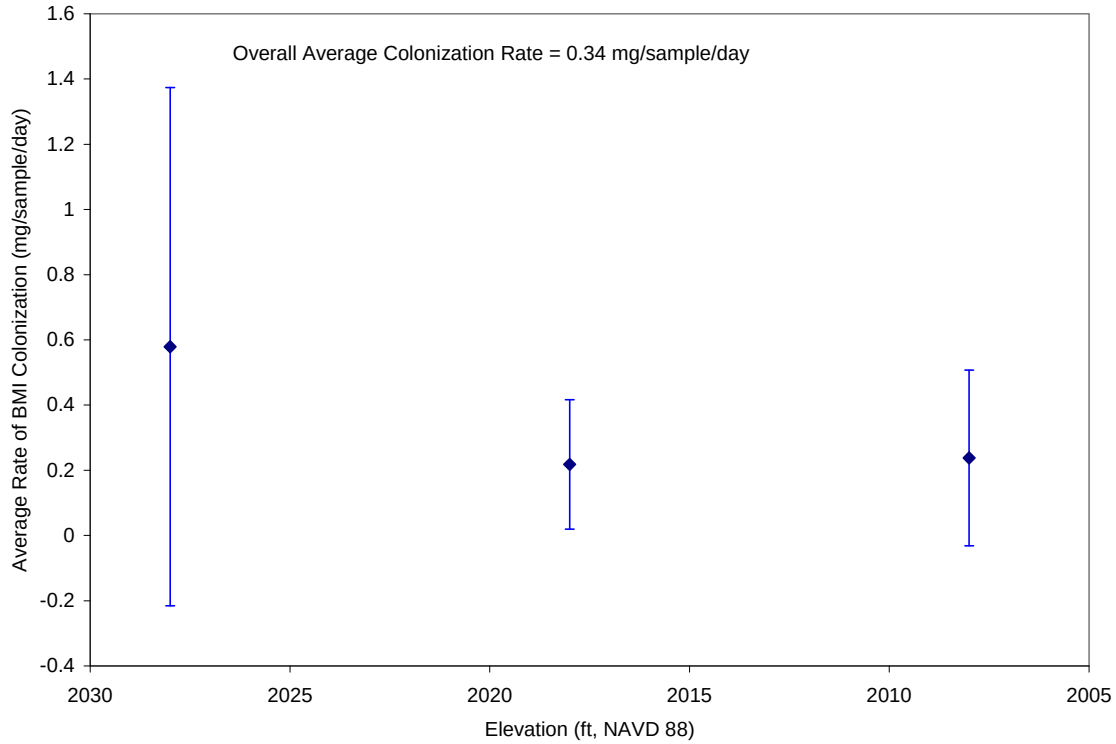


**Figure 6.3-4.** Average winter BMI colonization rates, 2007-2008.

## 6.4. BMI Comparison Study

Data collected from artificial rock baskets in 2007 showed a large number of *Hydra* sp. colonized on these substrates (Tables 6.4-1 and 6.4-2). The comparison among substrate types in this study revealed that *Hydra* sp. does not colonize natural substrates in the same densities as on artificial rock baskets. Average biomass densities are higher on artificial substrates than on natural substrate. However, the quantity of biomass that accumulated on all substrate types and at each depth shows the same pattern among all the factors that might affect biomass accumulation tested in this study. *Hydra* sp. biomass on artificial substrates can be eliminated from further evaluation when determining BMI response to depth, velocity, and substrate HSI curves and be considered an artifact of the artificial substrate effect in the colonization process.

The range of biomass observations among all three substrate types (e.g., artificial rock basket, single layer of rocks in a basket, and natural substrate) revealed no significant difference in biomass estimates at both the 17-foot and 25-foot depths when biomass from *Hydra* sp. is excluded (Figures 6.4-1 and 6.4-2). The artificial rock basket results reflect conditions measured from natural substrate and can be used to develop BMI biomass responses to depth, velocity, and substrate.

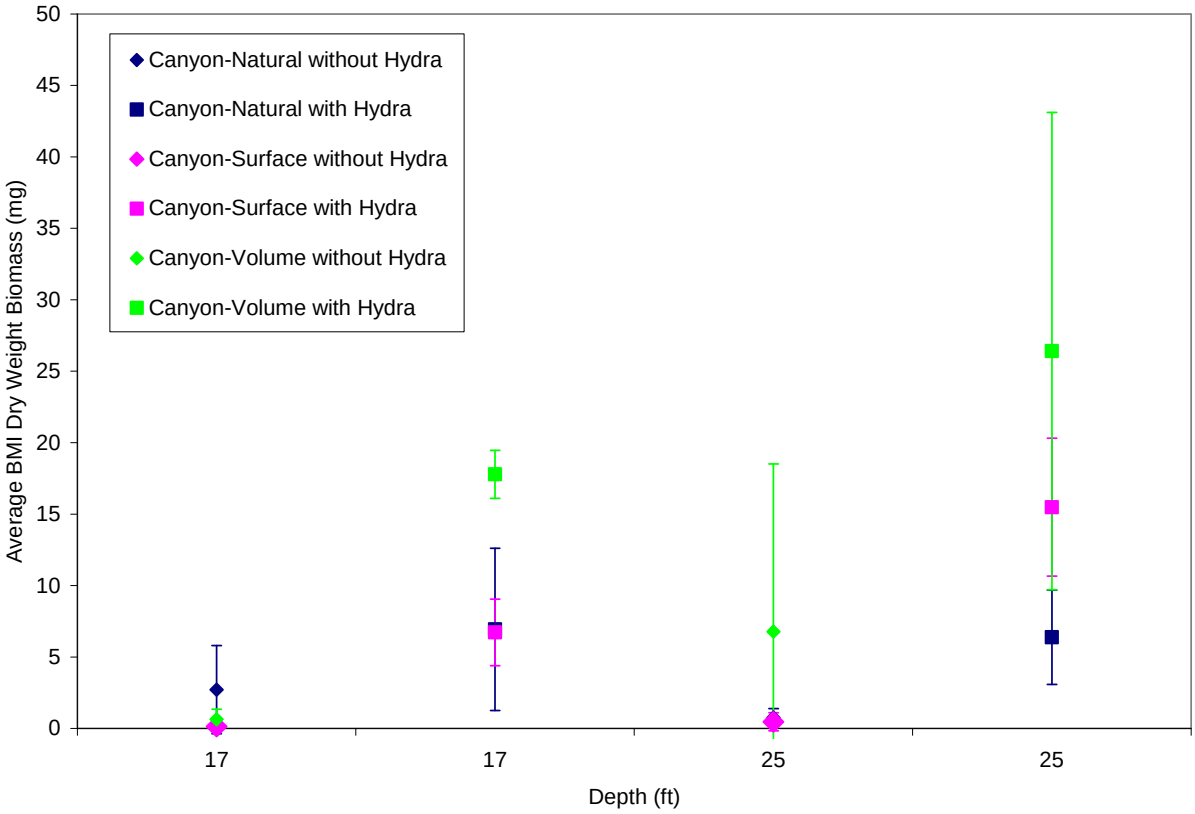


**Figure 6.4-1.** Comparison Study data, Canyon Reach, May 2008.

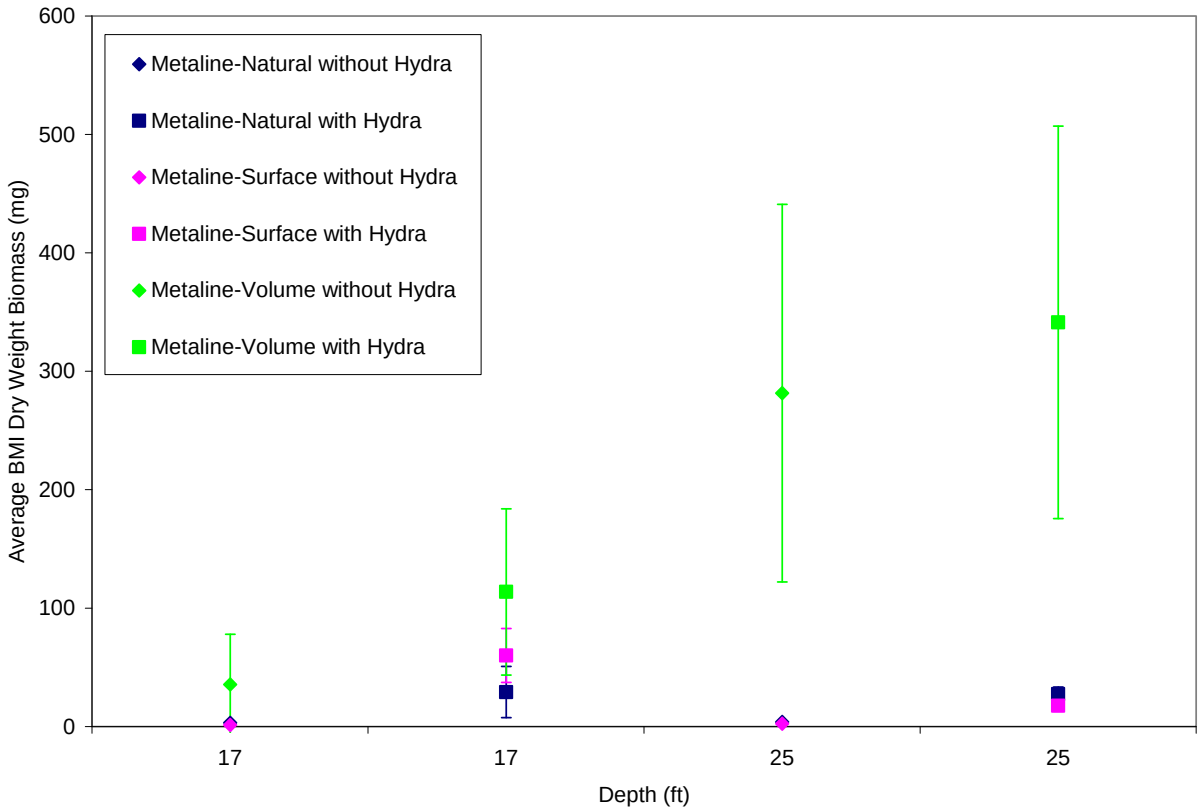


**Figure 6.4-2.** Comparison Study Data, Metaline Reach, May 2008.

**Table 6.4-1.** Average BMI biomass without hydra (standard deviations) found in artificial and natural substrates in April 2008 in Boundary Reservoir.

| Date | Depth | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) (STDEV) | | | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) (STDEV) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Canyon Natural | Canyon Surface | Canyon Volume | | Metaline Natural | Metaline Surface | Metaline Volume |
| April-08 | 17 | 1,970 (1,966) | 2.72 (3.08) | 0.14 (0.11) | 0.65 (0.70) | 1,974 (1,970) | 3.19 (1.16) | 1.30 (0.52) | 35.63 (42.37) |
| | 25 | 1,964 (1,960) | 0.77 (0.62) | 0.46 (0.64) | 6.79 (11.72) | 1,966 (1,962) | 3.96 (0.65) | 2.43 (0.88) | 281.40 (159.45) |

**Table 6.4-2.** Average BMI biomass with hydra (standard deviations) found in artificial and natural substrates in April 2008 in Boundary Reservoir.

| Date | Depth | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) (STDEV) | | | Elevation ft, NAVD 88 (ft, NGVD 29) | Average BMI Biomass (mg/sample) (STDEV) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Canyon Natural | Canyon Surface | Canyon Volume | | Metaline Natural | Metaline Surface | Metaline Volume |
| April-08 | 17 | 1,970 (1,966) | 6.94 (5.68) | 6.73 (2.33) | 17.78 (1.69) | 1,974 (1,970) | 29.14 (21.53) | 60.04 (22.80) | 113.70 (70.19) |
| | 25 | 1,964 (1,960) | 6.38 (3.29) | 15.49 (4.82) | 26.41 (16.70) | 1,966 (1,962) | 27.47 (5.95) | 17.54 (4.49) | 341.33 (165.74) |

# 7 FINAL BMI HSI CURVES

Following the literature review and development of literature-based (provisional) habitat suitability curves, site specific field monitoring data were used to calibrate the BMI HSI curves for Boundary Reservoir. The HSI curves for each benthic metric were reviewed by a panel of relicensing participants and regional experts. Panel members reviewed the literature-based curves, along with the site-specific data to develop the final set of HSI curves. The panel consisted of relicensing participants and regional experts (agency, tribal, industry, and university researchers). The final benthic HSI curves were used in the aquatic habitat modeling study to predict Project operations effects based on several environmental gradients and are discussed below.

## 7.1. Calibration of BMI HSI Curves

Once all BMI monitoring data were collected, field data along with results from the HRM were used to further refine and calibrate HSI curves for depth, velocity, substrate, and duration of inundation and dewatering. The HRM provided information concerning site-specific water surface elevations during the sampling period so the depth of each sample and the duration of inundation and dewatering could be determined for the entire period of sample exposure. The HRM also provided information on the water velocity at each treatment site throughout the sample exposure period. Using the information provided by the HRM, the calculated depth, the duration of inundation and dewatering of each sample, the average BMI biomass at each treatment site, and the type of substrate used during the experiment, the literature-based HSI curves were refined and calibrated to become the final HSI curves for Boundary Reservoir.

### 7.1.1. Depth

Sampling for BMI occurred in two distinct areas of the Project area: the Canyon reach and the Metaline reach. Sampling also occurred in Box Canyon Reservoir, which provided a control for the other two sampling sites. Data collected from artificial substrates at each elevation were divided based on the position in the Project area (e.g., Canyon reach versus Metaline reach) and then combined to determine if there were differences in the shape of the depth response curve (Figure 7.1-1).

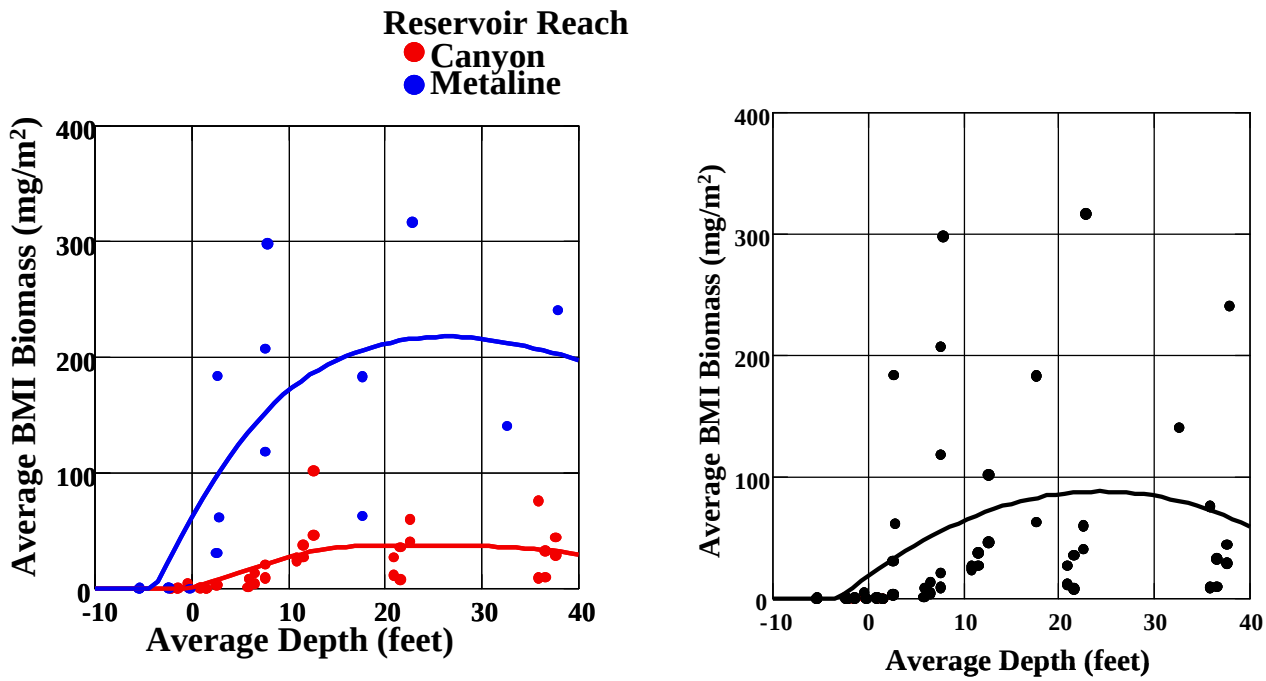


**Figure 7.1-1.** BMI biomass response to depth on hard substrate separated by reservoir reach (leftmost graph) and combined (rightmost graph) reservoir areas.

Variability was high in some BMI biomass estimates collected from the same elevation within the Metaline reach (Figure 7.1-1). The Canyon reach biomass estimates had smaller variability from repeated measurements at the same depth intervals. Variability of biomass estimates was approximately the same when combining the Metaline and Canyon reach data as compared to variability of the Metaline reach biomass estimates. Further interpretation of actual data from elevations used the combination of the two data sets for derivation of an observed depth response curve that was compared with the provisional depth response curve (Figure 7.1-1).

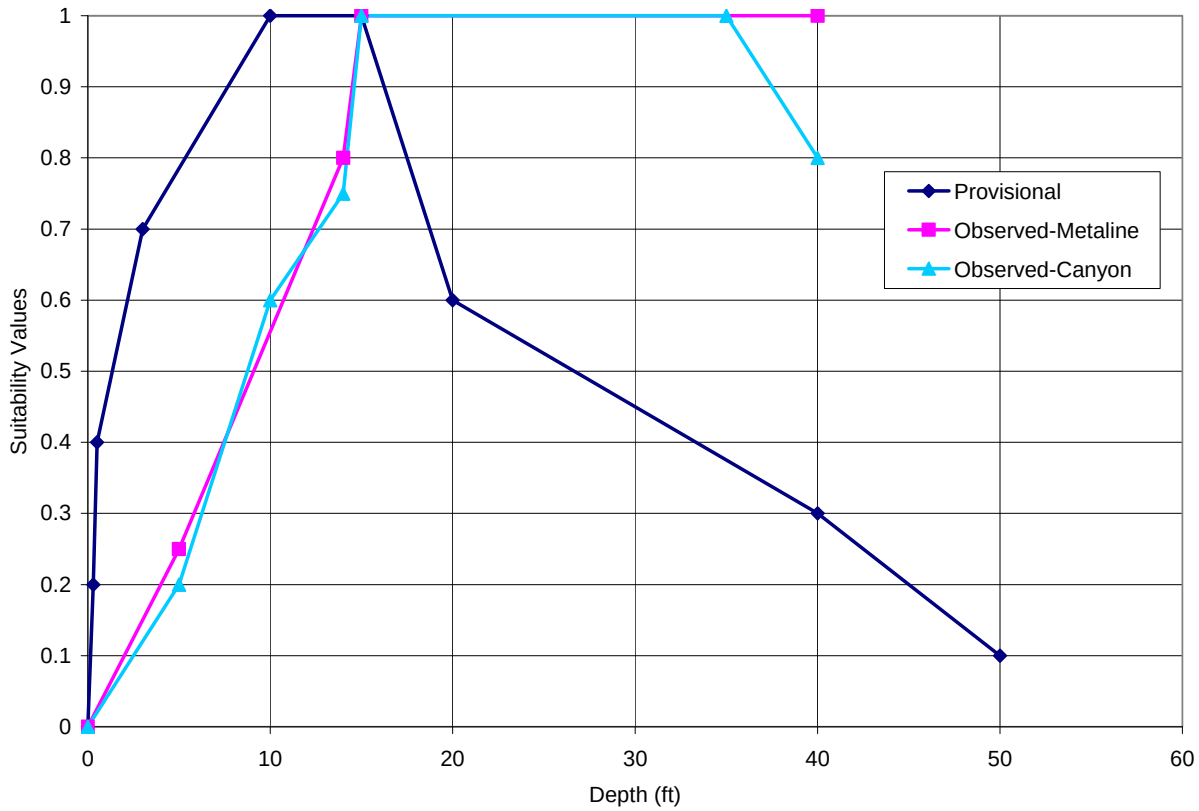


**Figure 7.1-2.** Provisional depth suitability values for BMI compared to observed depth suitability curves for BMI in the Canyon reach and the Metaline reach in Boundary Reservoir.

### 7.1.2. Velocity

Velocity measurements were estimated for each of the artificial substrate locations from the HRM. The range of velocities estimated for each of the biomass sample locations was much smaller than what was synthesized for the provisional velocity curve developed from the literature survey (Figure 6.1-2). Collection devices were placed close to shorelines and so velocity estimates were not as high as some of those reported from literature-based observations. In addition, the literature-based velocity observations were developed from natural stream settings where flow regulation was not present and gradients were often higher than those in this reservoir. Biomass estimates from all depth intervals were plotted against estimated velocity values (Figure 7.1-3). A further visual comparison of the observed biomass responses to velocity and those derived from the literature (representing the provisional velocity response curve) is found in Figure 7.1-4.

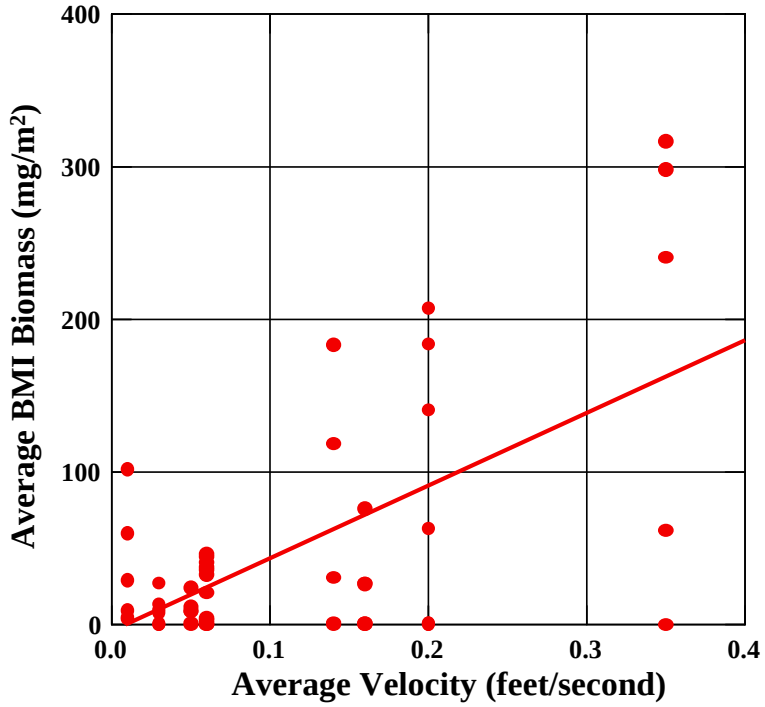


**Figure 7.1-3.** BMI biomass response to velocity (feet/second) from samples collected on hard substrate (vertical and shoreline) in Boundary reservoir (Canyon and Metaline reach).

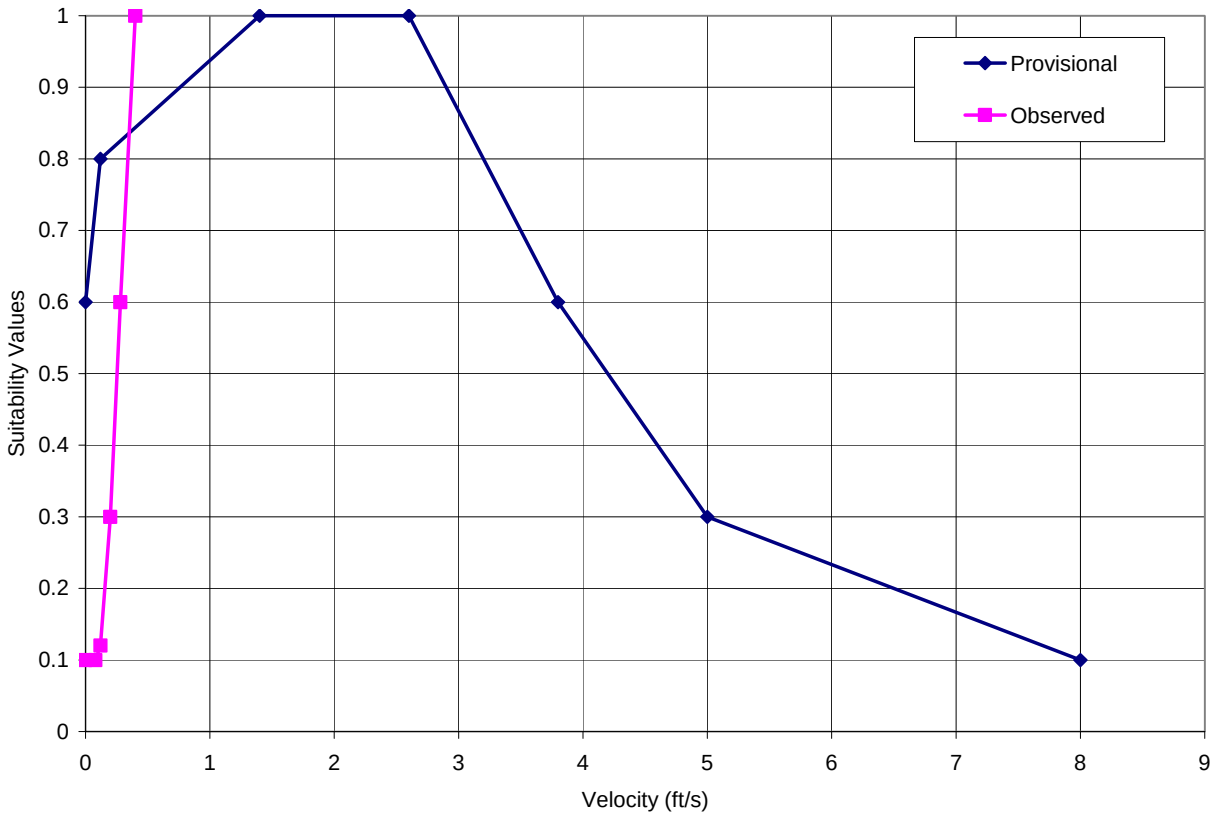


**Figure 7.1-4.** Provisional velocity suitability values for BMI compared to observed velocity suitability curve for BMI in Boundary Reservoir.

### 7.1.3. Substrate

BMI community biomass was characterized by collection from natural soft substrates and artificial hard substrate samplers. The distribution of BMI biomass in soft and hard substrates is reported in Figure 7.1-5 as cumulative distribution frequency curves using combined data from both the Canyon Reach (lower reservoir) and Metaline Reach (upper reservoir) sampling sites. Most soft substrate sites (75 percent) had BMI biomass estimates below 100 mg/sample in contrast to a larger number of hard substrate sites with higher BMI biomass estimates. The soft substrate suitability was limited in comparison to the positive influence hard substrate had on promoting higher BMI biomass estimates (Figure 7.1-5). Provisional substrate suitability values derived from literature-based information were visually compared with the observed substrate suitability in Figure 7.1-6.

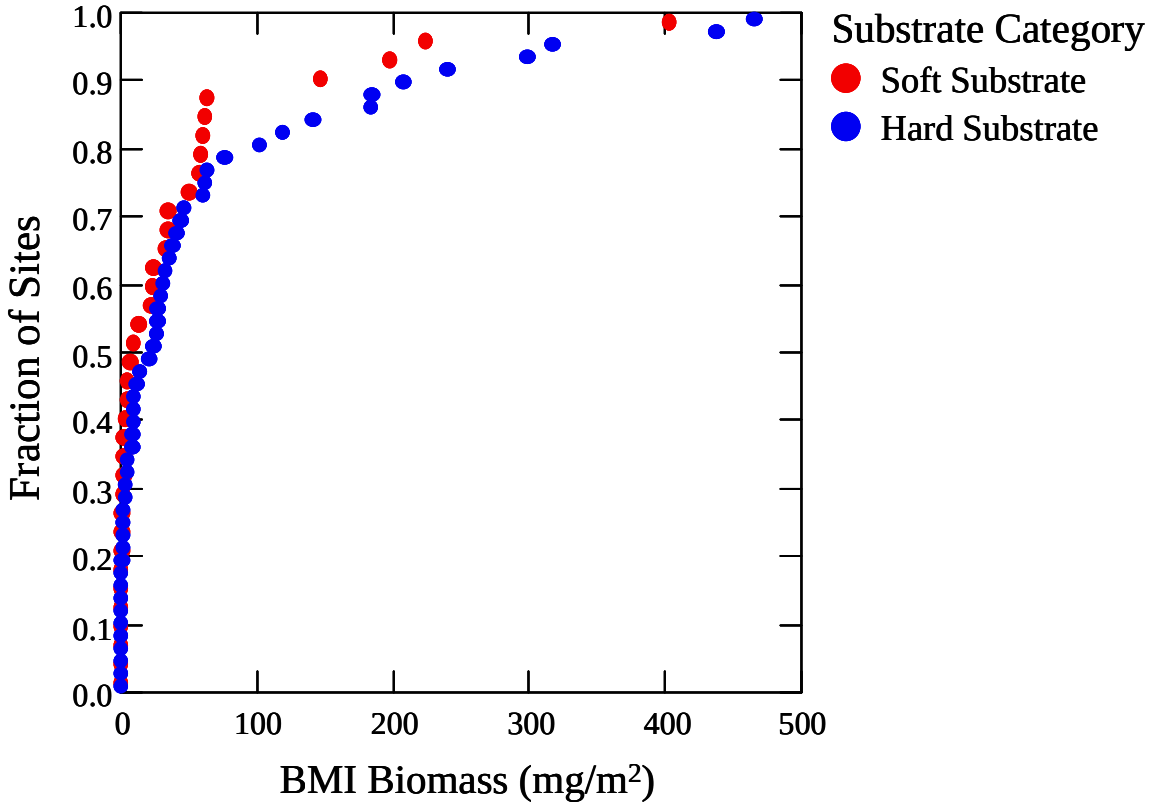


**Figure 7.1-5.** BMI biomass response to substrate type (soft and hard) from combined lower (Canyon Reach) and upper (Metaline Reach) reservoir areas.

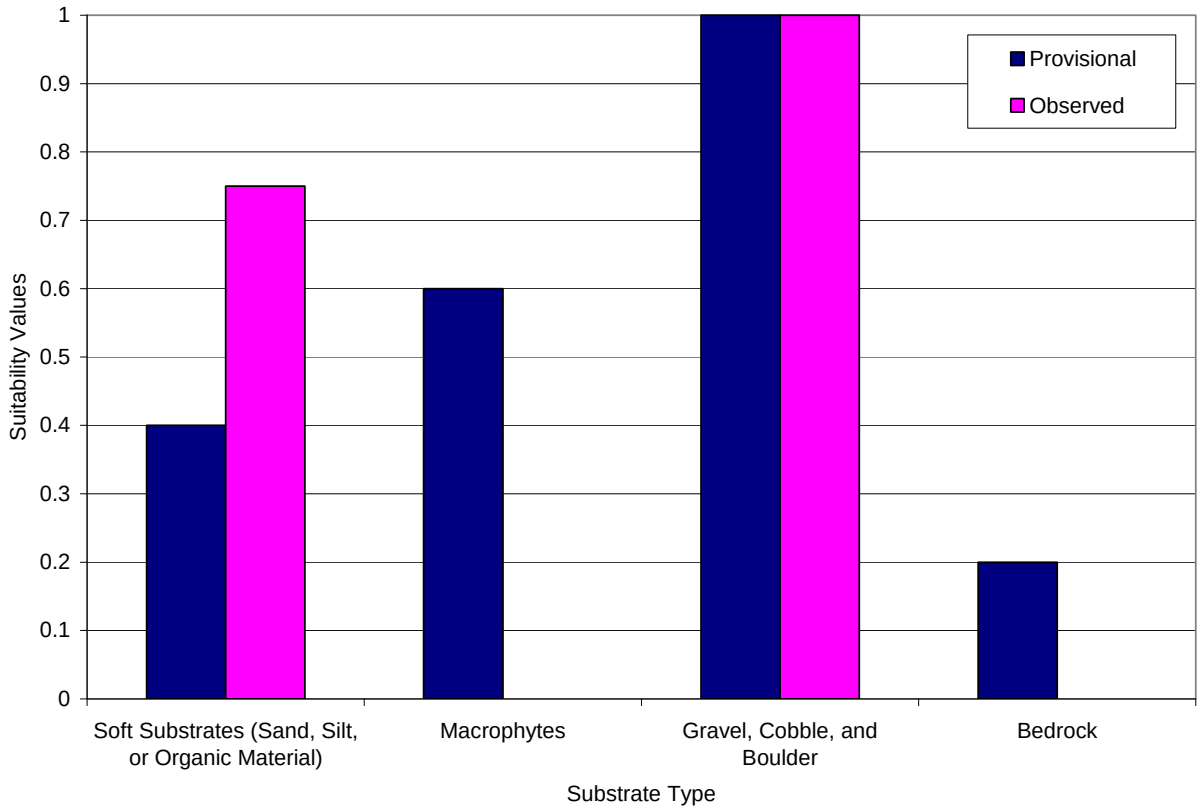


**Figure 7.1-6.** Provisional substrate suitability values for BMI compared to substrate suitability curve for BMI in Boundary Reservoir.

### 7.1.4. Duration of Dewatering

Biomass estimates for intervals of dewatering (hrs) were recorded from BMI communities collected on artificial substrates. BMI biomass variability was high on substrates that were dewatered for less than ten hours. The BMI biomass collected from artificial substrates that were dewatered on average for greater than a 15-hour period resulted in little or no BMI biomass estimates. Substrates exposed to air for more than 16 hours were devoid of any BMI (Figure 7.1-7). Observed HSI BMI values resembled the provisional curve values and so only minor revisions suggested from the original provisional values (Figure 7.1-8).

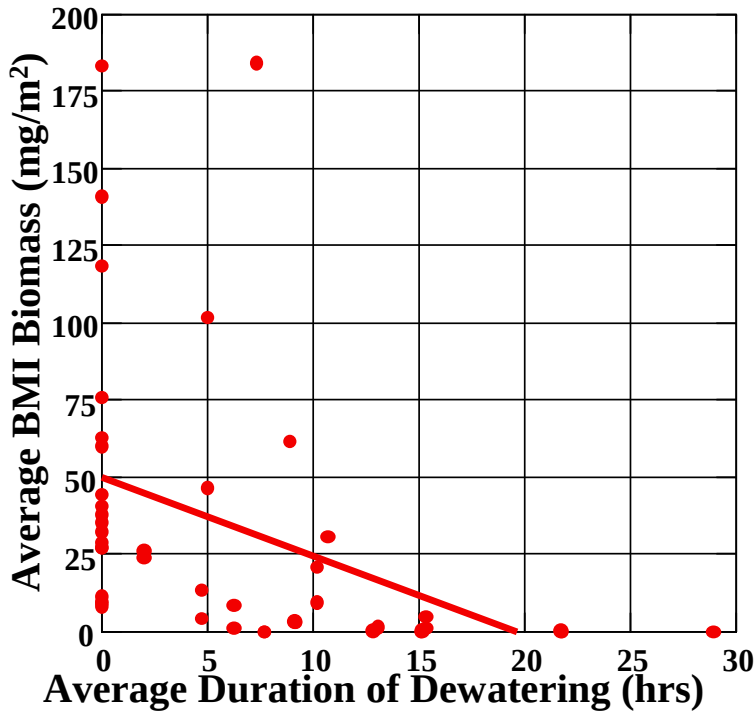


**Figure 7.1-7.** BMI biomass response and average duration of dewatering (hours) from samples collected on hard substrate (vertical and shoreline) in Boundary Reservoir (Canyon and Metaline reach).

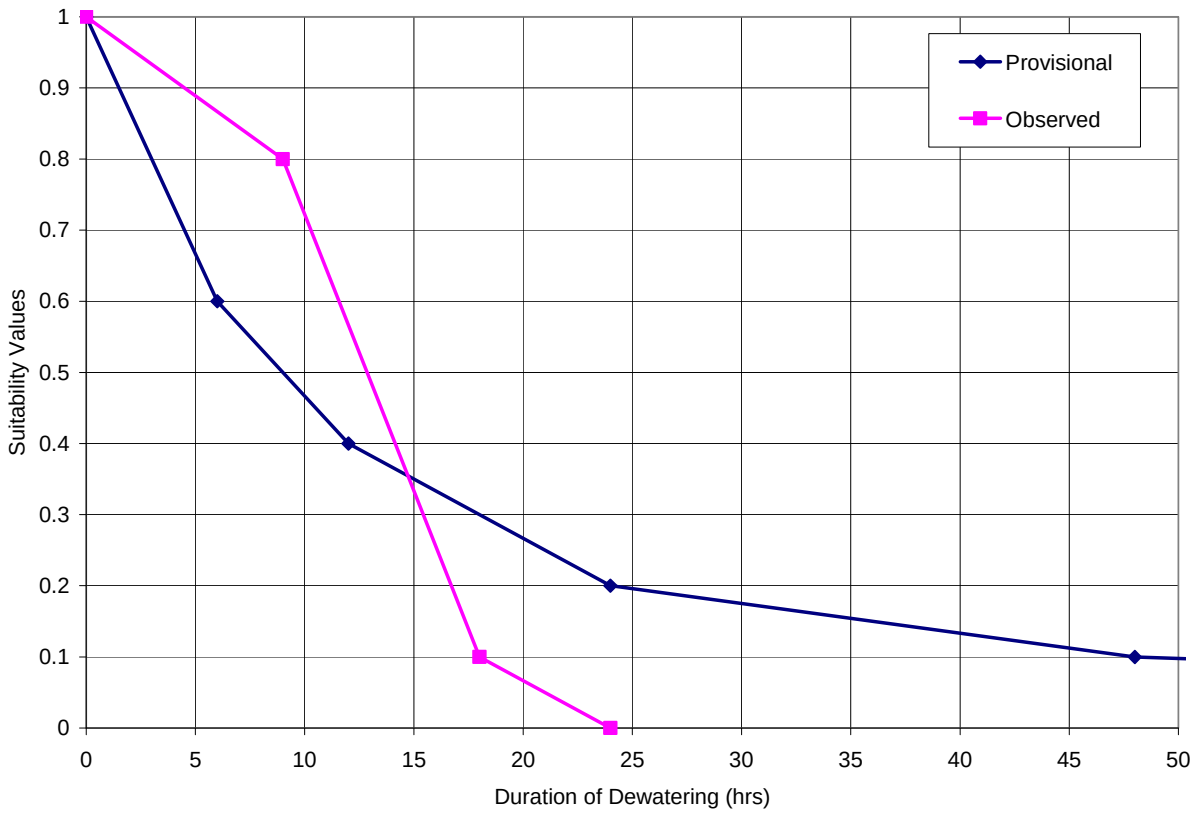


**Figure 7.1-8.** Provisional duration of dewatering suitability values for BMI compared to duration of dewatering suitability curve for BMI in Boundary Reservoir.

### 7.1.5. Duration of Inundation

BMI collected on artificial substrates reached highest biomass when inundation of substrate was greater than fifty hours (Figure 7.1-9). Variability of biomass estimates was high from repeated samples collected on artificial substrates from between 5- and 10-hour average inundation intervals. Inundation intervals of less than three hours resulted in little or no BMI biomass. Inundation intervals greater than 8 hours are necessary for accumulation of measurable biomass on artificial substrate. Suitability values do not increase until the duration of inundation period is longer than 9 days (216 hours) (Figure 7.1-10).

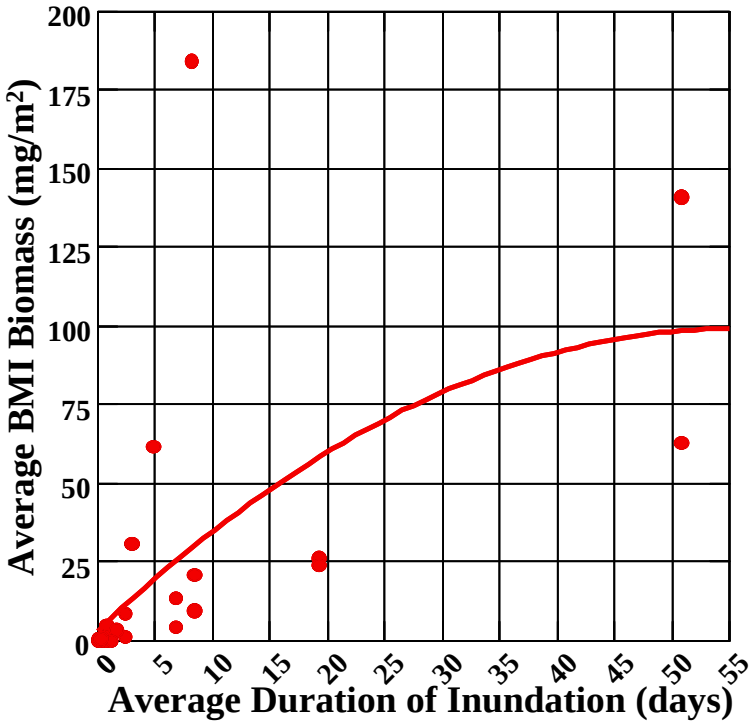


**Figure 7.1-9.** BMI biomass response and average duration of inundation (days) from samples collected on hard substrate (vertical and shoreline) in Boundary Reservoir (Canyon and Metaline reach).

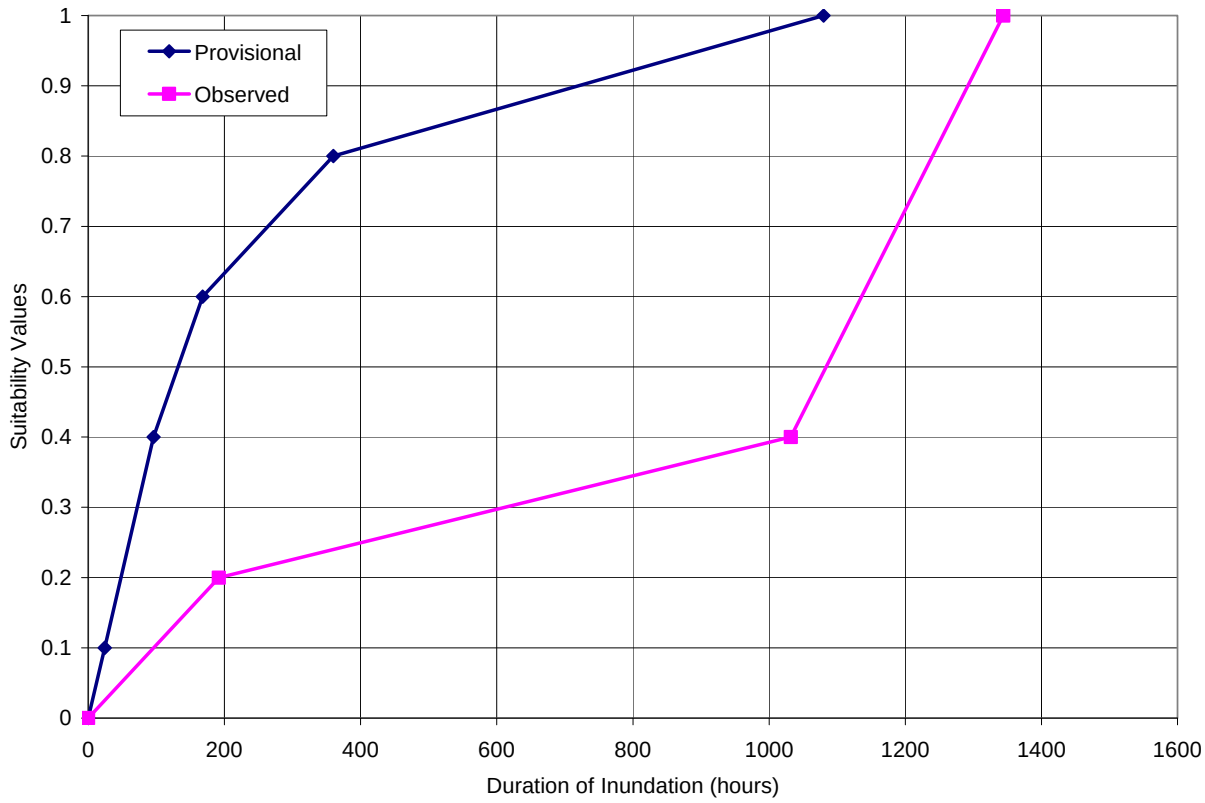


**Figure 7.1-10.** Provisional duration of inundation suitability values for BMI compared to duration of inundation suitability curve for BMI in Boundary Reservoir.

## 7.2. Final BMI HSI Curves

Development of the final BMI HSI curves for the environmental gradients began with the development of provisional curves, which were then compared against observed response curves developed from field data, and finalized based on meetings and discussion with Relicensing Participants. The final curves are a combination of knowledge acquired through examination of the literature-based provisional curves and refinement through development of observed curves based on field measurements.

Discussion of refinements of the provisional curves based as compared to observed (field data-based) curves occurred with relicensing participants at three meetings: 1) Water Quality Workgroup meeting (July 15, 2008); 2) Fish and Aquatics Workgroup meeting (August 7, 2008); and 3) Fish and Aquatics Workgroup meeting (August 27, 2008). Further clarification was provided to Washington Department of Fish and Wildlife relicensing participants on how the substrate comparison study results were used to develop the final depth BMI HSI curve (teleconference on September 5, 2008).

### 7.2.1. Depth

The BMI biomass HSI curve for depth was refined to reflect presence of measurable quantities of biomass over a broader range of deeper portions of the reservoir. The original provisional curves were based on literature representing mostly non-regulated rivers and lakes. Results from the field data indicated that BMI biomass occupies a broader range of optimal depths than described for a variety of locations in the literature. The optimal range (HSI = 1.0) for BMI preference for depth was extended from the provisional curve with a decrease in optimization past forty feet in depth (Figure 7.2-1 and Table 7.2-1). BMI were found at greater depths in the Boundary reservoir than literature-reported values as supported by results from the colonization studies and from dredge samples collected from the Study 4 Toxics evaluation (forebay sample at 275 feet). There was measurable BMI biomass at depths greater than 60 feet, which was acknowledged by applying a Suitability Index score of 0.1 to the 60-foot depth (Figure 7.2-1).

BMI data used for developing observed HSI curves did not include *Hydra* sp. in further analysis for three reasons. First, the *Hydra* sp. collected from artificial substrates were less than 3 mm in body size and were not considered to be a predator of colonizing benthic macroinvertebrates due to the fact that they were generally much smaller than the other colonizing invertebrates, which would effectively prevent predation. Second, the artificial substrate basket, which used a standard volume of rocks, attracted large numbers of *Hydra* sp. which were not shown to naturally aggregate on surface samples of natural substrate as shown in the comparison study. Third, tests comparing two types of artificial substrate (volume and surface area of rocks within baskets) with colonization of BMI on natural substrate were used to determine if *Hydra* sp. was an important fraction of the BMI biomass that responded to HSI variables (e.g., depth) in a distinct way. These tests showed that, for natural substrate, *Hydra sp*. did not vary with depth, and so, could be eliminated from the artificial substrate samplers using a standard volume.

Substrate comparison results were examined to determine if BMI biomass estimates were similar when the following elements were compared: 1) natural versus artificial substrates, and 2) if exclusion of *Hydra* sp. biomass enables identification of a distinct response to an environmental gradient like depth. Results of BMI collection in the Canyon Reach indicated that natural and artificial substrate estimates were generally the same (Figure 6.4-1). However, an identifiable response to the depth gradient using BMI biomass estimates was identified by samples collected from the Metaline Reach when *Hydra* sp. were excluded from this analysis (Figure 6.4-2). This response was not the same for artificial substrate in the volume sampler as it was for natural substrate and artificial substrate measured in the surface area sampler. The depth response in the volume samples for artificial substrate showed a biomass increase with depth, while the depth response for the natural and surface area artificial samplers showed a biomass decrease with increasing depth. Nevertheless, the exclusion of *Hydra* sp. in biomass estimates was supported based on results from the substrate comparison study and an important analytical observation: although the volume samples from the artificial substrate did not exactly mimic the response of the natural substrate in all cases, this difference was not affected by the presence of *Hydra* sp. in the sample, therefore, the biomass results from *Hydra* sp. can be removed from the analysis without affecting the results.

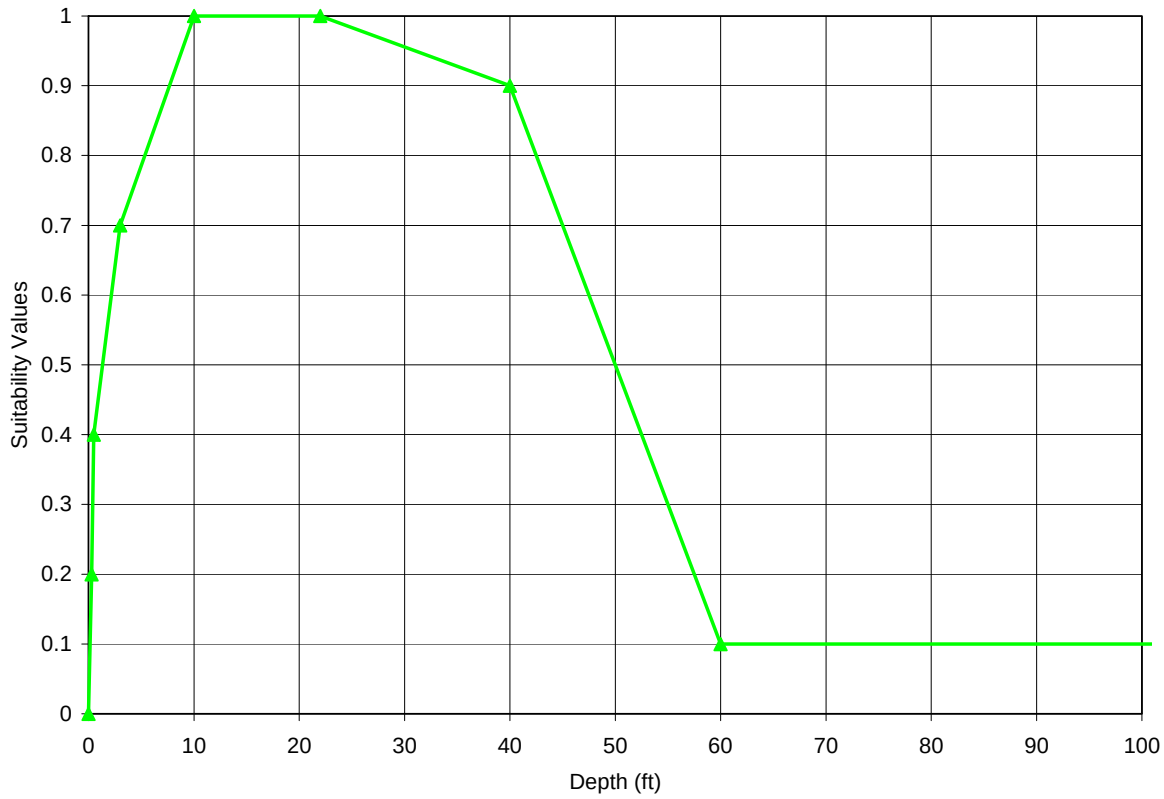


**Figure 7.2-1.** Final depth suitability curve for BMI. Maximum depth for presence of BMI exceeds 60 feet.

**Table 7.2-1.** Final depth suitability values for BMI in Boundary Reservoir.

| Depth (ft) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 0.3 | 0.2 |
| 0.5 | 0.4 |
| 3 | 0.7 |
| 10 | 1.0 |
| 22 | 1.0 |
| 40 | 0.9 |
| 60 | 0.1 |
| 275 | 0.1 |

### 7.2.2. Velocity

Velocities were estimated from the HRM for each location where BMI biomass was collected. The range of results represented only a fraction of the range reported for suitability scores determined from a review of the literature. The decision was made to use most of the suitability scores suggested from the provisional, literature-based HSI curve for velocity. However, the maximum velocity where BMI biomass aggregation would be zero was reduced from original suggestions. The reason for this reduced maximum velocity score was that the HRM did not predict velocities beyond 10 fps (Figure 7.2-2 and Table 7.2-2).

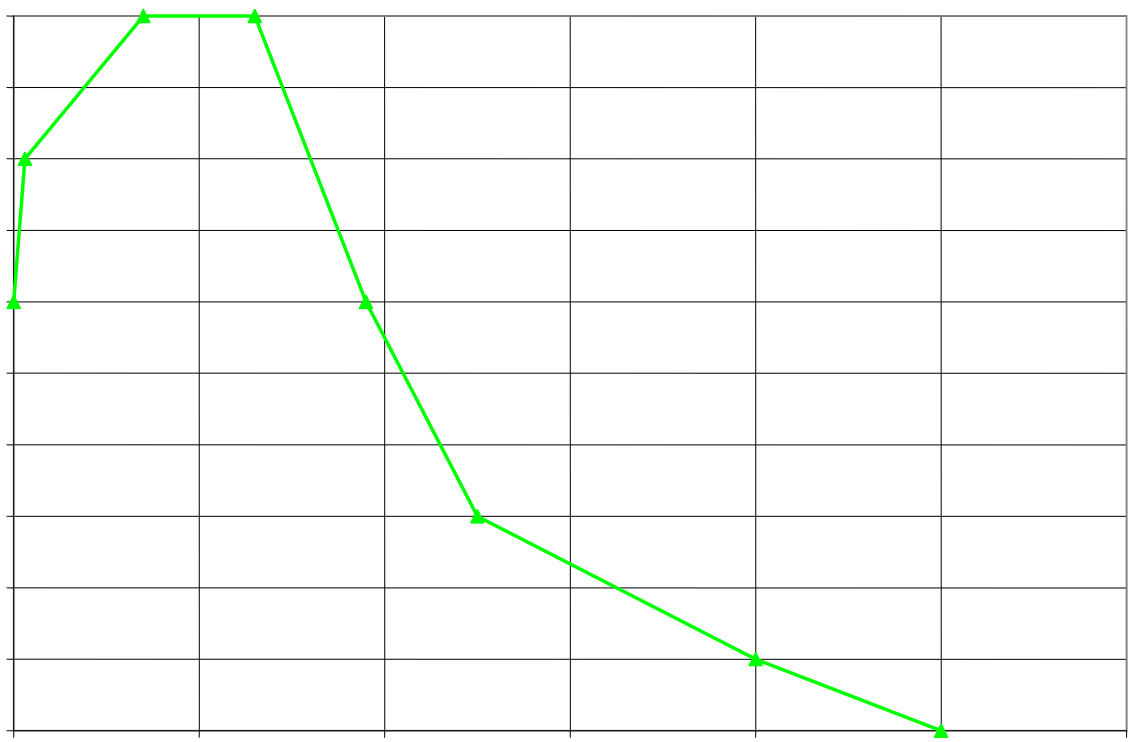

**Figure 7.2-2.** Final velocity (fps) suitability curve for BMI.

**Table 7.2-2.** Final velocity suitability values for BMI in Boundary Reservoir.

| Velocity (fps) | Final Suitability Values |
|---|---|
| 0 | 0.6 |
| 0.12 | 0.8 |
| 1.4 | 1.0 |
| 2.6 | 1.0 |
| 3.8 | 0.6 |
| 5.0 | 0.3 |
| 8.0 | 0.1 |
| 10 | 0 |

### 7.2.3. Substrate

Suitability scores for BMI biomass response to substrate referred to results from field observations (Figure 7.2-3 and Table 7.2-3). Seventy-five percent of the BMI biomass estimates from soft substrates were below 100 mg/sample. A larger fraction of BMI biomass observations from artificial (hard) substrates were much greater than 100 mg/sample. Scoring for each of these substrate types was assigned based on the fraction of observations (75th percentile) where the hard substrate results showed consistently higher biomass aggregation. Hard substrates provide for a greater variety of habitable interstitial space than do the more tightly compacted sand and silt grains found in soft substrates. Also, large-bodied organisms are able to populate substrate with larger interstitial space and can result in much higher BMI biomass estimates than those found in soft substrates. Macrophytes and bedrock were not targeted as part of the field sampling and so the values from the provisional curves were carried to the final curves for these substrate categories.

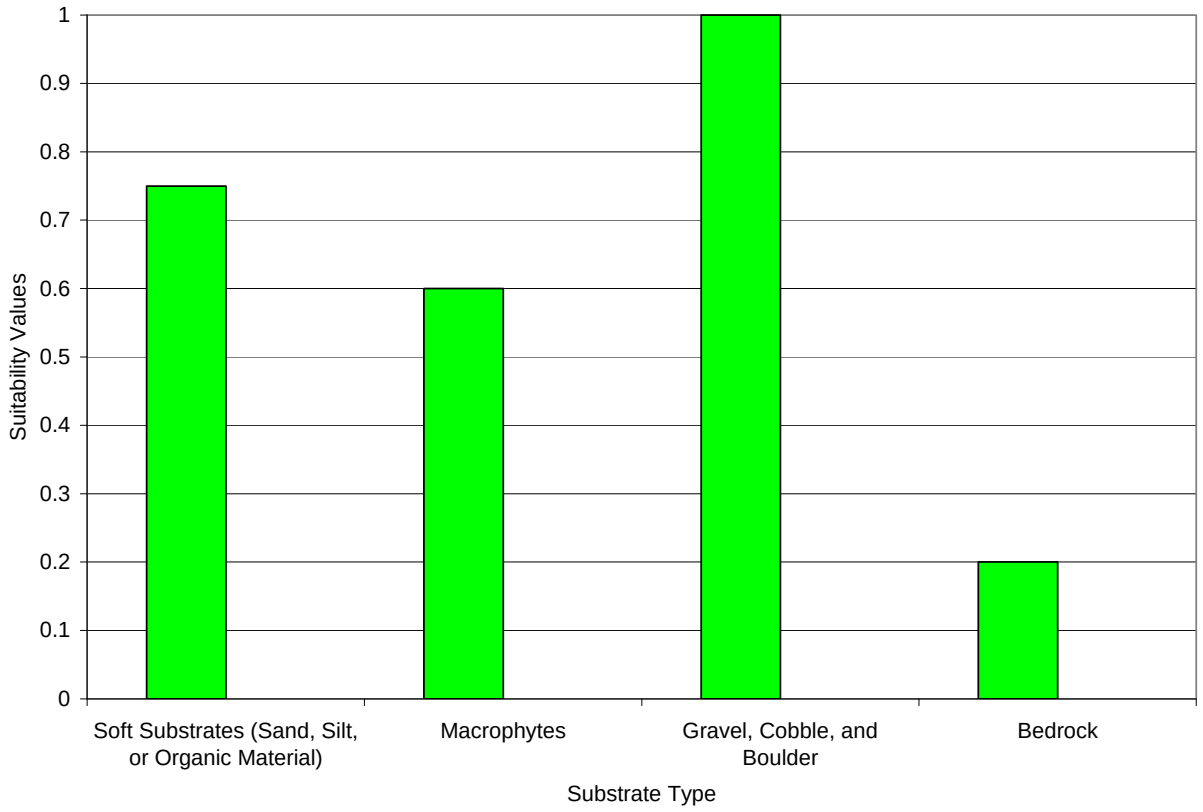


**Figure 7.2-3.** Final substrate suitability values BMI.

**Table 7.2-3.** Final substrate suitability values for BMI in Boundary Reservoir.

| Substrate | Final Suitability Values |
|---|---|
| Soft Substrates (Sand, Silt, or Organic Material) | 0.75 |
| Macrophytes | 0.6 |
| Gravel, Cobble, and Boulder | 1.0 |
| Bedrock | 0.2 |

### 7.2.4. Duration of Dewatering

The provisional HSI curve displayed a gradual BMI biomass response to increased time of dewatering, but field results showed a distinct time interval when biomass aggregation declined rapidly. Dewatering intervals that lasted beyond 10 hours resulted in consistently low BMI biomass estimates and the suitability value reflects the slight decline in preference for a zero to 10-hour duration of dewatering interval, followed by a significant decline for dewatering intervals greater than 10 hours. Field observations showed that a duration of dewatering interval greater than 23 hours resulted in no measurable BMI biomass. The final curve represents these field observations and modifications (Figure 7.2-4).

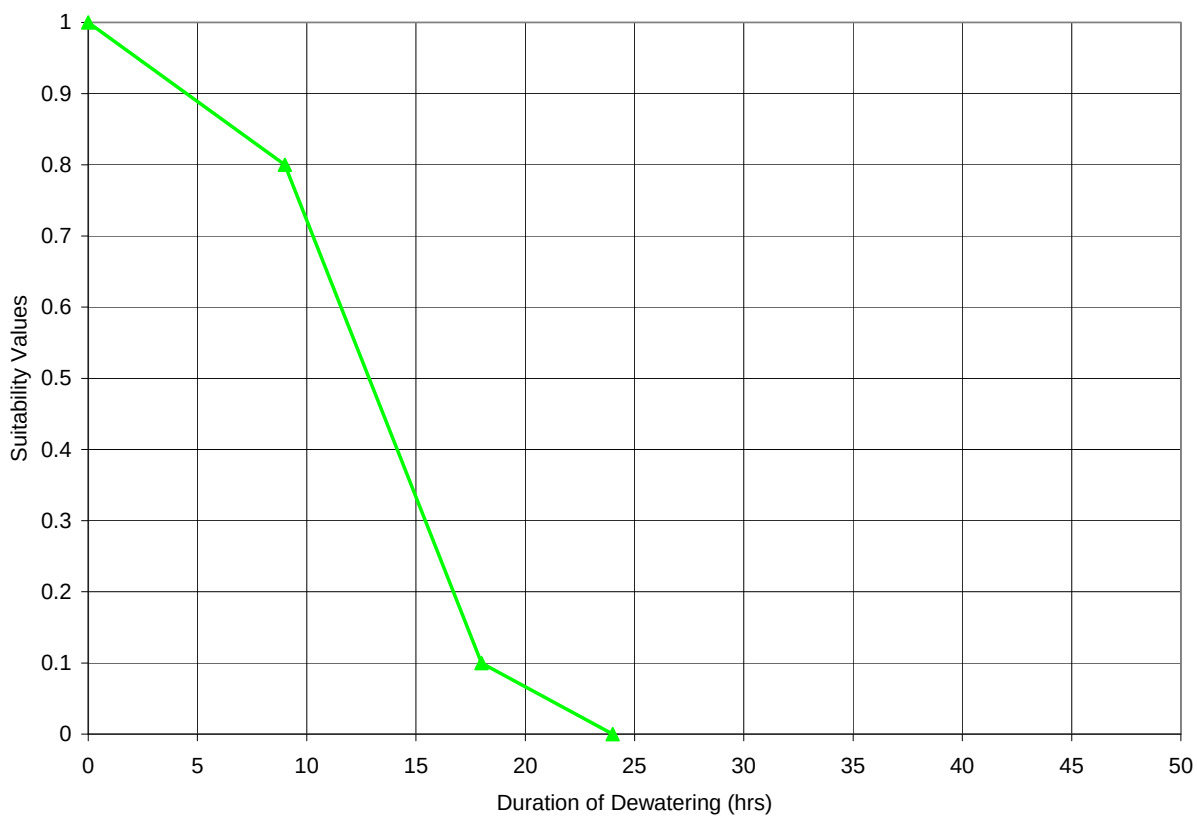


**Figure 7.2-4.** Final duration of dewatering (hours) suitability curve for BMI.

**Table 7.2-4.** Final duration of dewatering suitability values for BMI in Boundary Reservoir.

| Duration of Dewatering (hrs) | Final Suitability Values |
|---|---|
| 0 | 1.0 |
| 9 | 0.8 |
| 18 | 0.1 |
| 24 | 0 |

### 7.2.5. Duration of Inundation

The duration of inundation suitability curve was modified from the literature-based, provisional curve based on field observations (Figure 7.2-5 and Table 7.2-5). Field observations for BMI biomass estimates at longer durations of inundation showed similar results to shorter inundation intervals. The field results for BMI biomass response to duration of inundation produced a suitability curve different from the provisional curve (July 15, 2008, Water Quality Workgroup meeting). As shown in Figure 7.1-10, the duration of inundation interval between 10 and 40 days (240 to 960 hours) from the observed curve did not change substantially until a period after 50 days (1,200 hours). The final curve represents a compromise between the observed field results and the provisional, literature-based suitability curve. The shape of the final curve maintains the general shape of the provisional suitability curve, but reflects a lower expected biomass over longer duration of inundation intervals.

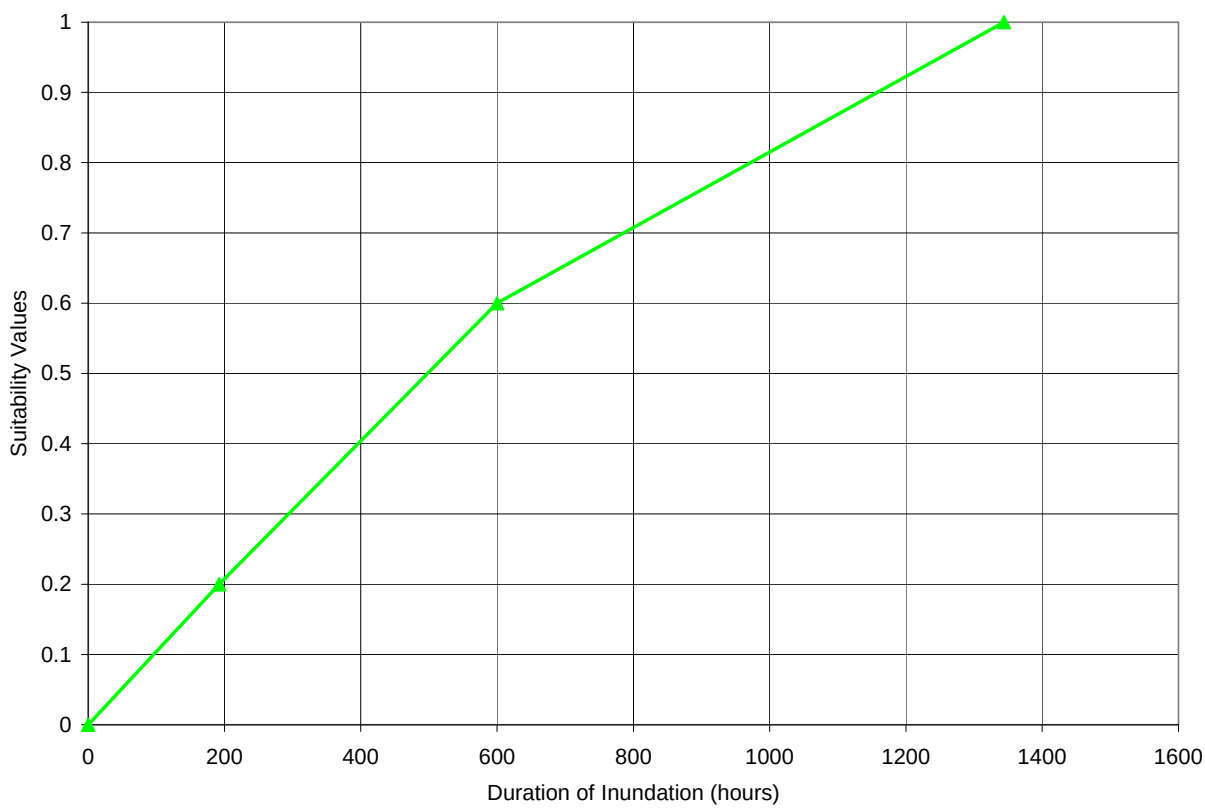


**Figure 7.2-5.** Final duration of inundation (days) suitability curve for BMI.

**Table 7.2-5.** Final duration of inundation suitability values for BMI in Boundary Reservoir.

| Duration of Inundation (hours) | Final Suitability Values |
|---|---|
| 0 | 0 |
| 192 | 0.2 |
| 600 | 0.6 |
| 1344 | 1.0 |

## 8 MODEL RESULTS

The final BMI HSI curves were used in the Mainstem Aquatic Habitat Model to determine the weighted usable area (WUA) available for BMI in Boundary Reservoir. The Mainstem Aquatic Habitat Model was run for three water years: a wet year (1997), a dry year (2001), and an average year (2002). An example of model output for BMI WUA for the Upper Reservoir Reach in a dry year is presented in Figure 8.1-1. The figure presents the WUA time period plotted on the x-axis and the corresponding hourly WUA values for BMI on the y-axis. Table 8.1-1 is an example of tabular model output for BMI WUA. Complete models results and discussion of BMI WUA can be found in Section 5.8 of the Study 7, Mainstem Aquatic Habitat Modeling Study Final Report (SCL 2009a). A more detailed discussion of BMI production can be found in the Study 11, Productivity Assessment Final Report (SCL 2009b).

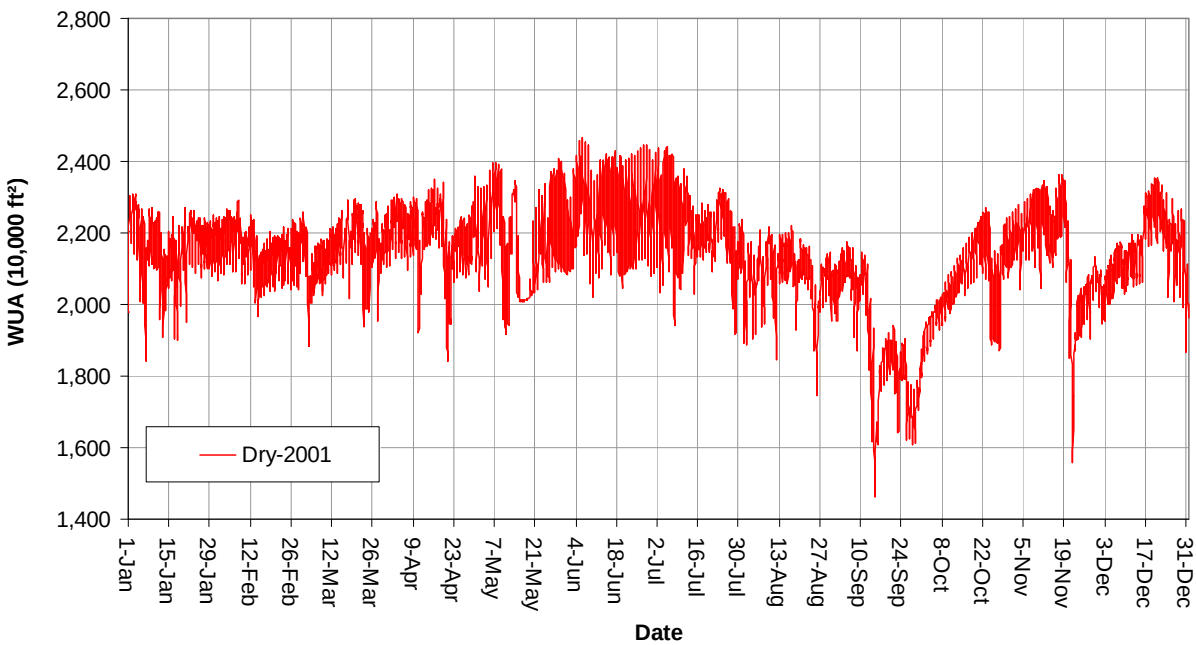


**Figure 8.1-1.** Habitat WUA for BMI in the Upper Reservoir Reach of Boundary Reservoir, determined by the Mainstem Aquatic Habitat Model, for a dry water year (2001).

**Table 8.1-1.** Summary of monthly BMI WUA (10,000 sq. ft) in the Upper Reservoir Reach determined by the Mainstem Aquatic Habitat Model for Boundary Reservoir.

| Month | Wet Year 1997 | | | | Dry Year 2001 | | | | Average Year 2002 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | Max | Min | Stdev. | Avg. | Max | Min | Stdev. | Avg. | Max | Min | Stdev. |
| January | 2,407 | 2,548 | 2,153 | 90.0 | 2,160 | 2,309 | 1,841 | 84.4 | 2,213 | 2,376 | 1,838 | 90.4 |
| February | 2,414 | 2,569 | 2,186 | 85.8 | 2,150 | 2,290 | 1,967 | 57.1 | 2,208 | 2,389 | 1,810 | 114.7 |
| March | 2,333 | 2,562 | 2,059 | 121.4 | 2,157 | 2,296 | 1,881 | 70.5 | 2,113 | 2,271 | 1,833 | 98.0 |
| April | 2,318 | 2,535 | 2,047 | 116.3 | 2,195 | 2,357 | 1,840 | 86.8 | 2,111 | 2,362 | 1,899 | 103.0 |
| May | 2,190 | 2,222 | 2,133 | 23.1 | 2,168 | 2,408 | 1,917 | 123.2 | 2,203 | 2,503 | 1,914 | 158.8 |
| June | 2,292 | 2,460 | 2,107 | 97.8 | 2,255 | 2,465 | 2,022 | 109.6 | 2,077 | 2,141 | 1,960 | 50.9 |
| July | 2,457 | 2,681 | 2,246 | 116.0 | 2,221 | 2,442 | 1,912 | 93.2 | 2,389 | 2,669 | 2,057 | 136.0 |
| August | 2,365 | 2,643 | 1,879 | 145.7 | 2,083 | 2,222 | 1,747 | 78.8 | 2,329 | 2,490 | 2,064 | 83.1 |
| September | 2,359 | 2,485 | 2,122 | 76.3 | 1,898 | 2,174 | 1,462 | 168.3 | 2,281 | 2,393 | 1,977 | 67.5 |
| October | 2,322 | 2,520 | 2,082 | 110.1 | 2,065 | 2,270 | 1,795 | 101.2 | 2,332 | 2,459 | 2,056 | 73.6 |
| November | 2,359 | 2,519 | 2,069 | 100.6 | 2,142 | 2,363 | 1,557 | 143.3 | 2,311 | 2,434 | 2,015 | 65.8 |
| December | 2,370 | 2,517 | 2,014 | 95.9 | 2,155 | 2,356 | 1,868 | 94.1 | 2,274 | 2,440 | 1,817 | 101.4 |

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# Appendix 9: Fish Habitat Suitability Index for Species of Interest Final Report

# *Boundary Hydroelectric Project (FERC No. 2144)*

## *Study 7: Mainstem Aquatic Habitat Modeling*

## *Appendix 9*

## *Fish Habitat Suitability Index for Species of Interest*

## *Final Report*

**Prepared for**
**Seattle City Light**

**Prepared by**
**Mark Allen**
**Thomas R. Payne and Associates**
**(Under Contract to Tetra Tech)**

**March 2009**

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# Study 7 Appendix 9
# Fish Habitat Suitability Index for Species of Interest
# Final Report
# Boundary Hydroelectric Project (FERC No. 2144)

## 1 INTRODUCTION

The efforts in this study provide information for the Mainstem Fish Habitat Modeling effort. The habitat suitability indices (HSIs) development provides depth, velocity, substrate, and/or cover HSIs for selected fish species and life stages. The HSI curves are used in the Mainstem Physical Habitat Model to translate physical characteristics present for different operations scenarios to indices representing the potential habitat that is suitable for the selected species. HSIs are applied to describe the response of each species of interest[1] to depth, velocity, and substrate or cover conditions. Each HSI curve is scaled between 0 and 1, where 1 represents optimal habitat conditions and 0 represents wholly unsuitable conditions.

## 2 OBJECTIVES

The primary objective of the fish HSI development process was to develop curves that describe the relative suitability of depths, mean column water velocities, substrate types, and cover types for the fish species and life stages of interest in the Project area. The species selected for habitat modeling in the Boundary Project area were mountain whitefish (*Prosopium williamsoni*), bull trout (*Salvelinus confluentus*), westslope cutthroat trout (*Oncorhynchus clarkii lewisii*), redband trout (*O. mykiss gairdneri*), smallmouth bass (*Micropterus dolomieui*), and several cyprinid species intended to represent forage for larger predator species: northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and redside shiner (*Richardsonius balteatus*). The life stages of interest were based on the known or suspected occurrence in the Project area, and included spawning (for whitefish and smallmouth bass), fry rearing (for all species except bull trout), juvenile rearing (all species), and adult rearing (all species). The forage cyprinid group only represented smaller individuals <10cm in total length. Redband trout were intended for modeling within the tailrace reach only; all other species were modeled in both tailrace and reservoir reaches.

## 3 METHODS

HSI curves can be developed using professional judgment with reference to existing curves developed from other locations; they can be developed by collecting site-specific habitat use data from a project area, then formed into a new HSI curve; or they can be developed from a

[1] The term target species specifically refers to native salmonids including bull trout, cutthroat trout, redband/rainbow trout and mountain whitefish. The target species as well as other species for which HSI curves were developed are species of interest. To simplify discussions, all species for which HSI curves were developed and WUA and ESI/PSI analysis were performed are collectively referred to as species of interest except when native salmonids are solely being discussed.

combination of the above. Given sufficient fish densities and HSI sample sizes, site-specific HSI curves were proposed for development to best represent habitat suitability in the Project area. New, site-specific HSI curves are generally thought to best represent the unique characteristics of a particular project area; however fish densities must be adequate to generate sufficient sample sizes to accurately represent fish selectivity. As a general rule-of-thumb, a sample size of 150 habitat use observations is considered necessary to develop representative HSI curves (Bovee 1986). The Study 9, Fish Distribution, Timing, and Abundance Study (SCL 2009a) was intended, in part, to collect site-specific HSI data within the Project area. The Study 9 Final Report (SCL 2009a) describes the methodologies utilized to collect habitat use data within the Project area. Because several target species were known to occur in the Project area at very low densities, it was anticipated that site-specific HSI curves could not be developed for those species. Consequently, previously existing HSI data were collected from literature sources in order to develop provisional HSI curves for each species. The site-specific data collected during Study 9 (SCL 2009a) was then compared to the literature-based curves, and new, judgment-based HSI curves were developed based on consensus from a panel of relicensing participants that were experienced with HSI models. Where sufficient data were collected from the Project area, new site-specific HSI curves were developed and evaluated by the relicensing participants.

Two meetings were held with relicensing participants to discuss fish HSI curves (April 23 and August 27, 2008). Each HSI curve was assessed in relation to the literature-based data (e.g., source location, data strengths and weaknesses, etc.), the available site-specific data, and the unique characteristics of the Project area, and final HSI curve points were determined by workgroup consensus. Specific details regarding the HSI presentation materials, subsequent discussion, and curve decisions from the two workgroup meetings are available at the SCL website at: http://www.seattle.gov/light/news/issues/bndryRelic/br_schedule.asp).

## 4 LITERATURE-BASED HSI CURVES

The existing literature-based HSI curves were obtained from published papers, white papers, state or federal curve libraries, and from the consultant's own HSI studies. The existing HSI curves include those developed from actual field data as well as curves drawn solely by professional judgment (usually by consensus of gathered "experts"). Some of the "curves" were not originally developed for use in instream flow studies and did not take the form of an HSI curve; in such cases an HSI curve was derived from the available data. For each species and life stage, the literature-based HSI curves were plotted on a common axis and visually compared to identify overall suitability trends, particularly in relation to the ranges in depth and velocity where suitability is maximum, and those ranges where suitability goes to zero. Because literature-based substrate and cover HSI could not easily be plotted on a common axis (due to differences in coding systems used by various researchers), provisional substrate (for spawning) and cover (for rearing) HSI curves were developed based on professional judgment, then presented to an HSI workgroup for evaluation and approval. Size definitions of fry, juvenile, and adult fish vary among data sets, and actual length classifications are shown in the suitability tables where the data were available (but frequently it was not given). For the purposes of this report, approximate size class definitions are consistent with the periodicity tables (see Appendix 3 of the Study 7, Mainstem Aquatic Habitat Modeling Study Final Report [SCL 2009b]) as fry <55 millimeters (mm), juveniles 55-150 mm, and adults >150 mm.

Based on the literature search, over 60 HSI datasets were located. For most species and life-stages, all HSI curves found in the literature were plotted, yet HSI data remained rare for several species, including bull trout, cutthroat trout, and native northwestern cyprinids. For juvenile and adult rainbow trout, however, the number of available suitability curves was too large to effectively portray on a graph, consequently the list of available curves was screened to include only those datasets that met the following criteria: 1) curves were generated from site-specific data (e.g., not judgment-based curves); 2) sample sizes were at least 100 observations; and 3) sampling occurred at flows >100 cfs (to represent larger streams). Associated with each species curve set is a table describing the source of each plotted curve, which typically gives location, sample size, sampling design, and other details regarding the curve data. Some curve sets, however, contained little supporting data and such missing data are indicated by blank fields in the data tables. Other missing or difficult-to-find information were literature-based HSI curves designed to represent habitat suitability during cold winter months. Consequently, additional provisional curves were constructed, largely by professional judgment, to represent HSI for the cold water period, defined as November 1 through March 31. This period approximates the duration of Project water temperatures below $10^{o}$C.

The entire suite of literature-based HSI curves, along with the associated site-specific data and final HSI curves, are described and presented in Section 6 of this appendix.

## 5 USE OF FIELD DATA IN HSI DEVELOPMENT

Overlaid upon the literature-based curve sets for several species and life stages are data points showing site-specific habitat utilization data that were acquired during the Study 9 electrofishing and biotelemetry efforts in the study area (SCL 2009a). The HSI data based on biotelemetry studies were intended to be the primary source of information for adult individuals of the species of interest, due to the ability of telemetry crews to track fish throughout the entire study area. Boat electrofishing, in contrast, is highly limited to shallow, nearshore locations and was thus intended to provide auxiliary HSI information on adult fish, and primary HSI information on fry and juvenile fish that could not be tagged. For the salmonid target species, which occur at low densities in the Project area, the site-specific data were only expected to help select the most appropriate HSI curve or to fine-tune a new judgment-based curve. For the more abundant species (e.g., bass and cyprinid forage species), site-specific data could be used to create new HSI curves given sufficient sample sizes.

Even with adequate sample sizes, it should be noted however that differences in data collection techniques (e.g., nearshore electrofishing vs. mainstem biotelemetry) will result in large differences in the relationship between fish abundance and the number of suitability "observations," and care must be taken when assessing HSI observations from different sources. In particular, electrofishing was not expected to yield adequate HSI data for depths greater than approximately 10 feet. For both boat electrofishing and biotelemetry, it was not possible to identify the exact focal point of each fish with precision. The lack of precision was particularly evident for biotelemetry; consequently the site-specific HSI curves were derived from the boat electrofishing efforts, then adjusted as necessary with the biotelemetry data (for tagged adult fish) by professional judgment. Note that the sample sizes presented in Table 5.0-1 for

electrofishing are based on the "HSI cell" methodology that was designed to sample fish with a minimum of displacement prior to capture. Depth, velocity, substrate, and cover data were collected in each sampled cell whether species of interest were captured or not. Details describing the methodologies used to collect the HSI data by cell electrofishing and biotelemetry are presented in Study 9 (SCL 2009a).

As of February 2008, site-specific data were non-existent for bull trout, and were very uncommon for all other salmonids (Table 5.0-1). During the winter of 2008, it became evident that sample sizes for the target salmonid species would be insufficient for developing site-specific HSI curves, even with continued HSI electrofishing efforts. This information was presented to the relicensing participants at the March 26, 2008, Fish and Aquatics Workgroup meeting and it was agreed to terminate this aspect of the electrofishing effort. Consequently, the cell-based electrofishing efforts were suspended after the February field survey.

Given the HSI sample sizes shown in Table 5.0-1, new site-specific HSI curves were only generated for smallmouth bass and forage cyprinids based on the cell electrofishing data. Site-specific HSI data for the remaining species, if available, were plotted with the literature-based HSI curves and used to create new judgment-based curves through consensus with relicensing participants. Because cell electrofishing was not expected to accurately reflect the presence or absence of fish species of interest at depths greater than 10 feet, only those cells less than 10 feet and sampled during the summer months (April-October) were utilized for creating the bass and forage HSI curves. A total of 384 of the 594 electrofishing cells met the depth and summer criterion, which included the capture of 14 smallmouth bass fry, 92 juvenile bass, 48 adult bass, and 92 forage cyprinids (note: no bass or forage fish were captured in cells >10 feet). Where necessary, professional judgment in concert with literature-based HSI or site-specific biotelemetry data (for adult bass) was used to estimate suitability of depths greater than 10 feet.

When bass or forage fish were captured in the electrofishing cells, the number of individuals (or each species and life stage) rarely exceeded one or two fish ( only 15 of 384 cells), consequently the cell capture data was treated as presence-absence data and fitted with logistic regression. Logistic regression is a method particularly suited for binomial distributions where many samples do not contain the species of interest, and those that do contain fish contained only a few individuals. The distribution of captures from the cell electrofishing data followed this pattern, with most cells containing zero captures and few cells containing a more than two individuals of the fish species of interest.

This density-based method of HSI creation accounts in-part for habitat availability effects because all sampled cells are included in the analysis, both those cells that contained the fish species of interest and those cells that did not contain fish. This is in contrast to HSI curves constructed solely from habitat utilization data, where only those locations were fish are observed are used to construct the HSI curve. Logistic regressions were fit to the cell capture data (assuming an approximately equal sampling area for each electrofished cell) using polynomial orders of $2^{nd}$ or $3^{rd}$ degree. The predicted counts were normalized to 1.0 for the maximum value, then plotted on the HSI figures with the literature-based HSI curves. This suite of HSI curves were evaluated by the HSI workgroup and the new site-specific curve was either accepted as proposed, or was modified by consensus (with reference to other curves or biotelemetry data) then accepted, or else was used to create a new, consensus-based HSI curve.

**Table 5.0-1.** Summary of site-specific HSI data from cell electrofishing and biotelemetry on the Project, March 2007 through February 2008.

| Sampling Method | Sample Period | # Cells [1] Sampled | Bull Trout | Cut-throat Trout | Redband Trout (wild) | White-fish | SM Bass | | | Forage <10cm |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | <6 cm | 6-15 cm | >15 cm | |
| Boat Electro-fishing | Mar-07 | 11 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| | Apr-07 | 103 | 0 | 0 | 1 | 0 | 0 | 2 | 3 | 4 |
| | May-07 | 87 | 0 | 0 | 1 | 1 | 0 | 5 | 13 | 4 |
| | Jun-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Jul-07 | 60 | 0 | 0 | 0 | 0 | 1 | 5 | 5 | 0 |
| | Aug-07 | 97 | 0 | 0 | 0 | 0 | 9 | 24 | 15 | 14 |
| | Sep-07 | 96 | 0 | 0 | 0 | 0 | 3 | 19 | 4 | 7 |
| | Oct-07 | 32 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 4 |
| | Nov-07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Dec-07 | 35 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 2 |
| | Jan-08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Feb-08 | 73 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 8 |
| | # Cells[2,3] | 594 | 0 | 1 | 4 | 5 | 13 | 59 | 43 | 44 |
| | # Fish[4] | - | 0 | 1 | 4 | 7 | 14 | 96 | 51 | 130 |
| Bio-telemetry | # Tagged | - | 0 | 5 | 0 | 13 | 0 | 0 | 19 | 0 |
| | # HSI[5] Obs | - | 0 | 18 | 0 | 19 | 0 | 0 | 49 | 0 |

Notes:
1 Number of HSI cells sampled by electrofishing.
2 Number of cells with species of interest present (in species columns).
3 Only EF cells <10 ft (n=384) were used to develop summer (Apr-Oct) HSC for smallmouth bass and cyprinids
4 Total number of fish in all EF cells.
5 Number of biotelemetry HSI observations includes multiple observations for several tagged fish.

## 6 FINAL CURVES

After plotting together all literature-based HSI curves for a particular species and life stage along with all available site-specific HSI observations from the Study 9 field work (SCL 2009a), a provisional Boundary HSI curve was then fit by eye to the suite of existing curve sets and site-specific data. As described above, new site-specific HSI curves were also derived for smallmouth bass and forage cyprinids. These provisional literature-based or site-specific HSI curves were then presented to an HSI workgroup, consisting of relicensing participants including biologists from SCL, SCL contracted consultants, and various state, federal, and tribal agencies, in two meetings (April 23 and August 27, 2008). Consensus was reached on all HSI curves (with the exception noted below), with the final curves presented in the following figures and tables.

The only curves included below that were not discussed and accepted by the HSI workgroup were the winter HSI curves for cutthroat trout, redband trout, and smallmouth bass fry. It was initially assumed that the fry life stages for all species of interest would not extend through the winter months; therefore the group only discussed winter HSI curves for juvenile and adult life stages. Following the development of the species periodicity dates, however, fry periodicities for those three species were extended into the winter. Consequently, the winter fry curves were derived independently of the HSI workgroup by using the relationship between juvenile winter:summer HSI curve points to modify the summer fry curves in a similar manner. For example, the winter HSI value for juvenile cutthroat decreased to zero suitability at 2 feet per second (fps), which was 33 percent slower than the summer HSI curve at 3 fps. Therefore, the summer velocity curve for cutthroat fry velocity was reduced at its fastest point from 2 fps to 1.25 fps, a decrease of approximately one-third. The remaining curve points for winter velocity, depth, and cover HSI for cutthroat fry, redband fry, and smallmouth bass fry were likewise modified according to the relationship between summer and winter curve points from the juvenile curves.

## 6.1. Mountain Whitefish

HSI curves for mountain whitefish are extremely rare, and most available data sets are derived from studies in Alberta (Table 6.1-1). Site-specific habitat use observations are available from five electrofishing cells (representing seven fish) and 13 adult fish tagged with radio or CART tags, representing 19 HSI observations (all but two in winter). The final HSI curve points for whitefish are listed in Table 6.1-2.

**Table 6.1-1**. HSI datasets for whitefish.

| Curve Name | Lifestage | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °C | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bovee | S,F,J,A | | ? | UT/MT | | | | | | | Cat II | | Bovee 78 |
| Saskatchewan | S,F,J,A | | | Alberta | Sask Basin streams | | | | | | Cat I | 1 | Addley et al 03 |
| Alberta | S | | 2 | Alberta | Sheep River | | | | | | Cat II | 2 | Thompson & Davies 76 |
| Kananaskis | F,J,A | <7,7-24 | ?,101,458 | Alberta | Kananaskis | ~75-150 | 70 | | RCH | DOuw | Cat I,III,III | 3 | Courtney et al 98 |
| Red Deer | F,J,A | | | Alberta | Red Deer | | ~700 | | | | Cat I | 4 | Golder 99 |
| WA Fallback | J,A | | | WA | | | | | | | | 5 | WDFW & WDE 04 |
| Sheep | A | | | Alberta | Sheep River | | | | | DOuw | Cat III | 6,7 | Locke 88 |
| Misc | A | | | PacNW | | | | | | | | 8 | Wydoski & Whitney 03 |

Notes:
Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 Enveloped use HSC by expert panel
2 Data is ranges w approx means from two spawning locations
3 Delphi curves based on site-specific observations
4 Some site-specific data is presented, but final curves were Cat I
5 WA "Recommended" curves, from Locke 2002
6 Only velocity data is presented in symposium paper, original report probably contains all HSC data
7 Curve pts taken from graph
8 No HSC, note that adults in most "northern" lakes <30ft deep, schools in Box Canyon Res were over gravel near tributary deltas

**Table 6.1-2.** Final HSI values for whitefish according to life stage, season, and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Whitefish | spawning | n/a | 0.00 | 0.00 | 0.50 | 0.00 | fines | 0.00 |
| | | | 1.30 | 1.00 | 1.50 | 1.00 | sand | 0.00 |
| | | | 3.60 | 1.00 | 10.00 | 1.00 | sm grv | 0.30 |
| | | | 5.90 | 0.00 | 30.00 | 0.00 | med grv | 1.00 |
| | | | | | | | lrg grv | 1.00 |
| | | | | | | | sm cob | 1.00 |
| | | | | | | | lrg cob | 0.80 |
| | | | | | | | bldr | 0.30 |
| | | | | | | | bed | 0.00 |
| | fry | summer | 0.00 | 0.80 | 0.00 | 0.00 | NONE | 0.00 |
| | <55mm | | 0.10 | 1.00 | 1.00 | 1.00 | RVG | 0.30 |
| | | | 1.00 | 1.00 | 2.50 | 1.00 | AQV | 0.30 |
| | | | 1.50 | 0.40 | 4.00 | 0.30 | LWD | 0.30 |
| | | | 3.50 | 0.00 | 8.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | juvenile | summer | 0.00 | 0.20 | 0.25 | 0.00 | NONE | 0.20 |
| | 55-150mm | | 1.00 | 1.00 | 1.50 | 1.00 | RVG | 0.20 |
| | | | 2.50 | 1.00 | 4.50 | 1.00 | AQV | 0.20 |
| | | | 3.00 | 0.50 | 6.00 | 0.50 | LWD | 0.20 |
| | | | 4.00 | 0.00 | 10.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 1.00 | 0.00 | NONE | 0.00 |
| | | | 1.00 | 1.00 | 2.00 | 1.00 | RVG | 0.20 |
| | | | 3.00 | 0.00 | 5.00 | 1.00 | AQV | 0.20 |
| | | | | | 20.00 | 0.00 | LWD | 0.50 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | adult | summer | 0.00 | 0.20 | 1.00 | 0.00 | NONE | 0.30 |
| | >150mm | | 1.50 | 1.00 | 2.00 | 1.00 | RVG | 0.30 |
| | | | 3.00 | 1.00 | 20.00 | 1.00 | AQV | 0.30 |
| | | | 6.00 | 0.00 | 50.00 | 0.20 | LWD | 0.30 |
| | | | | | 100.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 1.00 | 0.00 | NONE | 0.30 |
| | | | 1.50 | 1.00 | 4.00 | 1.00 | RVG | 0.30 |
| | | | 2.00 | 0.50 | 20.00 | 1.00 | AQV | 0.30 |

**Table 6.1-2, continued...**

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| | | | 6.00 | 0.00 | 50.00 | 0.20 | LWD | 0.30 |
| | | | | | 200.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:
1 Summer=1 April to 31 October, winter=1 November-31 March
2 Substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.1.1. Spawning

Mountain whitefish are suspected of spawning in Boundary Reservoir and/or in associated tributaries. An attempt was made to locate aggregations of spawning whitefish during the late-fall and winter of 2007 (SCL 2009a), however spawning could not be verified and no HSI data was obtained. Consequently, the final spawning HSI curve was based on professional judgment by reference to the three literature-based data sets, one of which was a consensus curve and another was based on the observation of only two spawning locations (Table 6.1-1, Figure 6.2-1). The final Boundary curve for both velocity and depth are broad to account for the uncertainty in the suitability data and to encompass the data at hand. Only the initial limb of the Bovee depth curve, which appeared too shallow for a large river system with fluctuating flows, was excluded from the Boundary curve. The final HSI curve for dominant substrate type gives high suitability for gravel and cobble, with intermediate suitability for boulders and zero suitability for fines, sand, and bedrock.

### 6.1.2. Fry

The whitefish fry HSI curves show high variability in velocity suitability, but are more consistent for depth (Table 6.1-1, Figure 6.2-2). The consensus-based Saskatchewan curve envelopes all other data, but the final Boundary curve is more intermediate in nature. The cover HSI curve for whitefish fry emphasizes that species close association with hard substrate types, and gives relatively low suitability to margin-related cover types (e.g., riparian vegetation and large woody debris) and aquatic vegetation, which typically occurs in areas with finer substrates. Winter HSI curves were not developed for whitefish fry since length-frequency distributions from site-specific electrofishing data suggested that the early-emerging fry exceeded 55 mm in length by the end of summer.

### 6.1.3. Juvenile

The available HSI curves for juvenile whitefish also show high variability in both velocity and depth (Table 6.1-1, Figure 6.2-3). The final Boundary curves are relatively broad and only exclude the fastest velocities and assigns intermediate suitability to deep water. The cover HSI curve for juveniles was similar to fry with highest suitability only for larger substrate types and lower suitability for other cover types. The winter HSI curves for velocity and depth followed a

consistent pattern with most other species by giving higher suitability for slower velocities and deeper depths, reflecting a general movement towards deeper and slower microhabitats. The winter cover curve was also consistent with most other fry and juvenile curves by showing a closer association with dense cover types such as woody debris, versus aquatic vegetation which is largely absent during the winter months.

### 6.1.4. Adult

The adult whitefish HSI curves are relatively consistent for both depth and velocity, except for the Kananaskis velocity curve which only gives high suitability for slow velocities (whereas the Kananaskis juvenile curve is very fast). The final Boundary curves are likewise broad and bracket most of the available data, except for the shallow limb of the Saskatchewan curve and the slow end of the Kananaskis curve (Table 6.1-1, Figure 6.2-4). The site-specific electrofishing and biotelemetry data fall within the interim curves, with the deepest telemetry observations (at over 80 feet) illustrating the positive suitability for deeper water. The winter HSI curves also bracket the site-specific data while showing increased suitability for slower and deeper habitats (the deep water suitability is increased for depths over 50 feet, not shown in the figure). The cover HSI curves for adult whitefish are similar to the juvenile curves, but identical curves for winter and summer and limited suitability for no cover, due to decreased threat of predation.

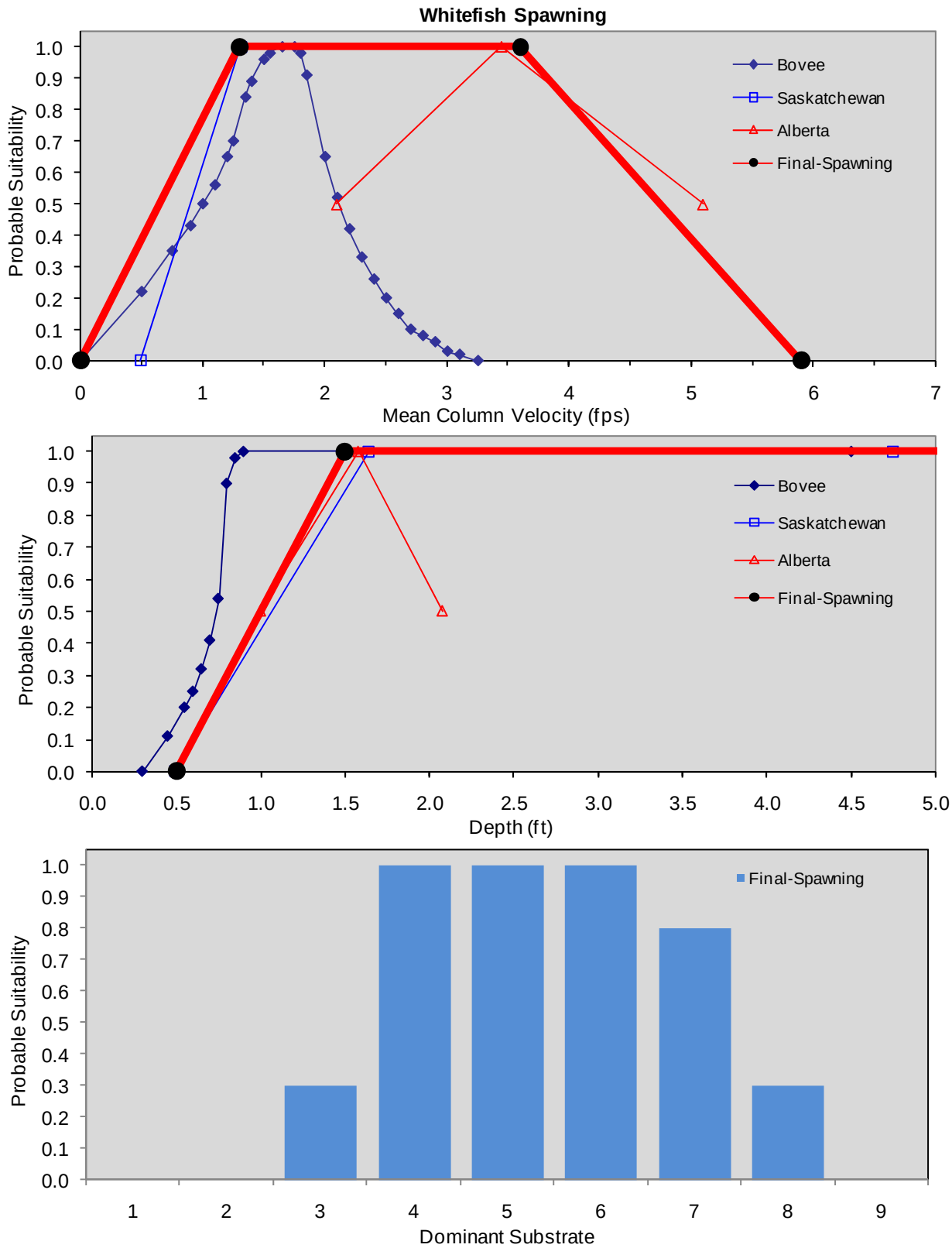


**Figure 6.2-1.** Literature-based and final Project HSI curves for whitefish spawning velocity, depth, and substrate type. See Table 6.1-1 for substrate type definitions.

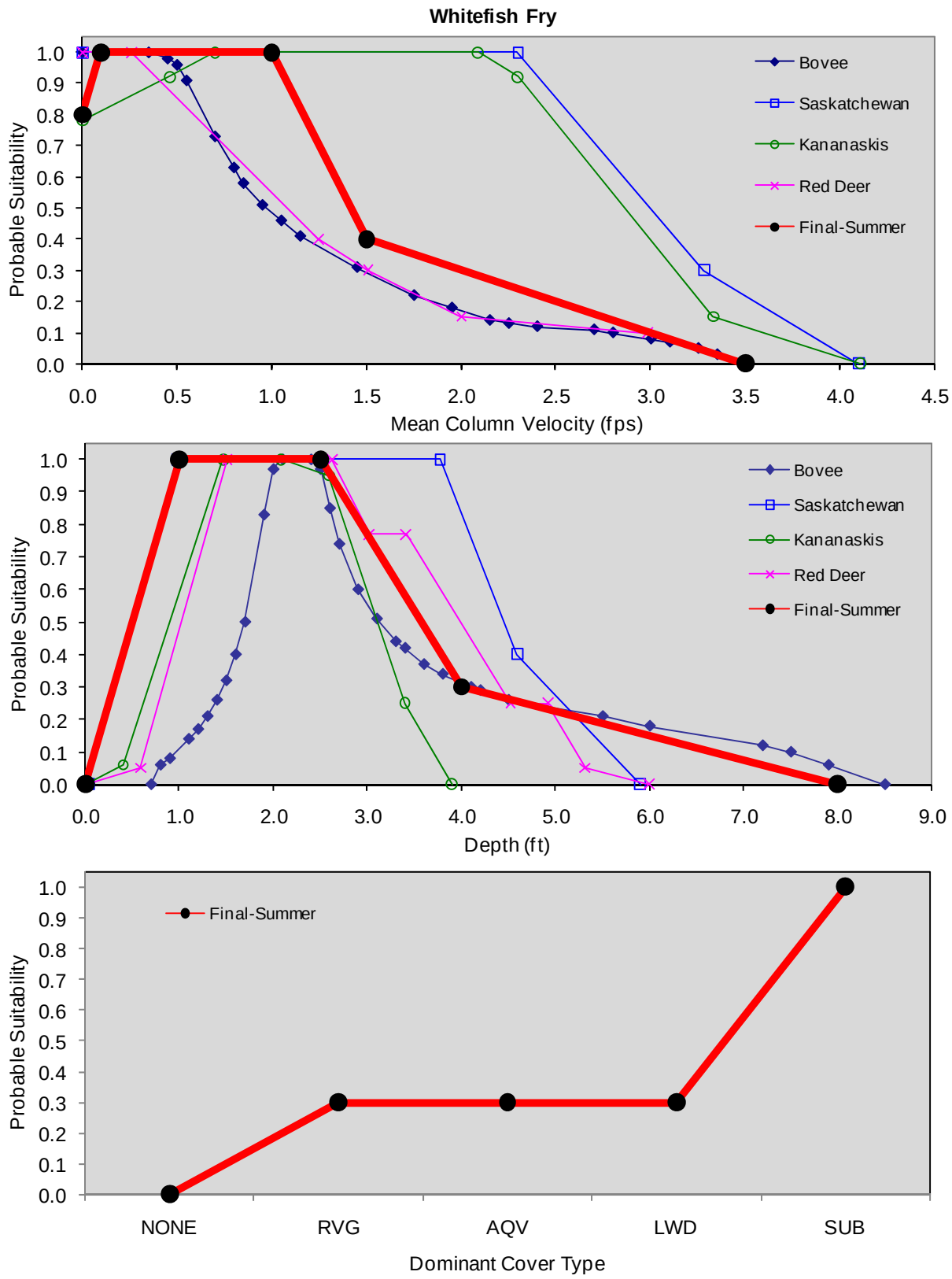


**Figure 6.2-2.** Literature-based and final Project HSI curves for whitefish fry velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

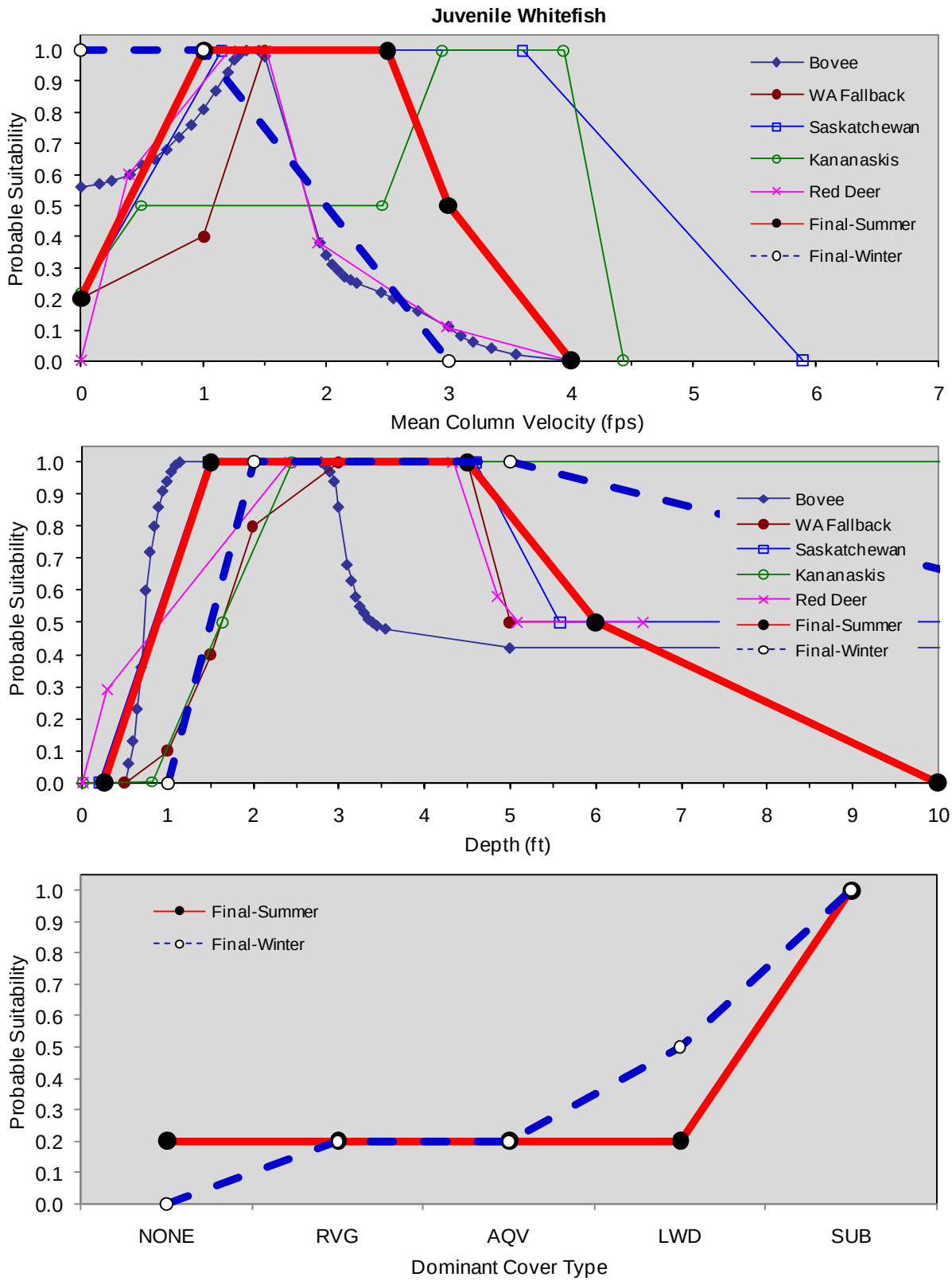


**Figure 6.2-3**. Literature-based and final Project HSI curves for juvenile whitefish velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

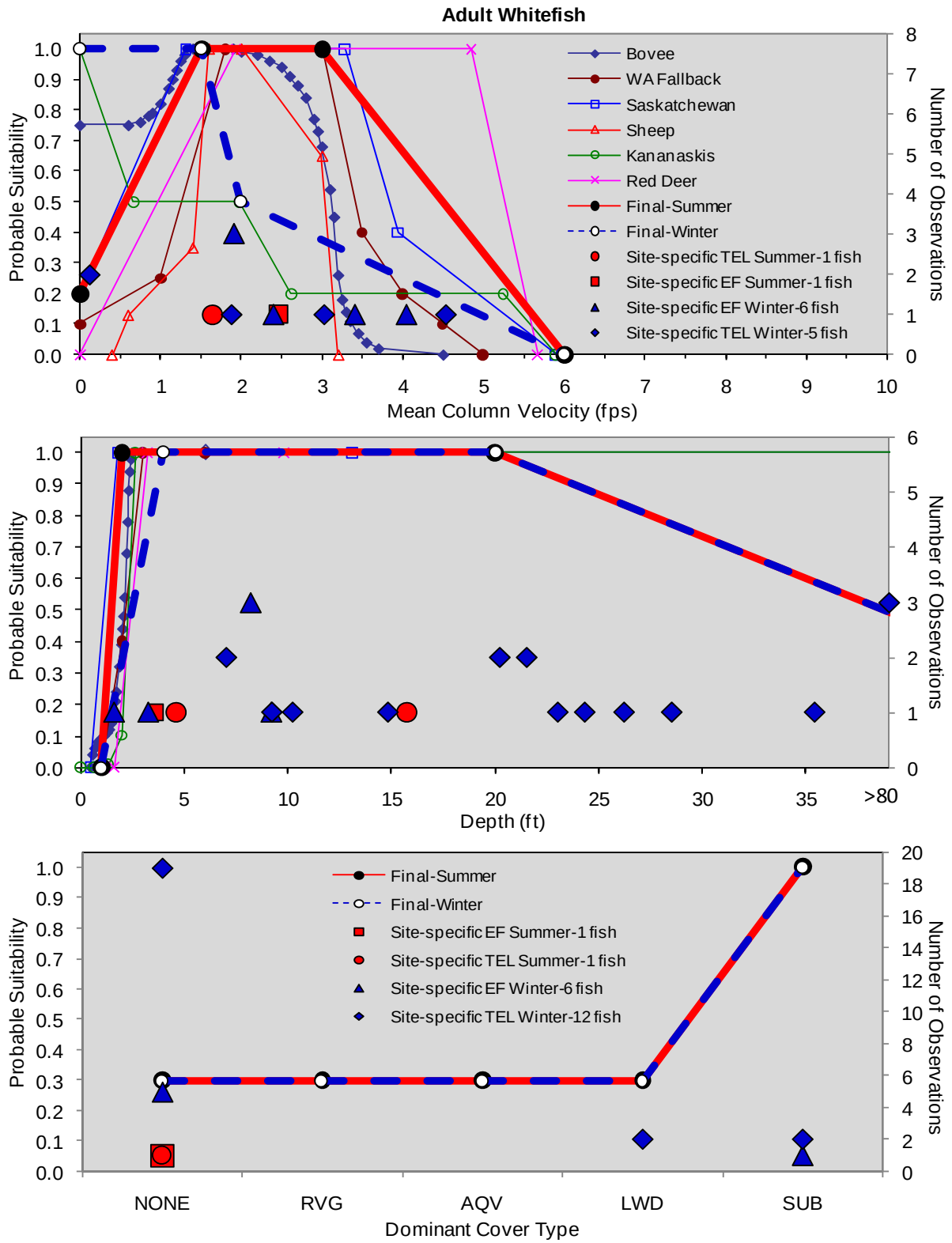


**Figure 6.2-4.** Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing, TEL=biotelemetry) for adult whitefish velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

## 6.2. Bull Trout

Bull trout are not known to spawn in the Project area or in any of the tributaries, but are known to immigrate into Boundary Reservoir (from upstream sources) and the tailwater reach (from downstream sources). Consequently, only juvenile and adult rearing will be modeled for fish habitat. Bull trout HSI data are very rare, and the data that are available are mostly from smaller streams (Table 6.2-1). To expand the available literature sources, HSI data from Dolly Varden trout (*Salvelinus malma*), are also included as a surrogate species for bull trout. Sample sizes for most bull trout and Dolly Varden HSI curves are small or unknown. Only the Flathead River data for juvenile bull trout and the Hells Canyon adult data were derived from a large river, but those data were based on relatively few fish regularly re-located using telemetry. No site-specific data were obtained for bull trout habitat use in the Project area (Table 5.0-1). Final HSI points for bull trout are given in Table 6.2-2.

**Table 6.2-1.** HSI datasets for bull trout.

| Curve Name | Lifestages | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °C | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WA DOE | J+A | | | WA | ? | | | | | | Cat I? | 1 | Rittmeuller pers com |
| WA Fallback | J+A | | 39 | WA | 2,4 streams | | | | | | | 2 | WDFW & WDE 04 |
| Saskatchewan | J,A | | | Alberta | Sask Basin streams | | | | | | Cat I | 3 | Addley et al 03 |
| Prince Wales | J | <8,8+ | 72 | AL | Bonnie Crk | <7 | 25-67 | <18 | | | | 4 | Bugert et al 91 |
| Alaska | J+A | | 1050 | AL | Chakachamna & McArthur tribs/SC's | | | | PROP | | Cat II | 5 | Voos & Lifton 88 |
| Montana | F+J+A | <21 | 150 | MT | tribs to NF, MF, & SF Flathead | ~6-60 | ~10-40 | 5-15 | RCH | | density | 6 | Pratt 84 |
| SE Wash | F+J+A | all | 57 | WA | Tuscannon R+Mill Crk | ~10-40 | ~3-30 | 4-8 | units | | Cat II | 7 | Underwood et al 95 |
| Flathead-wint day | J | 26-37 | 95 | MT | Flathead R | 250 | 3300-4030 | 2-5 | | TEL | Cat II | 8 | Muhlfeld et al 03 |
| Flathead-wint nite | J | 26-37 | 95 | MT | Flathead R | 250 | 3300-4030 | 2-5 | | TEL | Cat II | 8 | Muhlfeld et al 03 |
| Hells Canyon | A | 29-50 | 23 | ID | Snake River | | 7282-32420 | | | TEL | Cat II | 9 | Chandler 03 |

Notes:

Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 HSC sent by Pete Rittmeuller (2/05), curves "approved" by WDFW
2 WA "Recommended" curves, essentially eye-smoothed versions of the calculated curves
3 Enveloped use HSC by expert panel
4 Curves taken from frequency plots, focal velocities?, other position data recorded
5 Curves presented in Slauson 1988
6 Includes fry, curves drawn from Pratt 1984 thesis, figures 10 and 11
7 Includes fry and adults, nose velocities only
8 Daytime curve pts taken from histograms, cover data also collected but histograms not presented
9 Bottom velocities estimated with formula for 0.2m above the bottom (but fish depth not known), dist to bank also recorded

**Table 6.2-2.** Final HSI values for bull trout according to life-stage, season, and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Bull | juvenile | summer | 0.00 | 0.80 | 0.00 | 0.00 | NONE | 0.25 |
| Trout | 55-150mm | | 0.25 | 1.00 | 0.75 | 1.00 | RVG | 0.50 |
| | | | 1.50 | 1.00 | 4.00 | 1.00 | AQV | 0.75 |
| | | | 2.25 | 0.40 | 8.00 | 0.50 | LWD | 1.00 |
| | | | 4.00 | 0.00 | 20.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.00 |
| | | | 1.00 | 1.00 | 2.00 | 1.00 | RVG | 0.25 |
| | | | 2.00 | 0.00 | 10.00 | 1.00 | AQV | 0.25 |
| | | | | | 20.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | adult | summer | 0.00 | 0.80 | 1.00 | 0.00 | NONE | 0.25 |
| | >150mm | | 0.20 | 1.00 | 2.00 | 1.00 | RVG | 0.50 |
| | | | 2.25 | 1.00 | 30.00 | 1.00 | AQV | 0.50 |
| | | | 3.50 | 0.40 | 50.00 | 0.20 | LWD | 1.00 |
| | | | 5.25 | 0.00 | 400.00 | 0.20 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 1.00 | 0.00 | NONE | 0.00 |
| | | | 1.00 | 1.00 | 5.00 | 1.00 | RVG | 0.25 |
| | | | 2.00 | 0.25 | 30.00 | 1.00 | AQV | 0.25 |
| | | | 4.00 | 0.00 | 50.00 | 0.20 | LWD | 1.00 |
| | | | | | 400.00 | 0.20 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:

1 Summer=1 April to 31 October, winter=1 November-31 March

2 Substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.2.1. Juvenile

Most microhabitat studies of bull trout appear to emphasize the juvenile life stage, and nine HSI curves are shown, many of which also include fry or adults (Table 6.2-1, Figure 6.2-5). Only the Flathead River winter curves appear to be based on a larger river, and many of the curves are based on relatively few fish. The final Boundary curve for velocity encompasses the majority of the slower curves, but does not fully include the faster half of the Washington fallback or the Saskatchewan consensus curves. The depth curves consistently show highest suitability for depths less than four feet, except for the winter Flathead curve (that peaks at about 10 feet) and the Washington fallback curve that maintains suitability at 1.0 into deep water. The final

Boundary curve gives peak suitability for shallower depths (up to 4 feet) but also maintains intermediate suitability (0.5) into deep water. Like whitefish, the winter HSI curves for bull trout give increased suitability for slower but deeper habitat than do the summer curves. For cover, the HSI curve gives low suitability in the absence of cover, with maximum suitability for large woody debris or large substrate elements, and intermediate suitability for riparian or aquatic vegetation. In winter, the suitability remains the same for LWD and substrate, but declines for the remaining types. These cover curves is identical to the HSI curves for juvenile cutthroat and redband trout.

### 6.2.2. Adult

The adult bull trout HSI curves only show the broader, judgment-based curves from the Saskatchewan Basin and the Washington Fallback curves, along with the adult-only curve from the Hells Canyon portion of the Snake River (Table 6.2-1, Figure 6.2-6). The other juvenile+adult curves shown with the juvenile data are narrower and were not felt to represent a large adult fish in a large river. The final Boundary curve for velocity essentially replicates the broad Saskatchewan curve, whereas the Boundary depth curve is intermediate to the shallower judgment-based curves and the deeper Hells Canyon curve. The winter HSI curves for velocity and depth follow the previously-described trend towards deeper and slower habitat. The summer HSI curve for cover is similar to the juvenile curve except for lower suitability for aquatic vegetation; the winter cover curve is identical to the juvenile curve.

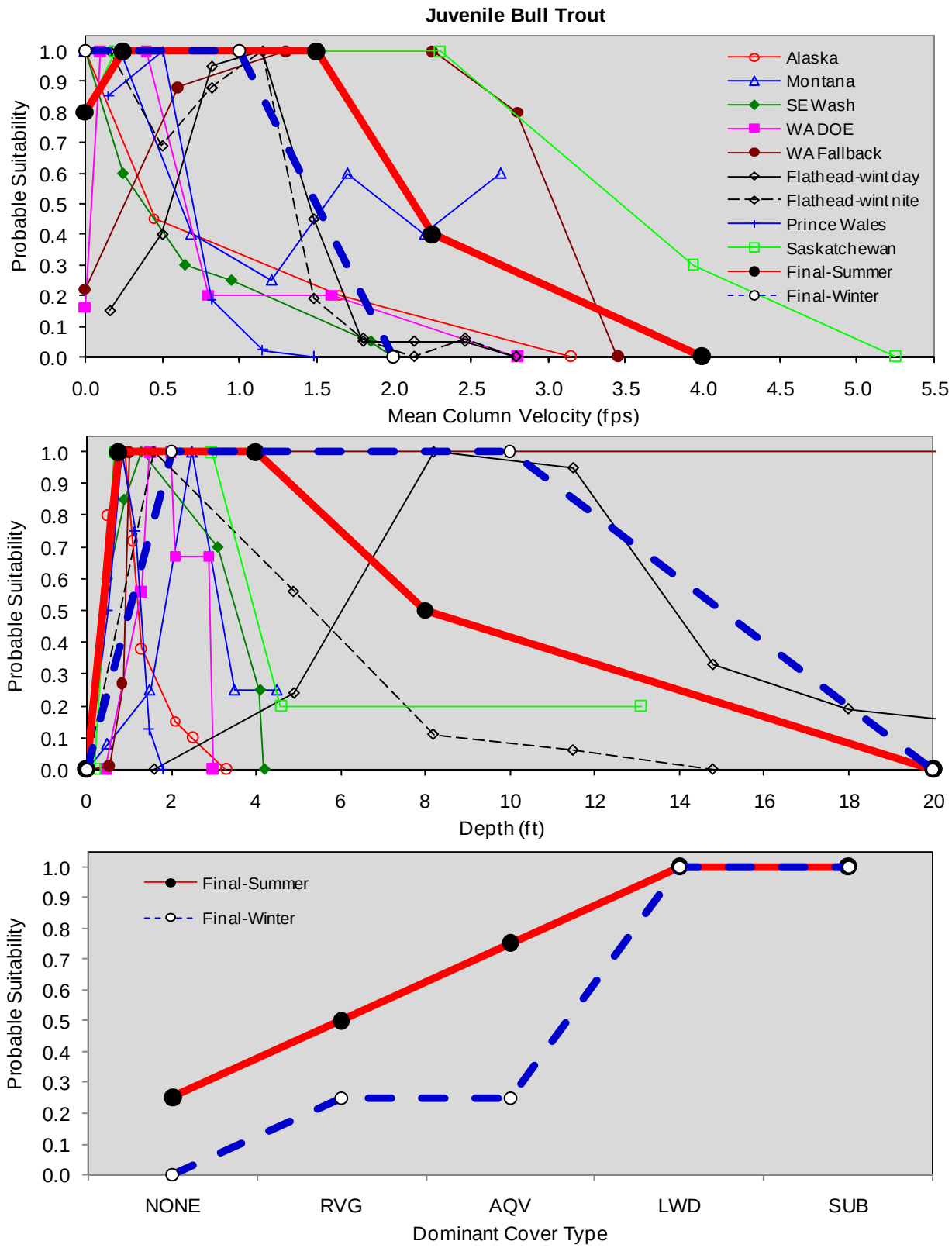


**Figure 6.2-5.** Literature-based and final Project HSI curves for juvenile bull trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

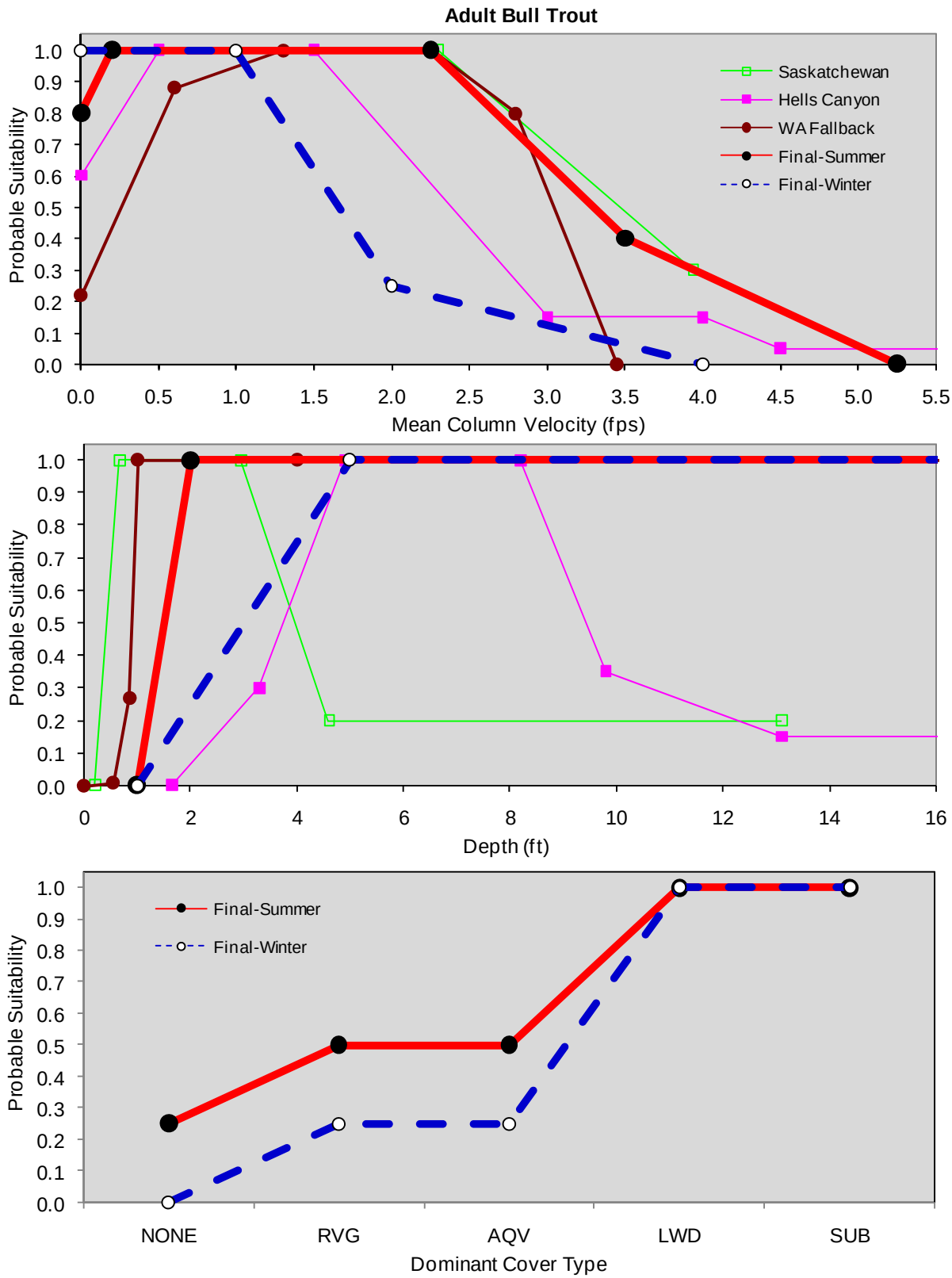


**Figure 6.2-6**. Literature-based and final Project HSI curves for adult bull trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

## 6.3. Westslope Cutthroat Trout

HSI data for westslope cutthroat trout are somewhat more common than for bull trout, but curves are typically limited in sample size or are largely based on small stream habitats (Table 6.3-1). Spawning habitat was not modeled for cutthroat trout, but HSI curves were used to estimate rearing habitat for fry, juvenile, and adult trout. Very limited site-specific data were available for this species: as of March 2008 five adults were tagged with radio or CART telemetry tags (Table 5.0-1), yielding 18 HSI depth observations and half as many velocity observations, equally split between summer and winter periods. Only a single cutthroat was captured in the reservoir during the Study 9 cell electrofishing efforts (SCL 2009a). Final HSI points are given in Table 6.3-2.

**Table 6.3-1**. HSI datasets for cutthroat trout.

| Curve Name | Lifestages | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °C | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WA Fallback | J+A | | 251 | WA | 6,5 studies | | | | | | III? | 1 | WDFW & WDE 04 |
| WA Fallback-wint | J+A | | | WA | | | | | | | II? | 1,7 | WDFW & WDE 04 |
| Bovee | F,J,A | | | OR/WA | | | | | | | | | Bovee 78 |
| Utah | F,J,A | | | UT | | | | | | | II | 2 | Valdez 78 |
| Wyoming | F | <5 | 1240 | WY | 7 headwater streams | | | | | | III v, II d | | Bozek & Rahel 91 |
| Cascades | F,J,A | | | OR/WA | | | | | | | III | 2,3 | Sanford 84 |
| Tokul | F,J | | | WA? | | | 20 | | | | | 4,5 | Weyerhaeuser unpub |
| Idaho | J,A | <20,20+ | 37,7 | ID | | | | | | | II ? | | Cochnauer & Elms-Cockrun 86 |
| Montana | J | 2-20 | 84 | MT | Flathead tribs | | | | reaches | | II | 2,6 | Pratt 84 |
| Snake wint | J | | 203-235 | MT | SF Snake | | | | | | II | | Schrader & Griswold 92 |
| BC | A | 9-32 | 302 | | headwater stream | | | | | | II | 4 | Heggenes et al 91 |
| Alberta | A | av 26-32 | 45 | Alberta | Ram R tribs | | 27-235 | | | TEL | III | 8 | Brown & Mackay 95 |
| Alberta-wint | A | av 26-32 | 45 | Alberta | Ram R tribs | | 27-235 | 0 | | TEL | III | 8 | Brown & Mackay 95 |

Notes:

Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 WA "Recommended" curves, essentially eye-smoothed versions of the calculated curves
2 Curve points from IFG summaries
3 May be based on WA state fallback data
4 Curve points approximated from graphs
5 Velocity only
6 Nose velocities only, distance to cover (objects large enough to provide shade, visual isolation, or velocity cover)
7 WA recommends use of resident rainbow winter curves for cutthroat
8 No velocities, data combined from 2 streams, ratios calculated from use/avail histograms

**Table 6.3-2.** Final HSI values for cutthroat trout according to life-stage, season, and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Cutthroat | fry | summer | 0.00 | 0.60 | 0.00 | 0.00 | NONE | 0.00 |
| Trout | <55mm | | 0.10 | 1.00 | 0.25 | 1.00 | RVG | 1.00 |
| | | | 0.50 | 1.00 | 1.50 | 1.00 | AQV | 1.00 |
| | | | 1.00 | 0.40 | 2.00 | 0.25 | LWD | 1.00 |
| | | | 2.00 | 0.00 | 4.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.00 |
| | | | 0.25 | 1.00 | 0.50 | 1.00 | RVG | 0.50 |
| | | | 0.50 | 0.20 | 3.00 | 1.00 | AQV | 0.25 |
| | | | 1.00 | 0.00 | 10.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEPTH | 1.00 |
| | juvenile | summer | 0.00 | 0.50 | 0.00 | 0.00 | NONE | 0.25 |
| | 55-150mm | | 0.25 | 1.00 | 1.00 | 1.00 | RVG | 0.50 |
| | | | 1.00 | 1.00 | 2.25 | 1.00 | AQV | 0.75 |
| | | | 1.50 | 0.50 | 3.00 | 0.60 | LWD | 1.00 |
| | | | 3.00 | 0.00 | 20.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.00 |
| | | | 0.50 | 1.00 | 2.00 | 1.00 | RVG | 0.25 |
| | | | 1.00 | 0.20 | 5.00 | 1.00 | AQV | 0.25 |
| | | | 2.00 | 0.00 | 20.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | adult | summer | 0.00 | 0.50 | 0.00 | 0.00 | NONE | 0.50 |
| | >150mm | | 0.25 | 1.00 | 1.50 | 1.00 | RVG | 0.50 |
| | | | 1.50 | 1.00 | 30.00 | 1.00 | AQV | 0.75 |
| | | | 2.50 | 0.30 | 50.00 | 0.50 | LWD | 1.00 |
| | | | 6.00 | 0.00 | 400.00 | 0.50 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.25 |
| | | | 0.50 | 1.00 | 5.00 | 1.00 | RVG | 0.25 |
| | | | 1.00 | 0.20 | 30.00 | 1.00 | AQV | 0.25 |
| | | | 4.00 | 0.00 | 50.00 | 0.50 | LWD | 1.00 |
| | | | | | 400.00 | 0.50 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:

1 Summer=1 April to 31 October, winter=1 November-31 March

2 Substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.3.1. Fry

Westslope cutthroat trout are not known to spawn in Boundary Reservoir and cutthroat trout fry are very rare or absent from the reservoir according to Study 9 surveys (SCL 2009a); however habitat was modeled using HSI curves for both cutthroat and redband trout fry. Literature-based HSI curves for cutthroat trout fry are available from five sources, four of which appear to be site-specific studies and one included over 1,000 fish from a variety of small streams (Table 6.3-1, Figure 6.3-1). The depth and velocity curves both show a fair range of suitability, most of which were encompassed by the final Boundary curve for depth. For velocity, the final Boundary curve did not extend as far into fast velocities as does the Cascades curve, which seemed excessive for a small salmonid fry. Instead, a low suitability tail was extended into faster water. For cover, both cutthroat and redband trout HSI curves gave maximum suitability for all available cover types, but zero suitability to the absence of cover (due to the fry's susceptibility to predation). The periodicity dates used in this study assume the presence of both cutthroat and redband trout fry into the winter months, consequently winter HSI curves were developed for fry of these species, as described in a previous section of this appendix. The shift in HSI values from summer to winter was similar for fry as for juvenile trout, with an increase in suitability for slower but deeper water, and a general shift in cover suitability that emphasizes dense cover types (e.g., LWD and large substrate elements).

### 6.3.2. Juvenile

As expected, HSI curves for juvenile cutthroat showed a wider range of suitable depths and velocities than did the fry curves (Table 6.3-1, Figure 6.3-2). Nine HSI curves, most (if not all) based on actual field measurements, showed relatively similar patterns for depth (except for suitability in deep water), but wider variation in velocity suitability. Only the winter data from the Snake River are known to be from a large river, however other data sets may also include large river observations. The final Boundary curve for velocity encompassed most of the curves except for the winter curve, which only showed positive suitability for near-zero velocity. The Boundary curve for winter did contain the Snake winter curve, but mirrored the Washington winter fallback curve for resident trout (both cutthroat and rainbow). The final Boundary depth curve bracketed the majority of available curves, except for the very shallow end of the Washington winter curve, and gave intermediate suitability for deeper water. As for the preceding species, the winter depth curve showed higher suitability for deep water. The cover HSI curves for juvenile trout in summer and winter are identical for all of the trout species, and show maximum suitability for large woody debris and large substrate, minimum suitability (zero in winter) for no cover, and intermediate suitability for riparian and aquatic vegetation.

### 6.3.3. Adult

Nine HSI curves were also available to represent adult cutthroat trout, although none of the curves were identified as being developed from large rivers (Table 6.3-1, Figure 6.3-3). The final Boundary curve encompasses most of the available velocity curves, and gives an intermediate suitability (0.5) for zero velocity. Four of the five summer velocity measurements taken at the estimated positions of radio tagged adult were generally within the range of the HSI curve, but one observation (estimated at 8.6 fps!) was well outside of the Boundary and all literature-based HSI curves. That extreme data point was not encompassed by the Boundary HSI

curve because the precision of measuring mean column velocities at estimated focal positions of tagged trout was known to be limited. The winter HSI curve also encompassed the available site-specific information from telemetered fish and one adult captured in the electrofishing HSI cells. For depth, the final Boundary curve ignores the shallow BC curve (taken from very small headwater streams) and the initial leg of the Washington winter curve, and then maintains maximum suitability to 30 feet, followed by intermediate suitability (at 0.5) from 50-400 feet. The 30 feet depth is consistent with one of the radio-tagged adults that was observed on five separate occasions holding over water 10-30 feet in depth, with a focal depth (based on CART tag information) of approximately 5-10 feet. Although all radio-tracked fish were estimated to occur at depths less than 30 feet, it was assumed that the pelagic nature of trout in large water bodies would result in some suitability of the entire reservoir. The cover HSI curves for adult cutthroat was identical to the cover curve for juveniles except for somewhat higher suitability for areas lacking cover, based on an assumption of lower susceptibility of predation by the larger adults as well as the observation of several adults distant from any discernable cover.

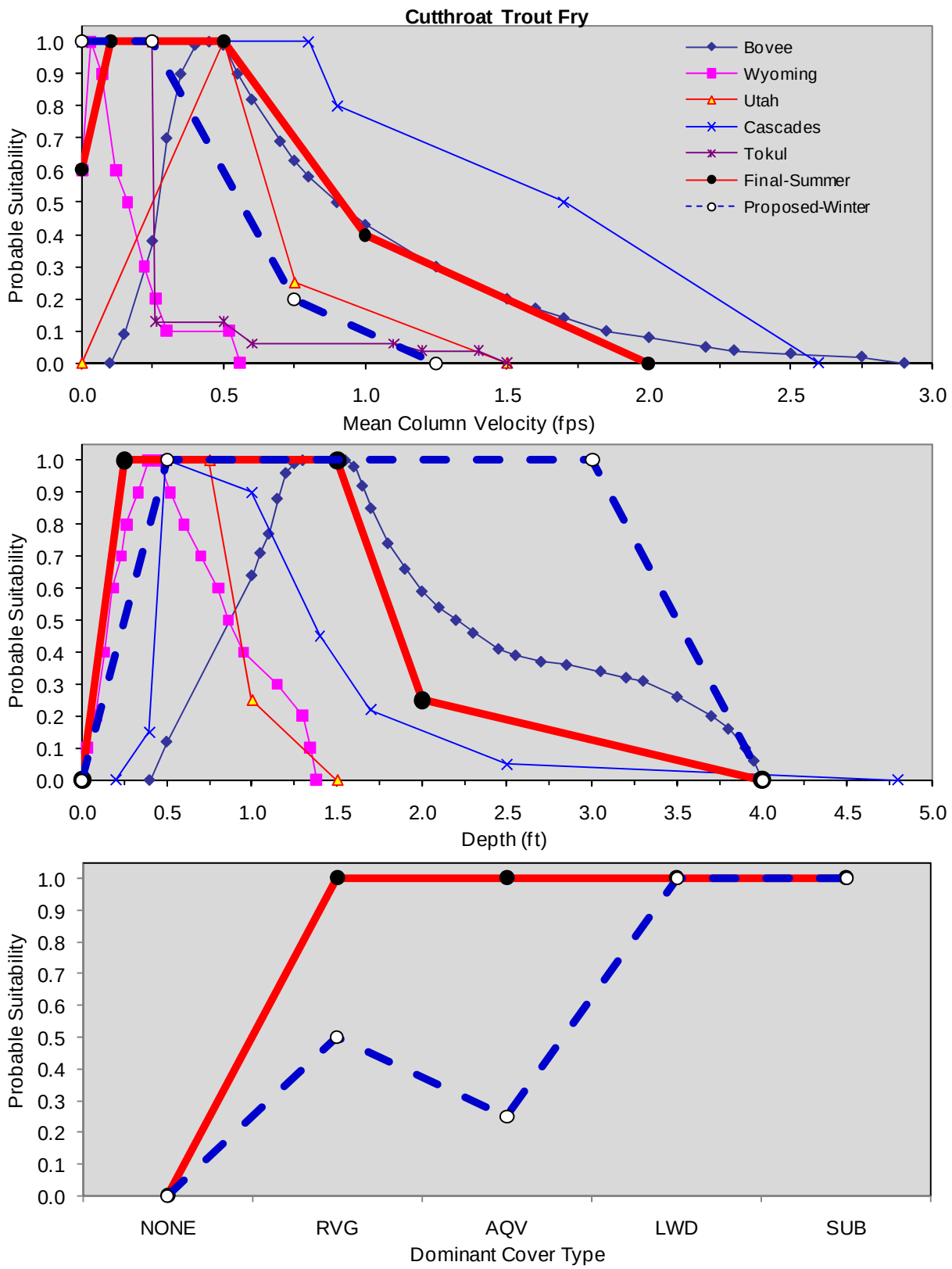


**Figure 6.3-1**. Literature-based and final Project HSI curves for cutthroat trout fry velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

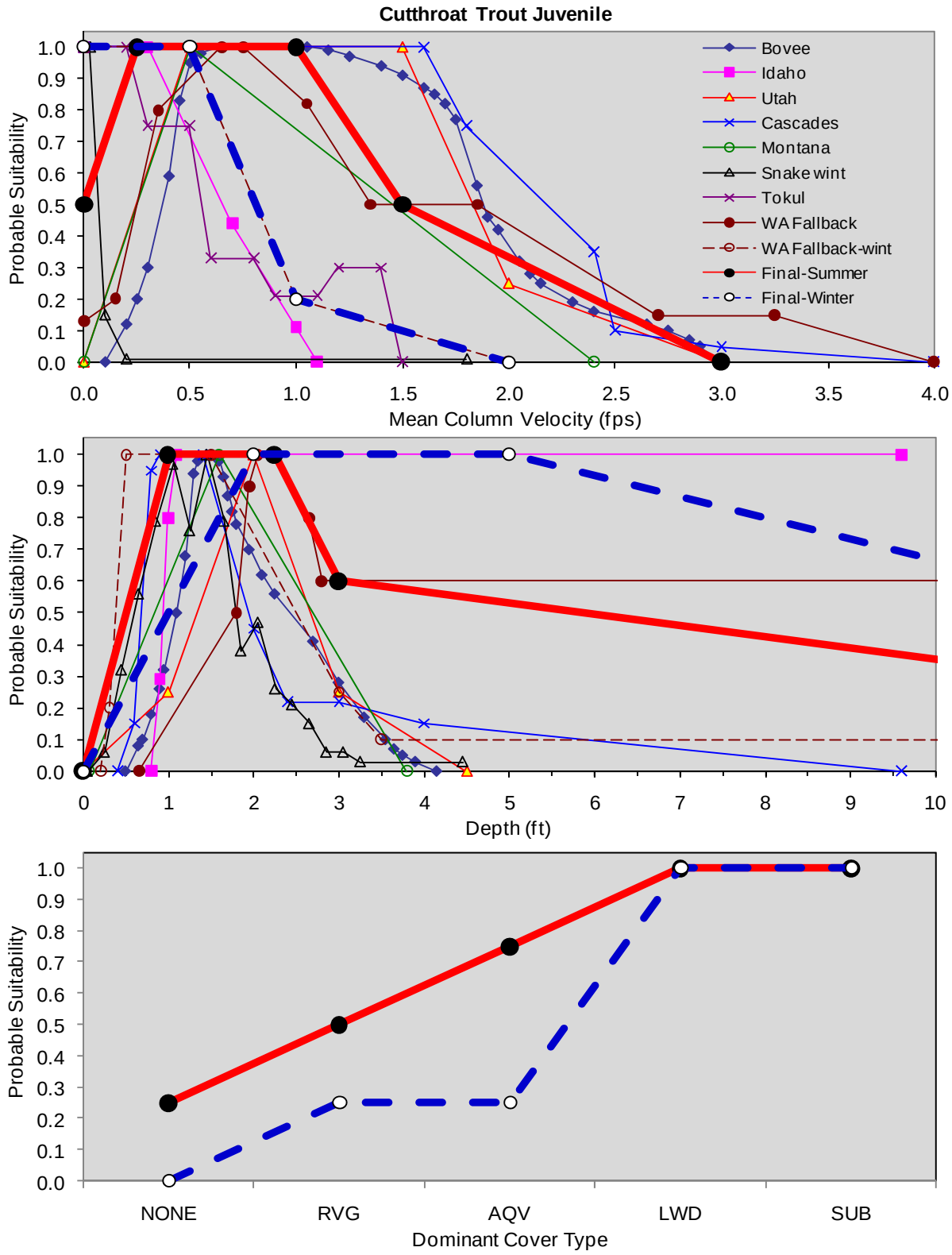


**Figure 6.3-2**. Literature-based and final Project HSI curves for juvenile cutthroat trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

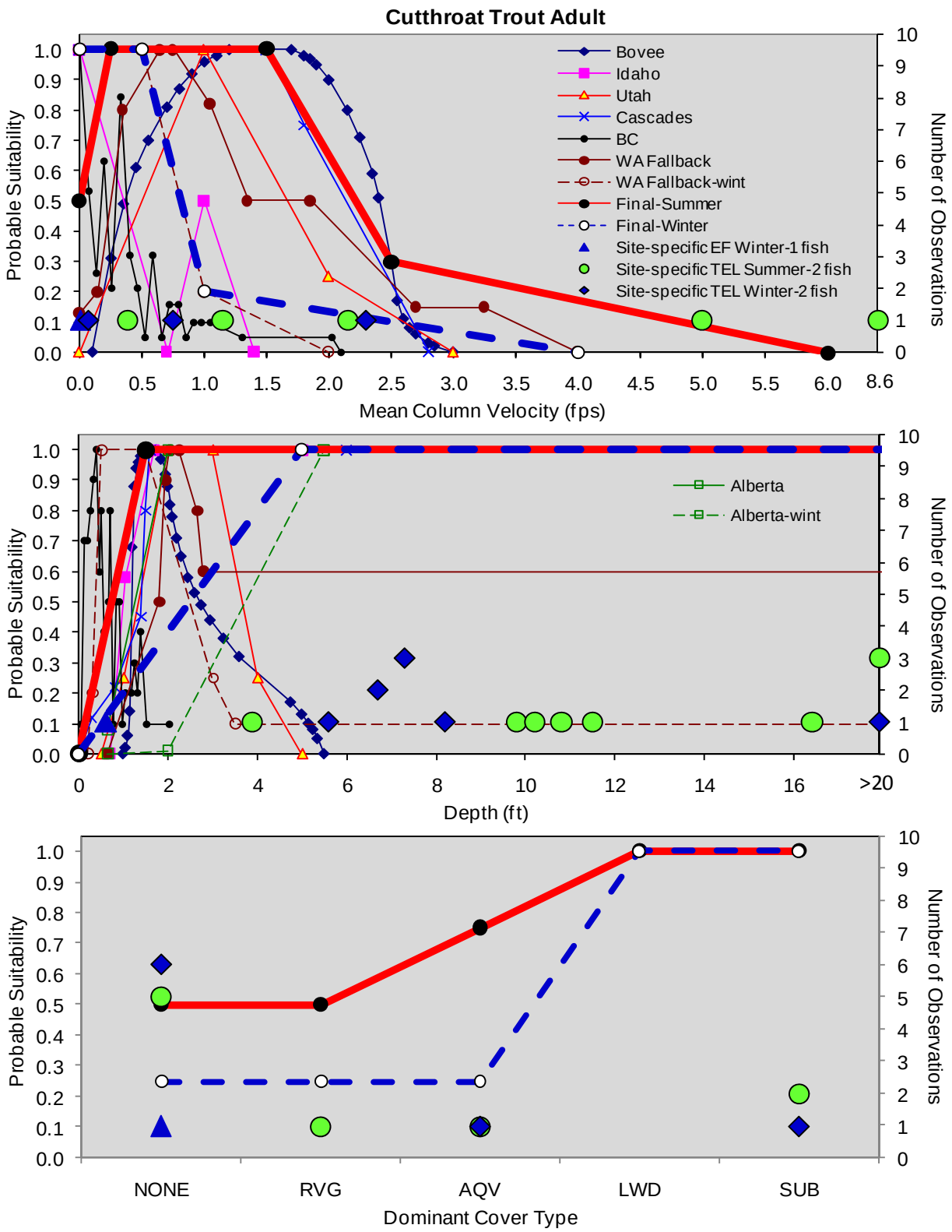


**Figure 6.3-3**. Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing, TEL=biotelemetry) for adult cutthroat trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

## 6.4. Redband Trout

Habitat for redband trout was modeled for the tailrace reach using HSI curves for fry, juveniles, and adults. Most HSI curves for *O. mykiss* represent subspecies of rainbow trout other than redband; however, some data sets were derived from interior streams containing the redband subspecies, and several data sets represent large river systems (Table 6.4-1). Because the complete list of candidate curves to represent redband trout was very large, the list was filtered down for juvenile and adult trout according to several criteria as described in the methods, which included emphasis on redband populations and on large river data sets. Electrofishing within HSI cells resulted in the capture of only four wild redband trout (Table 5.0-1), although stocked triploid trout (not a species of interest) were commonly encountered. None of the captured redband trout were tagged with radio or CART tags. Final HSI points are given in Table 6.4-2.

**Table 6.4-1**. HSI datasets for redband trout.

| Curve Name | Lifestages | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °C | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bovee | S,F | | | OR,ID,BC | various | | | | | | Cat II | | Bovee 78 |
| Raleigh | S,F | | | OR,ID,CA,BC | various | | | | | | Cat I | | Raleigh et al 84 |
| Up NF Feather | S,J,A | <15,16-42 | 172,437,179 | CA | upper NF Feather | 40-50 | 35-150 | 46-72 | RCH,EA | DO uw | Cat II,III | 16 | TRPA 02 |
| Butt | S | 15-40 | 57 | CA | Butt Creek | 18 | 5-10 | 48-52 | RCH | DO uw | Cat II | | TRPA 02 |
| NF Kings | S,F,A | 14-30 | 51,51,351 | CA | NF Kings & tribs | | <5-30 | | PROP | | Cat II | | EA 87 |
| E Sierras | S,F | <5 | ?,50 | CA | various | 7-26 | | | RCH | DO uw | Cat III | | Smith & Aceituno 87 |
| Montana | S,F | | 178 | MY | Beavhd,Yellwstn | | | | | | Cat II | 1,2,3 | Sando 81 |
| Up Klamath | S,F,J,A | <4,5-15 | 66,175,501,164 | OR | Upper Klamath | 87 | 325 | 50-62 | RCH | DOuw/o | Cat II,III | 6,12 | TRPA 04 |
| Saskatchewan | S,F | | | Alberta | Sask Basin streams | | | | | | Cat I | 5 | Addley et al 03 |
| Alt Flows U/A | F,J,A | | ?,594,211 | CA | Tule, Willow | 11-27 | 2-38 | 53 | EA | DO uw | Cat III | | Wise et al. 98 |
| Pit | F,J,A | <5,5-15 | 61,179,252 | CA | Pit | 40-200 | 50-150 | 65 | PROP | DO uw | Cat III | 1,7 | Baltz & Vondracek 85 |
| Deer Use | F | <5 | | CA | Deer | | 100-200 | 55 | RCH | DO uw | Cat II | 1 | Moyle & Baltz 85 |
| Yosemite | F,J,A | <4,5-12 | 406,301,362 | CA | Eleanor,Cherry | | 15-36 | 46-73 | RCH | DO uw | Cat II | 8 | Baltz & Moyle 84 |
| Colorado | F | | | CO | | | | | | | | | Nehring&Anderson 93 |
| Battle | F,J,A | <4,5-15 | 212,822,164 | CA | Battle | 14-29 | 4-108 | 36-73 | EA | DO uw | Cat II | | TRPA 98 |
| Alberta U/A | F | 3.6-5.8 | | Alberta | Threepoint Crk | | 90 | | | DOow,EF | Cat III | 9 | Locke 87 |
| Bucks/Grizzly | F,J,A | <5,5-15 | 47,253,168 | CA | Bucks, Grizzly | 2-62 | 6-50 | 47-62 | EA | DO uw | Cat II | 10 | TRPA 91 |
| Kootenai | F,J,A | <4,4-12 | 106,442,332 | MT,ID | Callahan & Basin Crks | | | | RR | DO uw | Cat III | 11 | Muhlfeld et al 01 |
| NF Stanislaus | J,A | 5-15,16+ | 287,243 | CA | NF Stanislaus | 10-86 | 26-333 | 49-64 | EA | DO uw | Cat II | | TRPA 93 |
| SF Stanislaus U/A | J | 15-May | 108 | CA | SF Stanislaus | 41-49 | 8-30 | 50-69 | EA micr | DO uw | Cat III | 13,14 | TRPA 02 |
| SF Amer Basin | J,A | 5-15,16-50 | 169,145 | CA | SF Amer + tribs | 13-90 | 10-154 | 46-71 | EA | DO uw | Cat II | 15 | TRPA 2000 |
| Clavey | J,A | <15,16+ | 662,474 | CA | Clavey | | 24-130 | | RCH | DO uw | Cat II | 8 | Tuol Co/Turlock 93 |
| S Platte Suit | J,A | 7-17,18+ | 188,163 | CO | So Platte | | 250-600 | | EA | DO uw | Cat II | 17 | Thomas & Bovee 93 |
| Oldman | A | 25+? | 151 | Alberta | Oldman,Crowsnest | | | | | DO uw/EF | Cat III? | 8,18 | Fernet et al 90 |
| Hells Canyon | A | 26-46 | 75 | ID | Snake res | | 7282-32420 | | | TEL | Cat II | 19 | Chandler 03 |

Notes:

Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 curve points taken from IFG HSC summary
2 may include brown trout
3 curve shown is my combination of curves from the 2 rivers
4 enveloped use HSC by expert panel
5 adjacent velocity and bioenergetics data also collected
6 data reweighted to simulate equal-area sampling
7 Curve points approximated from graphs
8 U/A curves derived from one stream using PHABSIM output to estimate habitat availability
9 these HSC curves were not presented in the cited report (i.e., curves were fit to the raw data at a later date)
10 curve pts normalized from electivity index (averaged between 2 streams for juvenile and adults)
11 most (86%) of juveniles were 5-9cm, adjacent velocity and bioenergetics data also collected
12 these HSC curves were not presented in the cited report (I.e., curves were fit to the raw data at a later date)
13 equal-area sampling according to mesohabitat type and microhabitat type (deep v shallow, fast v slow)
14 a variety of substrate and cover codes were also used in a transferability test
15 use, U/A, and density curve-types were averaged to develop the composite curve, cover curves are U/A
16 optimal habitat was defined as the central 50% of observations, suitable was defined as the central 95%
17 juvenile curves based on earlier study in Oldman River (Fernet & Matkowski 1986)-we don't have that report
18 bottom vels estimated with formula for 0.2m above the btm (but fish depth not known), dist to bank also recorded

**Table 6.4-2.** Final HSI values for redband trout according to life-stage, season, and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Redband | fry | summer | 0.00 | 0.60 | 0.00 | 0.00 | NONE | 0.00 |
| Trout | <55mm | | 0.10 | 1.00 | 0.25 | 1.00 | RVG | 1.00 |
| | | | 0.50 | 1.00 | 1.50 | 1.00 | AQV | 1.00 |
| | | | 1.00 | 0.40 | 2.00 | 0.25 | LWD | 1.00 |
| | | | 2.00 | 0.00 | 4.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.00 |
| | | | 0.25 | 1.00 | 0.50 | 1.00 | RVG | 0.50 |
| | | | 0.50 | 0.20 | 2.50 | 1.00 | AQV | 0.25 |
| | | | 1.00 | 0.00 | 10.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEPTH | 1.00 |
| | juvenile | summer | 0.00 | 0.50 | 0.00 | 0.00 | NONE | 0.25 |
| | 55-150mm | | 0.25 | 1.00 | 1.00 | 1.00 | RVG | 0.50 |
| | | | 1.00 | 1.00 | 3.00 | 1.00 | AQV | 0.75 |
| | | | 2.00 | 0.50 | 5.00 | 0.60 | LWD | 1.00 |
| | | | 4.00 | 0.00 | 10.00 | 0.25 | SUB | 1.00 |
| | | | | | 20.00 | 0.00 | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.00 |
| | | | 0.50 | 1.00 | 2.00 | 1.00 | RVG | 0.25 |
| | | | 1.00 | 0.20 | 5.00 | 1.00 | AQV | 0.25 |
| | | | 2.00 | 0.00 | 20.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | adult | summer | 0.00 | 0.75 | 0.50 | 0.00 | NONE | 0.50 |
| | >150mm | | 0.50 | 1.00 | 2.00 | 1.00 | RVG | 0.50 |
| | | | 1.50 | 1.00 | 30.00 | 1.00 | AQV | 0.75 |
| | | | 2.50 | 0.50 | 50.00 | 0.50 | LWD | 1.00 |
| | | | 5.50 | 0.00 | 400.00 | 0.50 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.25 |
| | | | 0.50 | 1.00 | 5.00 | 1.00 | RVG | 0.25 |
| | | | 1.00 | 0.20 | 30.00 | 1.00 | AQV | 0.25 |
| | | | 2.00 | 0.00 | 50.00 | 0.50 | LWD | 1.00 |
| | | | | | 400.00 | 0.50 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:

1 Summer=1 April to 31 October, winter=1 November-31 March

2 Substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.4.1. Fry

Redband fry are represented by 19 data sets, two of which are largely judgment-based (Category 1) curves (Table 6.4-1, Figure 6.4-1). Although most curves show high suitability only for velocities under 1 fps, the Saskatchewan consensus curve gives much higher suitability for faster velocities. The final Boundary curve does not follow that consensus curve but instead follows most other curves to reflect low suitability for velocities over 1 fps. The final Boundary depth curve essentially encompasses all of the available fry curves, except for lower suitability of moderate depths (from 2.0-3.5 feet). The winter HSI curves for velocity and depth show the expected shift into slower and deeper water, respectively. The cover HSI curves give maximum suitability for all cover types and zero suitability for no cover, with a reduction in suitability for riparian and aquatic vegetation during winter. The Boundary HSI curves for redband trout fry are identical to the cutthroat HSI curves.

### 6.4.2. Juvenile

Almost 40 HSI curves were located for rainbow trout juveniles, but these were filtered down to 12 curves based on curve type (all from site-specific studies), sample size ($\geq$100 observations), and stream size (flows $\geq$100 cfs) to better represent the redband subspecies in larger habitats. The final Boundary curve for velocity brackets most of the available curves, with an intermediate suitability (0.5) for zero velocity (Table 6.4-1, Figure 6.4-2). The final Boundary curve for depth likewise encompasses most available curves, and extends low suitability into deeper water. The winter HSI curves follow the aforementioned procedure of shifting suitability towards slower and deeper water. Although the Boundary HSI curves for juvenile redband trout are slightly faster and deeper than for cutthroats, the cover curves are identical.

### 6.4.3. Adult

Forty-five HSI curves for adult redband trout were filtered down to a subset of 13 data sets according to the criteria listed for juvenile trout (Table 6.4-1, Figure 6.4-3). Only the Hells Canyon curve was represented by <100 observations, but it represented the most similar habitat conditions to the Boundary project area and thus was retained for consideration. The majority of curves give maximum suitability for velocities from 1-1.5 fps, but the interim Boundary curve is somewhat broadened to better represent larger river systems (where higher mean column velocities can occur with ample slower velocities nearer the substrate). The Boundary depth curve brackets all but the shallowest curves, and maintains high suitability into deeper water. The three wild redband trout captured by electrofishing all occurred within the range of depths and velocities encompassed by the interim HSI curves, although the observed depths (5.3-7.2 feet) are at the deepest range of most literature curves. The interim Boundary curves for adult redband trout are slightly deeper and faster than the cutthroat curves, and are likewise deeper and faster than the juvenile redband curves.

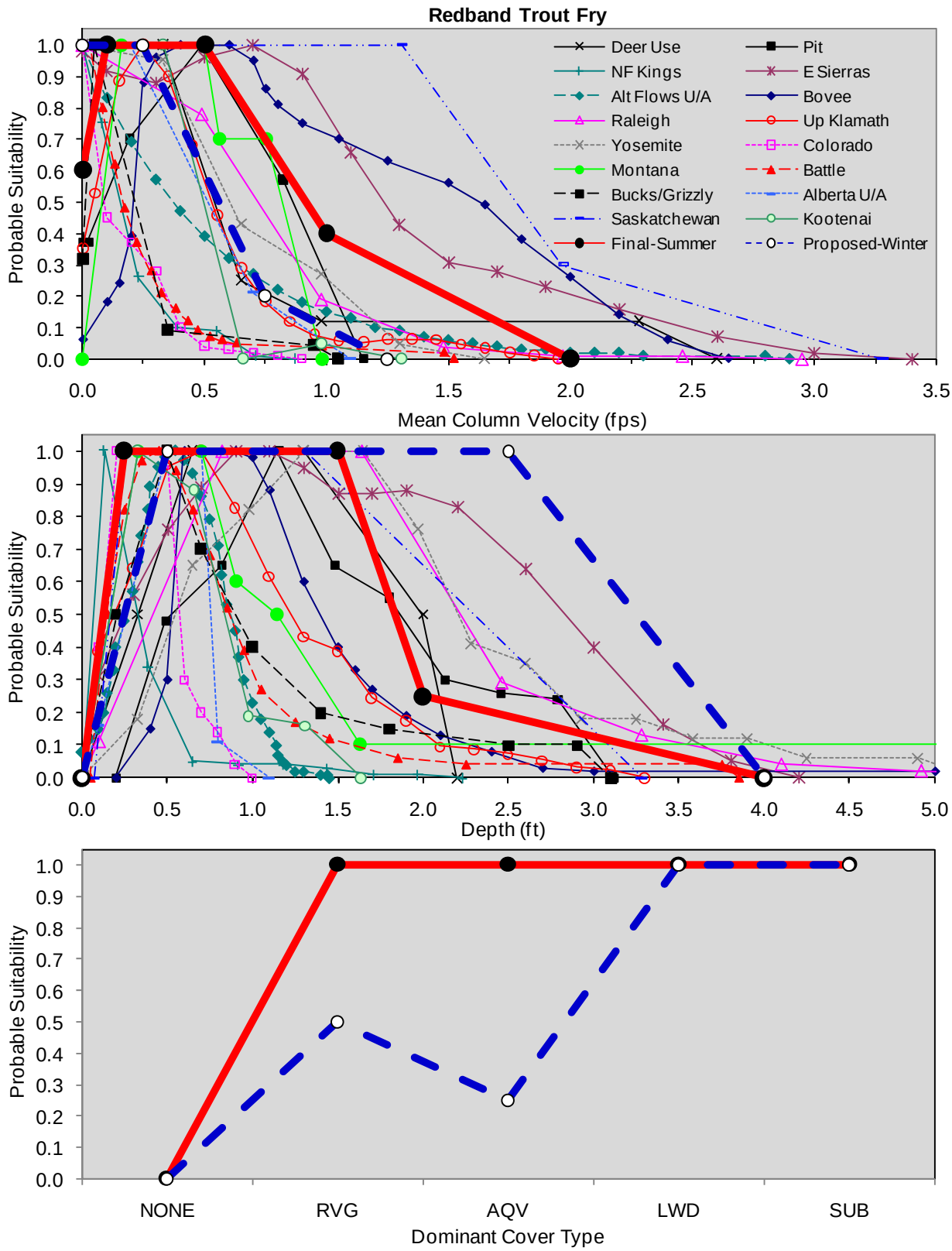


**Figure 6.4-1**. Literature-based and final Project HSI curves for redband trout fry velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

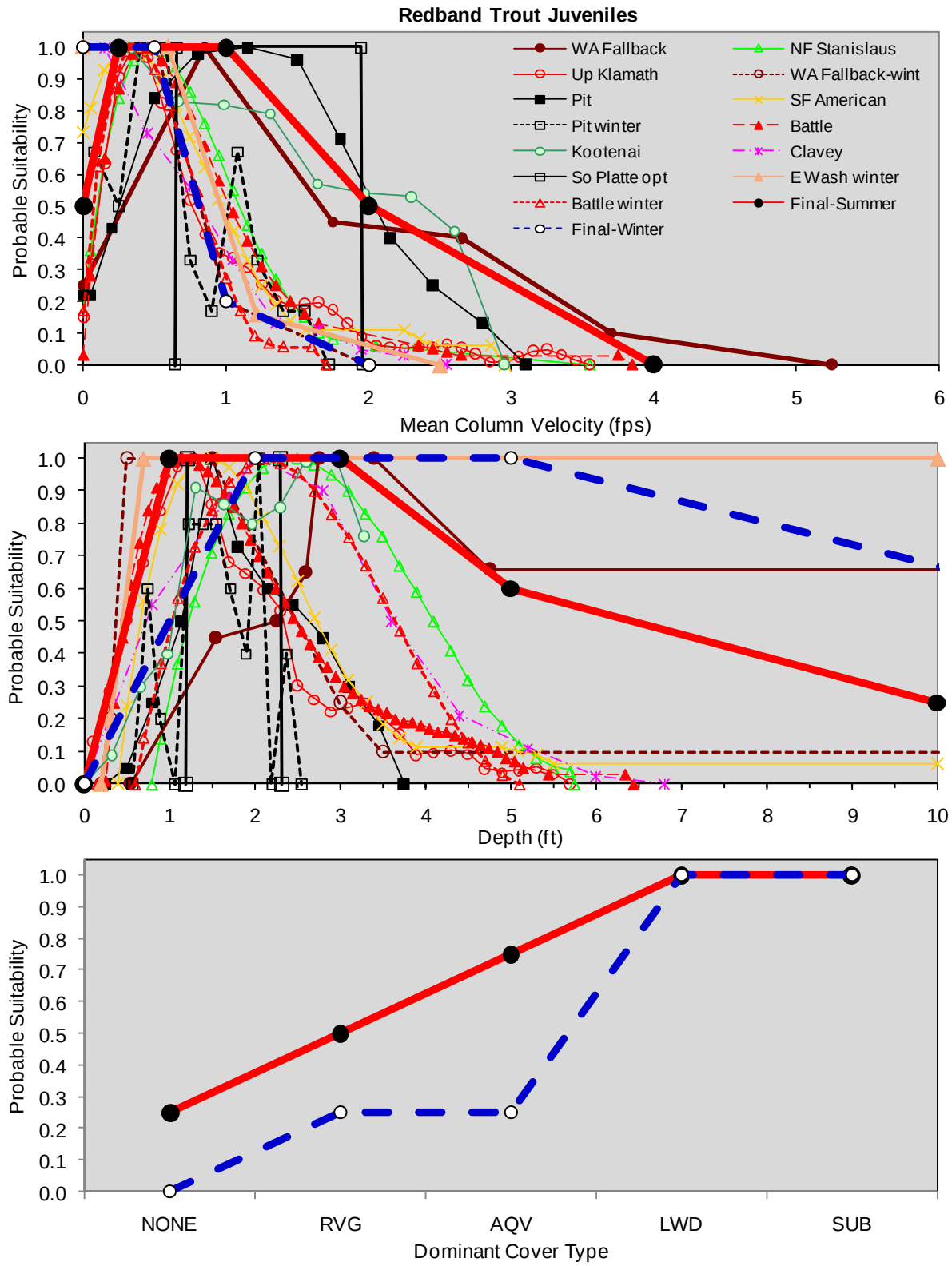


**Figure 6.4-2**. Literature-based and final Project HSI curves for juvenile redband trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

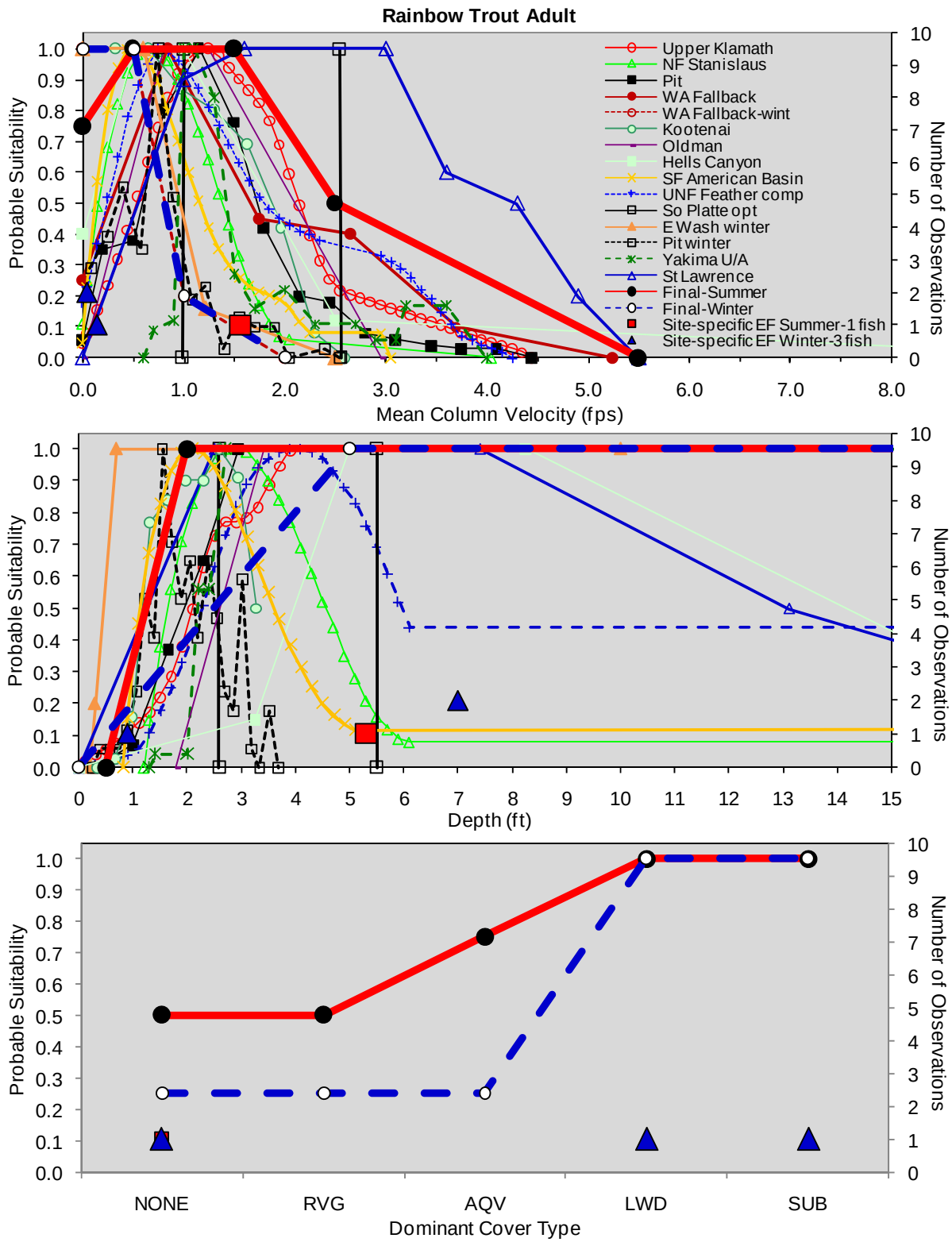


**Figure 6.4-3**. Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing) for adult redband trout velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

## 6.5. Smallmouth Bass

Smallmouth bass are intensively studied in eastern and midwestern states, but only two of the available HSI curves are from the western U.S. (the Brownlee and Southern California data sets). Microhabitat data from several streams suggested little difference in habitat use between juvenile and adult bass; therefore some literature-based curves represent both size classes combined together (Table 6.5-1). Smallmouth bass were the most numerous of the species of interest that were captured by electrofishing (161 fish in 115 HSI cells), and 19 adult bass were implanted with telemetry tags yielding 49 HSI observations (Table 5.0-1). Because of the relatively large sample size for the electrofishing HSI data, site-specific HSI curves were developed for fry, juvenile, and adult bass (see curve-fitting methodology in Section 5 of this appendix). In many cases, the site-specific curves were used to guide the development of a new, judgment-based curve for the Project area; in other cases the site-specific curve was used without modification. Final HSI points for smallmouth bass are given in Table 6.5-2.

**Table 6.5-1**. HSI datasets for smallmouth bass.

| Curve Name | Lifestages | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °C | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bovee | S,F,J,A | | | | | | | | | | I,II | 1,7,8,14 | Bovee fishfile |
| Brownlee | S | | 96 | ID | Brownlee Res (Snake) | | | | | DO uw | II | 23 | Richter 03 |
| Susquehanna | S,F,J+A | <12,12-46 | 50,196,129 | PA | Susquehanna | 3,900 | 3600-50200 | <20-27 | EA | DO uw | II | 2,9 | Allen 96 |
| Huron | S | | | MI | Huron | 115 | | | RCH | DOuw,EF | II | 4 | Bovee et al 94 |
| W Virginia | S,F,A | | 14,876,49 | WV | 4 rivers | | | | | DO?,EF,NET | II | 3,5,12 | Joy et al 81 |
| Minnesota | S,F,J,A | | 178,130,333,384,141 | MN | 5 rivers | | | | RCH | DOw,PPS | III | 6 | Aadland & Kuitinen 06 |
| Bain | F,J,A | | | | | | | | | | III | | IFG HSC summaries |
| Cacapon | F,J+A | 2.5-7,8+ | 255,394 | WV | Cacapon | 50-200 | 53-159 | | EA | DO uw | II | 10 | Newcomb et al 95 |
| Greenbrier | F,J+A | 2.5-7,8+ | 189,188 | WV | Greenbrier | 98-295 | 78-353 | | EA | DO uw | II | 10 | Newcomb et al 95 |
| Knapp | F,J+A | 2.5-7,8+ | 53,51 | WV | Knapp | 16-102 | 18-53 | | EA | DO uw | II | 10 | Newcomb et al 95 |
| Huron | F,J,A | <10,11-19 | ?,101,109 | MI | Huron | 115 | | 18-21 | RCH | DOuw,EF | II | 11 | Monahan 91 |
| SoCal | F,J,A | <7.5,10-20 | 229,586,90 | CA | 4 rivers | | 2-460 | 18-28 | RCH | DO uw | II | 13 | Studley et al 86 |
| Oklahoma | J,A | | 40,55 | OK | | | | | | | III | 15,16 | Edwards et al 83 |
| Salt Fork | J,A | <27,27+ | 66,53 | IL | Salt Fork Branch | | 1050 | | | EF,TEL,DOow | II | 3,22 | Larimore & Garrels 82 |
| Glover | J,A | <10,10+? | | OK | Glover Crk | | | | | | III | 3 | Orth et al 82 |
| Virginia | J,A | 10-20,20+ | 152,111 | VA | N Anna & Craig | 80-115 | 40-100 | | RCH | DO uw | III | 17 | Groshens & Orth 94 |
| WV Meadow | J | | 231 | WV | Meadow | | | | | DO?,EF,NET | II | 3,5 | Joy et al 81 |
| WV New | J | | 200 | WV | New | | | | | DO?,EF,NET | II | 3,5 | Joy et al 81 |
| WV Greenbriar | J | | 180 | WV | Greenbrier | | | | | DO?,EF,NET | II | 3,5 | Joy et al 81 |
| WV Tygart | J | | 166 | WV | Tygart | | | | | DO?,EF,NET | II | 3,5,18 | Joy et al 81 |
| Feather | A | 16+ | 52 | CA | Feather | 70-106 | 96-131 | 18-22 | EA | DO uw | IV | 19,20 | TRPA 01 |
| St. Lawrence | A | 27-44 | 53 | QE | St. Lawrence | | 250,000-406,000 | | | TEL | II | 3,21 | Leclerc ~83 |

Notes:

Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 from "clear" curve, USFWS essentially equivalent (therefore not entered)
2 HSC curves later derived from frequency histograms, used Bovee curve for spawning depth
3 curve points from Instream Flow Group HSC summary
4 no sample size or stream size/flow info found, winter and summer-nighttime HSC data also available in paper
5 data combined among streams for adults & spawning, separate by rivers for fry & juveniles
6 not sure how Cat III curves or Poisson regression was performed for spawning life-stage
7 from "turbid" curve (no clear curve available)
8 based on swimming performance tests
9 HSC curves later derived from frequency histograms, used Bovee curve for spawning depth
10 the 0.5 curve pts taken from graph, others from table, cover for juvenile/adult based only on juveniles (adults showed less cover use), values based on normalized relative freq data, see paper for substrate data
11 winter, summer-nighttime, dist to cover and dist to shear HSC data also available
12 data combined among streams for adults & spawning, separate by rivers for fry & juveniles
13 substrate code arranged from smoothest to roughest (most cover)
14 from "turbid" curve (no clear curve available)
15 based on data from Don Orth
16 curve pts taken from graph
17 general curves from both streams combined
18 velocity data not given
19 presence/absence curve, use, use/avail, and density curves available
20 cover based on utilization data
21 depth curve should go to zero at zero depth
22 SAME CURVE PTS AS ST LAWRENCE
23 bank slope HSC also available

**Table 6.5-2.** Final HSI values for smallmouth bass according to life-stage, season, and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Smallmouth | spawning | n/a | 0.00 | 1.00 | 0.50 | 0.00 | fines | 0.00 |
| Bass | | | 0.50 | 1.00 | 2.00 | 1.00 | sand | 0.10 |
| | | | 1.00 | 0.20 | 5.00 | 1.00 | sm grv | 0.50 |
| | | | 2.50 | 0.00 | 12.00 | 0.10 | med grv | 0.50 |
| | | | | | 30.00 | 0.00 | lrg grv | 1.00 |
| | | | | | | | sm cob | 0.05 |
| | | | | | | | lrg cob | 0.00 |
| | | | | | | | bldr | 0.00 |
| | | | | | | | bed | 0.00 |
| | fry | summer | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.50 |
| | <55mm | | 0.30 | 1.00 | 0.20 | 1.00 | RVG | 1.00 |
| | | | 0.50 | 0.40 | 1.50 | 1.00 | AQV | 1.00 |
| | | | 1.00 | 0.35 | 3.50 | 0.40 | LWD | 1.00 |
| | | | 2.00 | 0.00 | 10.00 | 0.00 | SUB | 0.50 |
| | | | | | | | DEP | 1.00 |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.25 |
| | | | 0.25 | 0.20 | 0.40 | 1.00 | RVG | 0.25 |
| | | | 1.00 | 0.00 | 3.00 | 1.00 | AQV | 0.25 |
| | | | | | 4.50 | 0.40 | LWD | 1.00 |
| | | | | | 10.00 | 0.00 | SUB | 0.50 |
| | | | | | | | DEPTH | 1.00 |
| | juvenile | summer | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.50 |
| | 55-150mm | | 0.50 | 1.00 | 0.20 | 0.92 | RVG | 0.75 |
| | | | 0.75 | 0.50 | 0.60 | 0.94 | AQV | 1.00 |
| | | | 2.00 | 0.30 | 1.00 | 0.96 | LWD | 1.00 |
| | | | 3.00 | 0.00 | 1.40 | 0.98 | SUB | 1.00 |
| | | | | | 1.80 | 0.99 | DEP | 1.00 |
| | | | | | 2.20 | 1.00 | | |
| | | | | | 2.60 | 1.00 | | |
| | | | | | 3.00 | 1.00 | | |
| | | | | | 3.40 | 1.00 | | |
| | | | | | 3.80 | 0.99 | | |
| | | | | | 4.20 | 0.98 | | |
| | | | | | 4.60 | 0.96 | | |
| | | | | | 5.00 | 0.94 | | |
| | | | | | 5.40 | 0.92 | | |
| | | | | | 5.80 | 0.90 | | |
| | | | | | 6.20 | 0.87 | | |
| | | | | | 6.60 | 0.84 | | |
| | | | | | 7.00 | 0.81 | | |

**Table 6.5-2, continued…**

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| | | | | | 7.40 | 0.77 | | |
| | | | | | 7.80 | 0.73 | | |
| | | | | | 8.20 | 0.70 | | |
| | | | | | 8.60 | 0.66 | | |
| | | | | | 9.00 | 0.62 | | |
| | | | | | 9.40 | 0.58 | | |
| | | | | | 10.00 | 0.52 | | |
| | | | | | 12.00 | 0.33 | | |
| | | | | | 14.00 | 0.19 | | |
| | | | | | 16.00 | 0.09 | | |
| | | | | | 80.00 | 0.00 | | |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.25 |
| | | | 0.50 | 0.25 | 2.00 | 1.00 | RVG | 0.25 |
| | | | 1.50 | 0.00 | 10.00 | 1.00 | AQV | 0.25 |
| | | | | | 20.00 | 0.10 | LWD | 1.00 |
| | | | | | 80.00 | 0.00 | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |
| | adult | summer | 0.00 | 0.67 | 0.00 | 0.00 | NONE | 0.75 |
| | >150mm | | 0.20 | 0.77 | 0.40 | 0.00 | RVG | 0.75 |
| | | | 0.40 | 0.86 | 0.80 | 0.26 | AQV | 1.00 |
| | | | 0.60 | 0.93 | 1.20 | 0.34 | LWD | 1.00 |
| | | | 0.80 | 0.98 | 1.60 | 0.43 | SUB | 1.00 |
| | | | 1.00 | 1.00 | 2.00 | 0.53 | DEP | 1.00 |
| | | | 1.20 | 0.99 | 2.40 | 0.63 | | |
| | | | 1.40 | 0.96 | 2.80 | 0.73 | | |
| | | | 1.60 | 0.90 | 3.20 | 0.82 | | |
| | | | 1.80 | 0.82 | 3.60 | 0.90 | | |
| | | | 2.00 | 0.73 | 4.00 | 0.96 | | |
| | | | 2.20 | 0.63 | 4.40 | 0.99 | | |
| | | | 2.40 | 0.52 | 4.80 | 1.00 | | |
| | | | 2.60 | 0.42 | 15.00 | 1.00 | | |
| | | | 2.80 | 0.33 | 30.00 | 0.50 | | |
| | | | 3.00 | 0.25 | 100.00 | 0.00 | | |
| | | | 3.20 | 0.18 | | | | |
| | | | 3.40 | 0.13 | | | | |
| | | | 3.60 | 0.09 | | | | |
| | | | 3.80 | 0.06 | | | | |
| | | | 4.00 | 0.04 | | | | |
| | | | 4.20 | 0.02 | | | | |
| | | | 4.40 | 0.01 | | | | |
| | | | 4.60 | 0.01 | | | | |

**Table 6.5-2, continued…**

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| | | | 4.80 | 0.00 | | | | |
| | | winter | 0.00 | 1.00 | 2.00 | 0.00 | NONE | 0.50 |
| | | | 0.25 | 1.00 | 10.00 | 1.00 | RVG | 0.50 |
| | | | 1.00 | 0.25 | 50.00 | 1.00 | AQV | 0.50 |
| | | | 2.00 | 0.00 | 100.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:
1 summer=1 April to 31 October, winter=1 November-31 March
2 substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.5.1. Spawning

Virtually all bass spawning curves show maximum suitability for zero or near zero velocities, but some curves also extend high suitability into faster water (Table 6.4-2, Figure 6.5-1). Bass nest data collected in the mainstem Susquehanna River (by TRPA) illustrated that bass require near zero velocities within and immediately above their nests in order to prevent suspended bass fry from washing downstream, but such nests were commonly found within velocity shelters (largely formed by aquatic vegetation) where mean column velocities were well above zero. Consequently, the final Boundary curve for bass spawning gives positive suitability for velocities greater than several other studies, but not to the extent suggested by the Bovee curve. For portions of the project area that do not contain large-element velocity shelters (e.g., large boulders or aquatic vegetation), the Boundary velocity curve may over-represent suitable spawning habitat. For depth, the final Boundary curve brackets most other curves, except for the extremely shallow West Virginia curve and the somewhat deeper Brownlee Reservoir curve. Bass biologists have suggested that maximum depths of bass nests are dictated by light penetration, probably through effects of light on egg incubation and/or fry food availability. The spawning substrate HSI curve shows highest suitability for large gravel (1.5-3.0 inches diameter), with medium suitability for smaller gravel and low or zero suitability for all other substrate types.

### 6.5.2. Fry

Most of the literature-based fry HSI curves appear to represent fish after leaving the nest and show wide variability in the velocity curves, where some show suitability only at velocities <0.5 fps, and others give high suitability for higher velocities (Table 6.4-2, Figure 6.5-2). The site-specific HSI curve was developed from a very small sample size of bass fry (fry were captured in only 13 electrofishing cells), consequently the final Boundary curve for velocity utilized the faster end of the site-specific curve (for velocities >0.5 fps), but the slower end was modified to better match the literature-based curves. Only the very fast Huron River curve was largely

excluded from the final Boundary curve. The final depth curve for fry did not follow the site-specific curve due to a questionable fit, but instead it brackets most of the literature-based curves except the deeper Huron, Southern California, and Bovee curves. For cover, the summer HSI curve gives maximum suitability for vegetation cover and large woody debris, and intermediate suitability for no cover and large substrate cover. Like for the salmonid species, the Boundary HSI curves for bass in the winter months reflect greater suitability of slower and deeper habitats than do the summer curves, with less emphasis on vegetative cover types.

### 6.5.3. Juvenile

Literature-based HSI data for juvenile bass are abundant, but are fairly variable for fast and deep water (Table 6.4-2, Figure 6.5-3). The final Boundary curve for velocity was largely based on the site-specific HSI curve derived from the cell electrofishing data, but was modified to include a broader area of maximum suitability up to 0.5 fps. This modified curve bracketed most of the available curves, except for areas of intermediate velocity (1-2.5 fps) of several eastern U.S. curves. The final Boundary depth curve did utilize the site-specific curve, which bracketed virtually all of the literature-based curves (except those that maintained maximum suitability deeper water. Both Boundary curves encompass (and exceed) all of the site-specific data, in part because the capture efficiency of smaller fish by electrofishing is expected to decline in deeper and faster water, therefore the decline in catch in such areas may be due in part to sampling limitations. The summer cover HSI curve gives maximum suitability for all cover types except riparian vegetation (at 0.75) and no cover (at 0.5). Final HSI curves for winter months give higher suitability for slower velocities, deeper depths, and lower suitability for cover types except large woody debris and large substrate. Juvenile bass, like adults and even fry, were most often captured in areas lacking cover, but the final HSI curves follow the common assumption that the addition of cover will always provide equal or better suitability than no cover (e.g., the HSI curves do not suggest that fish will “avoid” cover), hence the HSI curves do not always match the observed frequency of habitat use based on the site-specific capture data. As noted for depth and velocity, capture efficiency is likely to be significantly higher in areas lacking dense cover than in areas possessing cover, which may in part explain the greater catch of bass in the absence of cover.

### 6.5.4. Adult

Sixteen HSI curves are available for adult smallmouth bass, most of which are encompassed by the final Boundary curves for velocity and depth (Table 6.4-2, Figure 6.5-4). The final velocity HSI curve is directly derived from the site-specific electrofishing data, as fit with the logistic regression procedures described in Section 5 of this appendix. This velocity curve effectively brackets most of the literature-based HSI curves, but unlike some curves and the site-specific habitat use data (unadjusted for habitat availability), the final HSI curve gives high, but not give maximum, suitability for zero velocity. The final HSI curve for depth was also based on the site-specific HSI curve on the ascending limb, but instead of declining to lower suitability at deeper depths, the final curve was kept at maximum suitability into deep water, eventually reaching zero suitability at 100 feet (Table 6.5-2).

This deep water modification was justified by the inherent limitations of electrofishing at depths over 10 feet, the site-specific biotelemetry data that showed frequent use of deep water areas, and

the known occupation of deep water by bass in many reservoirs. Smallmouth bass were also regularly observed at depths between 15-40 feet during the underwater video assessment of substrate characteristics along the physical habitat transects. The CART and video data further suggested that most bass held positions within 5-10 feet of the substrate. The cover HSI curve was identical to the juvenile bass curve except for higher suitability for no cover, again reflecting a decreased influence of predation with increased fish size. Relative few site-specific HSI observations were available for adult bass in winter, most of which supported the expected shift towards deeper and slower habitats. Given that aquatic vegetation is largely absent during winter months, the winter HSI curve for cover suggested high suitability only for those types providing dense structure, such as large woody debris or large substrate materials.

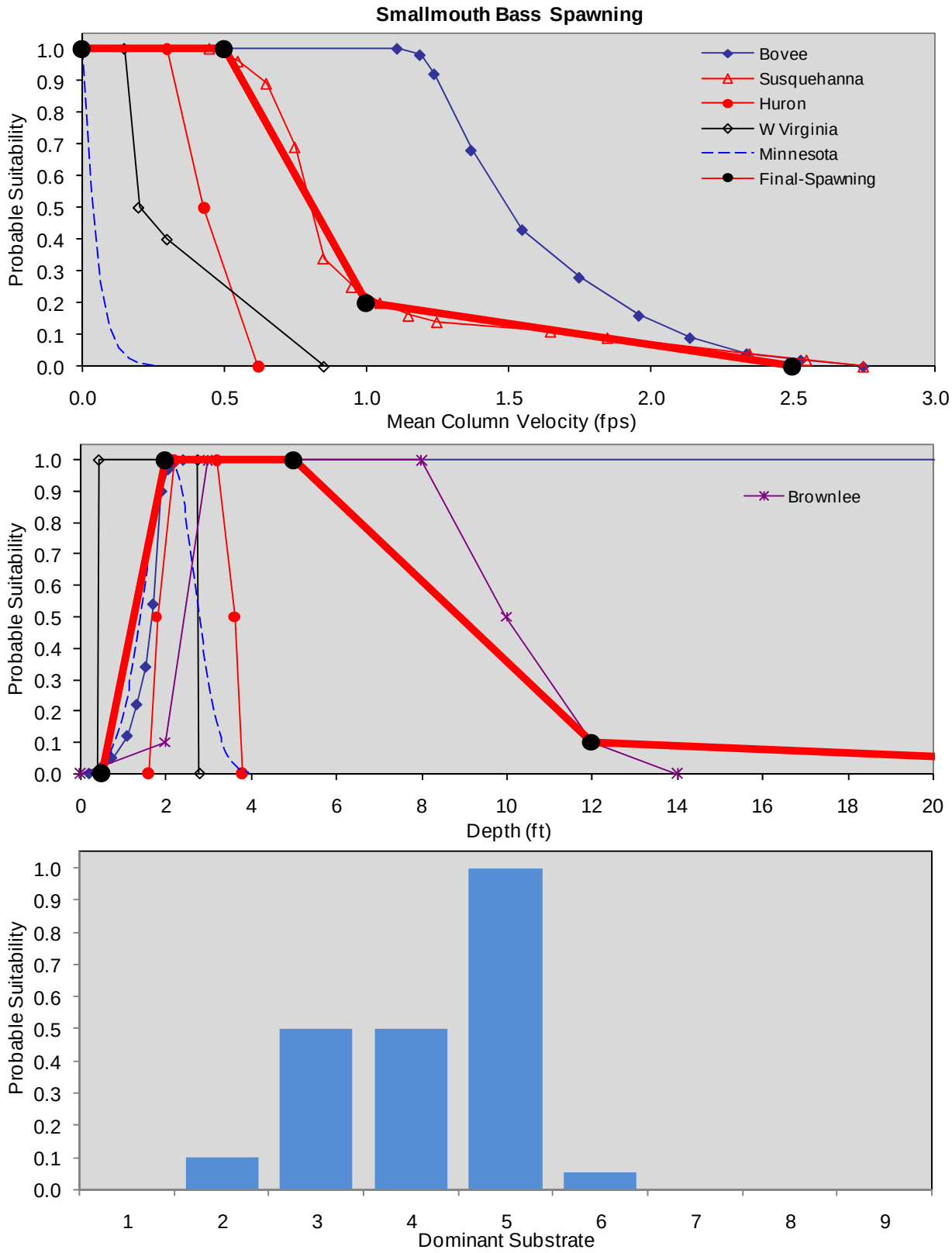


**Figure 6.5-1**. Literature-based and final Project HSI curves for smallmouth bass spawning velocity, depth, and substrate type. See Table 6.1-1 for substrate type definitions.

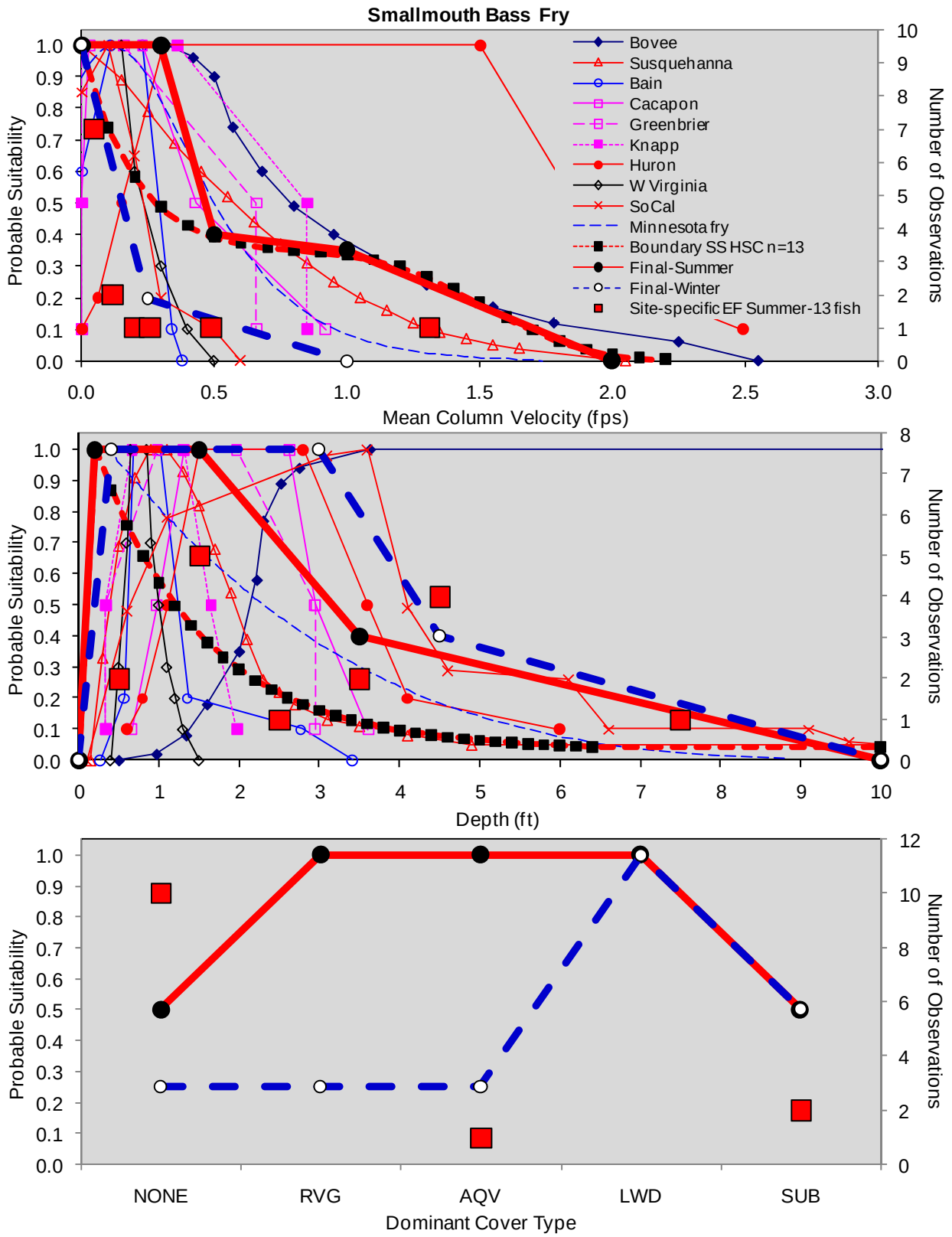


**Figure 6.5-2**. Literature-based and final Project HSI curves for smallmouth bass fry velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

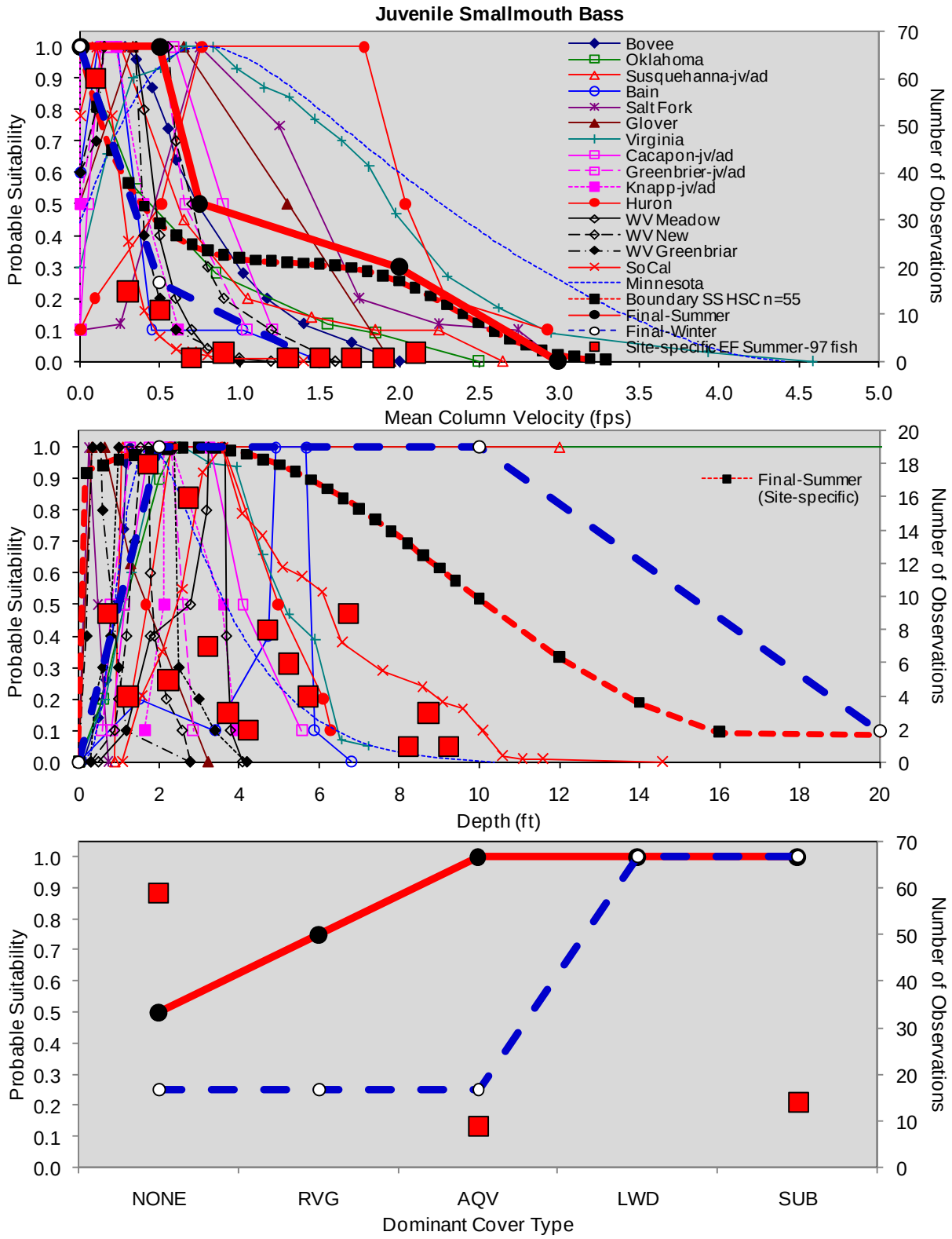


**Figure 6.5-3**. Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing) for juvenile smallmouth bass velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

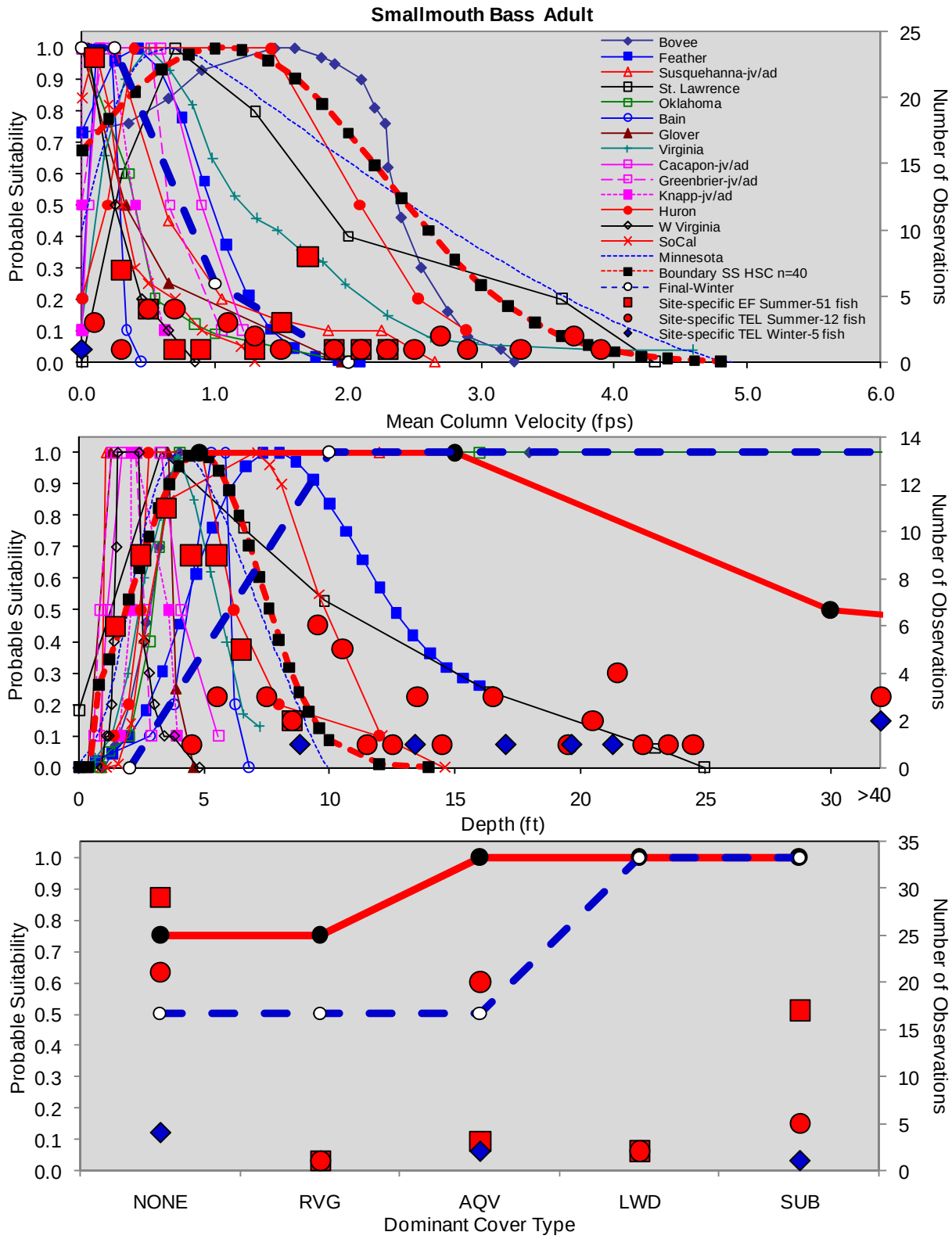


**Figure 6.5-4**. Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing, TEL=biotelemetry) for adult smallmouth bass velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

## 6.6. Cyprinid Forage Species

HSI curves could not be found for any of the cyprinid forage species found in the Boundary project area, although some closely related species (Sacramento pikeminnow and hardhead) are included (Table 6.6-1). Most cyprinid HSI curves are derived from eastern and midwestern states, and smaller adults species (<4 inches) that are reported to inhabit large rivers have been included as potential surrogates for redside shiner and peamouth (Pflieger 1975). Spawning HSI are not considered here, only rearing HSI representing fry, juvenile, or adult fish (for smaller species) up to 10 cm in length. Site-specific data for small cyprinids are also shown, although capture efficiency of the smallest individuals is probably very low given the depth of water at most sampling points and the practice of electrofishing at night. Electrofishing from a large boat may also limit the capture of small fish from very shallow water where the boat cannot operate. Site-specific HSI curves were developed for cyprinid forage fish based on the summertime capture of approximately 90 individual fish from 33 individual electrofishing cells (Table 5.0-1). Sample sizes were insufficient to construct site-specific curves from winter sampling. Final HSI points for forage fish are given in Table 6.6-2.

**Table 6.6-1**. HSI datasets for cyprinid forage species.

| Curve Name | Lifestages | Length cm | Sample Size | State / Prov | River | Width ft | Flow cfs | W Temp °F | Samp Design | Obs Method | Curve Type | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NE W Silvery Min | J+A | -12 | 180 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE Plains Min | J+A | -12 | 473 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE Speckled Chub | J+A | -8 | 28 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE Flathead Chub | J+A | -18 | 148 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE River Shiner | J | -3 | 78 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE Red Shiner | J | -3 | 176 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| NE Sand Shiner | J | -3 | 142 | NE | Platte | | ~600-10,000 | 50-85 | RCH | PPS | III | | Peters et al 89 |
| Pit Pikeminnow | J | | 88 | CA | Pit | 40-200 | 50-150 | | RCH | DO uw | III | 1,2 | Baltz & Vondracek 85 |
| Sierras Pikeminnow | J | 12 | 537 | CA | Sierra streams | 6-59 | | 49-77 | RCH | | II | 1,3 | Knight 85 |
| Feather PM/HH | J | 5-15 | 140 | CA | NF Feather | 70-106 | 96-131 | 64-72 | EA | DO uw | IV | 4,5 | TRPA 01 |
| Deer Juv Roach | J | -3 | 77 | CA | Deer | | 210 | 57-90 | RCH | DO uw | II | 1,6 | Moyle & Baltz 85 |
| Deer Adlt Roach | A | 4+ | 140 | CA | Deer | | 210 | 57-90 | RCH | DO uw | II | 1,6 | Moyle & Baltz 85 |
| Deer Juv Pikeminnow | J | -15 | 141 | CA | Deer | | 210 | 57-90 | RCH | DO uw | II | 1,6 | Moyle & Baltz 85 |
| MN Bluntnose Min | A | -8 | 3669 | MN | 9 rivers | | | | RCH | PPS | III | 7 | Aadland & Kuitunen 06 |
| MN Emerald Shiner | A | -8 | 5887 | MN | 5 rivers | | | | RCH | PPS | III | 7 | Aadland & Kuitunen 06 |
| MN Mimic Shiner | A | -8 | 140 | MN | 8 rivers | | | | RCH | PPS | III | 7 | Aadland & Kuitunen 06 |
| MN River Shiner | A | -8 | 1991 | MN | 5 rivers | | | | RCH | PPS | III | 7 | Aadland & Kuitunen 06 |
| Redside Shiner | | | | WY | Yellowstone Lake | | | | | | | 8 | Wydoski & Whitney 03 |

Notes:

Life stages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: RCH-representative reaches, PROP-sampling proportional to availability, EA-equal-area sampling, other. Observation methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, NET- seining or other net capture, TEL-radio or acoustic telemetry, Other (see comments). Curve types: Cat I - based on professional judgment, Cat II - based on habitat use data, Cat III - based on habitat use data adjusted by habitat availability data, Cat IV - other.

1 curve points approximated from graphs
2 HSC data re-weighted by mesohabitat type to simulate equal-area sampling
3 includes data from Moyle & Baltz 1985
4 four curve types presented, density HSC derived from strip transect counts partitioned according to depth and velocity patches+D1
5 the 140 curve points were derived from fewer individual fish or schools of fish with mean school characteristics (ie, ranges in depths & velocities) distributed among the individual school members
6 electivity values (+1 to -1) also available
7 approx adult size, common in large rivers (from Pflieger 1975, Fishes of Missouri)
8 reside shiners in Yellowstone Lake typically occurred in weedy bays at depths <11 ft

**Table 6.6-2.** Final HSI values for cyprinid forage fish according to season and habitat variable.

| Species | Life Stage | Season [1] | Mean Velocity | HSI | Depth | HSI | Substrate or Cover [2] | HSI |
|---|---|---|---|---|---|---|---|---|
| Cyprinid | fry & | summer | 0.00 | 0.64 | 0.00 | 0.00 | NONE | 0.75 |
| Forage | juvenile | | 0.10 | 0.76 | 0.50 | 1.00 | RVG | 1.00 |
| | <100mm | | 0.20 | 0.86 | 1.50 | 1.00 | AQV | 1.00 |
| | | | 0.30 | 0.94 | 2.50 | 0.30 | LWD | 1.00 |
| | | | 0.40 | 0.99 | 10.00 | 0.00 | SUB | 1.00 |
| | | | 0.50 | 1.00 | | | DEP | 1.00 |
| | | | 0.60 | 0.97 | | | | |
| | | | 0.70 | 0.91 | | | | |
| | | | 0.80 | 0.82 | | | | |
| | | | 0.90 | 0.70 | | | | |
| | | | 1.00 | 0.58 | | | | |
| | | | 1.10 | 0.46 | | | | |
| | | | 1.20 | 0.35 | | | | |
| | | | 1.30 | 0.25 | | | | |
| | | | 1.40 | 0.17 | | | | |
| | | | 1.50 | 0.11 | | | | |
| | | | 1.60 | 0.07 | | | | |
| | | | 1.70 | 0.04 | | | | |
| | | | 1.80 | 0.02 | | | | |
| | | | 1.90 | 0.01 | | | | |
| | | | 2.10 | 0.00 | | | | |
| | | winter | 0.00 | 1.00 | 0.00 | 0.00 | NONE | 0.50 |
| | | | 0.50 | 0.20 | 0.50 | 1.00 | RVG | 0.50 |
| | | | 1.00 | 0.00 | 6.00 | 1.00 | AQV | 0.50 |
| | | | | | 20.00 | 0.00 | LWD | 1.00 |
| | | | | | | | SUB | 1.00 |
| | | | | | | | DEP | 1.00 |

Notes:

1 Summer=1 April to 31 October, winter=1 November-31 March

2 Substrate used for spawning (1-fines, 2-sand <0.1", 3-sml grav 0.1-0.5", 4-med grav 0.5-1.5", 5-lrg grav 1.5-3", 6-sml cob 3-6", 7-lrg cob 6-12", 8-boulder >12", 9-bedrock); cover for fry, juvenile, and adult rearing (NONE; RVG=terrestrial vegetation; AQV=aquatic vegetation; LWD=large woody debris; SUB=substrate particles >1.5" diameter; DEP=water depths >50ft)

### 6.6.1. Fry/Juvenile/Adult Rearing

The available HSI curves for velocity and depth show relatively wide ranges of habitat suitability, although most curves tend towards highest suitability in slow (<1 fps), shallow (<2 feet) water (Table 6.6-1, Figure 6.6-1). The final Boundary HSI curve for velocity was developed from the site-specific electrofishing data, and shows maximum suitability for slow velocities. Several of the Nebraska and Minnesota HSI curves are not encompassed by the site-specific curve, however those curves are based on different species. The site-specific depth curve did not appear realistic for the Boundary Project area, but was largely driven by the capture of cyprinids in several of the shallowest electrofishing cells (which, being rare in samples, produced high suitability values). Consequently, the site-specific depth curve was modified to produce a broader range of maximum suitability for the final Boundary curve. The cover HSI curve for cyprinids was similar to the salmonid fry curves, except for higher suitability for areas devoid of cover. This difference was based on the frequent observation of small cyprinids along exposed shorelines in the Project area. The winter HSI curves for velocity, depth, and cover followed the practice of shifting suitability towards slower, deeper water with greater emphasis on dense cover types.

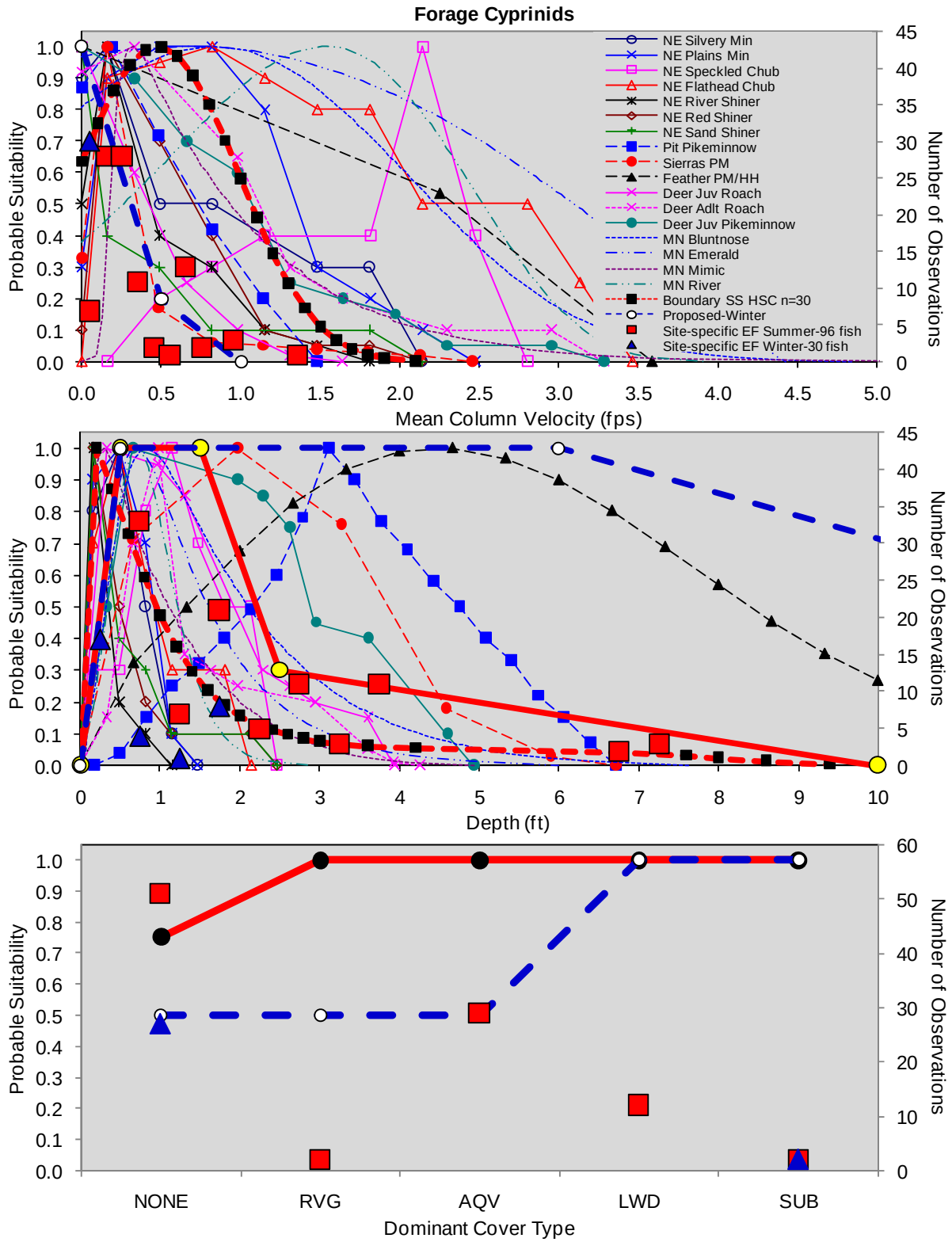


**Figure 6.6-1**. Literature-based and final Project HSI curves, and site-specific observations (EF=electrofishing) for cyprinid forage species velocity, depth, and cover type. See Table 6.1-1 for cover type definitions (Depth cover not shown, HSI=1.0).

# 7 MODEL RESULTS

This section describes the format of the results from the fish habitat model and the spawning model; discussion of these model outputs can be found in Section 5.9 of the main report. Outputs from both models were calculated at an hourly interval for the three years representing wet (1997), dry (2001), and average (2002) hydrologic conditions. Weighted usable area (WUA) was calculated for fry, juvenile, and adult life stages, whereas potential and effective widths were calculated for the spawning adults and for egg incubation. The calculated WUA values are presented in Section 7.1; the model outputs of potential and effective spawning widths are provided in Section 7.2.

## 7.1. Fish Habitat – Weighted Usable Area

WUA values, the output from the fish habitat model, were calculated as indices of habitat for fry, juvenile, and adult life stages in each of the four study reaches. The WUA was calculated as the product of HSI values and available habitat area. Section 4.9.1.1 of the Study 7 Final Report (SCL 2009b) provides a detailed description of the modeling approach; only an overview is presented here. The hourly WUA values were plotted for each of the three representative years to illustrate changes in WUA over time and serve as an index for comparing the influence of Project operations on fish habitat. As described in Section 6 of this report, the summer and winter seasons have different HSI values, but the values are consistent within each season. The HRM computed the mainstem water surface elevation at each hour within each of the three representative years as a function of inflow to the Boundary Reservoir and water surface elevation in the forebay. At selected habitat transects throughout the study area, the WUA model translated these water surface elevations into habitat area. The habitat area at a transect was calculated in cells (or incremental widths) across the wetted width associated with a water surface elevation at a specific hour. Depending on factors affecting habitat quality, such as flow velocity, substrate size, and depth, the habitat area at each cell was weighted by the appropriate HSI values. On an hourly basis, the WUA values could change as a function of available habitat area and/or as a function of the suitability of the available habitat.

WUA calculations did not consider flows exceeding 80,000 cfs. Once flows exceeded this threshold, the calculated WUA for a particular fish species and life stage was not included in either the plotted results or numerical values of the WUA. Extending the modeling effort by 25,000 cfs beyond the maximum powerhouse discharge of 55,000 cfs ensured the incorporation of all flows potentially influenced by Project operations. When flows exceed 55,000 cfs, pool level fluctuations are typically dominated by inflow hydrology not Project operations as shown by the hydraulic routing model. Therefore, the influence of Project operations on WUA during these higher flow rates was not expected to be significant.

The WUA values output from the fish habitat model were plotted over the duration of each representative year to illustrate hourly, seasonal, and annual variability; these plots are included in Attachment A. The figures in Attachment A are organized by reach starting with the Forebay Reach and progressing upstream to the Upper Reservoir Reach. The Tailrace Reach can be found after the Upper Reservoir Reach. An example of the figures contained within Attachment A is presented in Figure 7.1-1. This figure presents the WUA per linear foot of channel length on the y-axis. On the x-axis is the corresponding date for which the WUA was calculated. The

output for the wet year is shown in the top plot, the dry year output is shown in the middle plot, and the average year output is shown in the bottom plot.

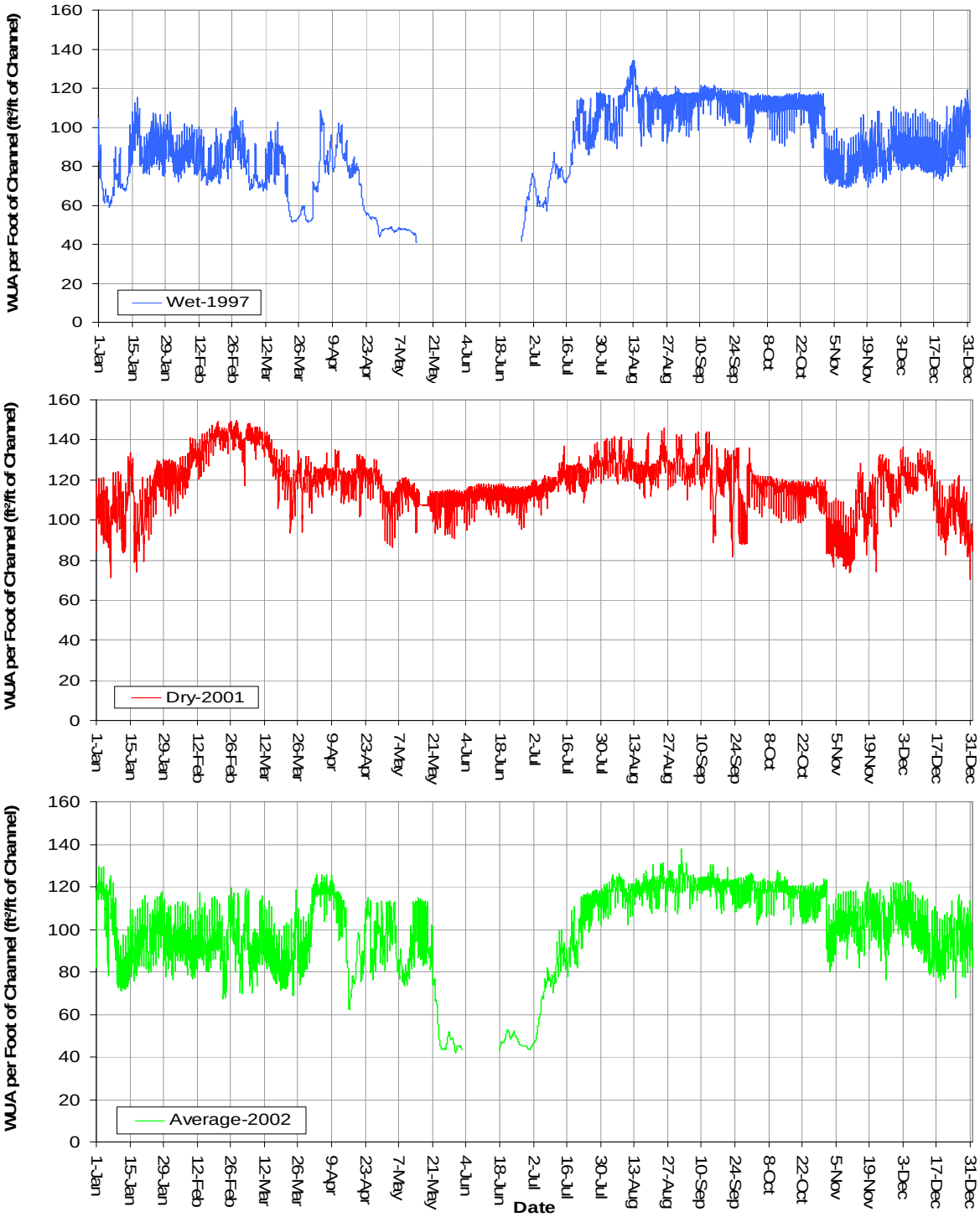


**Figure 7.1-1**. Juvenile cutthroat trout WUA per foot of channel length in the Upper Reservoir Reach for the three representative years.

The mean, maximum, and minimum monthly WUA values were tabulated from the hourly values to provide indicators of monthly changes and trends. A separate table was compiled for each reach during each of the three representative years. A total of 12 tables are provided (see Attachment A). An example table showing the mean, maximum, and minimum monthly WUA values within the Upper Reservoir Reach during the average year is provided as Table 7.1-1.

**Table 7.1-1.** Monthly WUA for a given species in the Upper Reservoir Reach during the average year (2002).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 143 | 238 | 54 | 97 | 192 | 132 | 52 | 97 | 173 | 31 | 92 | 170 | -- | 121 | 370 |
| | **Max.** | 188 | 382 | 71 | 129 | 364 | 191 | 69 | 129 | 361 | 49 | 146 | 391 | -- | 148 | 485 |
| | **Min.** | 105 | 136 | 32 | 71 | 108 | 95 | 31 | 71 | 87 | 18 | 60 | 68 | -- | 92 | 259 |
| **February** | **Mean** | 136 | 223 | 53 | 93 | 180 | 128 | 51 | 93 | 157 | 32 | 87 | 152 | -- | 119 | 357 |
| | **Max.** | 169 | 327 | 66 | 120 | 286 | 175 | 64 | 120 | 274 | 45 | 129 | 295 | -- | 136 | 456 |
| | **Min.** | 98 | 138 | 34 | 67 | 111 | 86 | 33 | 67 | 89 | 19 | 58 | 71 | -- | 94 | 245 |
| **March** | **Mean** | 131 | 206 | 52 | 89 | 167 | 123 | 50 | 89 | 144 | 31 | 83 | 138 | -- | 114 | 340 |
| | **Max.** | 166 | 316 | 67 | 119 | 292 | 182 | 65 | 119 | 280 | 45 | 134 | 298 | -- | 135 | 447 |
| | **Min.** | 100 | 134 | 32 | 69 | 106 | 91 | 31 | 69 | 86 | 17 | 59 | 68 | -- | 93 | 246 |
| **April** | **Mean** | 165 | 428 | 22 | 101 | 435 | 53 | 22 | 109 | 477 | 71 | 221 | 454 | 33 | 41 | 348 |
| | **Max.** | 206 | 537 | 61 | 126 | 598 | 96 | 61 | 143 | 627 | 139 | 289 | 598 | 53 | 53 | 389 |
| | **Min.** | 93 | 364 | 12 | 62 | 349 | 24 | 12 | 60 | 380 | 35 | 120 | 351 | 17 | 17 | 297 |
| **May** | **Mean** | 125 | 399 | -- | 79 | 404 | 36 | -- | 82 | 447 | 49 | 167 | 417 | 23 | 31 | 336 |
| | **Max.** | 182 | 495 | -- | 115 | 502 | 71 | -- | 122 | 549 | 86 | 251 | 524 | 42 | 51 | 389 |
| | **Min.** | 61 | 331 | -- | 42 | 358 | 23 | -- | 43 | 387 | 33 | 94 | 343 | 14 | 10 | 253 |
| **June** | **Mean** | 69 | 336 | 19 | 47 | 360 | 26 | 19 | 47 | 391 | 38 | 96 | 352 | 15 | 12 | 267 |
| | **Max.** | 78 | 346 | 23 | 53 | 365 | 29 | 23 | 52 | 400 | 41 | 99 | 364 | 15 | 14 | 285 |
| | **Min.** | 61 | 327 | 15 | 43 | 356 | 23 | 15 | 43 | 384 | 33 | 94 | 340 | 14 | 10 | 249 |
| **July** | **Mean** | 142 | 420 | 18 | 89 | 423 | 41 | 18 | 93 | 467 | 55 | 190 | 442 | 26 | 35 | 348 |
| | **Max.** | 201 | 539 | 37 | 121 | 590 | 80 | 37 | 139 | 621 | 109 | 283 | 595 | 47 | 51 | 391 |
| | **Min.** | 63 | 325 | 12 | 44 | 353 | 22 | 12 | 44 | 382 | 33 | 94 | 341 | 14 | 10 | 250 |
| **August** | **Mean** | 193 | 502 | 23 | 119 | 552 | 64 | 23 | 124 | 578 | 84 | 272 | 558 | 39 | 38 | 323 |
| | **Max.** | 217 | 541 | 59 | 131 | 623 | 95 | 59 | 147 | 646 | 139 | 299 | 613 | 54 | 53 | 377 |
| | **Min.** | 160 | 410 | 13 | 102 | 405 | 36 | 13 | 100 | 439 | 50 | 223 | 416 | 26 | 29 | 263 |
| **September** | **Mean** | 196 | 505 | 23 | 121 | 573 | 64 | 23 | 125 | 593 | 86 | 282 | 571 | 39 | 36 | 303 |
| | **Max.** | 225 | 539 | 60 | 138 | 626 | 96 | 60 | 151 | 647 | 141 | 307 | 614 | 55 | 53 | 347 |
| | **Min.** | 168 | 402 | 13 | 107 | 417 | 40 | 13 | 105 | 439 | 56 | 243 | 418 | 29 | 27 | 236 |

**Table 7.1-1, continued…**

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **October** | **Mean** | 189 | 498 | 22 | 117 | 534 | 63 | 22 | 123 | 565 | 82 | 265 | 546 | -- | 39 | 337 |
| | **Max.** | 209 | 542 | 59 | 128 | 615 | 95 | 59 | 144 | 641 | 138 | 302 | 608 | -- | 53 | 371 |
| | **Min.** | 160 | 392 | 13 | 102 | 381 | 36 | 13 | 99 | 418 | 50 | 222 | 388 | -- | 29 | 255 |
| **November** | **Mean** | 150 | 262 | 55 | 102 | 209 | 139 | 52 | 102 | 189 | 31 | 98 | 191 | -- | 127 | 397 |
| | **Max.** | 175 | 350 | 68 | 122 | 299 | 181 | 65 | 122 | 290 | 43 | 134 | 316 | -- | 139 | 473 |
| | **Min.** | 112 | 152 | 36 | 76 | 120 | 101 | 34 | 76 | 96 | 20 | 65 | 78 | -- | 100 | 270 |
| **December** | **Mean** | 142 | 238 | 54 | 97 | 192 | 133 | 52 | 97 | 170 | 31 | 92 | 168 | -- | 121 | 373 |
| | **Max.** | 175 | 349 | 67 | 123 | 304 | 181 | 65 | 123 | 295 | 45 | 136 | 323 | -- | 139 | 471 |
| | **Min.** | 99 | 141 | 32 | 68 | 112 | 87 | 31 | 68 | 91 | 17 | 58 | 74 | -- | 95 | 248 |

Note:
Redband trout are assumed to occur in the Tailrace Reach below Boundary Dam; however, WUA results are reported for all reaches.

A second set of plots was developed to illustrate the percent of each season that a particular WUA value was equaled or exceeded. These figures, referred to as WUA duration curves, were compiled for the selected species and life stage combination within each of the four reaches. A total of 60 figures were developed (15 fish species-life stage combinations in each of the four study reaches). The curves compiled for adult cutthroat trout in the Upper Reservoir Reach are shown in Figure 7.1-2. All figures are provided in Attachment B.

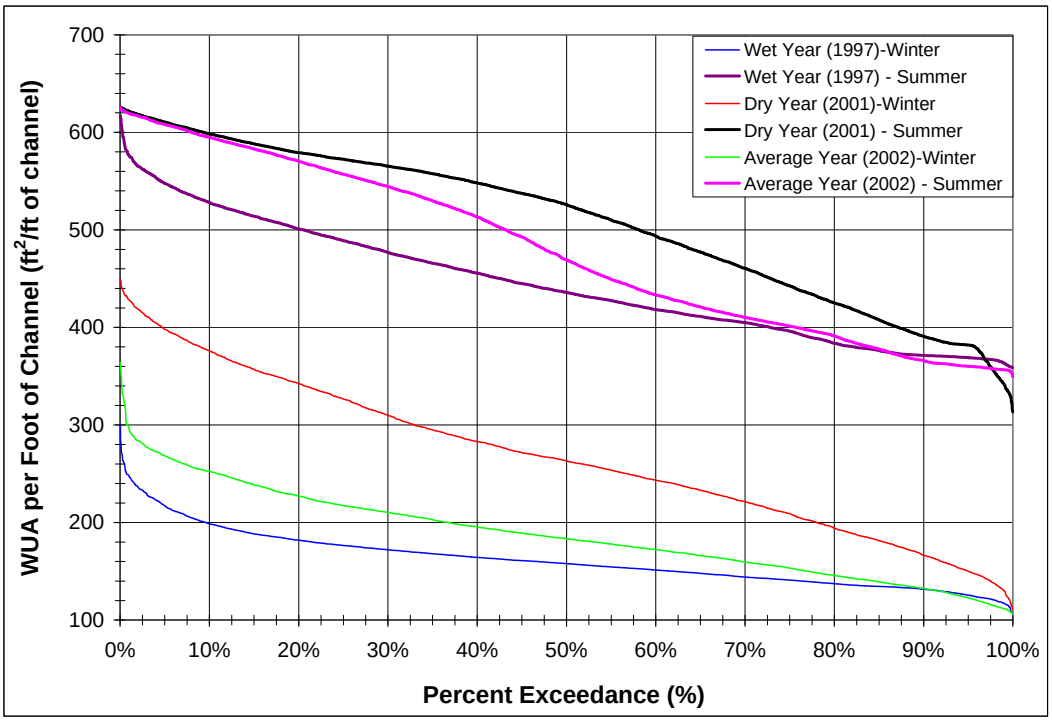


**Figure 7.1-2**. WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reservoir Reach.

## 7.2. Fish Habitat – Potential and Effective Spawning Widths

Potential spawning index (PSI) and effective spawning index (ESI) widths were calculated for the spawning adults and for egg development using the HSI curves presented in Section 6 of this report and the Physical Habitat Simulation (PHABSIM) modeling routine. A detailed description of the modeling approach is presented in Section 4.9.1.2 of the Study 7 Final Report (SCL 2009b); the model output is discussed in Section 5.9.2 of the same. The information in this section of this report describes the format of the model output.

These PSI and ESI widths were calculated for mountain whitefish and smallmouth bass at selected transects for the three years in the historic record representing wet (1997), dry (2001), and average (2002) hydrologic conditions. An example of the PSI and ESI widths calculated for smallmouth bass at habitat transect U-17 is presented in Figure 7.2-1. The figure presents the spawning period plotted on the x-axis, elevation on the primary (left) y-axis, and spawning width on the secondary (right) y-axis. The wet year is shown in the top plot, the dry year in the middle plot, and the average year in the bottom plot. Figures for both fish species at all selected habitat transects are presented in Attachment C.

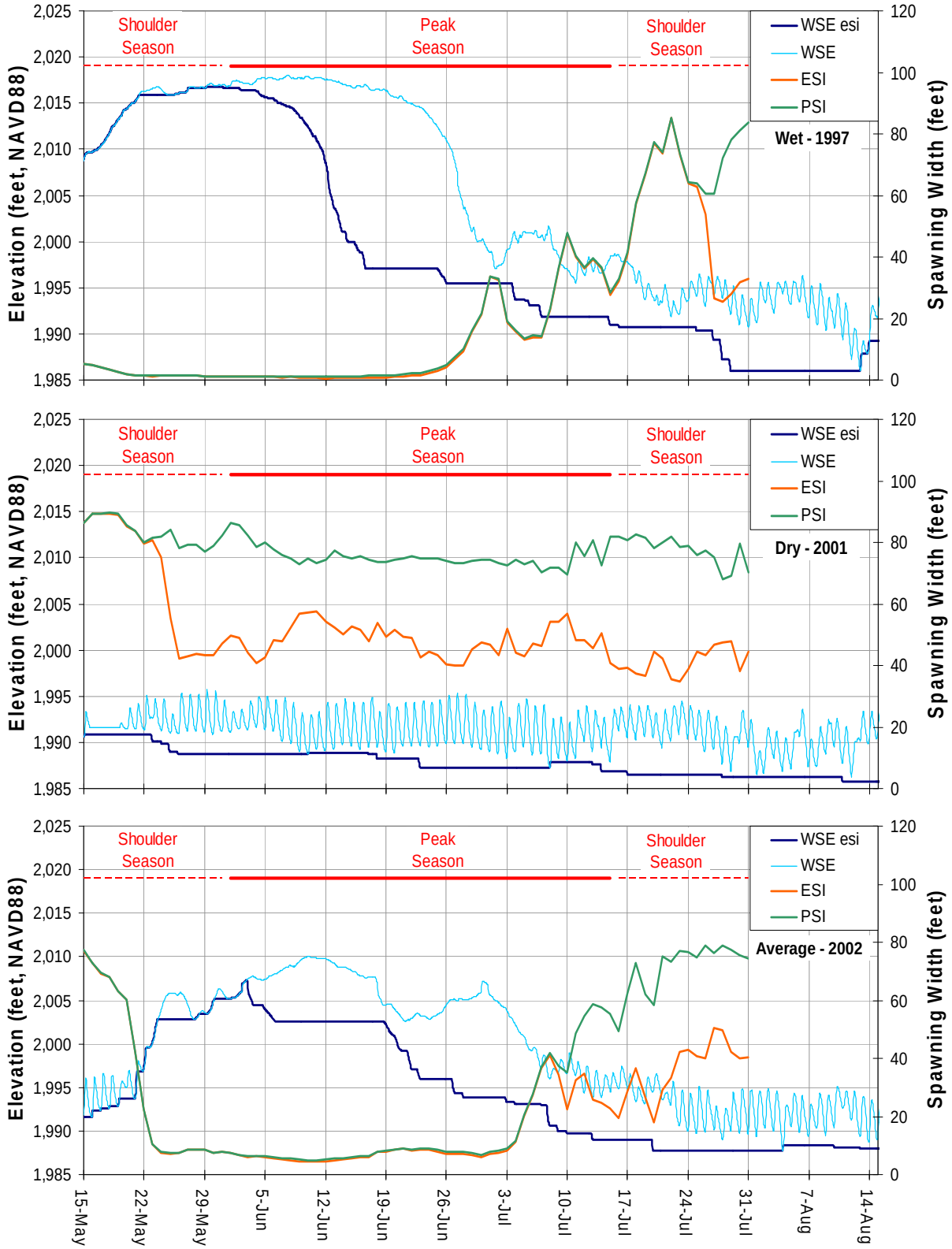


**Figure 7.2-1.** Daily PSI and ESI widths during representative years for smallmouth bass at habitat transect U-17.

In addition to plotting the PSI and ESI widths over the spawning seasons, the outputs from the spawning model were summarized in tabular form to facilitate comparisons. Three types of tables were assembled for each fish species. One type presents the mean, maximum, and minimum ESI widths for the shoulder and peak seasons by habitat transect. The values in this table only reflect the spawning season, and do not include any values once the season ends—even when the incubation period extends past the end of the season. The seasonal values are calculated as the mean of the daily values; the daily values were calculated using hourly weighting factors applied to the hourly output. Table 7.2-1 presents these results for mountain whitefish and Table 7.2-2 presents the results for smallmouth bass.

**Table 7.2-1.** Seasonal ESI widths calculated by spawning season for mountain whitefish.

| Transect | Season[1] | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. |
| U-05 | S1 | 539 | 580 | 500 | 419 | 500 | 382 | 499 | 552 | 427 |
| | Peak | 514 | 565 | 429 | 461 | 576 | 380 | 469 | 556 | 430 |
| | S2 | 520 | 586 | 462 | 504 | 593 | 424 | 488 | 584 | 446 |
| U-10 | S1 | 285 | 305 | 266 | 180 | 217 | 163 | 259 | 283 | 228 |
| | Peak | 291 | 373 | 252 | 232 | 296 | 162 | 247 | 284 | 230 |
| | S2 | 331 | 362 | 302 | 260 | 303 | 227 | 256 | 295 | 236 |
| U-11 | S1 | 355 | 383 | 327 | 231 | 285 | 206 | 319 | 360 | 267 |
| | Peak | 338 | 375 | 276 | 282 | 369 | 205 | 296 | 356 | 271 |
| | S2 | 342 | 387 | 298 | 314 | 377 | 266 | 309 | 377 | 279 |
| U-23 | S1 | 402 | 417 | 386 | 261 | 286 | 248 | 387 | 415 | 353 |
| | Peak | 393 | 420 | 348 | 337 | 392 | 245 | 344 | 381 | 320 |
| | S2 | 407 | 429 | 379 | 364 | 393 | 339 | 375 | 396 | 360 |
| U-24 | S1 | 355 | 380 | 331 | 348 | 393 | 325 | 364 | 404 | 338 |
| | Peak | 339 | 382 | 263 | 370 | 448 | 319 | 365 | 431 | 332 |
| | S2 | 348 | 385 | 306 | 372 | 433 | 343 | 379 | 436 | 351 |
| TR-15 | S1 | 54 | 58 | 50 | 56 | 64 | 46 | 57 | 66 | 47 |
| | Peak | 91 | 162 | 41 | 79 | 106 | 43 | 67 | 82 | 47 |
| | S2 | 75 | 91 | 54 | 75 | 93 | 59 | 61 | 77 | 46 |
| TR-16 | S1 | 64 | 68 | 58 | 65 | 74 | 54 | 67 | 78 | 55 |
| | Peak | 71 | 105 | 48 | 75 | 98 | 49 | 72 | 88 | 48 |
| | S2 | 63 | 79 | 45 | 75 | 94 | 61 | 71 | 82 | 55 |

Note:

1 S1 and S2 are shoulder spawning seasons (excluding incubation durations). S1 – 10/15 – 10/31; Peak - 11/1 – 1/15; S2 – 1/16 – 2/28.

**Table 7.2-2.** Seasonal ESI widths calculated by spawning season for smallmouth bass.

| Transect | Season[1] | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. |
| C-06 | S1 | 62 | 85 | 38 | 0.0 | 0.0 | 0.0 | 43 | 83 | 0.0 |
| | Peak | 33 | 88 | 5.2 | 6.9 | 65 | 0.0 | 45 | 84 | 2.4 |
| | S2 | 20 | 51 | 6.8 | 41 | 47 | 36 | 4.7 | 13 | 1.9 |
| C-07 | S1 | 33 | 48 | 19 | 0.0 | 0.0 | 0.0 | 24 | 47 | 0.0 |
| | Peak | 25 | 50 | 7.6 | 4.0 | 34 | 0.0 | 29 | 47 | 6.4 |
| | S2 | 16 | 26 | 10 | 19 | 25 | 15 | 9.2 | 19 | 4.9 |
| U-05 | S1 | 0.4 | 1.3 | 0.0 | 27 | 31 | 24 | 8.7 | 23.3 | 1.9 |
| | Peak | 2.2 | 11 | 0.0 | 27 | 31 | 23 | 3.8 | 15.2 | 1.2 |
| | S2 | 17 | 26 | 4.8 | 26 | 31 | 23 | 22 | 30 | 11 |
| U-06 | S1 | 15 | 19 | 14 | 0.4 | 1.6 | 0.0 | 15 | 20 | 3.7 |
| | Peak | 6.2 | 16 | 1.0 | 0.0 | 0.0 | 0.0 | 7.3 | 20 | 0.0 |
| | S2 | 1.6 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| U-07 | S1 | 58 | 68 | 23 | 0.2 | 1.0 | 0.0 | 17 | 26 | 2.9 |
| | Peak | 17 | 60 | 1.2 | 0.0 | 0.0 | 0.0 | 8.1 | 20 | 0.0 |
| | S2 | 0.9 | 1.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| U-10 | S1 | 6.6 | 9.9 | 3.4 | 3.5 | 4.8 | 1.8 | 9.3 | 12 | 6.5 |
| | Peak | 3.3 | 10 | 0.5 | 2.1 | 2.3 | 1.8 | 4.1 | 10 | 1.0 |
| | S2 | 3.5 | 5.0 | 1.6 | 2.0 | 2.4 | 1.8 | 1.8 | 2.2 | 1.3 |
| U-16 | S1 | 2.0 | 4.4 | 1.2 | 40 | 48 | 29 | 26 | 47 | 8.7 |
| | Peak | 8.9 | 33 | 1.0 | 20 | 36 | 10 | 11 | 30 | 4.1 |
| | S2 | 28 | 48 | 4.1 | 8.1 | 9.8 | 6.1 | 16 | 37 | 6.6 |
| U-17 | S1 | 2.2 | 5.2 | 1.2 | 69 | 89 | 42 | 32 | 77 | 7.2 |
| | Peak | 11 | 47 | 0.5 | 48 | 58 | 40 | 12 | 41 | 4.3 |
| | S2 | 52 | 85 | 26 | 41 | 48 | 35 | 36 | 51 | 18 |
| U-21 | S1 | 11 | 15 | 9.4 | 38 | 61 | 15 | 46 | 86 | 16 |
| | Peak | 21 | 73 | 1.8 | 17 | 20 | 14 | 15 | 56 | 7.1 |
| | S2 | 36 | 59 | 8.8 | 14 | 16 | 12 | 13 | 17 | 6.0 |

Note:
1 S1 and S2 are shoulder spawning seasons (excluding incubation durations). S1 – 5/15 –5/31; Peak - 6/1 – 7/15; S2 – 7/16 – 7/31.

The second type of table presents the annual PSI and ESI widths at modeled habitat transects. These widths were calculated by applying the seasonal weighting factors to the mean values within each season, and summing the resulting components. This type of table also includes a ratio of the ESI width to the PSI width as an indicator of the influence of fluctuations in water surface elevation over the incubation period. Without fluctuations in the water surface elevation, the ratio would be one; a ratio of near zero indicates a substantial influence of fluctuations. Table 7.2-3 illustrates the annual PSI and ESI widths, as well as the ratio of ESI to PSI for mountain whitefish; Table 7.2-4 shows the same information for smallmouth bass. Figures 7.2-2 and 7.2-3 show in bar chart form the same information in Tables 7.2-3 and 7.2-4, respectively.

**Table 7.2-3.** Annual PSI and ESI widths calculated for mountain whitefish.

| Transect | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] | PSI | ESI | Ratio[1] |
| U-05 | 534 | 509 | 0.95 | 567 | 472 | 0.83 | 566 | 477 | 0.84 |
| U-10 | 618 | 307 | 0.50 | 522 | 237 | 0.45 | 526 | 250 | 0.48 |
| U-11 | 566 | 335 | 0.59 | 516 | 289 | 0.56 | 518 | 301 | 0.58 |
| U-23 | 415 | 392 | 0.95 | 424 | 338 | 0.80 | 425 | 359 | 0.84 |
| U-24 | 346 | 334 | 0.97 | 390 | 372 | 0.95 | 383 | 367 | 0.96 |
| TR-15 | 355 | 88 | 0.25 | 303 | 78 | 0.26 | 309 | 65 | 0.21 |
| TR-16 | 564 | 69 | 0.12 | 462 | 74 | 0.16 | 477 | 71 | 0.15 |

Notes:
1 Ratio is the PSI width divided by the ESI width.
ESI – Effective Spawning Index
PSI – Potential Spawning Index

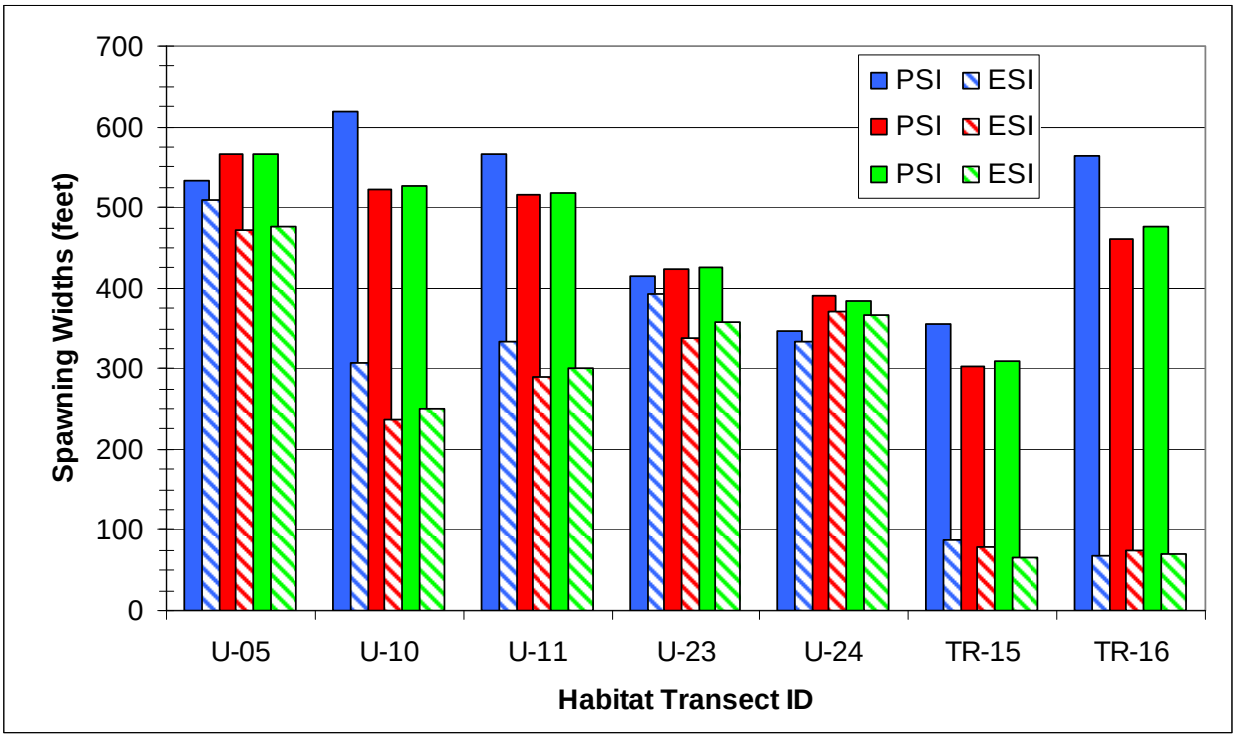


**Figure 7.2-2.** Annual PSI and ESI widths calculated for mountain whitefish at targeted habitat transects.

**Table 7.2-4.** Annual weighted PSI and ESI widths calculated for smallmouth bass.

| Transect | Wet Year Width (feet) | | | Dry Year Width (feet) | | | Average Year Width (feet) | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSI | ESI | Ratio1 | PSI | ESI | Ratio1 | PSI | ESI | Ratio1 |
| C-06 | 82 | 35 | 0.43 | 54 | 11 | 0.20 | 78 | 38 | 0.49 |
| C-07 | 47 | 25 | 0.53 | 32 | 5.7 | 0.18 | 45 | 25 | 0.56 |
| U-05 | 4.3 | 4.1 | 0.95 | 27 | 27 | 1.00 | 7.3 | 7.3 | 1.00 |
| U-06 | 15 | 6.8 | 0.45 | 4.4 | 0.1 | 0.01 | 17 | 7.3 | 0.43 |
| U-07 | 42 | 21 | 0.49 | 5.2 | 0.0 | 0.01 | 20 | 8.3 | 0.42 |
| U-10 | 8.4 | 3.8 | 0.45 | 6.2 | 2.3 | 0.37 | 10 | 4.5 | 0.45 |
| U-16 | 16 | 11 | 0.66 | 43 | 21 | 0.50 | 22 | 14 | 0.63 |
| U-17 | 19 | 16.1 | 0.86 | 77 | 50 | 0.65 | 27 | 19 | 0.70 |
| U-21 | 33 | 22 | 0.66 | 53 | 20 | 0.37 | 39 | 19 | 0.50 |

Notes:
1 Ratio is the PSI width divided by the ESI width.
ESI – Effective Spawning Index
PSI – Potential Spawning Index

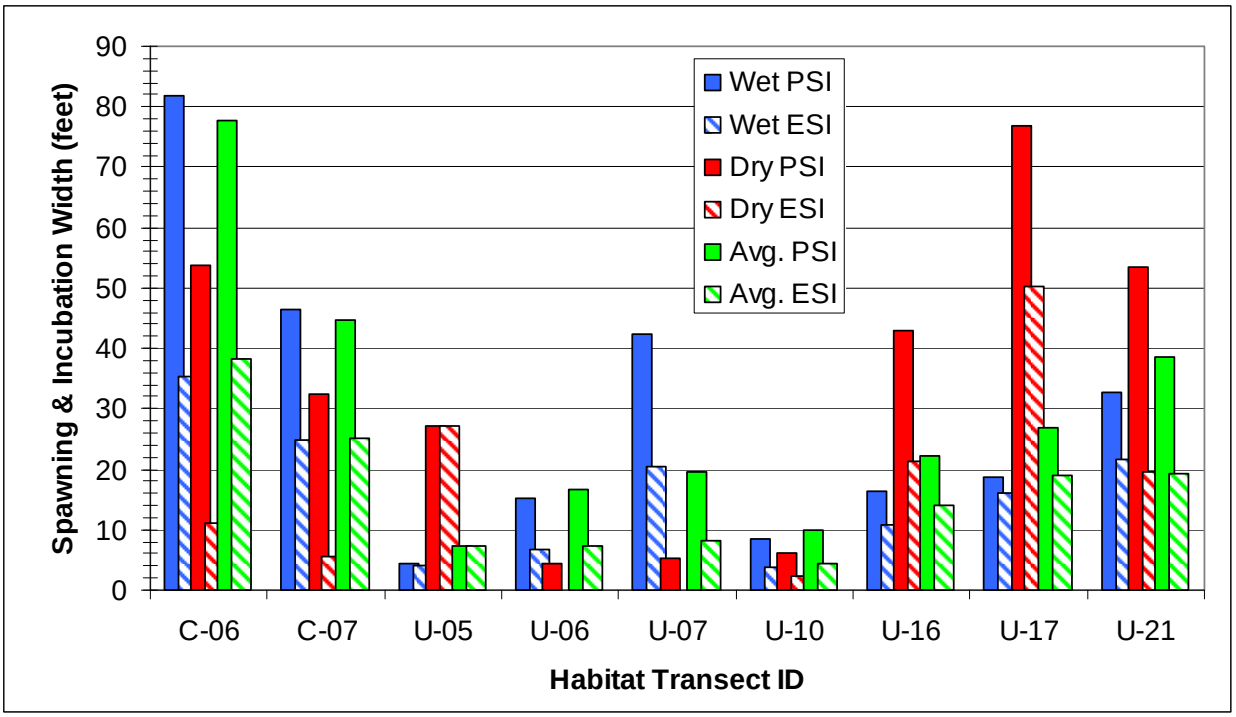


**Figure 7.2-3.** Annual weighted PSI and ESI widths calculated for smallmouth bass at targeted habitat transects.

The third type of table condenses the spawning index widths for all modeled transects in a study reach into a single value that is weighted by the PSI width at a transect relative to the total PSI

width summed for all transects within the reach. The transect-weighted, average channel widths are provided as a reference for the calculated spawning widths. Table 7.2-5 presents the transect-weighted, reach-averaged results for mountain whitefish and Table 7.2-6 presents the results for smallmouth bass.

**Table 7.2-5.** Transect-weighted, reach-averaged PSI widths, ESI widths, and ESI to PSI ratios for mountain whitefish during representative wet, dry, and average years.

| Reach | Weighted Average Channel Width (feet) | Wet Year Widths (feet) | | | Dry Year Widths (feet) | | | Ave. Year Widths (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PSI | ESI | Ratio | PSI | ESI | Ratio | PSI | ESI | Ratio |
| Upper Reservoir | 1,020 | 516 | 375 | 0.73 | 493 | 343 | 0.70 | 493 | 352 | 0.71 |
| Tailrace | 491 | 483 | 76 | 0.16 | 399 | 75 | 0.19 | 411 | 68 | 0.17 |

Notes:
ESI – Effective Spawning Index
PSI – Potential Spawning Index

**Table 7.2-6.** Transect-weighted, reach-averaged PSI widths, ESI widths, and ESI to PSI ratios for smallmouth bass during representative wet, dry, and average years.

| Reach | Weighted Average Channel Width (feet) | Wet Year Widths (feet) | | | Dry Year Widths (feet) | | | Ave. Year Widths (feet) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PSI | ESI | Ratio | PSI | ESI | Ratio | PSI | ESI | Ratio |
| Canyon[1] | 538[1] | 69 | 32 | 0.46 | 46 | 9.0 | 0.20 | 66 | 34 | 0.51 |
| Upper Reservoir | 1,020 | 28 | 16 | 0.57 | 53 | 30 | 0.57 | 25 | 14 | 0.56 |

Notes:
1 Average width of side channel to the west of Everett Island is approximately 306 feet.
ESI – Effective Spawning Index
PSI – Potential Spawning Index

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# Attachment A: Fish Habitat Weighted Usable Area (WUA) Model Output

This attachment contains the following tables:

Table A-1. Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the wet year (1997).
Table A-2. Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the dry year (2001).
Table A-3. Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the average year (2002).
Table A-4. Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the wet year (1997).4
Table A-5. Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the dry year (2001).
Table A-6. Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the average year (2002).
Table A-7. Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the wet year (1997).
Table A-8. Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the dry year (2001).
Table A-9. Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the average year (2002).
Table A-10. Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the wet year (1997).
Table A-11. Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the dry year (2001).
Table A-12. Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the average year (2002).

This attachment contains the following figures:

Figure A-1. Annual WUA for juvenile bull trout in the Forebay Reach during the three representative years.
Figure A-2. Annual WUA for adult bull trout in the Forebay Reach during the three representative years.
Figure A-3. Annual WUA for fry cutthroat trout in the Forebay Reach during the three representative years.
Figure A-4. Annual WUA for juvenile cutthroat trout in the Forebay Reach during the three representative years.
Figure A-5. Annual WUA for adult cutthroat trout in the Forebay Reach during the three representative years.
Figure A-6. Annual WUA for fry and juvenile cyprinids in the Forebay Reach during the three representative years.
Figure A-7. Annual WUA for fry redband trout in the Forebay Reach during the three representative years.
Figure A-8. Annual WUA for juvenile redband trout in the Forebay Reach during the three representative years.
Figure A-9. Annual WUA for adult redband trout in the Forebay Reach during the three representative years.

Figure A-10. Annual WUA for fry smallmouth bass in the Forebay Reach during the three representative years.
Figure A-11. Annual WUA for juvenile smallmouth bass in the Forebay Reach during the three representative years.
Figure A-12. Annual WUA for adult smallmouth bass in the Forebay Reach during the three representative years.
Figure A-13. Annual WUA for fry whitefish in the Forebay Reach during the three representative years.
Figure A-14. Annual WUA for juvenile whitefish in the Forebay Reach during the three representative years.
Figure A-15. Annual WUA for adult whitefish in the Forebay Reach during the three representative years.
Figure A-16. Annual WUA for juvenile bull trout in the Canyon Reach during the three representative years.
Figure A-17. Annual WUA for adult bull trout in the Canyon Reach during the three representative years.
Figure A-18. Annual WUA for fry cutthroat trout in the Canyon Reach during the three representative years.
Figure A-19. Annual WUA for juvenile cutthroat trout in the Canyon Reach during the three representative years.
Figure A-20. Annual WUA for adult cutthroat trout in the Canyon Reach during the three representative years.
Figure A-21. Annual WUA for fry and juvenile cyprinids in the Canyon Reach during the three representative years.
Figure A-22. Annual WUA for fry redband trout in the Canyon Reach during the three representative years.
Figure A-23. Annual WUA for juvenile redband trout in the Canyon Reach during the three representative years.
Figure A-24. Annual WUA for adult redband trout in the Canyon Reach during the three representative years.
Figure A-25. Annual WUA for fry smallmouth bass in the Canyon Reach during the three representative years.
Figure A-26. Annual WUA for juvenile smallmouth bass in the Canyon Reach during the three representative years.
Figure A-27. Annual WUA for adult smallmouth bass in the Canyon Reach during the three representative years.
Figure A-28. Annual WUA for fry whitefish in the Canyon Reach during the three representative years.
Figure A-29. Annual WUA for juvenile whitefish in the Canyon Reach during the three representative years.
Figure A-30. Annual WUA for adult whitefish in the Canyon Reach during the three representative years.
Figure A-31. Annual WUA for juvenile bull trout in the Upper Reservoir Reach during the three representative years.
Figure A-32. Annual WUA for adult bull trout in the Upper Reservoir Reach during the three representative years.

Figure A-33. Annual WUA for fry cutthroat trout in the Upper Reservoir Reach during the three representative years.
Figure A-34. Annual WUA for juvenile cutthroat trout in the Upper Reservoir Reach during the three representative years.
Figure A-35. Annual WUA for adult cutthroat trout in the Upper Reservoir Reach during the three representative years.
Figure A-36. Annual WUA for fry and juvenile cyprinids in the Upper Reservoir Reach during the three representative years.
Figure A-37. Annual WUA for fry redband trout in the Upper Reservoir Reach during the three representative years.
Figure A-38. Annual WUA for juvenile redband trout in the Upper Reservoir Reach during the three representative years.
Figure A-39. Annual WUA for adult redband trout in the Upper Reservoir Reach during the three representative years.
Figure A-40. Annual WUA for fry smallmouth bass in the Upper Reservoir Reach during the three representative years.
Figure A-41. Annual WUA for juvenile smallmouth bass in the Upper Reservoir Reach during the three representative years.
Figure A-42. Annual WUA for adult smallmouth bass in the Upper Reservoir Reach during the three representative years.
Figure A-43. Annual WUA for fry whitefish in the Upper Reservoir Reach during the three representative years.
Figure A-44. Annual WUA for juvenile whitefish in the Upper Reservoir Reach during the three representative years.
Figure A-45. Annual WUA for adult whitefish in the Upper Reservoir Reach during the three representative years.
Figure A-46. Annual WUA for juvenile bull trout in the Tailrace Reach during the three representative years.
Figure A-47. Annual WUA for adult bull trout in the Tailrace Reach during the three representative years.
Figure A-48. Annual WUA for fry cutthroat trout in the Tailrace Reach during the three representative years.
Figure A-49. Annual WUA for juvenile cutthroat trout in the Tailrace Reach during the three representative years.
Figure A-50. Annual WUA for adult cutthroat trout in the Tailrace Reach during the three representative years.
Figure A-51. Annual WUA for fry and juvenile cyprinids in the Tailrace Reach during the three representative years.
Figure A-52. Annual WUA for fry redband trout in the Tailrace Reach during the three representative years.
Figure A-53. Annual WUA for juvenile redband trout in the Tailrace Reach during the three representative years.
Figure A-54. Annual WUA for adult redband trout in the Tailrace Reach during the three representative years.
Figure A-55. Annual WUA for fry smallmouth bass in the Tailrace Reach during the three representative years.

Figure A-56. Annual WUA for juvenile smallmouth bass in the Tailrace Reach during the three representative years.
Figure A-57. Annual WUA for adult smallmouth bass in the Tailrace Reach during the three representative years.
Figure A-58. Annual WUA for fry whitefish in the Tailrace Reach during the three representative years.
Figure A-59. Annual WUA for juvenile whitefish in the Tailrace Reach during the three representative years.
Figure A-60. Annual WUA for adult whitefish in the Tailrace Reach during the three representative years.

**Table A-1.** Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the wet year (1997).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 31 | 325 | 17 | 27 | 838 | 63 | 17 | 27 | 838 | 13 | 52 | 246 | -- | 23 | 155 |
| | **Max.** | 38 | 336 | 20 | 31 | 851 | 75 | 20 | 31 | 851 | 19 | 63 | 258 | -- | 28 | 161 |
| | **Min.** | 14 | 308 | 11 | 13 | 811 | 52 | 11 | 13 | 811 | 10 | 35 | 215 | -- | 10 | 140 |
| **February** | **Mean** | 30 | 324 | 17 | 26 | 836 | 63 | 16 | 26 | 836 | 13 | 52 | 246 | -- | 23 | 154 |
| | **Max.** | 38 | 335 | 20 | 31 | 849 | 69 | 20 | 31 | 849 | 19 | 61 | 257 | -- | 28 | 160 |
| | **Min.** | 15 | 308 | 12 | 14 | 813 | 54 | 11 | 14 | 813 | 10 | 37 | 226 | -- | 11 | 140 |
| **March** | **Mean** | 30 | 324 | 17 | 26 | 835 | 60 | 16 | 26 | 835 | 12 | 49 | 239 | -- | 22 | 154 |
| | **Max.** | 38 | 335 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 20 | 61 | 256 | -- | 28 | 160 |
| | **Min.** | 6 | 300 | 5 | 5 | 798 | 35 | 5 | 5 | 798 | 8 | 28 | 219 | -- | 4 | 135 |
| **April** | **Mean** | 36 | 373 | 5 | 22 | 741 | 15 | 5 | 22 | 781 | 19 | 69 | 182 | 9 | 6 | 36 |
| | **Max.** | 38 | 389 | 7 | 26 | 831 | 25 | 7 | 24 | 830 | 33 | 78 | 195 | 11 | 7 | 45 |
| | **Min.** | 24 | 336 | 2 | 14 | 609 | 11 | 2 | 14 | 720 | 14 | 57 | 153 | 3 | 2 | 26 |
| **May** | **Mean** | 37 | 386 | -- | 24 | 817 | 15 | -- | 23 | 819 | 17 | 64 | 193 | 10 | 6 | 43 |
| | **Max.** | 38 | 392 | -- | 26 | 839 | 16 | -- | 25 | 837 | 19 | 66 | 197 | 11 | 7 | 47 |
| | **Min.** | 35 | 383 | -- | 22 | 799 | 12 | -- | 21 | 807 | 14 | 63 | 190 | 7 | 5 | 40 |
| **June** | **Mean** | 36 | 378 | 4 | 22 | 788 | 14 | 4 | 22 | 801 | 18 | 70 | 187 | 8 | 6 | 39 |
| | **Max.** | 39 | 385 | 7 | 24 | 828 | 21 | 7 | 25 | 829 | 30 | 77 | 195 | 10 | 7 | 45 |
| | **Min.** | 34 | 363 | 2 | 20 | 739 | 11 | 2 | 20 | 776 | 14 | 64 | 177 | 6 | 5 | 35 |
| **July** | **Mean** | 35 | 366 | 4 | 21 | 706 | 14 | 4 | 21 | 768 | 19 | 71 | 178 | 8 | 5 | 33 |
| | **Max.** | 39 | 386 | 7 | 25 | 812 | 21 | 7 | 25 | 815 | 31 | 78 | 192 | 11 | 7 | 42 |
| | **Min.** | 32 | 330 | 2 | 16 | 515 | 10 | 2 | 16 | 710 | 14 | 65 | 162 | 6 | 4 | 25 |
| **August** | **Mean** | 34 | 350 | 4 | 19 | 611 | 14 | 4 | 19 | 737 | 20 | 71 | 169 | 8 | 5 | 29 |
| | **Max.** | 37 | 372 | 7 | 22 | 709 | 19 | 7 | 23 | 769 | 30 | 78 | 179 | 10 | 6 | 34 |
| | **Min.** | 31 | 312 | 2 | 15 | 466 | 10 | 2 | 15 | 689 | 15 | 67 | 154 | 6 | 4 | 22 |
| **September** | **Mean** | 34 | 350 | 4 | 19 | 611 | 14 | 4 | 19 | 737 | 19 | 72 | 169 | 8 | 5 | 29 |
| | **Max.** | 37 | 367 | 7 | 22 | 695 | 19 | 7 | 22 | 762 | 30 | 78 | 177 | 10 | 6 | 32 |
| | **Min.** | 31 | 318 | 2 | 15 | 467 | 10 | 2 | 14 | 696 | 15 | 67 | 156 | 6 | 4 | 23 |
| **October** | **Mean** | 34 | 348 | 4 | 19 | 626 | 16 | 4 | 19 | 736 | 22 | 71 | 167 | -- | 5 | 29 |
| | **Max.** | 38 | 374 | 7 | 23 | 725 | 26 | 7 | 23 | 777 | 37 | 80 | 181 | -- | 6 | 35 |
| | **Min.** | 17 | 304 | 2 | 10 | 469 | 9 | 2 | 10 | 676 | 13 | 43 | 139 | -- | 2 | 20 |
| **November** | **Mean** | 28 | 321 | 17 | 24 | 833 | 62 | 16 | 24 | 833 | 14 | 50 | 242 | -- | 21 | 152 |
| | **Max.** | 38 | 335 | 20 | 31 | 850 | 71 | 20 | 31 | 850 | 20 | 63 | 257 | -- | 28 | 161 |
| | **Min.** | 10 | 304 | 8 | 9 | 804 | 42 | 7 | 9 | 804 | 10 | 29 | 220 | -- | 7 | 135 |
| **December** | **Mean** | 30 | 323 | 17 | 26 | 836 | 64 | 17 | 26 | 836 | 14 | 52 | 245 | -- | 22 | 153 |
| | **Max.** | 38 | 336 | 20 | 31 | 851 | 76 | 20 | 31 | 851 | 19 | 63 | 258 | -- | 28 | 161 |
| | **Min.** | 10 | 304 | 8 | 9 | 804 | 42 | 7 | 9 | 804 | 11 | 30 | 225 | -- | 7 | 135 |

**Table A-2.** Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the dry year (2001).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 30 | 324 | 17 | 26 | 836 | 66 | 17 | 26 | 836 | 15 | 54 | 248 | -- | 22 | 154 |
| | **Max.** | 38 | 334 | 20 | 31 | 848 | 71 | 20 | 31 | 848 | 20 | 63 | 257 | -- | 28 | 159 |
| | **Min.** | 10 | 303 | 7 | 9 | 803 | 41 | 7 | 9 | 803 | 10 | 31 | 232 | -- | 7 | 135 |
| **February** | **Mean** | 33 | 328 | 18 | 28 | 842 | 67 | 17 | 28 | 842 | 14 | 58 | 253 | -- | 25 | 156 |
| | **Max.** | 38 | 334 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 17 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 28 | 319 | 16 | 25 | 831 | 61 | 15 | 25 | 831 | 11 | 51 | 244 | -- | 22 | 152 |
| **March** | **Mean** | 32 | 327 | 18 | 27 | 840 | 67 | 17 | 27 | 840 | 14 | 57 | 251 | -- | 24 | 155 |
| | **Max.** | 38 | 335 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 19 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 18 | 310 | 14 | 16 | 818 | 60 | 14 | 16 | 818 | 11 | 42 | 235 | -- | 13 | 144 |
| **April** | **Mean** | 33 | 339 | 4 | 18 | 551 | 13 | 4 | 17 | 722 | 19 | 70 | 165 | 8 | 4 | 26 |
| | **Max.** | 37 | 369 | 7 | 22 | 730 | 19 | 7 | 23 | 770 | 31 | 78 | 179 | 10 | 6 | 34 |
| | **Min.** | 31 | 310 | 2 | 15 | 460 | 10 | 2 | 14 | 686 | 15 | 67 | 152 | 6 | 4 | 21 |
| **May** | **Mean** | 30 | 342 | -- | 17 | 632 | 15 | -- | 17 | 729 | 21 | 65 | 162 | 6 | 4 | 28 |
| | **Max.** | 38 | 374 | -- | 23 | 756 | 25 | -- | 24 | 783 | 34 | 78 | 183 | 10 | 6 | 36 |
| | **Min.** | 15 | 297 | -- | 8 | 465 | 8 | -- | 7 | 660 | 11 | 42 | 136 | 1 | 2 | 20 |
| **June** | **Mean** | 33 | 344 | 4 | 18 | 620 | 16 | 4 | 18 | 732 | 23 | 70 | 165 | 7 | 4 | 28 |
| | **Max.** | 38 | 370 | 7 | 22 | 724 | 25 | 7 | 23 | 771 | 34 | 78 | 179 | 10 | 6 | 34 |
| | **Min.** | 18 | 309 | 2 | 10 | 465 | 9 | 2 | 10 | 682 | 15 | 44 | 141 | 3 | 2 | 21 |
| **July** | **Mean** | 33 | 339 | 4 | 18 | 558 | 14 | 4 | 18 | 722 | 20 | 71 | 164 | 8 | 4 | 26 |
| | **Max.** | 37 | 369 | 7 | 22 | 713 | 24 | 7 | 23 | 769 | 33 | 78 | 179 | 10 | 6 | 33 |
| | **Min.** | 19 | 305 | 2 | 11 | 463 | 10 | 2 | 11 | 679 | 15 | 47 | 140 | 3 | 2 | 21 |
| **August** | **Mean** | 33 | 333 | 3 | 17 | 523 | 13 | 3 | 17 | 714 | 18 | 71 | 162 | 8 | 4 | 25 |
| | **Max.** | 36 | 352 | 7 | 20 | 602 | 19 | 7 | 20 | 737 | 28 | 78 | 170 | 10 | 5 | 29 |
| | **Min.** | 31 | 312 | 2 | 15 | 461 | 10 | 2 | 14 | 689 | 15 | 67 | 154 | 6 | 4 | 22 |
| **September** | **Mean** | 32 | 328 | 4 | 16 | 524 | 14 | 4 | 17 | 708 | 21 | 71 | 159 | 7 | 4 | 25 |
| | **Max.** | 37 | 356 | 7 | 21 | 641 | 24 | 7 | 21 | 742 | 34 | 78 | 171 | 10 | 5 | 30 |
| | **Min.** | 16 | 295 | 2 | 9 | 447 | 9 | 2 | 9 | 662 | 13 | 44 | 135 | 2 | 2 | 19 |
| **October** | **Mean** | 34 | 346 | 4 | 18 | 595 | 14 | 4 | 18 | 732 | 19 | 70 | 167 | -- | 5 | 28 |
| | **Max.** | 37 | 367 | 7 | 22 | 701 | 24 | 7 | 22 | 764 | 34 | 78 | 178 | -- | 6 | 33 |
| | **Min.** | 16 | 305 | 2 | 9 | 465 | 9 | 2 | 9 | 675 | 12 | 43 | 139 | -- | 2 | 20 |
| **November** | **Mean** | 30 | 324 | 17 | 26 | 836 | 65 | 17 | 26 | 836 | 14 | 54 | 248 | -- | 22 | 154 |
| | **Max.** | 38 | 335 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 21 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 9 | 303 | 7 | 9 | 803 | 41 | 7 | 9 | 803 | 10 | 30 | 227 | -- | 7 | 135 |
| **December** | **Mean** | 31 | 325 | 18 | 27 | 838 | 66 | 17 | 27 | 838 | 14 | 55 | 250 | -- | 23 | 155 |
| | **Max.** | 38 | 335 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 20 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 8 | 301 | 7 | 8 | 801 | 37 | 6 | 8 | 801 | 9 | 28 | 228 | -- | 6 | 135 |

**Table A-3.** Mean, maximum, and minimum monthly WUA for selected fish species in the Forebay Reach during the average year (2002).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 28 | 322 | 17 | 24 | 833 | 64 | 16 | 24 | 833 | 14 | 52 | 245 | -- | 21 | 152 |
| | **Max.** | 38 | 335 | 20 | 31 | 850 | 71 | 20 | 31 | 850 | 20 | 63 | 257 | -- | 28 | 161 |
| | **Min.** | 8 | 300 | 6 | 7 | 800 | 34 | 6 | 7 | 800 | 8 | 27 | 219 | -- | 5 | 135 |
| **February** | **Mean** | 28 | 321 | 17 | 24 | 832 | 64 | 16 | 24 | 832 | 15 | 51 | 245 | -- | 21 | 152 |
| | **Max.** | 37 | 333 | 20 | 31 | 848 | 71 | 19 | 31 | 848 | 20 | 63 | 256 | -- | 28 | 159 |
| | **Min.** | 6 | 299 | 3 | 5 | 797 | 37 | 3 | 5 | 797 | 7 | 29 | 228 | -- | 4 | 135 |
| **March** | **Mean** | 26 | 319 | 16 | 22 | 829 | 62 | 15 | 22 | 829 | 15 | 49 | 243 | -- | 19 | 150 |
| | **Max.** | 38 | 334 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 20 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 5 | 299 | 3 | 5 | 797 | 35 | 3 | 5 | 797 | 6 | 28 | 225 | -- | 4 | 135 |
| **April** | **Mean** | 33 | 351 | 4 | 19 | 650 | 15 | 4 | 19 | 743 | 22 | 70 | 169 | 8 | 5 | 30 |
| | **Max.** | 38 | 385 | 7 | 24 | 778 | 25 | 7 | 24 | 799 | 34 | 78 | 188 | 11 | 6 | 39 |
| | **Min.** | 15 | 311 | 1 | 9 | 463 | 8 | 1 | 9 | 687 | 11 | 42 | 142 | 1 | 2 | 21 |
| **May** | **Mean** | 34 | 366 | -- | 21 | 725 | 15 | -- | 21 | 774 | 20 | 68 | 178 | 8 | 5 | 35 |
| | **Max.** | 38 | 390 | -- | 26 | 836 | 25 | -- | 25 | 834 | 34 | 78 | 196 | 11 | 7 | 46 |
| | **Min.** | 16 | 307 | -- | 9 | 469 | 8 | -- | 9 | 680 | 11 | 42 | 141 | 1 | 2 | 21 |
| **June** | **Mean** | 37 | 383 | 3 | 23 | 816 | 14 | 3 | 23 | 818 | 17 | 68 | 192 | 8 | 6 | 43 |
| | **Max.** | 38 | 386 | 6 | 24 | 830 | 18 | 6 | 25 | 831 | 21 | 73 | 195 | 10 | 7 | 46 |
| | **Min.** | 35 | 379 | 2 | 22 | 799 | 12 | 2 | 21 | 806 | 14 | 64 | 189 | 7 | 5 | 40 |
| **July** | **Mean** | 35 | 362 | 4 | 20 | 692 | 15 | 4 | 21 | 762 | 20 | 72 | 176 | 8 | 5 | 33 |
| | **Max.** | 39 | 385 | 7 | 25 | 826 | 23 | 7 | 26 | 826 | 33 | 78 | 194 | 11 | 7 | 45 |
| | **Min.** | 31 | 319 | 2 | 15 | 467 | 10 | 2 | 14 | 697 | 14 | 66 | 154 | 5 | 3 | 23 |
| **August** | **Mean** | 34 | 343 | 4 | 18 | 570 | 13 | 4 | 18 | 727 | 19 | 71 | 166 | 8 | 5 | 27 |
| | **Max.** | 37 | 362 | 7 | 21 | 673 | 19 | 7 | 22 | 755 | 30 | 78 | 175 | 10 | 6 | 31 |
| | **Min.** | 31 | 318 | 2 | 15 | 465 | 10 | 2 | 14 | 696 | 15 | 67 | 157 | 6 | 4 | 23 |
| **September** | **Mean** | 34 | 341 | 4 | 18 | 556 | 13 | 4 | 17 | 724 | 18 | 70 | 165 | 8 | 4 | 27 |
| | **Max.** | 37 | 359 | 7 | 21 | 659 | 19 | 7 | 21 | 750 | 29 | 78 | 174 | 10 | 5 | 31 |
| | **Min.** | 31 | 316 | 2 | 15 | 464 | 10 | 2 | 14 | 693 | 15 | 67 | 155 | 6 | 4 | 22 |
| **October** | **Mean** | 34 | 345 | 4 | 18 | 584 | 13 | 4 | 18 | 730 | 19 | 71 | 167 | -- | 5 | 28 |
| | **Max.** | 37 | 365 | 7 | 22 | 674 | 19 | 7 | 22 | 758 | 31 | 78 | 176 | -- | 6 | 32 |
| | **Min.** | 31 | 315 | 2 | 15 | 467 | 10 | 2 | 14 | 693 | 15 | 67 | 155 | -- | 4 | 22 |
| **November** | **Mean** | 31 | 325 | 17 | 27 | 838 | 65 | 17 | 27 | 838 | 14 | 54 | 249 | -- | 23 | 155 |
| | **Max.** | 38 | 334 | 20 | 31 | 849 | 71 | 20 | 31 | 849 | 20 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 12 | 306 | 10 | 11 | 809 | 53 | 10 | 11 | 809 | 11 | 36 | 230 | -- | 8 | 137 |
| **December** | **Mean** | 29 | 323 | 17 | 25 | 835 | 64 | 16 | 25 | 835 | 14 | 52 | 246 | -- | 22 | 153 |
| | **Max.** | 38 | 334 | 20 | 31 | 848 | 71 | 20 | 31 | 848 | 20 | 63 | 257 | -- | 28 | 160 |
| | **Min.** | 6 | 300 | 5 | 6 | 798 | 37 | 5 | 6 | 798 | 8 | 29 | 228 | -- | 4 | 135 |

**Table A-4.** Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the wet year (1997).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 34 | 160 | 17 | 27 | 229 | 37 | 16 | 27 | 227 | 8 | 34 | 181 | -- | 26 | 144 |
| | **Max.** | 41 | 170 | 22 | 34 | 312 | 52 | 22 | 34 | 312 | 12 | 54 | 279 | -- | 31 | 150 |
| | **Min.** | 24 | 126 | 11 | 18 | 140 | 23 | 11 | 18 | 128 | 6 | 19 | 98 | -- | 18 | 127 |
| **February** | **Mean** | 34 | 163 | 16 | 27 | 233 | 36 | 16 | 27 | 231 | 8 | 34 | 184 | -- | 26 | 145 |
| | **Max.** | 40 | 169 | 21 | 33 | 305 | 48 | 20 | 33 | 305 | 11 | 48 | 260 | -- | 31 | 149 |
| | **Min.** | 26 | 145 | 12 | 19 | 168 | 25 | 11 | 19 | 161 | 6 | 22 | 127 | -- | 19 | 139 |
| **March** | **Mean** | 32 | 148 | 15 | 25 | 193 | 33 | 15 | 25 | 188 | 7 | 29 | 147 | -- | 25 | 139 |
| | **Max.** | 40 | 176 | 21 | 32 | 306 | 50 | 20 | 32 | 306 | 12 | 50 | 269 | -- | 30 | 156 |
| | **Min.** | 24 | 118 | 9 | 17 | 139 | 18 | 8 | 17 | 126 | 4 | 17 | 95 | -- | 18 | 123 |
| **April** | **Mean** | 32 | 185 | 6 | 21 | 292 | 13 | 6 | 22 | 300 | 14 | 48 | 148 | 10 | 8 | 79 |
| | **Max.** | 35 | 193 | 9 | 23 | 319 | 14 | 9 | 24 | 323 | 18 | 54 | 159 | 11 | 11 | 93 |
| | **Min.** | 25 | 168 | 4 | 16 | 243 | 11 | 4 | 17 | 260 | 10 | 39 | 132 | 6 | 5 | 63 |
| **May** | **Mean** | 33 | 173 | -- | 23 | 254 | 14 | -- | 24 | 271 | 14 | 44 | 136 | 11 | 10 | 85 |
| | **Max.** | 34 | 178 | -- | 23 | 266 | 14 | -- | 24 | 281 | 14 | 45 | 141 | 11 | 11 | 86 |
| | **Min.** | 32 | 164 | -- | 21 | 236 | 12 | -- | 22 | 254 | 12 | 41 | 129 | 9 | 10 | 84 |
| **June** | **Mean** | 31 | 175 | 5 | 21 | 259 | 12 | 5 | 22 | 273 | 12 | 44 | 135 | 9 | 9 | 86 |
| | **Max.** | 33 | 185 | 8 | 23 | 296 | 14 | 8 | 23 | 304 | 15 | 49 | 150 | 10 | 10 | 93 |
| | **Min.** | 28 | 157 | 4 | 18 | 222 | 11 | 4 | 20 | 240 | 10 | 39 | 119 | 8 | 6 | 80 |
| **July** | **Mean** | 31 | 187 | 5 | 21 | 297 | 12 | 5 | 21 | 304 | 13 | 49 | 149 | 10 | 8 | 75 |
| | **Max.** | 34 | 192 | 8 | 23 | 319 | 14 | 8 | 24 | 323 | 18 | 58 | 159 | 11 | 10 | 93 |
| | **Min.** | 28 | 173 | 4 | 17 | 237 | 10 | 4 | 18 | 255 | 10 | 41 | 124 | 7 | 5 | 47 |
| **August** | **Mean** | 31 | 188 | 6 | 19 | 301 | 12 | 6 | 20 | 308 | 14 | 54 | 149 | 10 | 6 | 58 |
| | **Max.** | 34 | 192 | 8 | 23 | 320 | 14 | 8 | 23 | 323 | 19 | 60 | 159 | 11 | 8 | 77 |
| | **Min.** | 27 | 166 | 3 | 14 | 206 | 9 | 3 | 15 | 268 | 11 | 47 | 127 | 8 | 4 | 31 |
| **September** | **Mean** | 31 | 188 | 5 | 19 | 301 | 12 | 5 | 20 | 308 | 14 | 54 | 149 | 10 | 6 | 58 |
| | **Max.** | 34 | 193 | 8 | 22 | 317 | 14 | 8 | 22 | 321 | 19 | 60 | 157 | 11 | 8 | 73 |
| | **Min.** | 27 | 174 | 3 | 15 | 239 | 9 | 3 | 15 | 276 | 11 | 48 | 133 | 8 | 4 | 34 |
| **October** | **Mean** | 30 | 189 | 5 | 19 | 301 | 12 | 5 | 19 | 307 | 14 | 51 | 148 | -- | 6 | 66 |
| | **Max.** | 34 | 203 | 8 | 23 | 320 | 14 | 8 | 23 | 324 | 19 | 60 | 159 | -- | 8 | 91 |
| | **Min.** | 22 | 176 | 4 | 14 | 250 | 7 | 4 | 14 | 283 | 9 | 34 | 137 | -- | 4 | 36 |
| **November** | **Mean** | 33 | 161 | 16 | 26 | 222 | 35 | 15 | 26 | 219 | 8 | 32 | 176 | -- | 25 | 145 |
| | **Max.** | 40 | 174 | 22 | 34 | 312 | 52 | 21 | 34 | 312 | 12 | 54 | 278 | -- | 31 | 150 |
| | **Min.** | 25 | 145 | 10 | 18 | 157 | 21 | 9 | 18 | 150 | 5 | 19 | 119 | -- | 18 | 139 |
| **December** | **Mean** | 34 | 164 | 17 | 27 | 243 | 38 | 16 | 27 | 241 | 9 | 36 | 198 | -- | 25 | 146 |
| | **Max.** | 41 | 175 | 22 | 34 | 313 | 53 | 22 | 34 | 313 | 13 | 56 | 281 | -- | 31 | 150 |
| | **Min.** | 26 | 152 | 10 | 19 | 172 | 23 | 10 | 19 | 166 | 6 | 21 | 133 | -- | 19 | 142 |

**Table A-5.** Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the dry year (2001).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 34 | 169 | 18 | 28 | 285 | 42 | 17 | 28 | 285 | 10 | 41 | 241 | -- | 26 | 147 |
| | **Max.** | 40 | 180 | 23 | 34 | 314 | 54 | 22 | 34 | 314 | 13 | 58 | 283 | -- | 30 | 153 |
| | **Min.** | 27 | 164 | 11 | 21 | 213 | 24 | 10 | 21 | 211 | 6 | 24 | 169 | -- | 19 | 145 |
| **February** | **Mean** | 36 | 169 | 19 | 31 | 304 | 47 | 19 | 31 | 304 | 11 | 48 | 266 | -- | 27 | 148 |
| | **Max.** | 40 | 172 | 23 | 34 | 314 | 55 | 22 | 34 | 314 | 13 | 59 | 284 | -- | 30 | 149 |
| | **Min.** | 32 | 166 | 16 | 27 | 241 | 35 | 15 | 27 | 240 | 7 | 34 | 193 | -- | 24 | 146 |
| **March** | **Mean** | 35 | 170 | 19 | 30 | 302 | 46 | 18 | 30 | 302 | 11 | 47 | 263 | -- | 27 | 148 |
| | **Max.** | 40 | 174 | 23 | 34 | 314 | 54 | 22 | 34 | 314 | 13 | 58 | 284 | -- | 31 | 149 |
| | **Min.** | 28 | 167 | 14 | 23 | 239 | 31 | 14 | 23 | 238 | 8 | 29 | 192 | -- | 20 | 146 |
| **April** | **Mean** | 30 | 182 | 5 | 18 | 277 | 12 | 5 | 18 | 295 | 15 | 56 | 141 | 9 | 5 | 44 |
| | **Max.** | 34 | 193 | 8 | 22 | 317 | 14 | 8 | 22 | 320 | 18 | 60 | 156 | 11 | 8 | 75 |
| | **Min.** | 26 | 161 | 3 | 14 | 188 | 9 | 3 | 14 | 261 | 11 | 47 | 125 | 7 | 3 | 28 |
| **May** | **Mean** | 28 | 193 | -- | 18 | 296 | 11 | -- | 18 | 302 | 13 | 46 | 147 | 8 | 6 | 76 |
| | **Max.** | 34 | 214 | -- | 23 | 319 | 14 | -- | 23 | 322 | 18 | 60 | 158 | 11 | 8 | 135 |
| | **Min.** | 20 | 172 | -- | 13 | 228 | 6 | -- | 13 | 271 | 6 | 29 | 131 | 5 | 4 | 33 |
| **June** | **Mean** | 29 | 190 | 5 | 18 | 298 | 11 | 5 | 19 | 305 | 14 | 50 | 147 | 9 | 6 | 66 |
| | **Max.** | 34 | 201 | 8 | 22 | 318 | 14 | 8 | 22 | 321 | 18 | 59 | 157 | 11 | 8 | 93 |
| | **Min.** | 22 | 174 | 4 | 14 | 244 | 7 | 4 | 15 | 279 | 10 | 34 | 135 | 6 | 4 | 36 |
| **July** | **Mean** | 30 | 183 | 5 | 17 | 278 | 12 | 5 | 18 | 295 | 14 | 55 | 141 | 9 | 5 | 47 |
| | **Max.** | 34 | 201 | 8 | 22 | 315 | 14 | 8 | 22 | 319 | 18 | 60 | 155 | 11 | 7 | 79 |
| | **Min.** | 22 | 162 | 3 | 13 | 191 | 8 | 3 | 14 | 261 | 10 | 37 | 124 | 6 | 4 | 28 |
| **August** | **Mean** | 29 | 179 | 5 | 16 | 259 | 11 | 5 | 16 | 285 | 14 | 57 | 136 | 9 | 5 | 38 |
| | **Max.** | 33 | 190 | 8 | 20 | 304 | 13 | 8 | 20 | 309 | 18 | 60 | 148 | 11 | 6 | 50 |
| | **Min.** | 26 | 160 | 3 | 13 | 182 | 9 | 3 | 13 | 257 | 11 | 54 | 122 | 8 | 3 | 27 |
| **September** | **Mean** | 28 | 182 | 5 | 16 | 263 | 11 | 5 | 16 | 285 | 14 | 55 | 135 | 8 | 4 | 41 |
| | **Max.** | 33 | 204 | 8 | 21 | 308 | 13 | 8 | 21 | 313 | 18 | 60 | 150 | 11 | 6 | 66 |
| | **Min.** | 21 | 161 | 3 | 12 | 183 | 7 | 3 | 12 | 257 | 10 | 40 | 122 | 6 | 3 | 28 |
| **October** | **Mean** | 30 | 187 | 5 | 19 | 295 | 12 | 5 | 19 | 305 | 14 | 54 | 147 | -- | 6 | 55 |
| | **Max.** | 34 | 205 | 8 | 22 | 317 | 14 | 8 | 22 | 321 | 19 | 60 | 157 | -- | 8 | 84 |
| | **Min.** | 21 | 169 | 3 | 14 | 218 | 7 | 3 | 14 | 270 | 10 | 36 | 130 | -- | 4 | 31 |
| **November** | **Mean** | 34 | 167 | 17 | 28 | 270 | 41 | 17 | 28 | 269 | 9 | 39 | 225 | -- | 26 | 147 |
| | **Max.** | 40 | 185 | 23 | 34 | 314 | 54 | 22 | 34 | 314 | 13 | 57 | 283 | -- | 31 | 155 |
| | **Min.** | 26 | 157 | 10 | 19 | 179 | 22 | 10 | 19 | 175 | 6 | 20 | 140 | -- | 19 | 143 |
| **December** | **Mean** | 35 | 169 | 18 | 29 | 288 | 43 | 18 | 29 | 287 | 10 | 42 | 242 | -- | 26 | 147 |
| | **Max.** | 40 | 182 | 23 | 34 | 314 | 54 | 22 | 34 | 314 | 13 | 59 | 283 | -- | 31 | 155 |
| | **Min.** | 27 | 163 | 9 | 20 | 198 | 20 | 9 | 20 | 196 | 5 | 22 | 159 | -- | 19 | 145 |

**Table A-6.** Mean, maximum, and minimum monthly WUA for selected fish species in the Canyon Reach during the average year (2002).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 33 | 167 | 17 | 27 | 258 | 39 | 16 | 27 | 257 | 9 | 37 | 213 | -- | 25 | 146 |
| | **Max.** | 41 | 177 | 23 | 34 | 314 | 54 | 22 | 34 | 314 | 13 | 57 | 283 | -- | 31 | 151 |
| | **Min.** | 25 | 148 | 8 | 18 | 161 | 17 | 8 | 18 | 154 | 4 | 18 | 123 | -- | 19 | 140 |
| **February** | **Mean** | 33 | 168 | 16 | 27 | 259 | 38 | 16 | 27 | 258 | 9 | 36 | 214 | -- | 25 | 147 |
| | **Max.** | 40 | 188 | 22 | 33 | 312 | 53 | 21 | 33 | 312 | 12 | 55 | 280 | -- | 30 | 160 |
| | **Min.** | 27 | 158 | 9 | 20 | 189 | 21 | 9 | 20 | 186 | 5 | 23 | 150 | -- | 19 | 144 |
| **March** | **Mean** | 32 | 168 | 16 | 26 | 250 | 36 | 15 | 26 | 248 | 9 | 34 | 204 | -- | 24 | 147 |
| | **Max.** | 40 | 188 | 22 | 34 | 312 | 53 | 21 | 34 | 312 | 13 | 55 | 283 | -- | 31 | 161 |
| | **Min.** | 26 | 148 | 9 | 18 | 168 | 19 | 8 | 18 | 161 | 4 | 19 | 128 | -- | 19 | 140 |
| **April** | **Mean** | 29 | 189 | 5 | 19 | 295 | 12 | 5 | 19 | 302 | 14 | 49 | 146 | 9 | 6 | 70 |
| | **Max.** | 34 | 205 | 9 | 23 | 318 | 14 | 9 | 24 | 322 | 18 | 60 | 159 | 11 | 10 | 105 |
| | **Min.** | 21 | 170 | 3 | 14 | 224 | 7 | 3 | 14 | 271 | 9 | 30 | 130 | 6 | 4 | 32 |
| **May** | **Mean** | 31 | 184 | -- | 20 | 284 | 12 | -- | 21 | 293 | 13 | 46 | 144 | 9 | 8 | 80 |
| | **Max.** | 34 | 203 | -- | 23 | 319 | 14 | -- | 24 | 323 | 19 | 59 | 159 | 11 | 11 | 109 |
| | **Min.** | 21 | 159 | -- | 14 | 224 | 7 | -- | 14 | 242 | 7 | 29 | 120 | 6 | 4 | 40 |
| **June** | **Mean** | 31 | 167 | 5 | 21 | 239 | 12 | 5 | 22 | 256 | 11 | 42 | 128 | 9 | 10 | 86 |
| | **Max.** | 33 | 173 | 8 | 23 | 252 | 14 | 8 | 23 | 268 | 13 | 44 | 133 | 10 | 10 | 88 |
| | **Min.** | 30 | 157 | 4 | 20 | 220 | 11 | 4 | 22 | 238 | 10 | 39 | 118 | 9 | 9 | 84 |
| **July** | **Mean** | 31 | 185 | 5 | 20 | 292 | 12 | 5 | 21 | 300 | 13 | 49 | 146 | 9 | 7 | 73 |
| | **Max.** | 34 | 195 | 8 | 23 | 318 | 14 | 8 | 23 | 322 | 17 | 59 | 159 | 11 | 10 | 89 |
| | **Min.** | 27 | 159 | 3 | 15 | 221 | 9 | 3 | 15 | 240 | 10 | 40 | 117 | 7 | 4 | 34 |
| **August** | **Mean** | 31 | 185 | 5 | 18 | 286 | 12 | 5 | 18 | 300 | 15 | 56 | 144 | 9 | 5 | 48 |
| | **Max.** | 34 | 193 | 8 | 22 | 315 | 14 | 8 | 22 | 318 | 18 | 60 | 155 | 11 | 7 | 67 |
| | **Min.** | 27 | 165 | 3 | 14 | 203 | 9 | 3 | 14 | 265 | 11 | 48 | 127 | 8 | 4 | 30 |
| **September** | **Mean** | 30 | 183 | 5 | 18 | 282 | 12 | 5 | 18 | 297 | 15 | 56 | 142 | 9 | 5 | 44 |
| | **Max.** | 33 | 192 | 8 | 21 | 312 | 14 | 8 | 21 | 315 | 18 | 60 | 153 | 11 | 7 | 61 |
| | **Min.** | 27 | 164 | 3 | 14 | 199 | 9 | 3 | 14 | 263 | 11 | 51 | 126 | 8 | 4 | 29 |
| **October** | **Mean** | 31 | 186 | 5 | 19 | 293 | 12 | 5 | 19 | 304 | 14 | 55 | 146 | -- | 6 | 51 |
| | **Max.** | 34 | 194 | 8 | 22 | 316 | 14 | 8 | 22 | 320 | 19 | 60 | 156 | -- | 7 | 69 |
| | **Min.** | 27 | 170 | 3 | 15 | 221 | 9 | 3 | 15 | 270 | 11 | 47 | 130 | -- | 4 | 31 |
| **November** | **Mean** | 35 | 168 | 18 | 28 | 273 | 41 | 17 | 28 | 272 | 9 | 40 | 226 | -- | 26 | 147 |
| | **Max.** | 40 | 175 | 22 | 34 | 312 | 52 | 22 | 34 | 312 | 12 | 54 | 280 | -- | 31 | 149 |
| | **Min.** | 27 | 162 | 11 | 20 | 200 | 25 | 11 | 20 | 197 | 7 | 23 | 159 | -- | 19 | 145 |
| **December** | **Mean** | 34 | 168 | 17 | 27 | 263 | 39 | 16 | 27 | 262 | 9 | 38 | 217 | -- | 25 | 147 |
| | **Max.** | 40 | 186 | 22 | 34 | 312 | 52 | 21 | 34 | 312 | 12 | 55 | 280 | -- | 30 | 158 |
| | **Min.** | 27 | 157 | 9 | 20 | 185 | 21 | 9 | 20 | 181 | 5 | 23 | 145 | -- | 19 | 143 |

**Table A-7.** Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the wet year (1997).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 127 | 203 | 41 | 81 | 168 | 114 | 39 | 81 | 143 | 22 | 81 | 156 | -- | 107 | 351 |
| | **Max.** | 163 | 331 | 65 | 115 | 271 | 169 | 62 | 115 | 258 | 35 | 121 | 292 | -- | 133 | 462 |
| | **Min.** | 92 | 129 | 25 | 59 | 116 | 84 | 24 | 59 | 93 | 10 | 62 | 75 | -- | 79 | 272 |
| **February** | **Mean** | 130 | 199 | 45 | 85 | 163 | 118 | 43 | 85 | 138 | 25 | 82 | 143 | -- | 109 | 345 |
| | **Max.** | 154 | 287 | 61 | 110 | 233 | 152 | 58 | 110 | 214 | 33 | 108 | 236 | -- | 127 | 430 |
| | **Min.** | 109 | 146 | 29 | 70 | 118 | 101 | 28 | 70 | 97 | 13 | 65 | 82 | -- | 95 | 281 |
| **March** | **Mean** | 108 | 166 | 37 | 70 | 146 | 98 | 35 | 70 | 123 | 18 | 70 | 140 | -- | 91 | 310 |
| | **Max.** | 145 | 242 | 58 | 104 | 214 | 144 | 56 | 104 | 194 | 32 | 101 | 203 | -- | 120 | 389 |
| | **Min.** | 77 | 131 | 24 | 51 | 106 | 68 | 23 | 51 | 86 | 8 | 54 | 68 | -- | 61 | 258 |
| **April** | **Mean** | 115 | 398 | 16 | 73 | 401 | 29 | 16 | 74 | 446 | 42 | 152 | 415 | 20 | 28 | 341 |
| | **Max.** | 172 | 466 | 23 | 109 | 459 | 59 | 23 | 117 | 509 | 73 | 223 | 479 | 38 | 51 | 379 |
| | **Min.** | 63 | 342 | 12 | 44 | 367 | 23 | 12 | 44 | 397 | 34 | 95 | 349 | 14 | 10 | 262 |
| **May** | **Mean** | 69 | 349 | -- | 47 | 370 | 27 | -- | 47 | 404 | 40 | 98 | 360 | 15 | 12 | 279 |
| | **Max.** | 72 | 355 | -- | 49 | 375 | 28 | -- | 48 | 409 | 41 | 100 | 366 | 15 | 13 | 286 |
| | **Min.** | 59 | 338 | -- | 41 | 365 | 23 | -- | 42 | 395 | 36 | 94 | 344 | 14 | 9 | 252 |
| **June** | **Mean** | 86 | 358 | 18 | 58 | 372 | 25 | 18 | 56 | 410 | 37 | 112 | 375 | 17 | 16 | 301 |
| | **Max.** | 107 | 397 | 23 | 71 | 398 | 29 | 23 | 68 | 444 | 41 | 139 | 412 | 19 | 22 | 345 |
| | **Min.** | 60 | 330 | 16 | 42 | 359 | 23 | 16 | 43 | 387 | 33 | 94 | 341 | 14 | 9 | 250 |
| **July** | **Mean** | 135 | 422 | 17 | 85 | 422 | 36 | 17 | 87 | 468 | 48 | 178 | 443 | 24 | 33 | 354 |
| | **Max.** | 187 | 528 | 29 | 118 | 546 | 71 | 29 | 126 | 587 | 86 | 265 | 563 | 42 | 50 | 390 |
| | **Min.** | 86 | 346 | 12 | 57 | 360 | 24 | 12 | 55 | 398 | 35 | 109 | 371 | 16 | 15 | 301 |
| **August** | **Mean** | 179 | 482 | 22 | 111 | 495 | 58 | 22 | 118 | 534 | 75 | 244 | 516 | 36 | 41 | 355 |
| | **Max.** | 221 | 539 | 61 | 134 | 617 | 96 | 61 | 149 | 641 | 142 | 299 | 610 | 56 | 57 | 390 |
| | **Min.** | 142 | 387 | 13 | 89 | 402 | 29 | 13 | 87 | 430 | 40 | 188 | 414 | 20 | 30 | 260 |
| **September** | **Mean** | 181 | 484 | 21 | 113 | 494 | 60 | 21 | 120 | 535 | 76 | 248 | 517 | 37 | 42 | 358 |
| | **Max.** | 200 | 537 | 45 | 122 | 582 | 84 | 45 | 140 | 615 | 124 | 284 | 588 | 50 | 52 | 387 |
| | **Min.** | 151 | 414 | 13 | 94 | 402 | 32 | 13 | 94 | 443 | 45 | 203 | 413 | 23 | 33 | 312 |
| **October** | **Mean** | 179 | 450 | 22 | 109 | 451 | 61 | 22 | 119 | 495 | 77 | 238 | 475 | -- | 43 | 359 |
| | **Max.** | 191 | 530 | 35 | 118 | 556 | 78 | 35 | 134 | 594 | 106 | 273 | 567 | -- | 51 | 391 |
| | **Min.** | 141 | 381 | 13 | 89 | 373 | 28 | 13 | 85 | 416 | 40 | 187 | 383 | -- | 29 | 327 |
| **November** | **Mean** | 125 | 191 | 44 | 81 | 157 | 114 | 42 | 81 | 133 | 25 | 79 | 137 | -- | 106 | 335 |
| | **Max.** | 156 | 306 | 62 | 110 | 262 | 161 | 60 | 110 | 247 | 37 | 113 | 276 | -- | 128 | 445 |
| | **Min.** | 106 | 140 | 28 | 69 | 113 | 98 | 27 | 69 | 92 | 12 | 62 | 74 | -- | 93 | 267 |
| **December** | **Mean** | 134 | 217 | 47 | 88 | 176 | 122 | 45 | 88 | 152 | 27 | 85 | 156 | -- | 113 | 359 |
| | **Max.** | 169 | 342 | 66 | 119 | 299 | 173 | 64 | 119 | 289 | 39 | 128 | 320 | -- | 136 | 468 |
| | **Min.** | 108 | 140 | 30 | 73 | 112 | 96 | 29 | 73 | 89 | 14 | 62 | 71 | -- | 94 | 258 |

**Table A-8.** Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the dry year (2001).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 161 | 286 | 60 | 109 | 231 | 149 | 57 | 109 | 216 | 34 | 106 | 216 | -- | 134 | 409 |
| | **Max.** | 193 | 386 | 71 | 134 | 375 | 200 | 69 | 134 | 373 | 49 | 154 | 399 | -- | 150 | 485 |
| | **Min.** | 105 | 152 | 40 | 71 | 118 | 93 | 39 | 71 | 96 | 22 | 62 | 78 | -- | 102 | 262 |
| **February** | **Mean** | 196 | 366 | 67 | 134 | 341 | 185 | 64 | 134 | 338 | 37 | 143 | 343 | -- | 147 | 460 |
| | **Max.** | 206 | 400 | 76 | 149 | 449 | 223 | 73 | 149 | 449 | 48 | 184 | 479 | -- | 163 | 486 |
| | **Min.** | 161 | 269 | 44 | 103 | 190 | 130 | 42 | 103 | 172 | 24 | 89 | 159 | -- | 137 | 400 |
| **March** | **Mean** | 191 | 350 | 67 | 129 | 314 | 177 | 64 | 129 | 309 | 38 | 134 | 310 | -- | 147 | 448 |
| | **Max.** | 209 | 400 | 78 | 148 | 440 | 221 | 75 | 148 | 440 | 54 | 178 | 465 | -- | 164 | 488 |
| | **Min.** | 142 | 215 | 45 | 94 | 159 | 124 | 43 | 94 | 138 | 24 | 85 | 117 | -- | 131 | 334 |
| **April** | **Mean** | 197 | 496 | 24 | 121 | 565 | 66 | 24 | 126 | 584 | 90 | 283 | 561 | 40 | 37 | 295 |
| | **Max.** | 221 | 539 | 61 | 135 | 626 | 97 | 61 | 150 | 648 | 142 | 304 | 615 | 55 | 58 | 388 |
| | **Min.** | 159 | 371 | 13 | 100 | 381 | 36 | 13 | 101 | 398 | 50 | 206 | 383 | 26 | 28 | 243 |
| **May** | **Mean** | 177 | 426 | -- | 108 | 431 | 62 | -- | 118 | 473 | 79 | 236 | 452 | 37 | 43 | 351 |
| | **Max.** | 201 | 539 | -- | 121 | 592 | 96 | -- | 140 | 623 | 138 | 286 | 594 | 52 | 52 | 391 |
| | **Min.** | 139 | 352 | -- | 86 | 337 | 28 | -- | 85 | 369 | 39 | 184 | 334 | 20 | 33 | 307 |
| **June** | **Mean** | 182 | 442 | 24 | 111 | 443 | 64 | 23 | 122 | 486 | 82 | 241 | 465 | 39 | 44 | 355 |
| | **Max.** | 193 | 528 | 50 | 118 | 549 | 87 | 45 | 136 | 589 | 125 | 275 | 567 | 49 | 52 | 391 |
| | **Min.** | 153 | 373 | 13 | 95 | 359 | 33 | 13 | 96 | 400 | 47 | 205 | 363 | 24 | 35 | 323 |
| **July** | **Mean** | 197 | 485 | 25 | 121 | 538 | 68 | 25 | 127 | 562 | 92 | 281 | 539 | 41 | 38 | 298 |
| | **Max.** | 227 | 538 | 60 | 139 | 625 | 97 | 60 | 152 | 648 | 144 | 313 | 613 | 56 | 55 | 387 |
| | **Min.** | 162 | 361 | 13 | 102 | 345 | 37 | 13 | 104 | 378 | 53 | 219 | 345 | 28 | 26 | 219 |
| **August** | **Mean** | 208 | 483 | 27 | 128 | 558 | 71 | 27 | 131 | 573 | 102 | 303 | 549 | 43 | 35 | 243 |
| | **Max.** | 230 | 534 | 60 | 146 | 621 | 97 | 60 | 153 | 643 | 146 | 322 | 607 | 58 | 56 | 296 |
| | **Min.** | 173 | 387 | 14 | 111 | 443 | 43 | 14 | 107 | 448 | 62 | 248 | 429 | 32 | 24 | 192 |
| **September** | **Mean** | 197 | 450 | 31 | 120 | 509 | 70 | 31 | 126 | 525 | 98 | 274 | 503 | 45 | 42 | 253 |
| | **Max.** | 230 | 536 | 60 | 144 | 625 | 97 | 60 | 153 | 647 | 145 | 320 | 614 | 57 | 62 | 324 |
| | **Min.** | 140 | 300 | 14 | 82 | 313 | 43 | 14 | 96 | 333 | 52 | 158 | 321 | 32 | 24 | 192 |
| **October** | **Mean** | 184 | 488 | 23 | 114 | 510 | 62 | 23 | 121 | 546 | 80 | 256 | 527 | -- | 40 | 345 |
| | **Max.** | 204 | 542 | 61 | 123 | 621 | 95 | 61 | 139 | 644 | 138 | 300 | 611 | -- | 52 | 382 |
| | **Min.** | 155 | 358 | 13 | 98 | 341 | 34 | 13 | 97 | 376 | 47 | 212 | 341 | -- | 29 | 263 |
| **November** | **Mean** | 153 | 263 | 54 | 102 | 213 | 139 | 52 | 102 | 195 | 31 | 99 | 197 | -- | 127 | 393 |
| | **Max.** | 192 | 384 | 74 | 133 | 371 | 197 | 71 | 133 | 368 | 50 | 153 | 393 | -- | 155 | 485 |
| | **Min.** | 108 | 143 | 32 | 73 | 111 | 87 | 30 | 73 | 89 | 16 | 61 | 70 | -- | 98 | 270 |
| **December** | **Mean** | 165 | 300 | 59 | 112 | 245 | 152 | 57 | 112 | 232 | 33 | 111 | 236 | -- | 134 | 420 |
| | **Max.** | 197 | 395 | 72 | 136 | 397 | 206 | 69 | 136 | 396 | 45 | 163 | 426 | -- | 150 | 488 |
| | **Min.** | 101 | 143 | 37 | 70 | 114 | 96 | 35 | 70 | 92 | 21 | 61 | 74 | -- | 96 | 252 |

**Table A-9.** Mean, maximum, and minimum monthly WUA for selected fish species in the Upper Reservoir Reach during the average year (2002).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 143 | 238 | 54 | 97 | 192 | 132 | 52 | 97 | 173 | 31 | 92 | 170 | -- | 121 | 370 |
| | **Max.** | 188 | 382 | 71 | 129 | 364 | 191 | 69 | 129 | 361 | 49 | 146 | 391 | -- | 148 | 485 |
| | **Min.** | 105 | 136 | 32 | 71 | 108 | 95 | 31 | 71 | 87 | 18 | 60 | 68 | -- | 92 | 259 |
| **February** | **Mean** | 136 | 223 | 53 | 93 | 180 | 128 | 51 | 93 | 157 | 32 | 87 | 152 | -- | 119 | 357 |
| | **Max.** | 169 | 327 | 66 | 120 | 286 | 175 | 64 | 120 | 274 | 45 | 129 | 295 | -- | 136 | 456 |
| | **Min.** | 98 | 138 | 34 | 67 | 111 | 86 | 33 | 67 | 89 | 19 | 58 | 71 | -- | 94 | 245 |
| **March** | **Mean** | 131 | 206 | 52 | 89 | 167 | 123 | 50 | 89 | 144 | 31 | 83 | 138 | -- | 114 | 340 |
| | **Max.** | 166 | 316 | 67 | 119 | 292 | 182 | 65 | 119 | 280 | 45 | 134 | 298 | -- | 135 | 447 |
| | **Min.** | 100 | 134 | 32 | 69 | 106 | 91 | 31 | 69 | 86 | 17 | 59 | 68 | -- | 93 | 246 |
| **April** | **Mean** | 165 | 428 | 22 | 101 | 435 | 53 | 22 | 109 | 477 | 71 | 221 | 454 | 33 | 41 | 348 |
| | **Max.** | 206 | 537 | 61 | 126 | 598 | 96 | 61 | 143 | 627 | 139 | 289 | 598 | 53 | 53 | 389 |
| | **Min.** | 93 | 364 | 12 | 62 | 349 | 24 | 12 | 60 | 380 | 35 | 120 | 351 | 17 | 17 | 297 |
| **May** | **Mean** | 125 | 399 | -- | 79 | 404 | 36 | -- | 82 | 447 | 49 | 167 | 417 | 23 | 31 | 336 |
| | **Max.** | 182 | 495 | -- | 115 | 502 | 71 | -- | 122 | 549 | 86 | 251 | 524 | 42 | 51 | 389 |
| | **Min.** | 61 | 331 | -- | 42 | 358 | 23 | -- | 43 | 387 | 33 | 94 | 343 | 14 | 10 | 253 |
| **June** | **Mean** | 69 | 336 | 19 | 47 | 360 | 26 | 19 | 47 | 391 | 38 | 96 | 352 | 15 | 12 | 267 |
| | **Max.** | 78 | 346 | 23 | 53 | 365 | 29 | 23 | 52 | 400 | 41 | 99 | 364 | 15 | 14 | 285 |
| | **Min.** | 61 | 327 | 15 | 43 | 356 | 23 | 15 | 43 | 384 | 33 | 94 | 340 | 14 | 10 | 249 |
| **July** | **Mean** | 142 | 420 | 18 | 89 | 423 | 41 | 18 | 93 | 467 | 55 | 190 | 442 | 26 | 35 | 348 |
| | **Max.** | 201 | 539 | 37 | 121 | 590 | 80 | 37 | 139 | 621 | 109 | 283 | 595 | 47 | 51 | 391 |
| | **Min.** | 63 | 325 | 12 | 44 | 353 | 22 | 12 | 44 | 382 | 33 | 94 | 341 | 14 | 10 | 250 |
| **August** | **Mean** | 193 | 502 | 23 | 119 | 552 | 64 | 23 | 124 | 578 | 84 | 272 | 558 | 39 | 38 | 323 |
| | **Max.** | 217 | 541 | 59 | 131 | 623 | 95 | 59 | 147 | 646 | 139 | 299 | 613 | 54 | 53 | 377 |
| | **Min.** | 160 | 410 | 13 | 102 | 405 | 36 | 13 | 100 | 439 | 50 | 223 | 416 | 26 | 29 | 263 |
| **September** | **Mean** | 196 | 505 | 23 | 121 | 573 | 64 | 23 | 125 | 593 | 86 | 282 | 571 | 39 | 36 | 303 |
| | **Max.** | 225 | 539 | 60 | 138 | 626 | 96 | 60 | 151 | 647 | 141 | 307 | 614 | 55 | 53 | 347 |
| | **Min.** | 168 | 402 | 13 | 107 | 417 | 40 | 13 | 105 | 439 | 56 | 243 | 418 | 29 | 27 | 236 |
| **October** | **Mean** | 189 | 498 | 22 | 117 | 534 | 63 | 22 | 123 | 565 | 82 | 265 | 546 | -- | 39 | 337 |
| | **Max.** | 209 | 542 | 59 | 128 | 615 | 95 | 59 | 144 | 641 | 138 | 302 | 608 | -- | 53 | 371 |
| | **Min.** | 160 | 392 | 13 | 102 | 381 | 36 | 13 | 99 | 418 | 50 | 222 | 388 | -- | 29 | 255 |
| **November** | **Mean** | 150 | 262 | 55 | 102 | 209 | 139 | 52 | 102 | 189 | 31 | 98 | 191 | -- | 127 | 397 |
| | **Max.** | 175 | 350 | 68 | 122 | 299 | 181 | 65 | 122 | 290 | 43 | 134 | 316 | -- | 139 | 473 |
| | **Min.** | 112 | 152 | 36 | 76 | 120 | 101 | 34 | 76 | 96 | 20 | 65 | 78 | -- | 100 | 270 |
| **December** | **Mean** | 142 | 238 | 54 | 97 | 192 | 133 | 52 | 97 | 170 | 31 | 92 | 168 | -- | 121 | 373 |
| | **Max.** | 175 | 349 | 67 | 123 | 304 | 181 | 65 | 123 | 295 | 45 | 136 | 323 | -- | 139 | 471 |
| | **Min.** | 99 | 141 | 32 | 68 | 112 | 87 | 31 | 68 | 91 | 17 | 58 | 74 | -- | 95 | 248 |

**Table A-10.** Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the wet year (1997).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 68 | 179 | 21 | 45 | 141 | 38 | 21 | 45 | 127 | 8 | 40 | 115 | -- | 59 | 225 |
| | **Max.** | 164 | 335 | 66 | 133 | 371 | 131 | 64 | 133 | 371 | 23 | 159 | 364 | -- | 129 | 329 |
| | **Min.** | 48 | 112 | 14 | 30 | 81 | 24 | 13 | 30 | 69 | 5 | 24 | 59 | -- | 42 | 160 |
| **February** | **Mean** | 67 | 188 | 21 | 45 | 145 | 38 | 20 | 45 | 130 | 8 | 40 | 119 | -- | 59 | 235 |
| | **Max.** | 114 | 303 | 36 | 72 | 260 | 62 | 35 | 72 | 254 | 12 | 71 | 238 | -- | 100 | 316 |
| | **Min.** | 50 | 122 | 14 | 31 | 90 | 25 | 13 | 31 | 77 | 5 | 26 | 67 | -- | 42 | 170 |
| **March** | **Mean** | 59 | 158 | 19 | 39 | 122 | 32 | 18 | 39 | 108 | 6 | 34 | 99 | -- | 51 | 206 |
| | **Max.** | 165 | 338 | 64 | 130 | 384 | 107 | 62 | 130 | 384 | 20 | 126 | 386 | -- | 132 | 330 |
| | **Min.** | 43 | 110 | 14 | 29 | 81 | 24 | 14 | 29 | 69 | 4 | 25 | 60 | -- | 37 | 157 |
| **April** | **Mean** | 44 | 219 | 8 | 28 | 197 | 13 | 8 | 31 | 218 | 11 | 47 | 147 | 14 | 17 | 192 |
| | **Max.** | 60 | 317 | 13 | 36 | 305 | 19 | 13 | 42 | 323 | 15 | 65 | 219 | 21 | 31 | 241 |
| | **Min.** | 36 | 162 | 6 | 23 | 150 | 10 | 6 | 25 | 164 | 8 | 37 | 114 | 11 | 10 | 145 |
| **May** | **Mean** | 36 | 175 | -- | 24 | 164 | 11 | -- | 25 | 180 | 11 | 41 | 122 | 11 | 11 | 154 |
| | **Max.** | 40 | 187 | -- | 25 | 174 | 12 | -- | 28 | 192 | 12 | 43 | 129 | 12 | 14 | 165 |
| | **Min.** | 36 | 166 | -- | 23 | 156 | 10 | -- | 25 | 170 | 10 | 41 | 118 | 11 | 10 | 147 |
| **June** | **Mean** | 40 | 199 | 7 | 26 | 182 | 12 | 7 | 28 | 201 | 12 | 44 | 135 | 13 | 14 | 175 |
| | **Max.** | 45 | 239 | 9 | 29 | 213 | 14 | 9 | 32 | 237 | 13 | 49 | 158 | 15 | 19 | 206 |
| | **Min.** | 36 | 166 | 6 | 24 | 155 | 10 | 6 | 25 | 169 | 10 | 41 | 117 | 10 | 10 | 147 |
| **July** | **Mean** | 48 | 248 | 8 | 31 | 226 | 14 | 8 | 33 | 248 | 12 | 52 | 167 | 16 | 18 | 206 |
| | **Max.** | 77 | 352 | 13 | 48 | 364 | 21 | 13 | 51 | 371 | 18 | 89 | 273 | 28 | 33 | 245 |
| | **Min.** | 36 | 179 | 6 | 24 | 165 | 11 | 6 | 25 | 184 | 9 | 41 | 125 | 11 | 10 | 157 |
| **August** | **Mean** | 60 | 297 | 9 | 38 | 280 | 16 | 9 | 41 | 299 | 14 | 71 | 209 | 19 | 21 | 204 |
| | **Max.** | 104 | 362 | 21 | 68 | 389 | 28 | 21 | 70 | 394 | 24 | 135 | 279 | 40 | 50 | 249 |
| | **Min.** | 43 | 222 | 6 | 28 | 187 | 11 | 6 | 30 | 208 | 10 | 50 | 145 | 14 | 8 | 73 |
| **September** | **Mean** | 64 | 277 | 10 | 40 | 256 | 17 | 10 | 44 | 275 | 14 | 71 | 196 | 21 | 25 | 199 |
| | **Max.** | 112 | 362 | 28 | 77 | 375 | 36 | 28 | 79 | 382 | 27 | 139 | 273 | 46 | 55 | 245 |
| | **Min.** | 47 | 197 | 6 | 29 | 165 | 12 | 6 | 30 | 182 | 9 | 48 | 131 | 14 | 8 | 65 |
| **October** | **Mean** | 61 | 277 | 10 | 39 | 258 | 17 | 10 | 42 | 276 | 14 | 70 | 193 | -- | 22 | 193 |
| | **Max.** | 108 | 365 | 22 | 72 | 388 | 31 | 22 | 73 | 393 | 26 | 136 | 280 | -- | 43 | 248 |
| | **Min.** | 43 | 202 | 6 | 28 | 170 | 11 | 6 | 29 | 191 | 9 | 44 | 131 | -- | 9 | 76 |
| **November** | **Mean** | 76 | 184 | 24 | 52 | 157 | 43 | 23 | 52 | 145 | 8 | 48 | 132 | -- | 64 | 225 |
| | **Max.** | 166 | 342 | 67 | 134 | 391 | 127 | 64 | 134 | 391 | 24 | 157 | 403 | -- | 132 | 331 |
| | **Min.** | 48 | 113 | 14 | 32 | 88 | 25 | 13 | 32 | 74 | 4 | 26 | 61 | -- | 42 | 162 |
| **December** | **Mean** | 84 | 199 | 28 | 60 | 178 | 53 | 27 | 60 | 167 | 10 | 60 | 153 | -- | 70 | 236 |
| | **Max.** | 166 | 340 | 72 | 135 | 388 | 155 | 69 | 135 | 388 | 30 | 185 | 399 | -- | 133 | 331 |
| | **Min.** | 51 | 124 | 14 | 32 | 95 | 26 | 13 | 32 | 81 | 5 | 27 | 67 | -- | 43 | 175 |

**Table A-11.** Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the dry year (2001).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 92 | 249 | 30 | 66 | 226 | 62 | 28 | 66 | 217 | 11 | 73 | 208 | -- | 77 | 277 |
| | **Max.** | 166 | 343 | 68 | 136 | 396 | 133 | 66 | 136 | 396 | 25 | 160 | 411 | -- | 133 | 332 |
| | **Min.** | 56 | 139 | 15 | 35 | 108 | 29 | 14 | 35 | 93 | 5 | 31 | 78 | -- | 48 | 190 |
| **February** | **Mean** | 104 | 279 | 33 | 74 | 263 | 70 | 32 | 74 | 256 | 12 | 83 | 247 | -- | 86 | 296 |
| | **Max.** | 166 | 343 | 69 | 136 | 395 | 133 | 66 | 136 | 395 | 25 | 161 | 412 | -- | 133 | 332 |
| | **Min.** | 62 | 145 | 18 | 42 | 111 | 32 | 18 | 42 | 95 | 7 | 33 | 79 | -- | 52 | 197 |
| **March** | **Mean** | 101 | 274 | 32 | 71 | 254 | 68 | 31 | 71 | 247 | 12 | 80 | 238 | -- | 83 | 294 |
| | **Max.** | 166 | 343 | 71 | 135 | 393 | 132 | 69 | 135 | 393 | 25 | 161 | 410 | -- | 131 | 332 |
| | **Min.** | 61 | 140 | 17 | 39 | 104 | 30 | 16 | 39 | 89 | 5 | 34 | 74 | -- | 52 | 195 |
| **April** | **Mean** | 72 | 303 | 11 | 44 | 285 | 19 | 11 | 47 | 306 | 16 | 85 | 221 | 24 | 24 | 183 |
| | **Max.** | 107 | 360 | 22 | 70 | 374 | 30 | 22 | 72 | 382 | 27 | 140 | 277 | 42 | 44 | 244 |
| | **Min.** | 45 | 232 | 6 | 29 | 192 | 12 | 6 | 31 | 234 | 11 | 49 | 159 | 14 | 8 | 67 |
| **May** | **Mean** | 59 | 266 | -- | 38 | 245 | 16 | -- | 40 | 264 | 14 | 66 | 184 | 19 | 22 | 193 |
| | **Max.** | 108 | 362 | -- | 71 | 387 | 30 | -- | 71 | 391 | 26 | 138 | 281 | 42 | 51 | 244 |
| | **Min.** | 42 | 177 | -- | 27 | 150 | 11 | -- | 30 | 167 | 8 | 38 | 117 | 14 | 8 | 73 |
| **June** | **Mean** | 62 | 265 | 10 | 40 | 243 | 17 | 9 | 43 | 261 | 14 | 70 | 185 | 21 | 23 | 187 |
| | **Max.** | 107 | 363 | 21 | 71 | 383 | 30 | 20 | 71 | 388 | 26 | 136 | 278 | 42 | 53 | 244 |
| | **Min.** | 44 | 183 | 6 | 29 | 154 | 11 | 6 | 32 | 172 | 8 | 42 | 121 | 14 | 9 | 77 |
| **July** | **Mean** | 75 | 288 | 12 | 47 | 268 | 20 | 12 | 50 | 287 | 17 | 86 | 210 | 26 | 26 | 177 |
| | **Max.** | 106 | 355 | 21 | 70 | 374 | 30 | 21 | 71 | 379 | 26 | 138 | 273 | 42 | 49 | 238 |
| | **Min.** | 45 | 204 | 6 | 29 | 173 | 12 | 6 | 31 | 192 | 9 | 45 | 134 | 14 | 9 | 68 |
| **August** | **Mean** | 75 | 318 | 10 | 46 | 301 | 19 | 10 | 47 | 325 | 17 | 94 | 237 | 22 | 21 | 164 |
| | **Max.** | 105 | 362 | 22 | 68 | 382 | 30 | 22 | 70 | 387 | 27 | 140 | 278 | 40 | 51 | 235 |
| | **Min.** | 56 | 231 | 6 | 33 | 192 | 14 | 6 | 30 | 234 | 13 | 66 | 185 | 16 | 8 | 67 |
| **September** | **Mean** | 71 | 323 | 9 | 43 | 303 | 18 | 9 | 44 | 331 | 17 | 92 | 239 | 20 | 18 | 164 |
| | **Max.** | 107 | 359 | 19 | 70 | 379 | 30 | 19 | 71 | 385 | 27 | 139 | 277 | 41 | 38 | 240 |
| | **Min.** | 53 | 274 | 6 | 32 | 213 | 14 | 6 | 31 | 277 | 12 | 62 | 199 | 15 | 8 | 68 |
| **October** | **Mean** | 61 | 300 | 9 | 39 | 281 | 17 | 9 | 41 | 302 | 15 | 74 | 211 | -- | 20 | 198 |
| | **Max.** | 107 | 361 | 20 | 70 | 378 | 30 | 20 | 70 | 385 | 25 | 135 | 276 | -- | 44 | 244 |
| | **Min.** | 46 | 219 | 6 | 29 | 183 | 12 | 6 | 32 | 203 | 9 | 49 | 146 | -- | 8 | 70 |
| **November** | **Mean** | 90 | 222 | 30 | 64 | 198 | 56 | 29 | 64 | 188 | 11 | 65 | 174 | -- | 76 | 255 |
| | **Max.** | 166 | 340 | 71 | 136 | 388 | 135 | 69 | 136 | 388 | 25 | 167 | 400 | -- | 133 | 332 |
| | **Min.** | 51 | 116 | 14 | 33 | 90 | 26 | 14 | 33 | 77 | 5 | 27 | 63 | -- | 44 | 166 |
| **December** | **Mean** | 93 | 230 | 32 | 67 | 201 | 58 | 31 | 67 | 192 | 11 | 67 | 178 | -- | 80 | 263 |
| | **Max.** | 166 | 344 | 69 | 136 | 396 | 134 | 67 | 136 | 396 | 25 | 164 | 413 | -- | 133 | 333 |
| | **Min.** | 55 | 144 | 14 | 34 | 110 | 28 | 14 | 34 | 95 | 5 | 29 | 84 | -- | 48 | 196 |

**Table A-12.** Mean, maximum, and minimum monthly WUA for selected fish species in the Tailrace Reach during the average year (2002).

| Month | | Bull Trout (Juvenile) | Bull Trout (Adult) | Cutthroat Trout (Fry) | Cutthroat Trout (Juvenile) | Cutthroat Trout (Adult) | Cyprinids & Forage Fish (Fry & Juvenile) | Redband Trout (Fry) | Redband Trout (Juvenile) | Redband Trout (Adults) | Smallmouth Bass (Fry) | Smallmouth Bass (Juvenile) | Smallmouth Bass (Adults) | Mountain Whitefish (Fry) | Mountain Whitefish (Juvenile) | Mountain Whitefish (Adults) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | **Mean** | 89 | 205 | 30 | 64 | 183 | 54 | 29 | 64 | 172 | 10 | 62 | 157 | -- | 75 | 241 |
| | **Max.** | 166 | 338 | 69 | 136 | 385 | 133 | 66 | 136 | 385 | 25 | 165 | 393 | -- | 132 | 330 |
| | **Min.** | 48 | 104 | 14 | 31 | 79 | 23 | 14 | 31 | 68 | 4 | 24 | 54 | -- | 41 | 152 |
| **February** | **Mean** | 86 | 217 | 28 | 62 | 194 | 54 | 27 | 62 | 183 | 10 | 62 | 171 | -- | 72 | 252 |
| | **Max.** | 166 | 342 | 69 | 135 | 392 | 133 | 67 | 135 | 392 | 24 | 163 | 404 | -- | 133 | 332 |
| | **Min.** | 54 | 120 | 14 | 34 | 90 | 26 | 14 | 34 | 76 | 4 | 28 | 62 | -- | 47 | 174 |
| **March** | **Mean** | 85 | 208 | 28 | 61 | 184 | 52 | 27 | 61 | 173 | 10 | 59 | 160 | -- | 72 | 244 |
| | **Max.** | 166 | 340 | 69 | 136 | 386 | 131 | 66 | 136 | 386 | 24 | 163 | 394 | -- | 133 | 332 |
| | **Min.** | 50 | 96 | 14 | 31 | 74 | 21 | 14 | 31 | 63 | 4 | 22 | 50 | -- | 45 | 144 |
| **April** | **Mean** | 56 | 260 | 9 | 35 | 237 | 16 | 9 | 38 | 258 | 13 | 61 | 179 | 18 | 22 | 200 |
| | **Max.** | 106 | 359 | 21 | 69 | 379 | 30 | 21 | 70 | 385 | 27 | 139 | 278 | 41 | 47 | 248 |
| | **Min.** | 40 | 174 | 6 | 25 | 148 | 11 | 6 | 28 | 165 | 7 | 38 | 115 | 12 | 8 | 68 |
| **May** | **Mean** | 47 | 222 | -- | 30 | 202 | 14 | -- | 33 | 221 | 12 | 50 | 151 | 16 | 19 | 187 |
| | **Max.** | 107 | 353 | -- | 72 | 355 | 28 | -- | 72 | 365 | 24 | 132 | 266 | 41 | 47 | 247 |
| | **Min.** | 36 | 166 | -- | 23 | 144 | 10 | -- | 25 | 162 | 8 | 37 | 112 | 11 | 10 | 81 |
| **June** | **Mean** | 37 | 176 | 7 | 24 | 165 | 11 | 7 | 26 | 180 | 11 | 42 | 123 | 11 | 11 | 155 |
| | **Max.** | 40 | 193 | 8 | 25 | 178 | 12 | 8 | 28 | 197 | 12 | 43 | 132 | 12 | 13 | 171 |
| | **Min.** | 36 | 167 | 6 | 23 | 157 | 10 | 6 | 25 | 171 | 10 | 41 | 118 | 10 | 10 | 147 |
| **July** | **Mean** | 52 | 233 | 9 | 33 | 210 | 15 | 9 | 37 | 230 | 12 | 55 | 160 | 17 | 22 | 194 |
| | **Max.** | 106 | 339 | 22 | 70 | 333 | 29 | 22 | 72 | 348 | 26 | 138 | 250 | 41 | 49 | 246 |
| | **Min.** | 36 | 167 | 6 | 23 | 147 | 10 | 6 | 25 | 163 | 8 | 40 | 114 | 11 | 10 | 70 |
| **August** | **Mean** | 65 | 308 | 9 | 40 | 290 | 17 | 9 | 42 | 312 | 16 | 80 | 220 | 19 | 20 | 190 |
| | **Max.** | 100 | 361 | 19 | 65 | 384 | 28 | 19 | 65 | 389 | 23 | 133 | 278 | 38 | 35 | 244 |
| | **Min.** | 49 | 239 | 6 | 31 | 205 | 12 | 6 | 29 | 226 | 10 | 52 | 158 | 14 | 8 | 71 |
| **September** | **Mean** | 71 | 300 | 11 | 44 | 282 | 19 | 11 | 47 | 303 | 16 | 83 | 219 | 23 | 24 | 187 |
| | **Max.** | 108 | 359 | 25 | 71 | 379 | 33 | 25 | 78 | 385 | 27 | 140 | 276 | 43 | 56 | 238 |
| | **Min.** | 53 | 214 | 6 | 32 | 195 | 13 | 6 | 31 | 215 | 10 | 55 | 173 | 15 | 8 | 66 |
| **October** | **Mean** | 64 | 300 | 10 | 40 | 281 | 17 | 10 | 43 | 302 | 15 | 77 | 213 | -- | 22 | 193 |
| | **Max.** | 108 | 363 | 26 | 71 | 386 | 37 | 26 | 79 | 391 | 26 | 134 | 279 | -- | 60 | 244 |
| | **Min.** | 49 | 207 | 6 | 31 | 181 | 12 | 6 | 30 | 201 | 9 | 50 | 147 | -- | 8 | 67 |
| **November** | **Mean** | 91 | 209 | 32 | 65 | 184 | 55 | 30 | 65 | 173 | 10 | 63 | 158 | -- | 77 | 246 |
| | **Max.** | 166 | 343 | 74 | 135 | 394 | 137 | 71 | 135 | 394 | 26 | 162 | 408 | -- | 132 | 332 |
| | **Min.** | 54 | 122 | 16 | 34 | 92 | 28 | 15 | 34 | 78 | 4 | 30 | 63 | -- | 46 | 176 |
| **December** | **Mean** | 87 | 223 | 29 | 62 | 201 | 56 | 28 | 62 | 191 | 10 | 64 | 180 | -- | 73 | 257 |
| | **Max.** | 166 | 343 | 71 | 135 | 396 | 134 | 68 | 135 | 396 | 25 | 164 | 412 | -- | 132 | 333 |
| | **Min.** | 53 | 126 | 14 | 33 | 96 | 27 | 14 | 33 | 82 | 5 | 28 | 67 | -- | 45 | 179 |

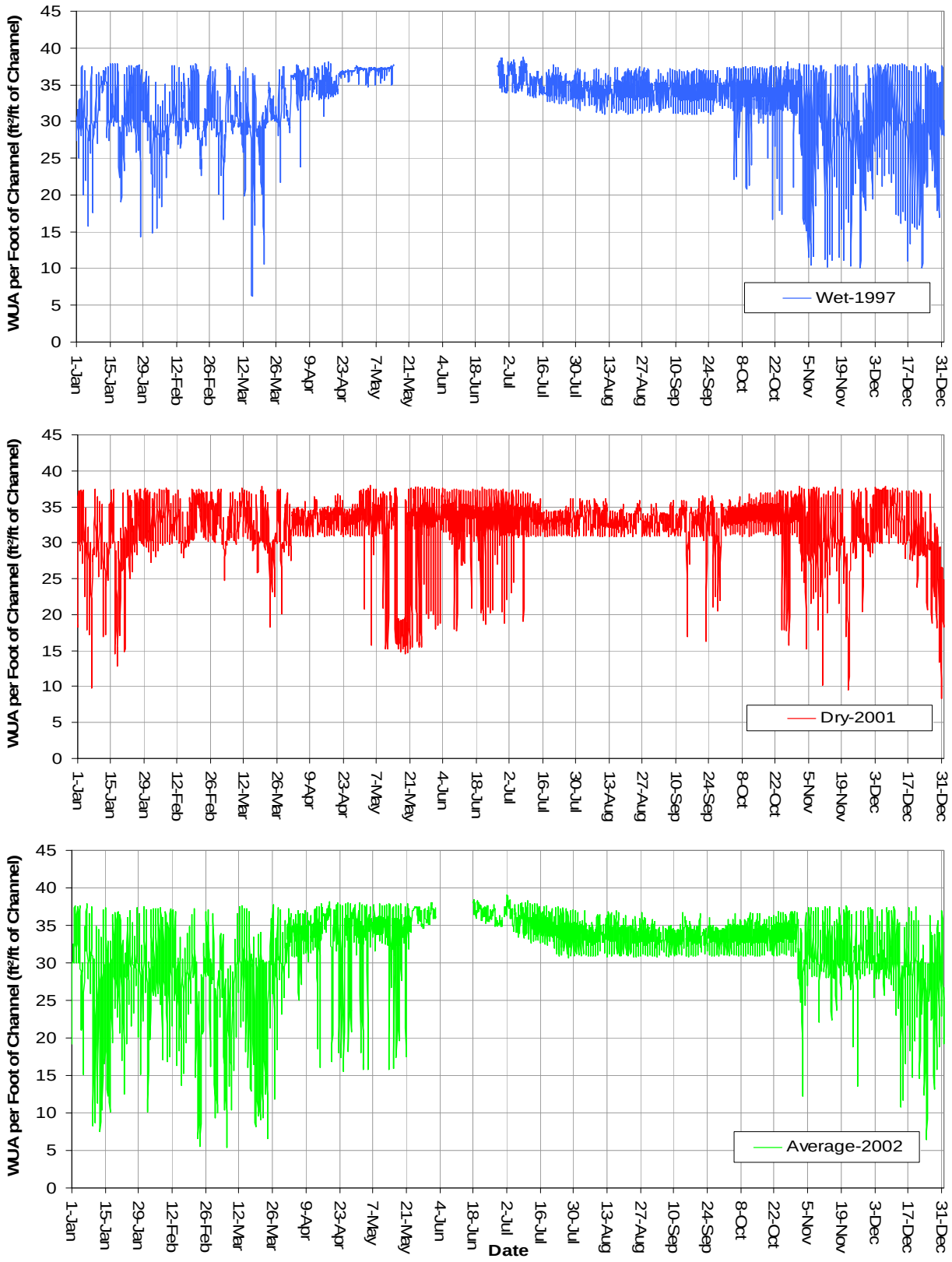


**Figure A-1.** Annual WUA for juvenile bull trout in the Forebay Reach during the three representative years.

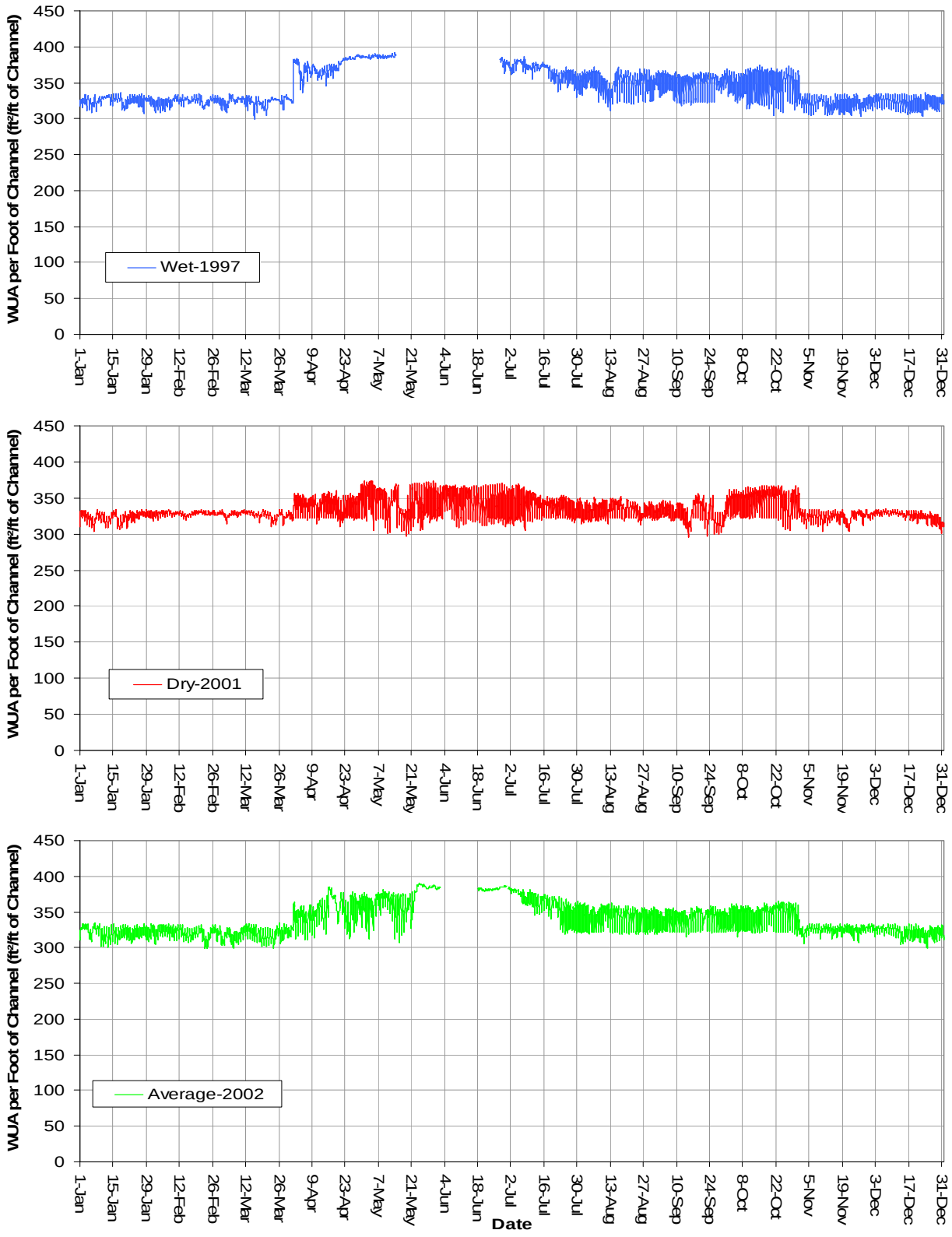


**Figure A-2.** Annual WUA for adult bull trout in the Forebay Reach during the three representative years.

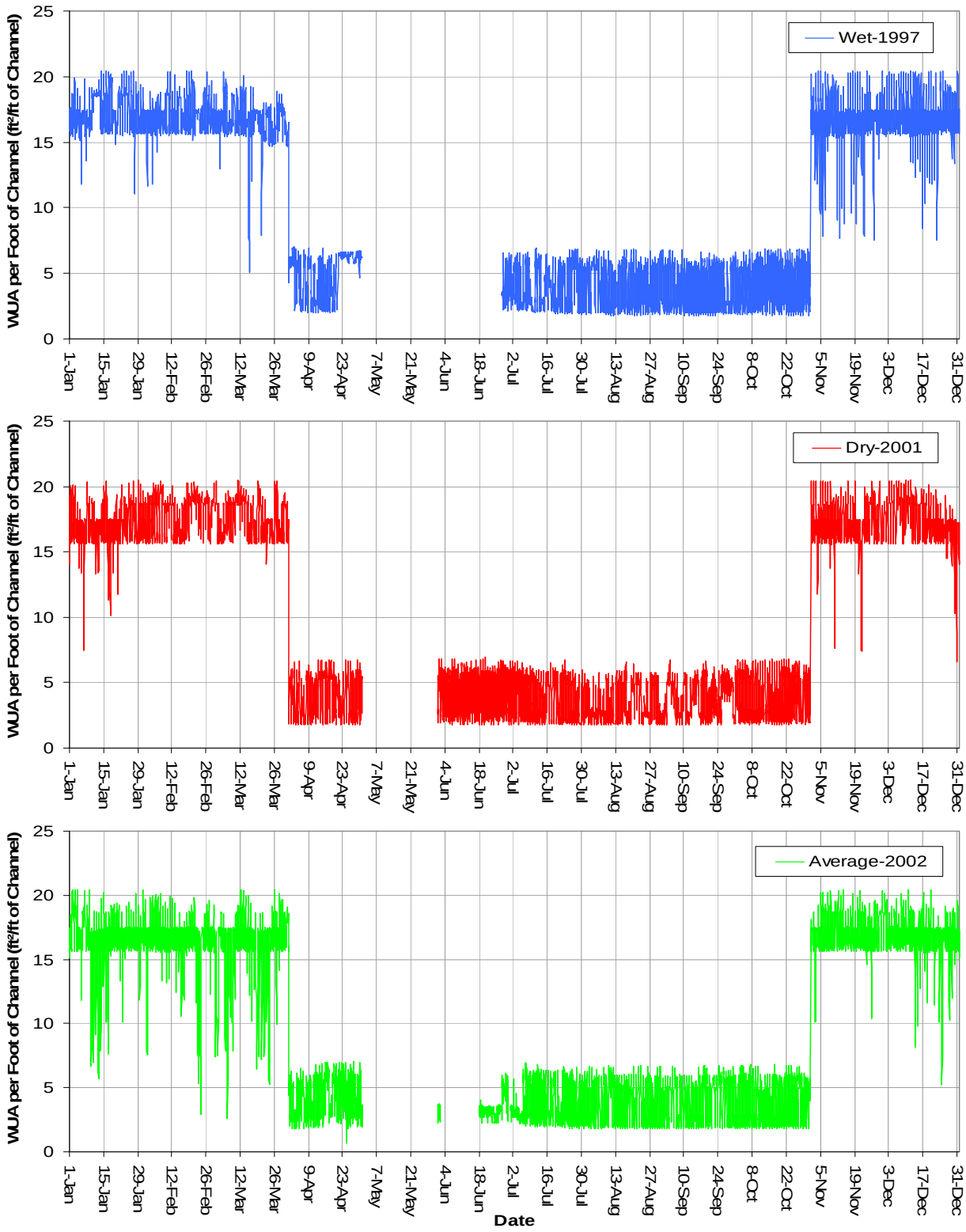


**Figure A-3.** Annual WUA for fry cutthroat trout in the Forebay Reach during the three representative years.

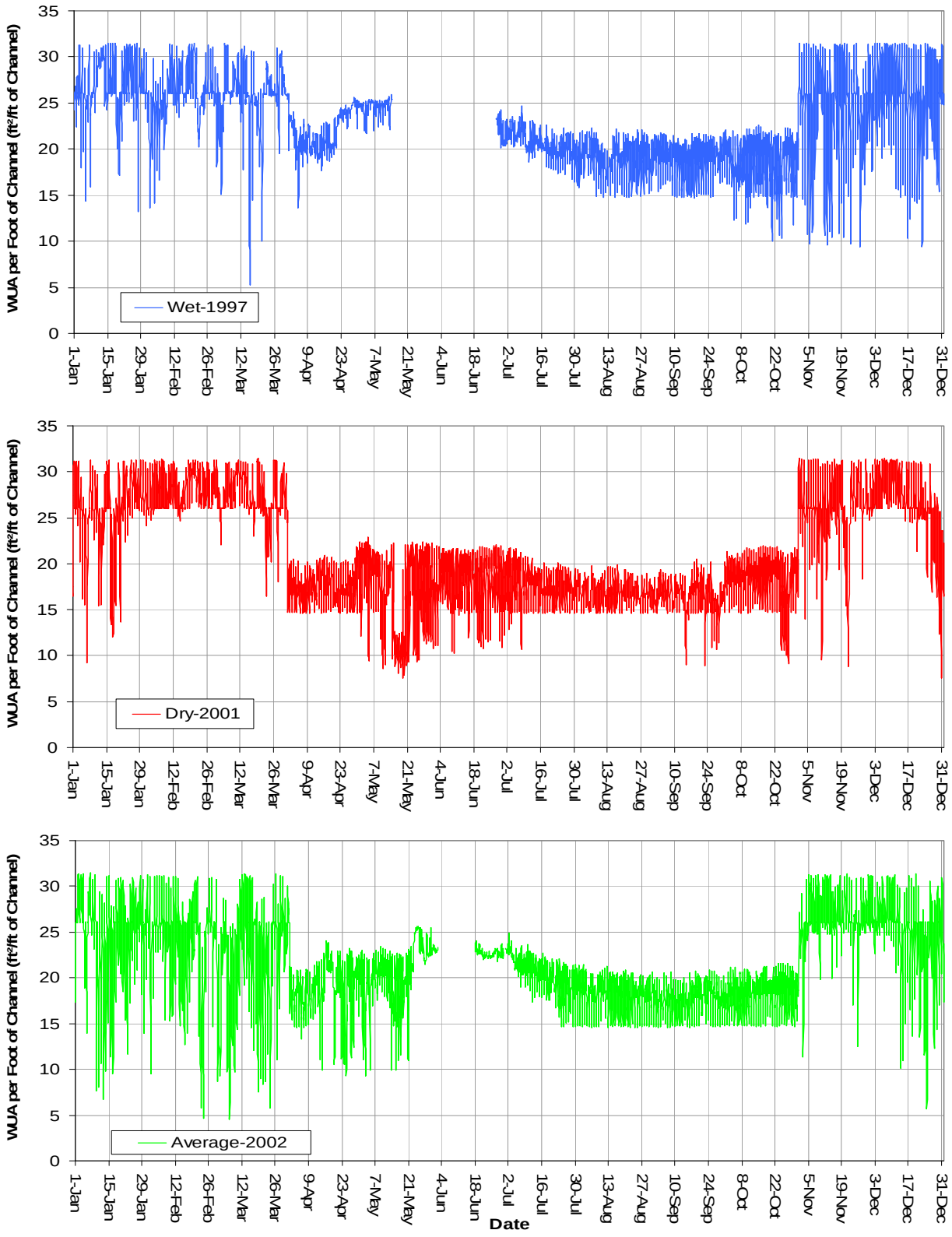


**Figure A-4.** Annual WUA for juvenile cutthroat trout in the Forebay Reach during the three representative years.

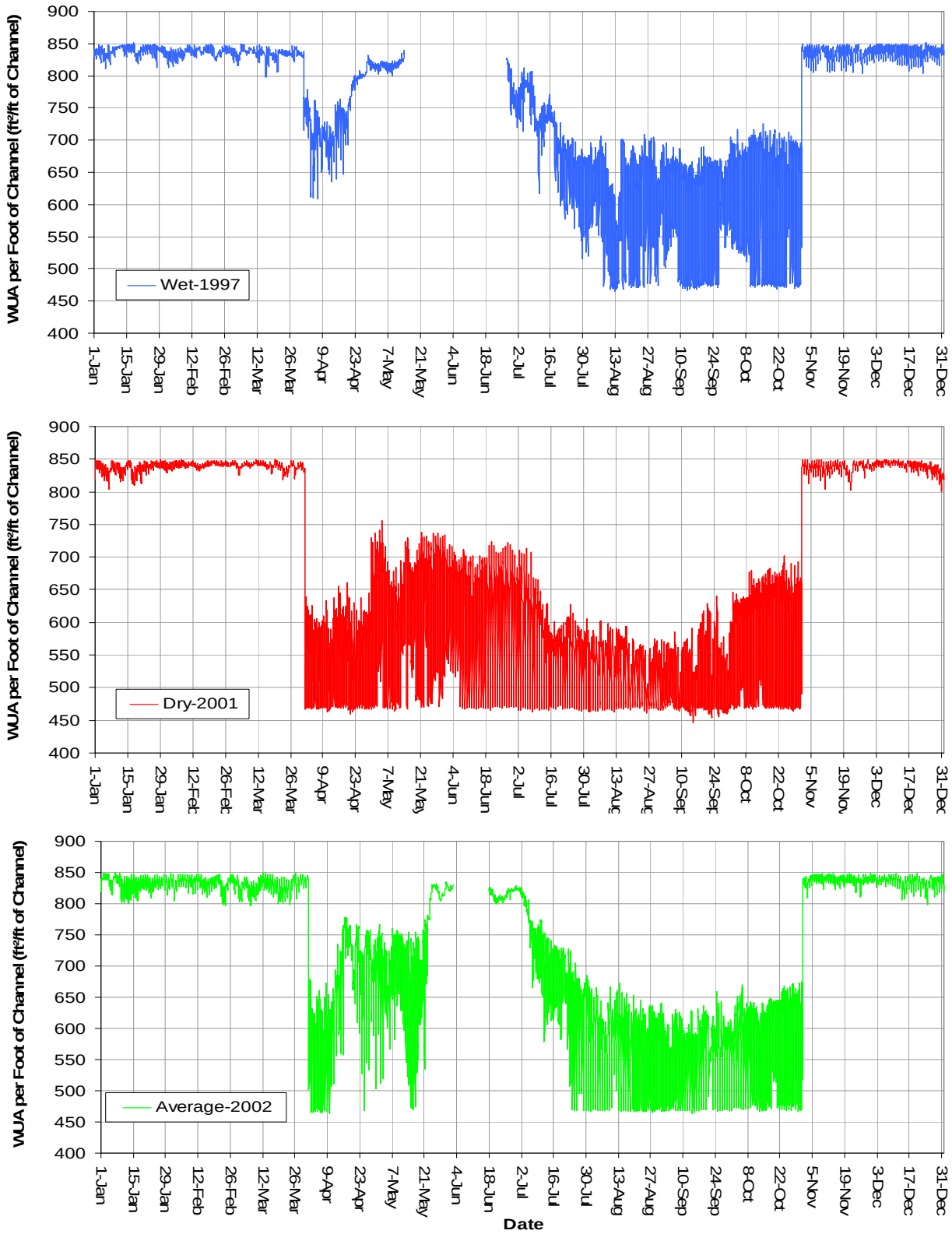


**Figure A-5.** Annual WUA for adult cutthroat trout in the Forebay Reach during the three representative years.

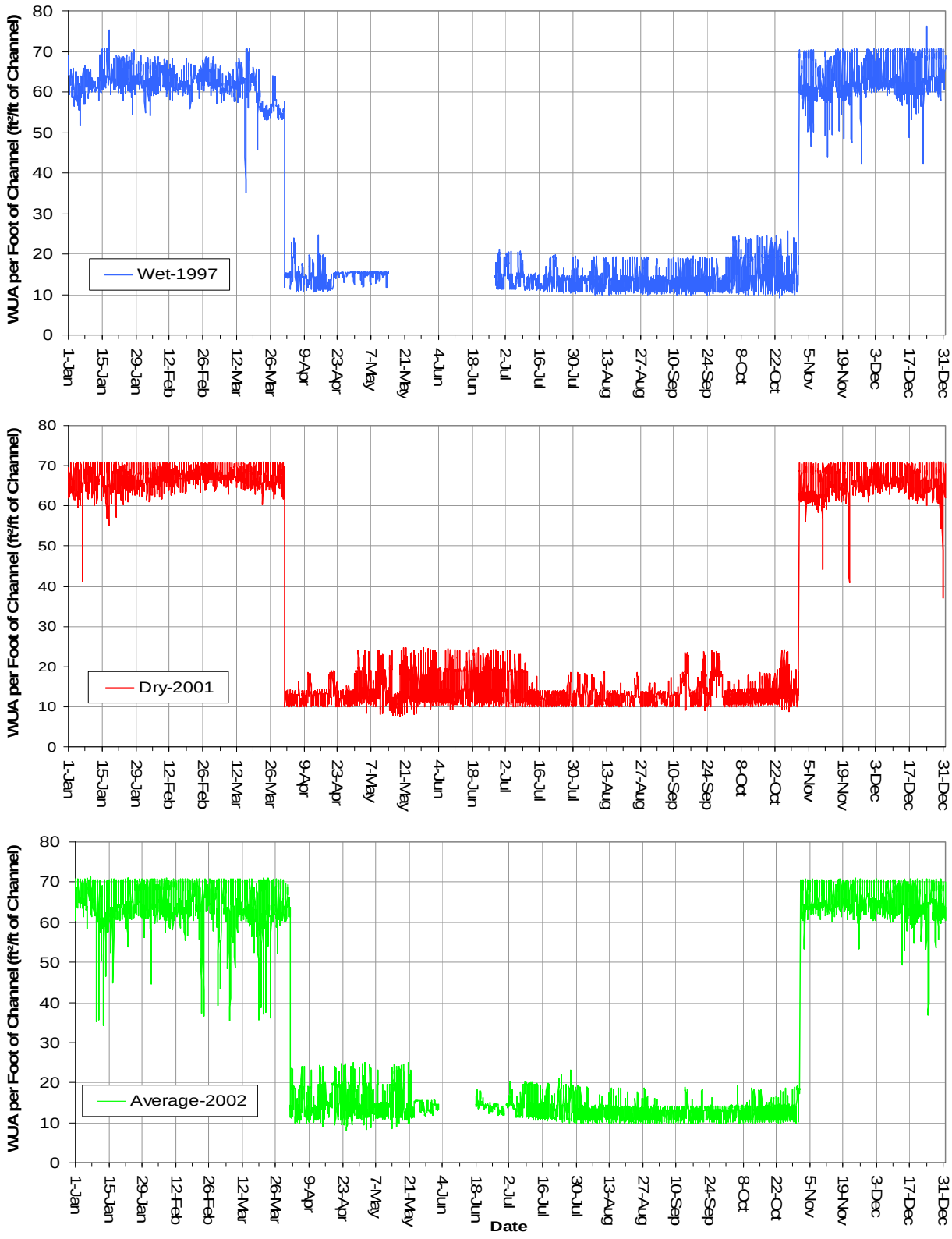


**Figure A-6.** Annual WUA for fry and juvenile cyprinids in the Forebay Reach during the three representative years.

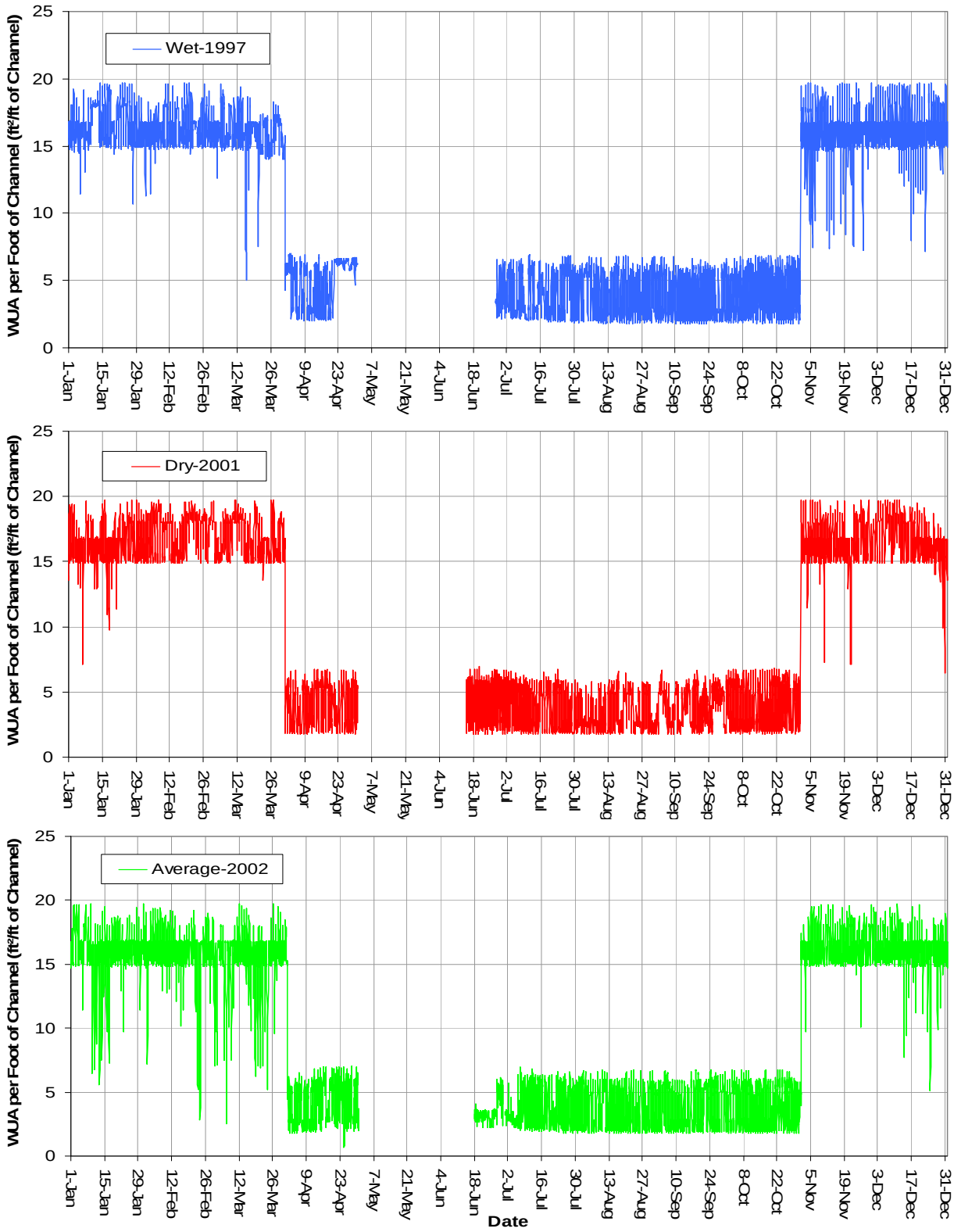


**Figure A-7.** Annual WUA for fry redband trout in the Forebay Reach during the three representative years.

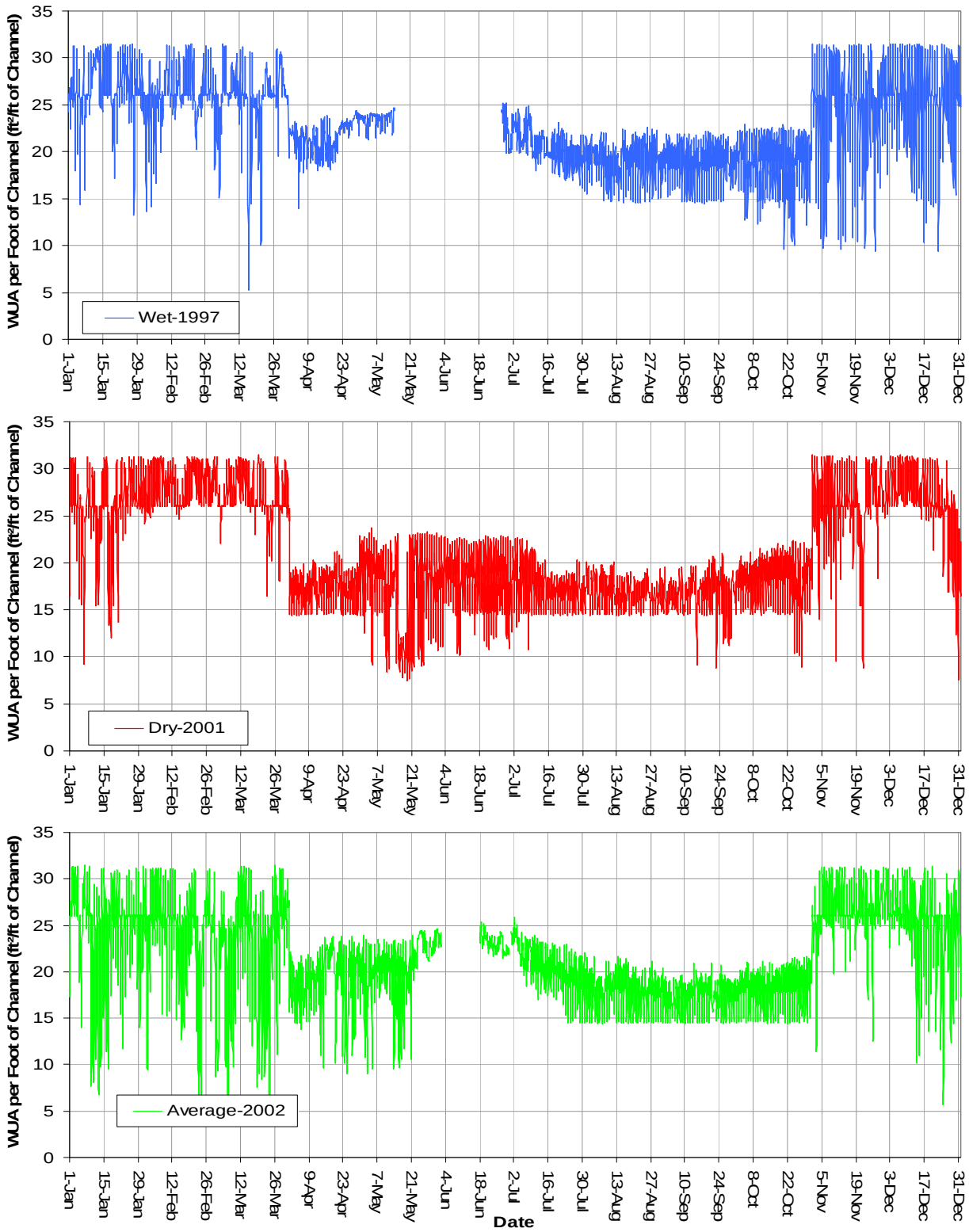


**Figure A-8.** Annual WUA for juvenile redband trout in the Forebay Reach during the three representative years.

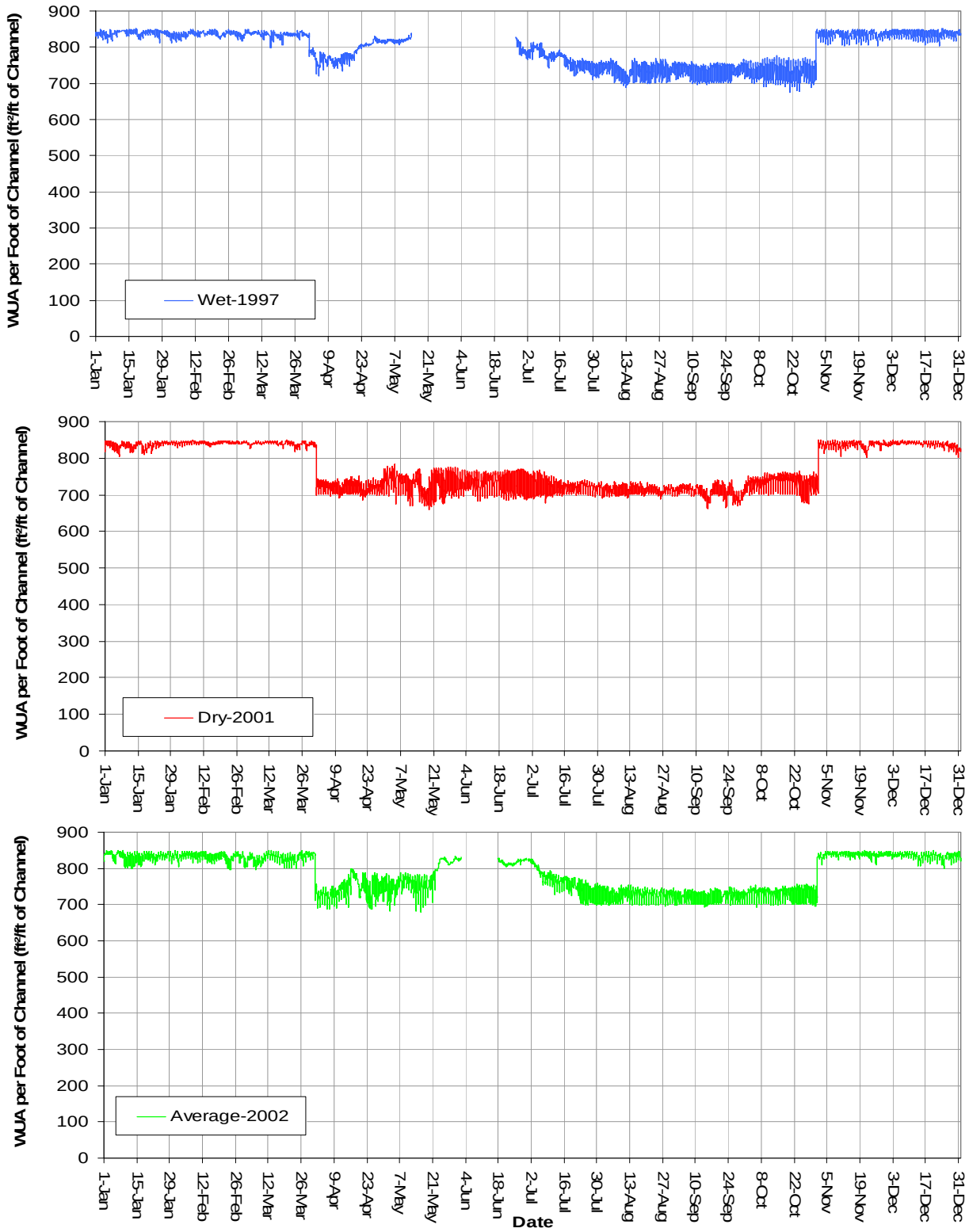


**Figure A-9.** Annual WUA for adult redband trout in the Forebay Reach during the three representative years.

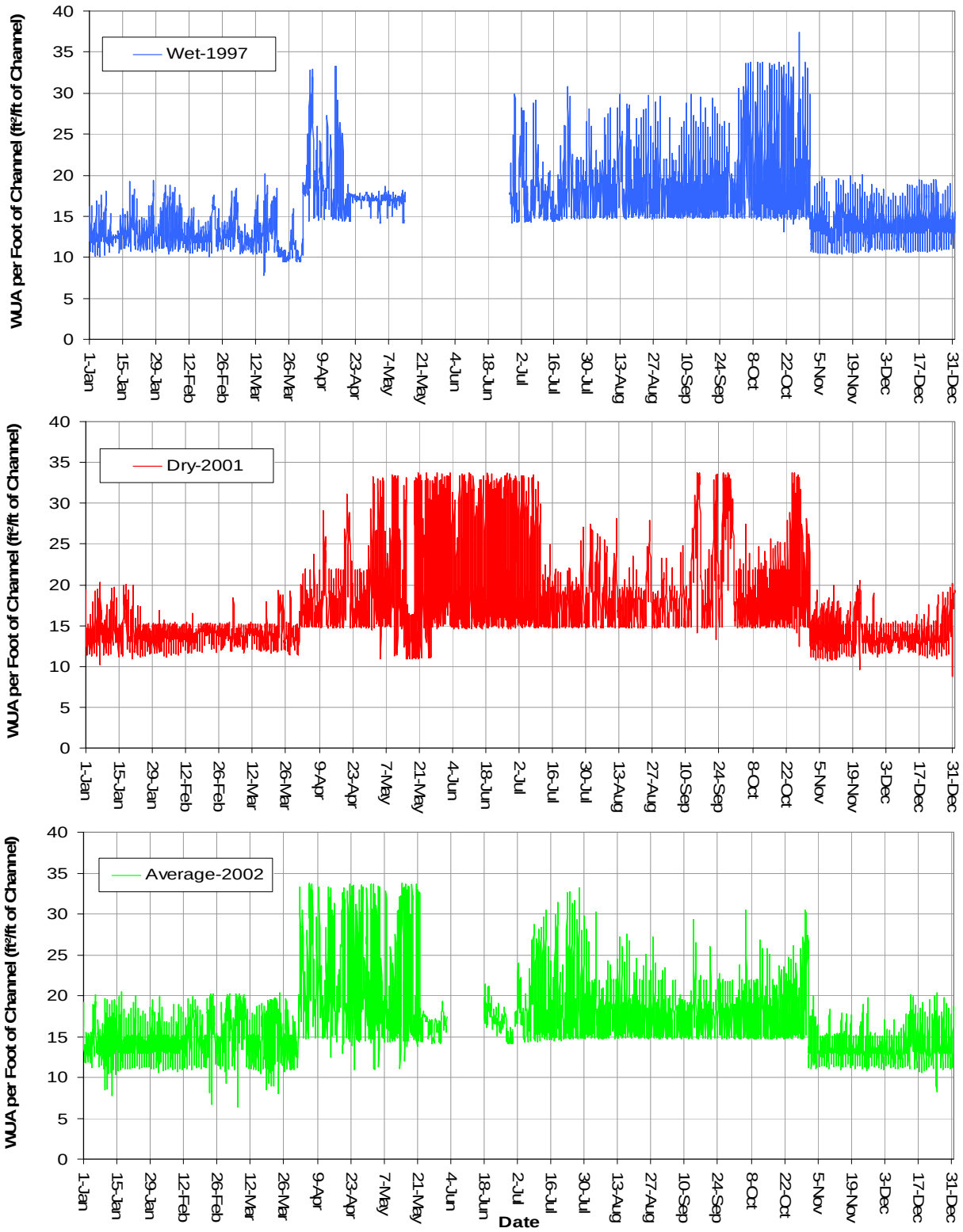


**Figure A-10.** Annual WUA for fry smallmouth bass in the Forebay Reach during the three representative years.

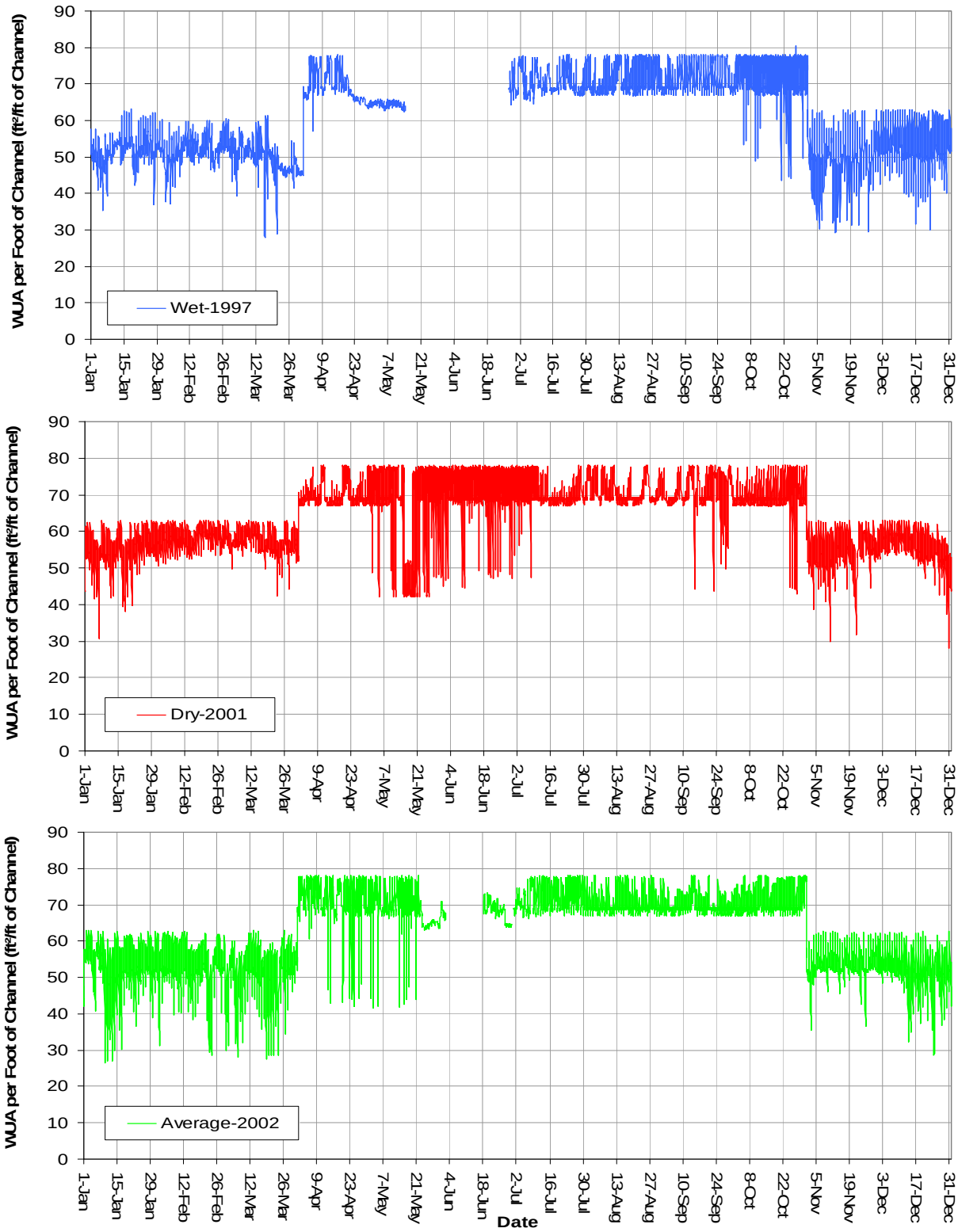


**Figure A-11.** Annual WUA for juvenile smallmouth bass in the Forebay Reach during the three representative years.

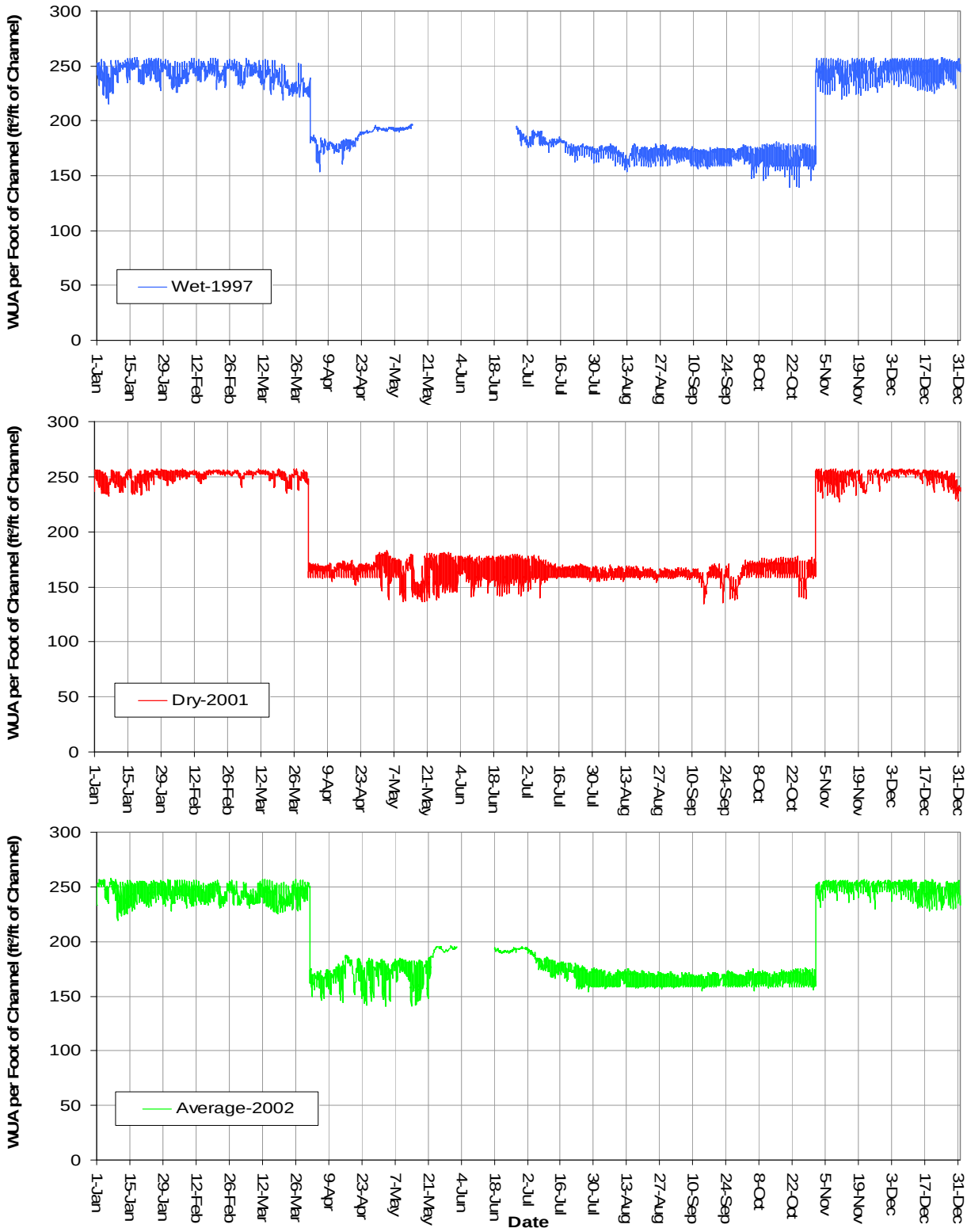


**Figure A-12.** Annual WUA for adult smallmouth bass in the Forebay Reach during the three representative years.

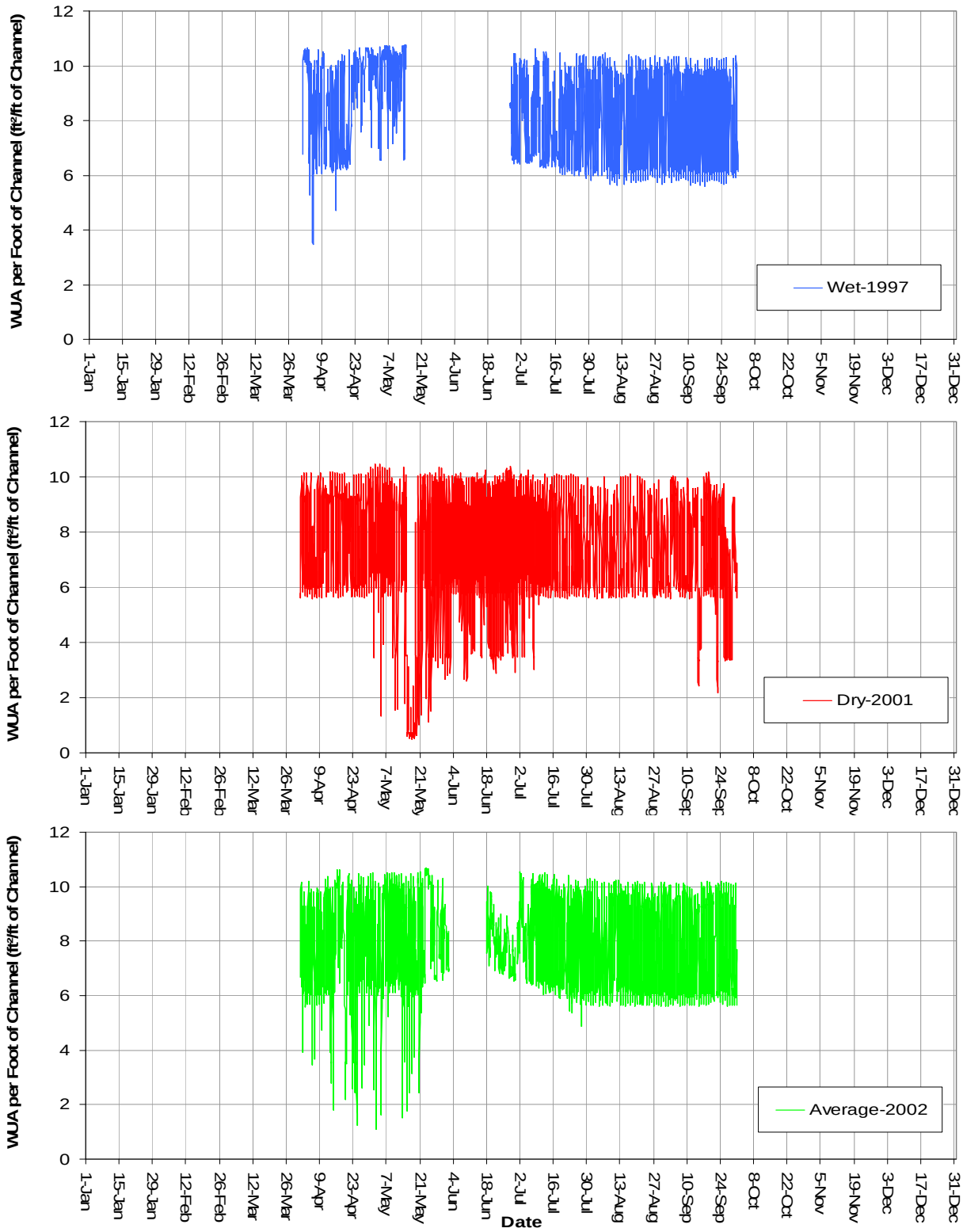


**Figure A-13.** Annual WUA for fry whitefish in the Forebay Reach during the three representative years.

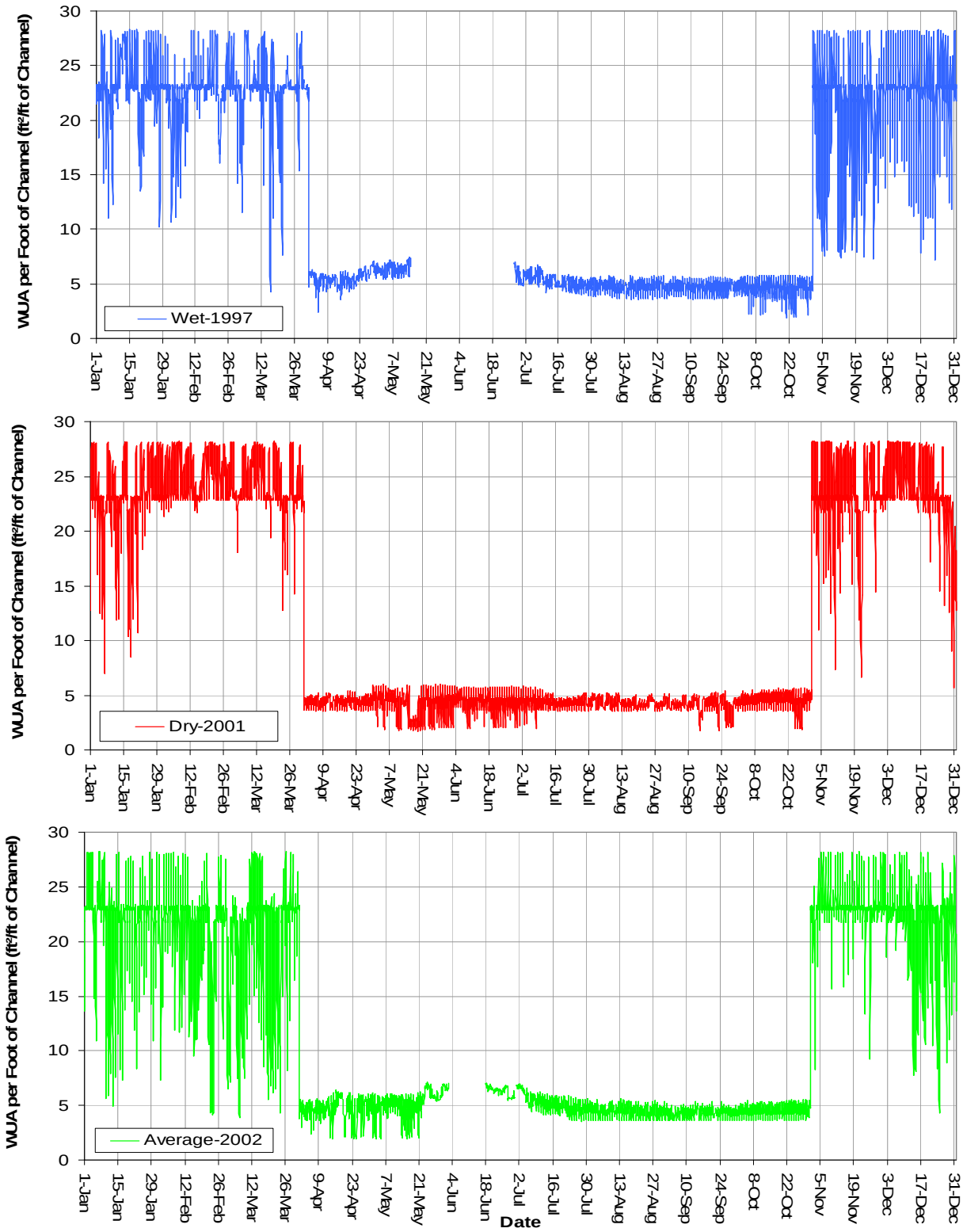


**Figure A-14.** Annual WUA for juvenile whitefish in the Forebay Reach during the three representative years.

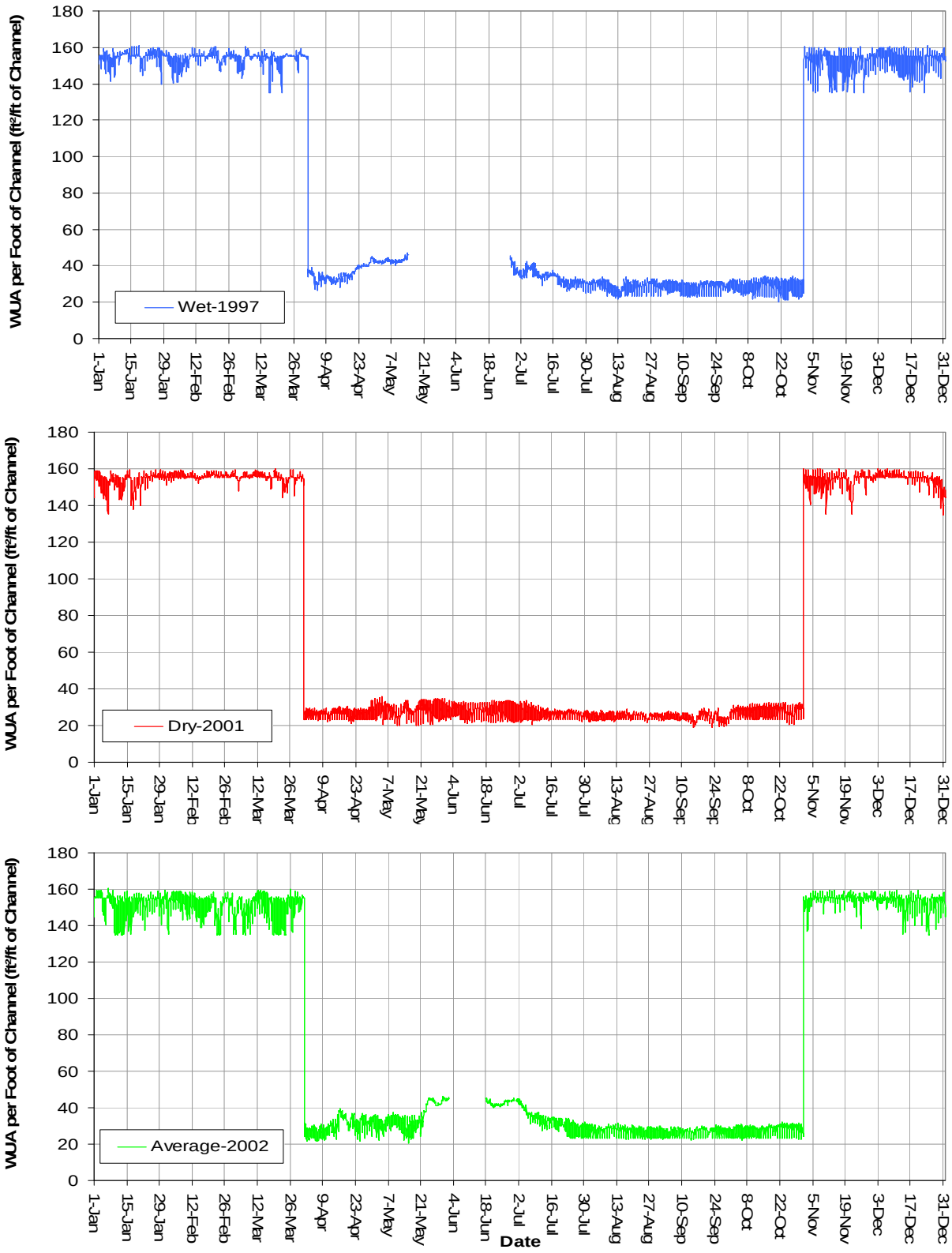


**Figure A-15.** Annual WUA for adult whitefish in the Forebay Reach during the three representative years.

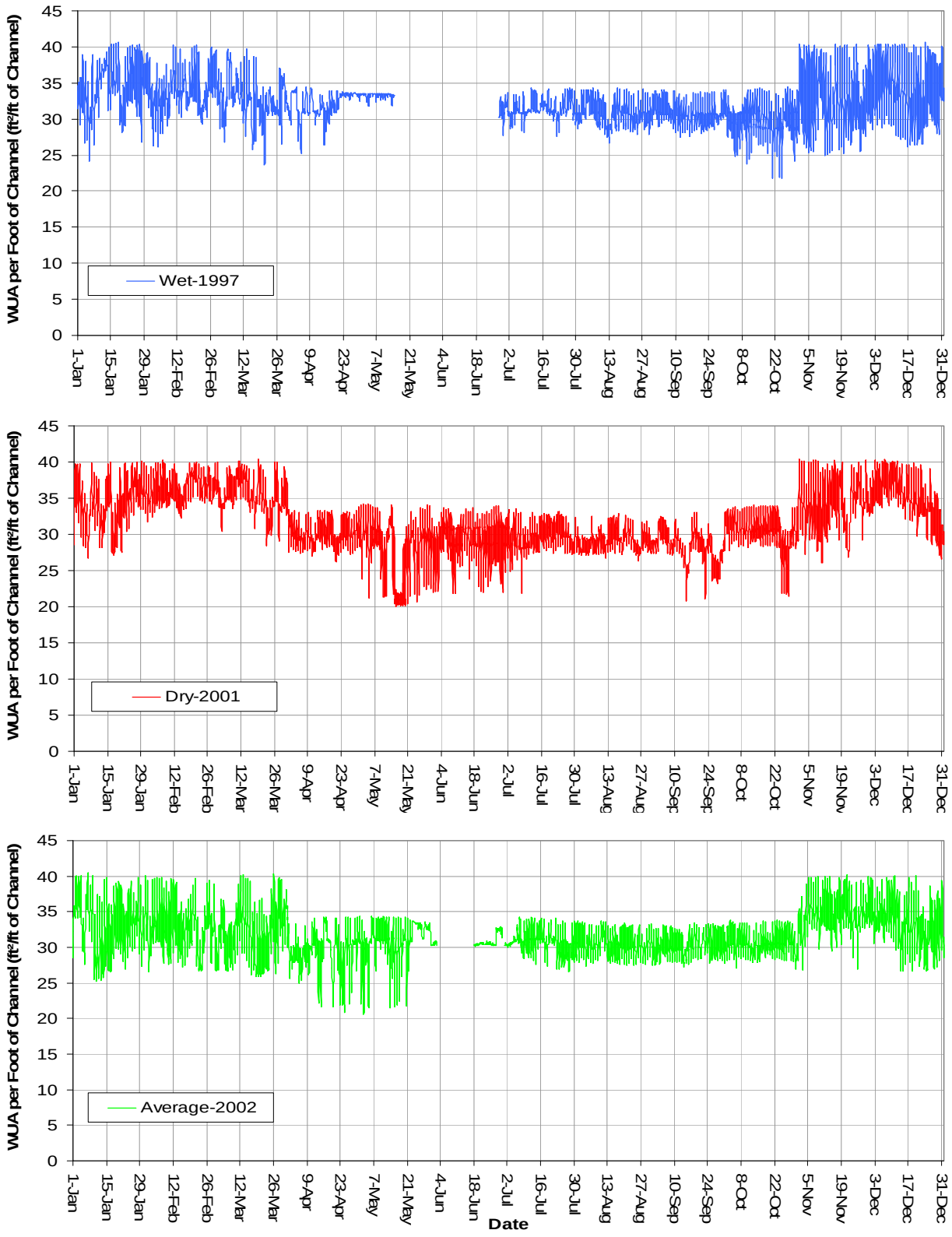


**Figure A-16.** Annual WUA for juvenile bull trout in the Canyon Reach during the three representative years.

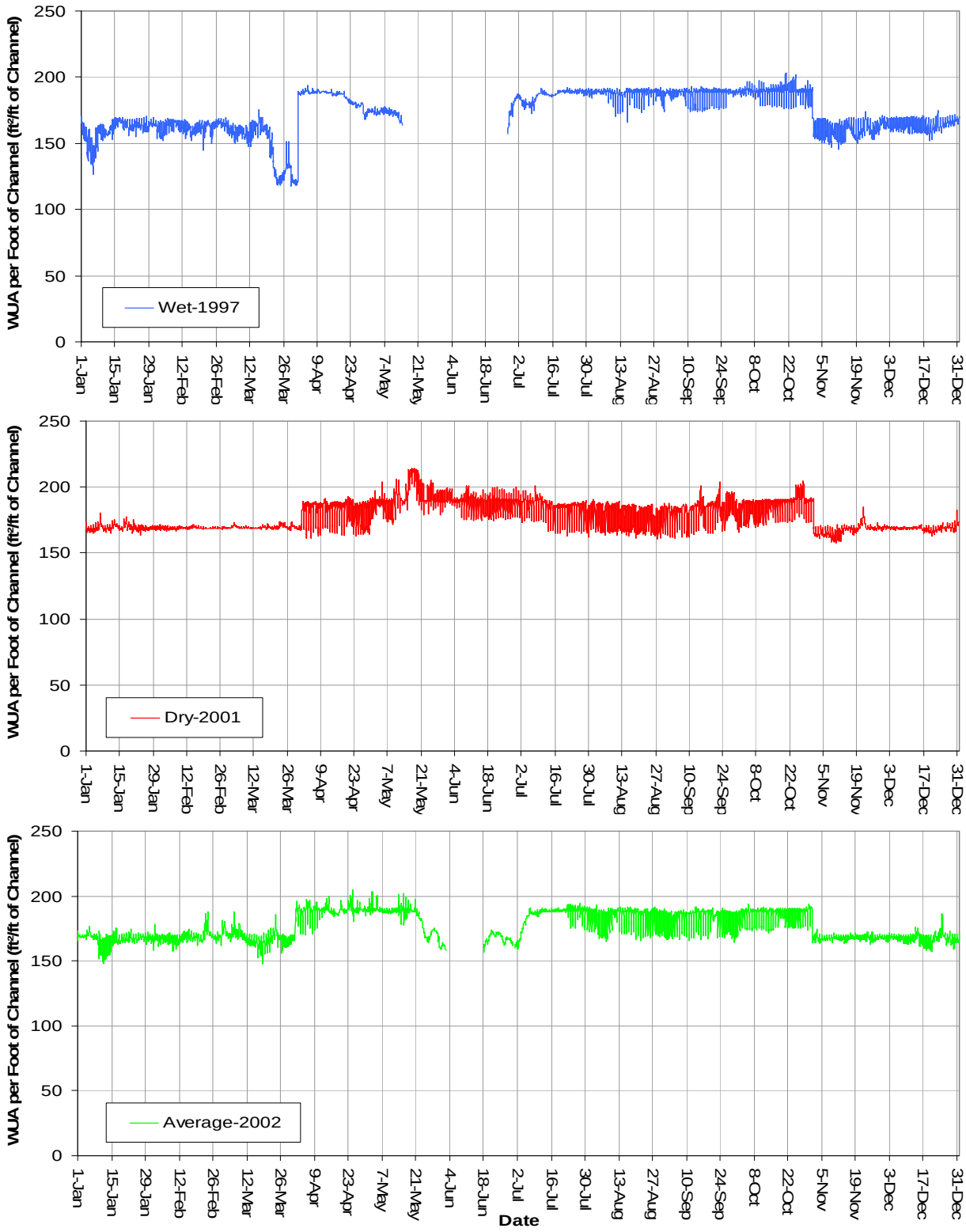


**Figure A-17.** Annual WUA for adult bull trout in the Canyon Reach during the three representative years.

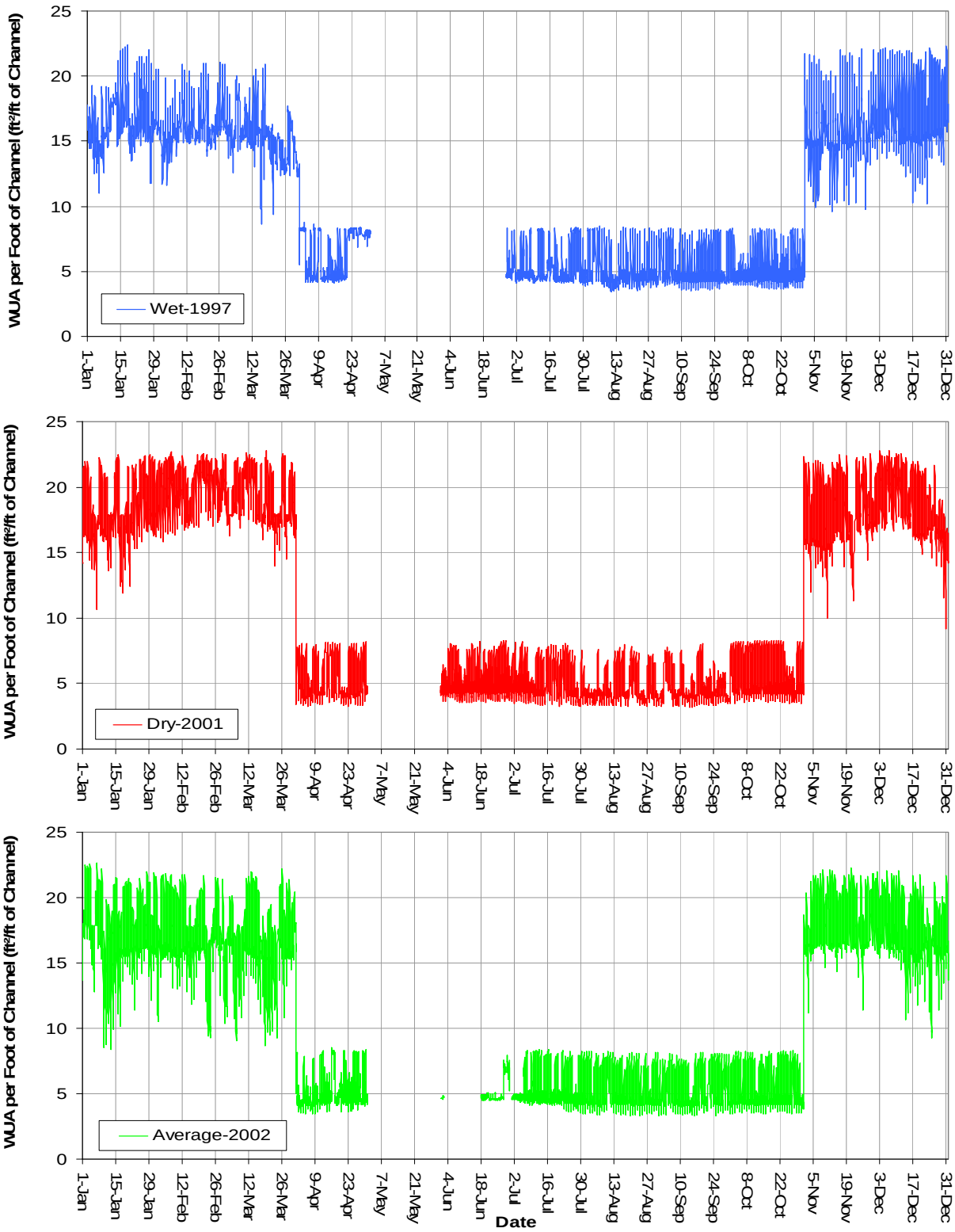


**Figure A-18.** Annual WUA for fry cutthroat trout in the Canyon Reach during the three representative years.

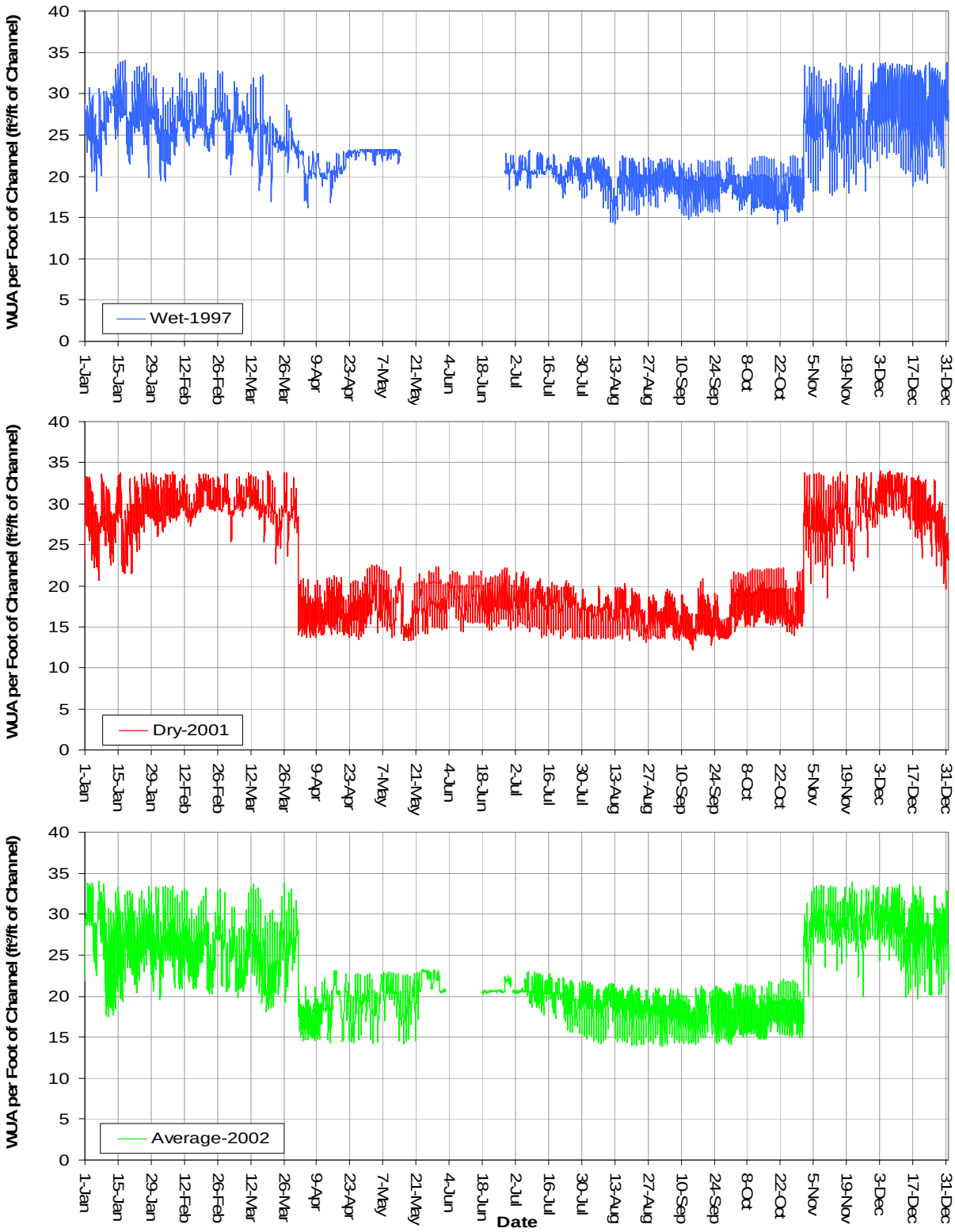


**Figure A-19.** Annual WUA for juvenile cutthroat trout in the Canyon Reach during the three representative years.

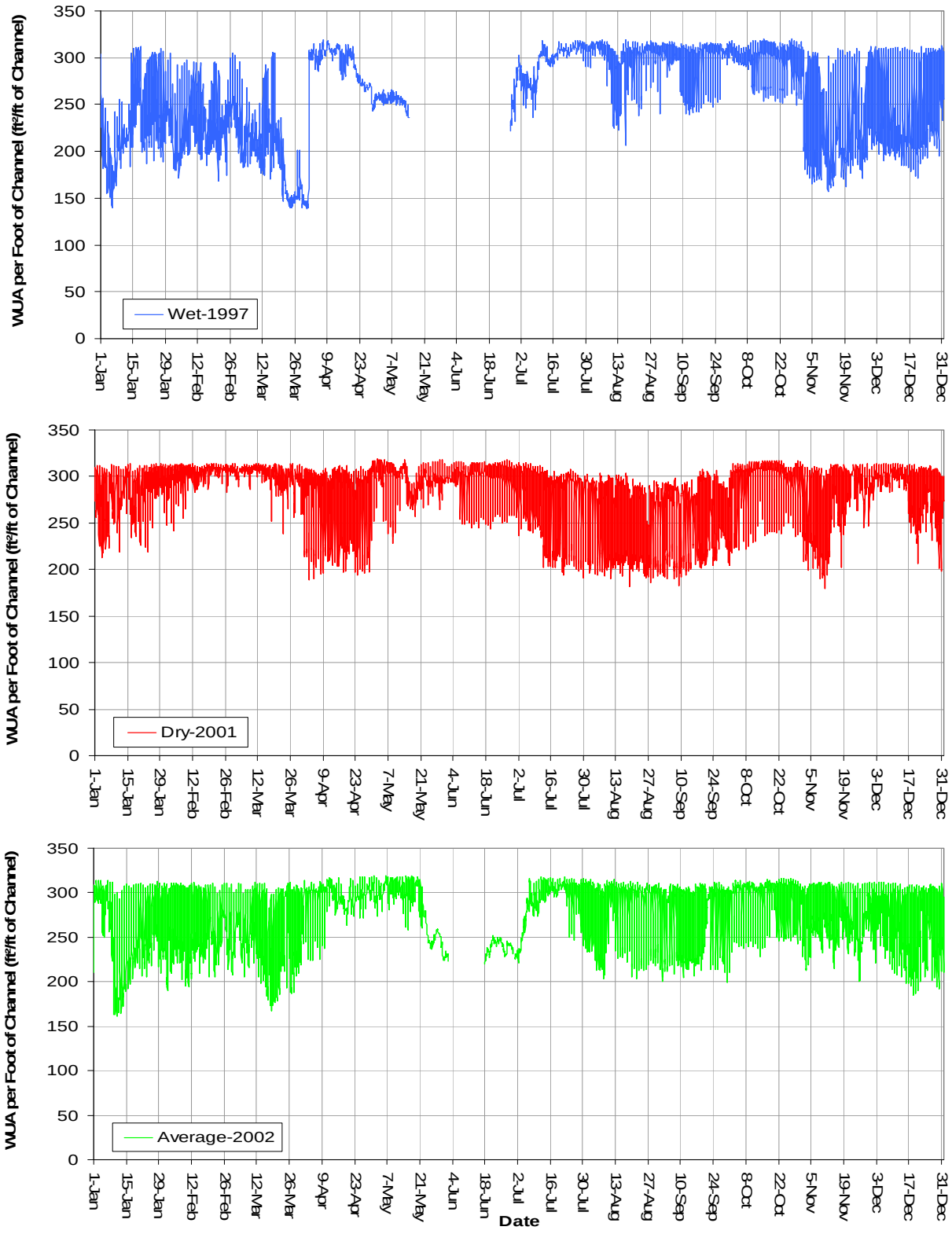


**Figure A-20.** Annual WUA for adult cutthroat trout in the Canyon Reach during the three representative years.

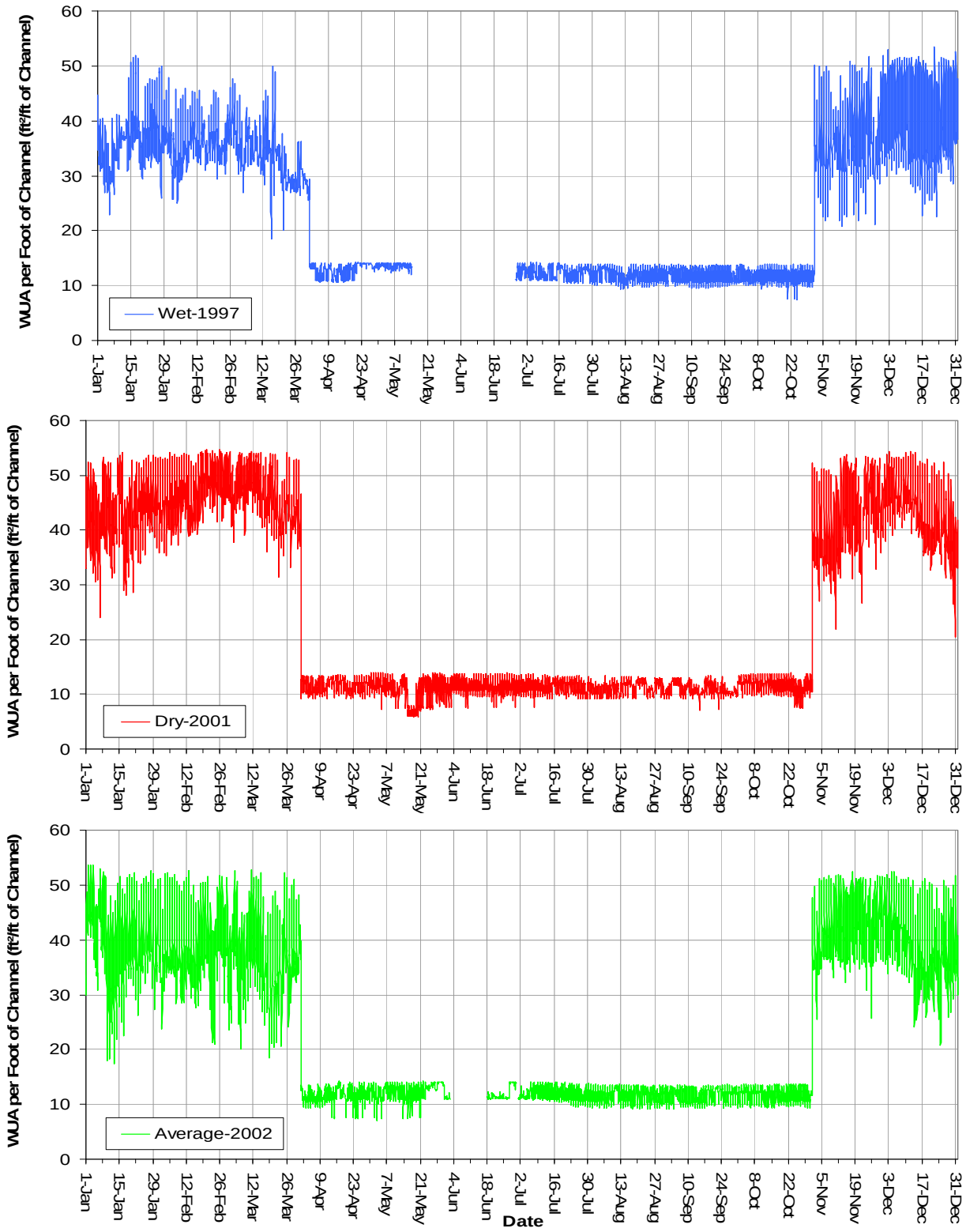


**Figure A-21.** Annual WUA for fry and juvenile cyprinids in the Canyon Reach during the three representative years.

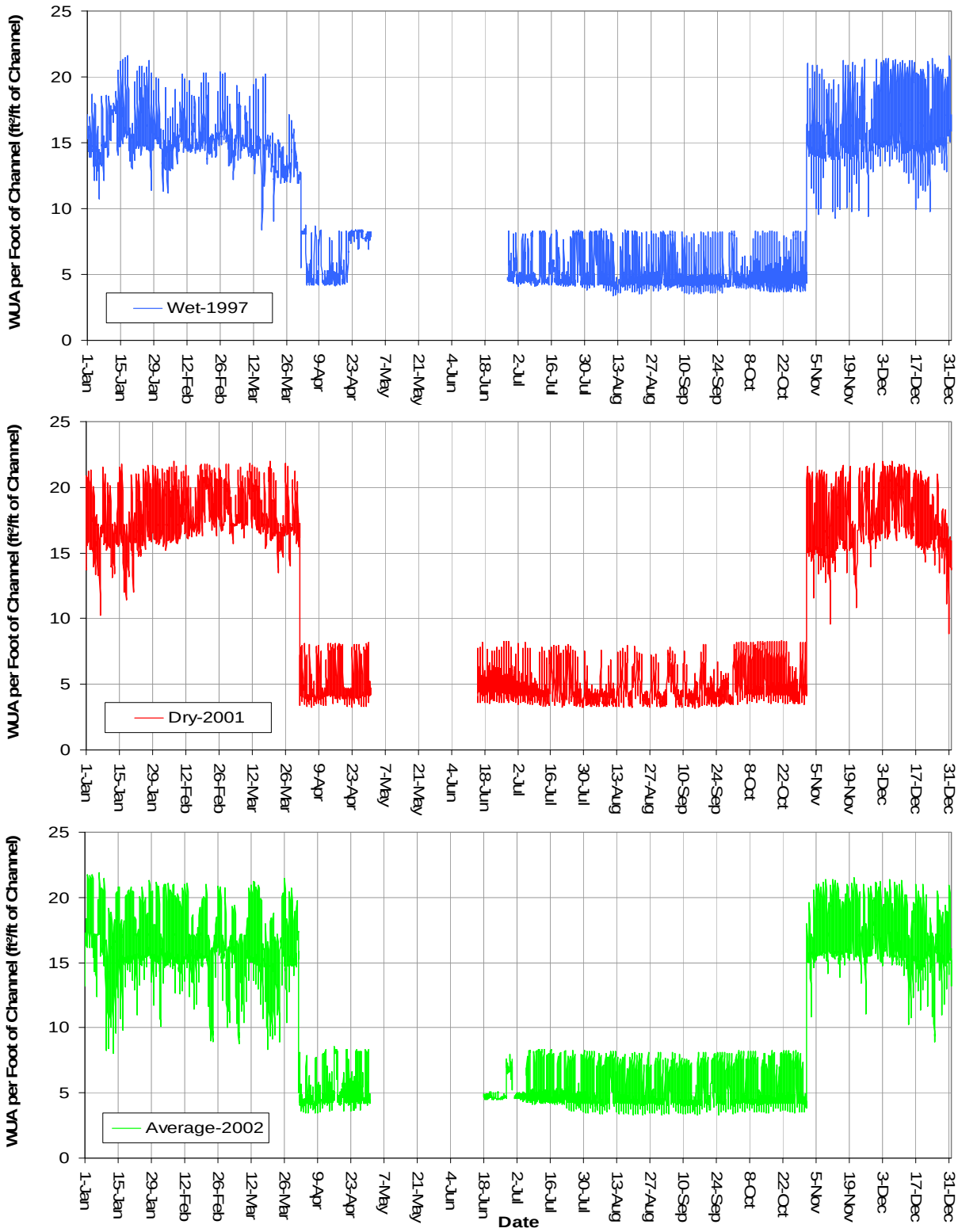


**Figure A-22.** Annual WUA for fry redband trout in the Canyon Reach during the three representative years.

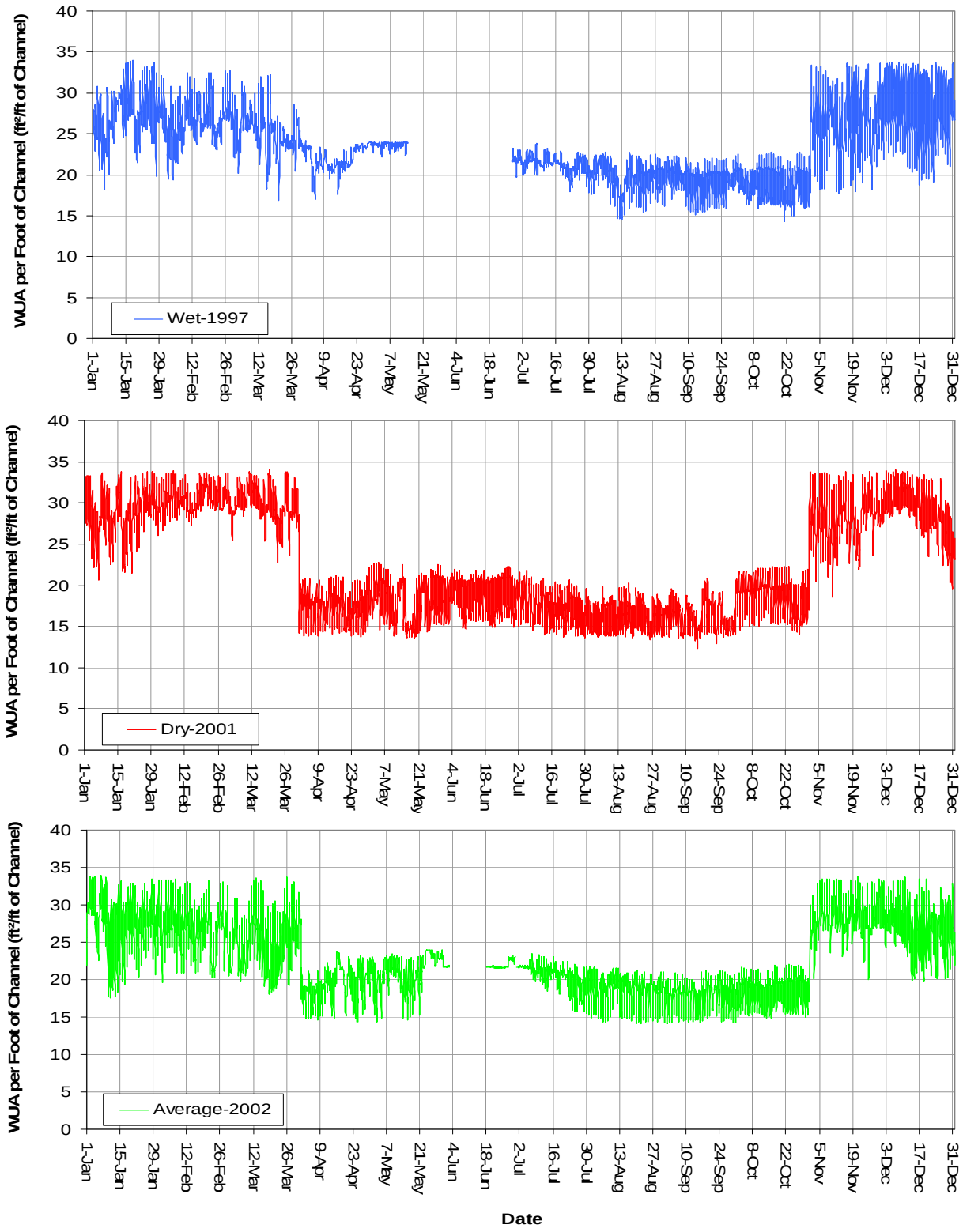


**Figure A-23.** Annual WUA for juvenile redband trout in the Canyon Reach during the three representative years.

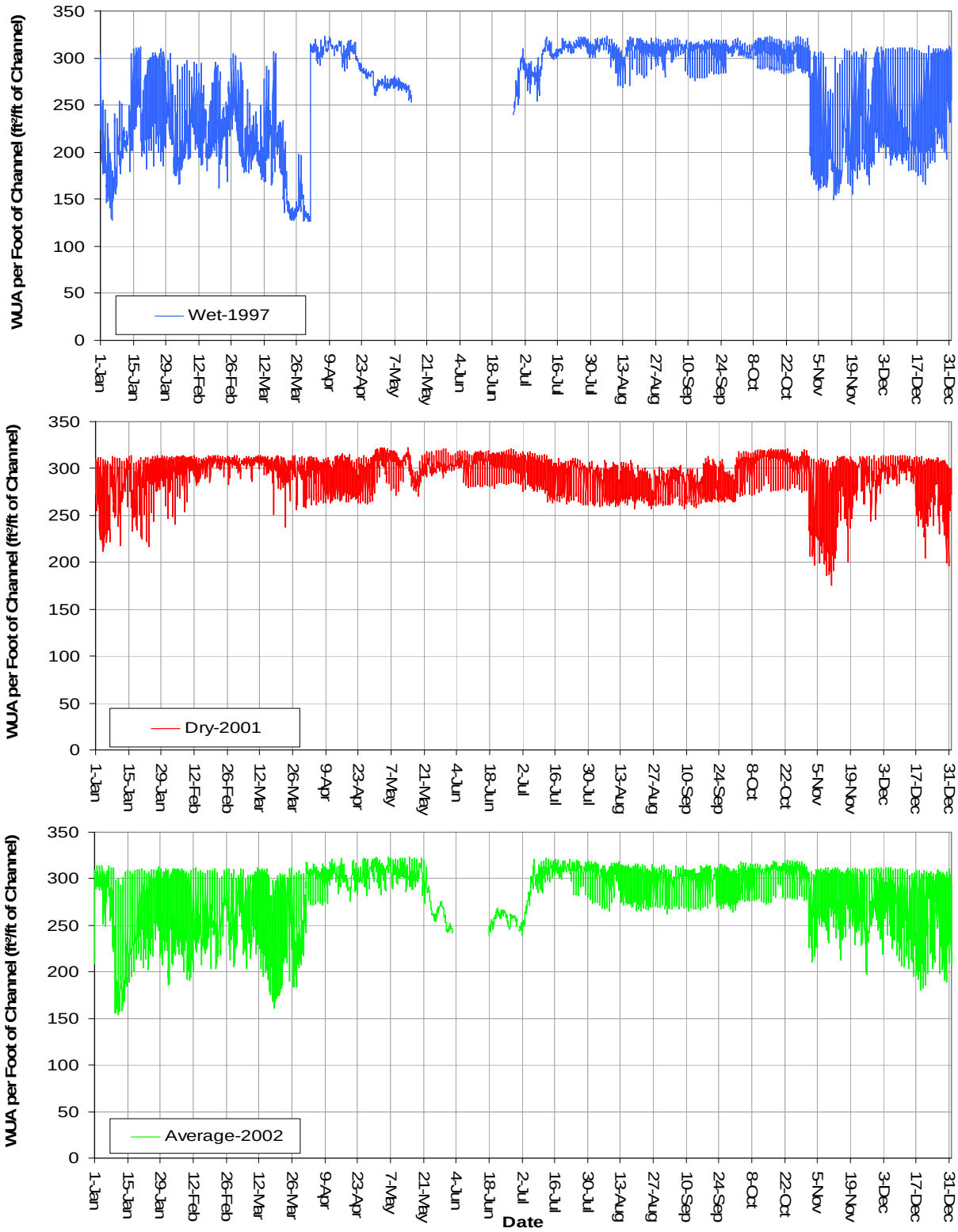


**Figure A-24.** Annual WUA for adult redband trout in the Canyon Reach during the three representative years.

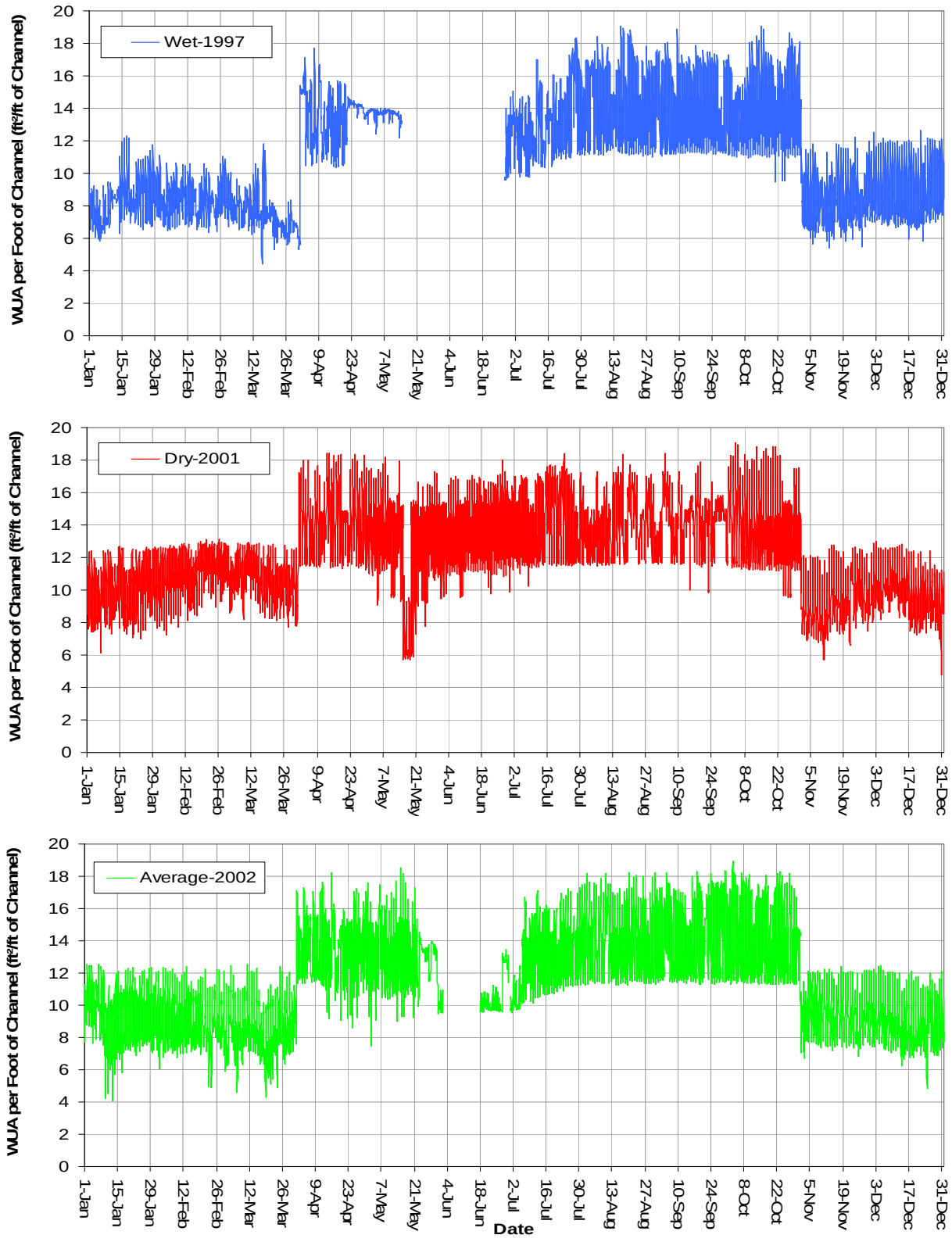


**Figure A-25.** Annual WUA for fry smallmouth bass in the Canyon Reach during the three representative years.

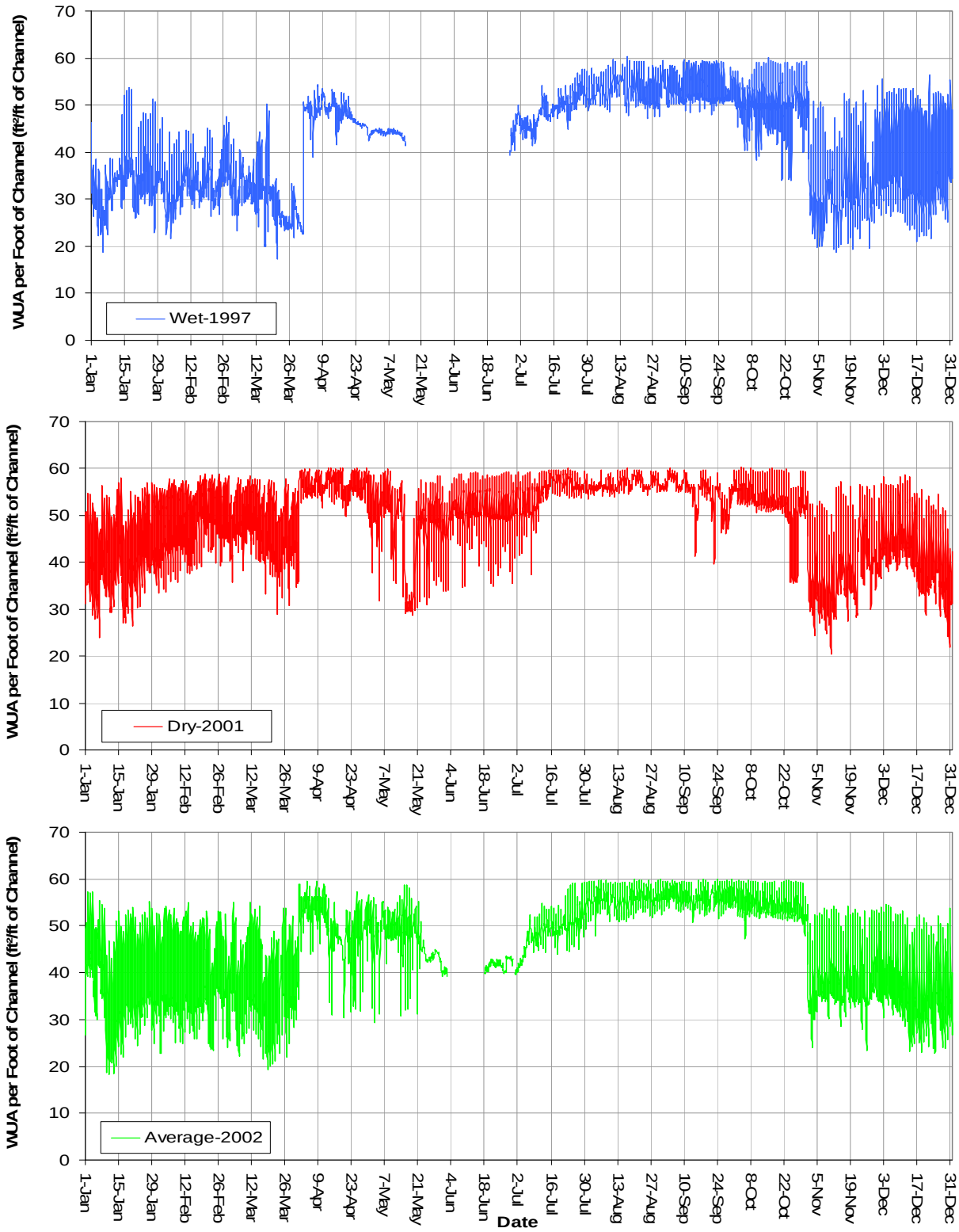


**Figure A-26.** Annual WUA for juvenile smallmouth bass in the Canyon Reach during the three representative years.

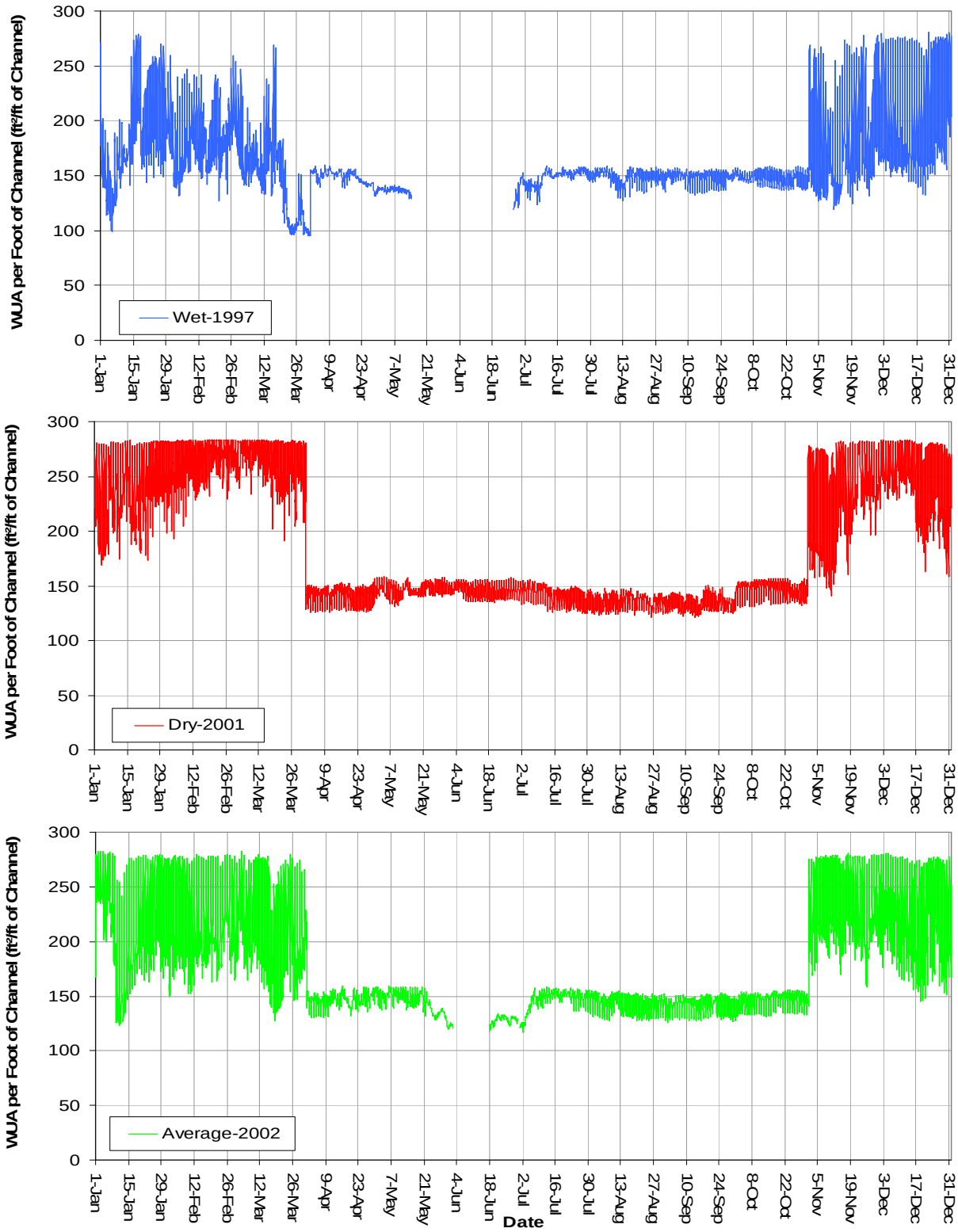


**Figure A-27.** Annual WUA for adult smallmouth bass in the Canyon Reach during the three representative years.

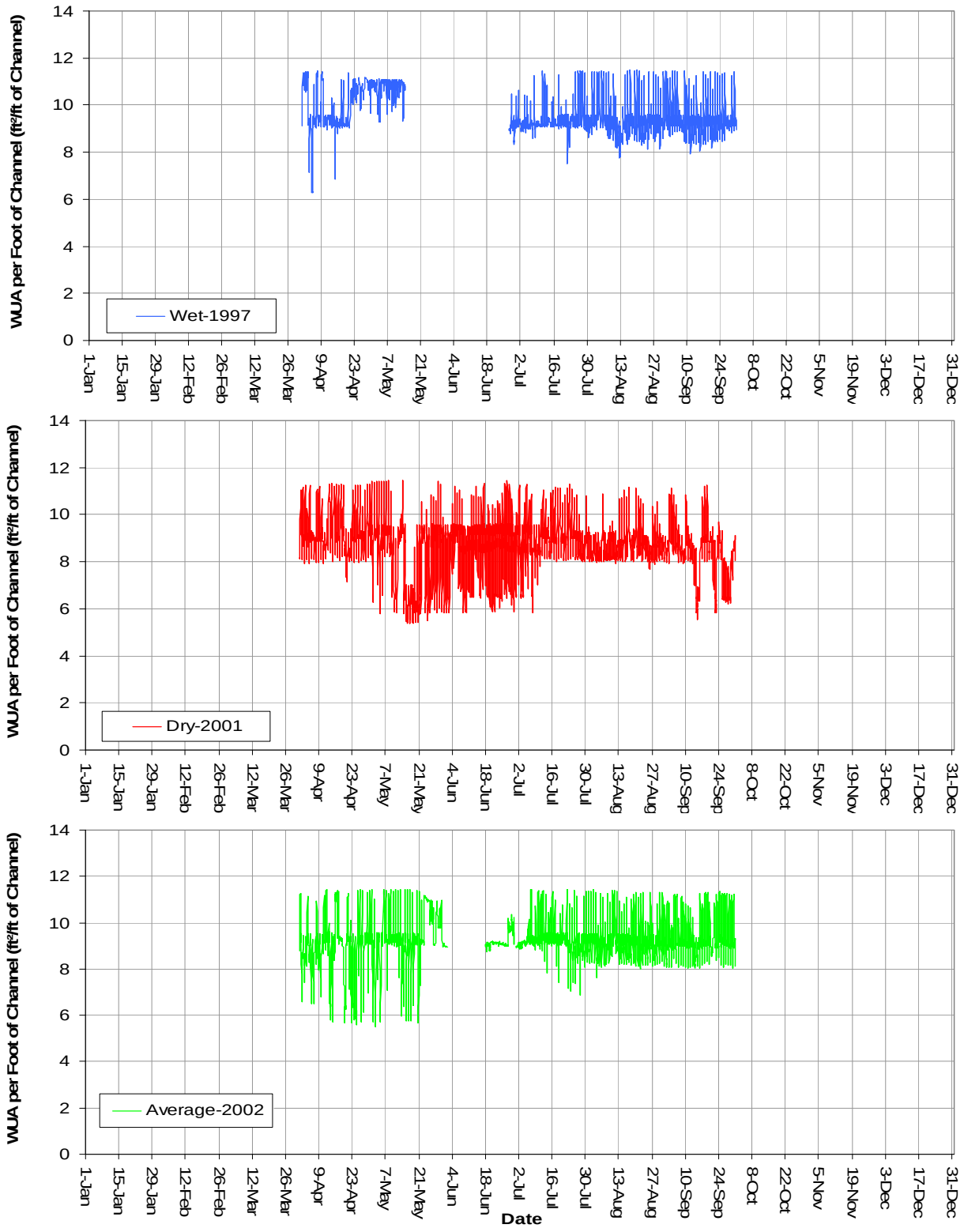


**Figure A-28.** Annual WUA for fry whitefish in the Canyon Reach during the three representative years.

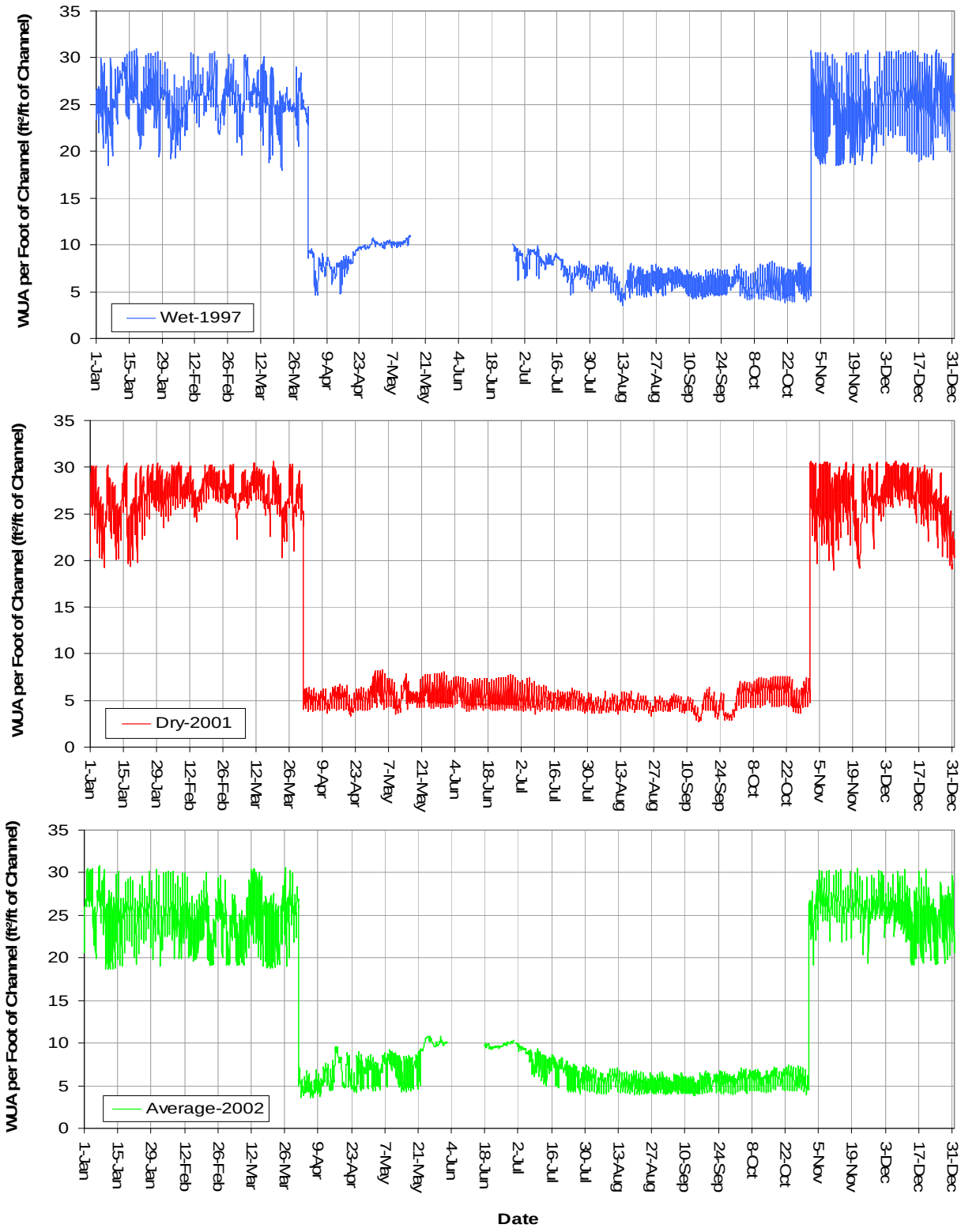


**Figure A-29.** Annual WUA for juvenile whitefish in the Canyon Reach during the three representative years.

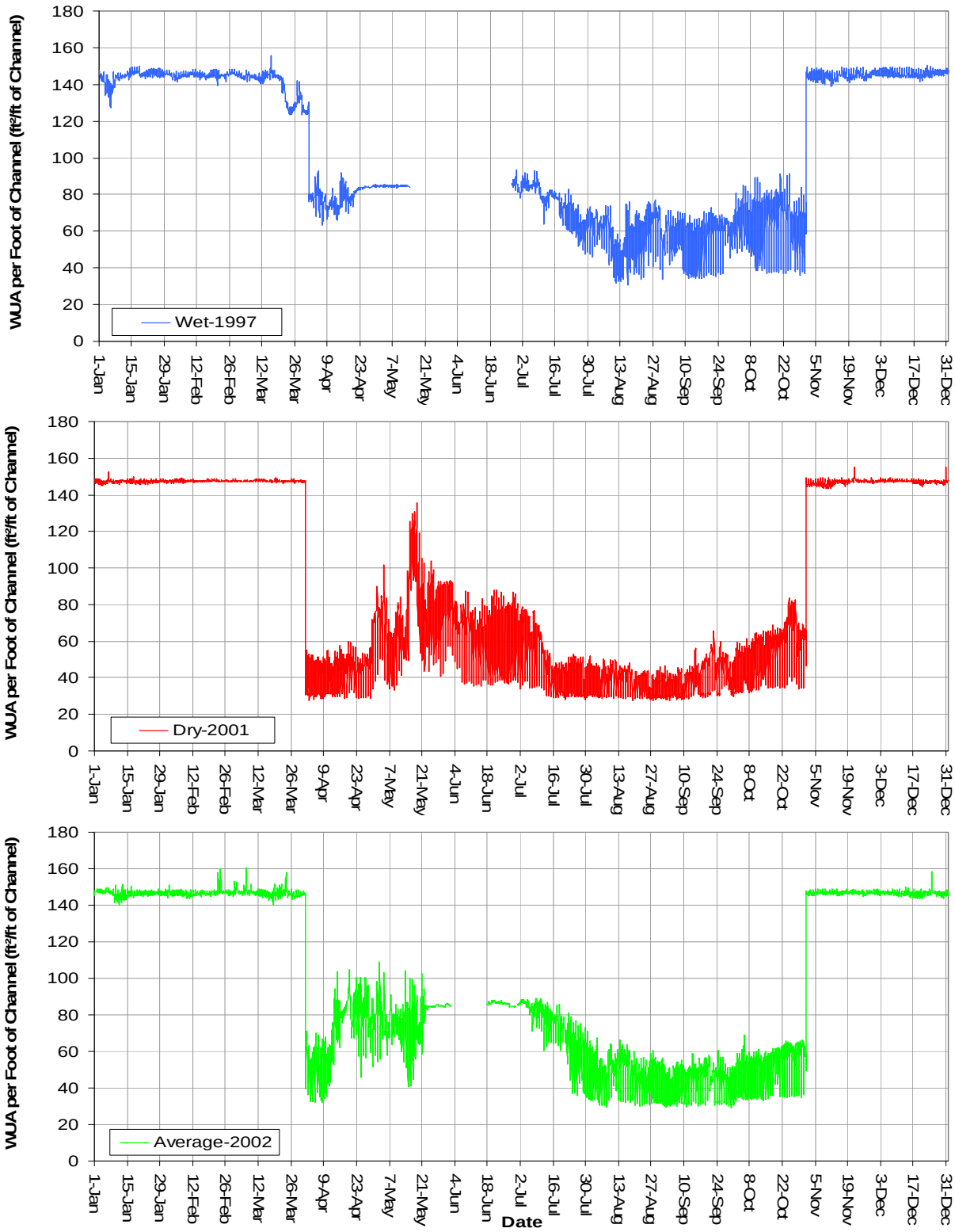


**Figure A-30.** Annual WUA for adult whitefish in the Canyon Reach during the three representative years.

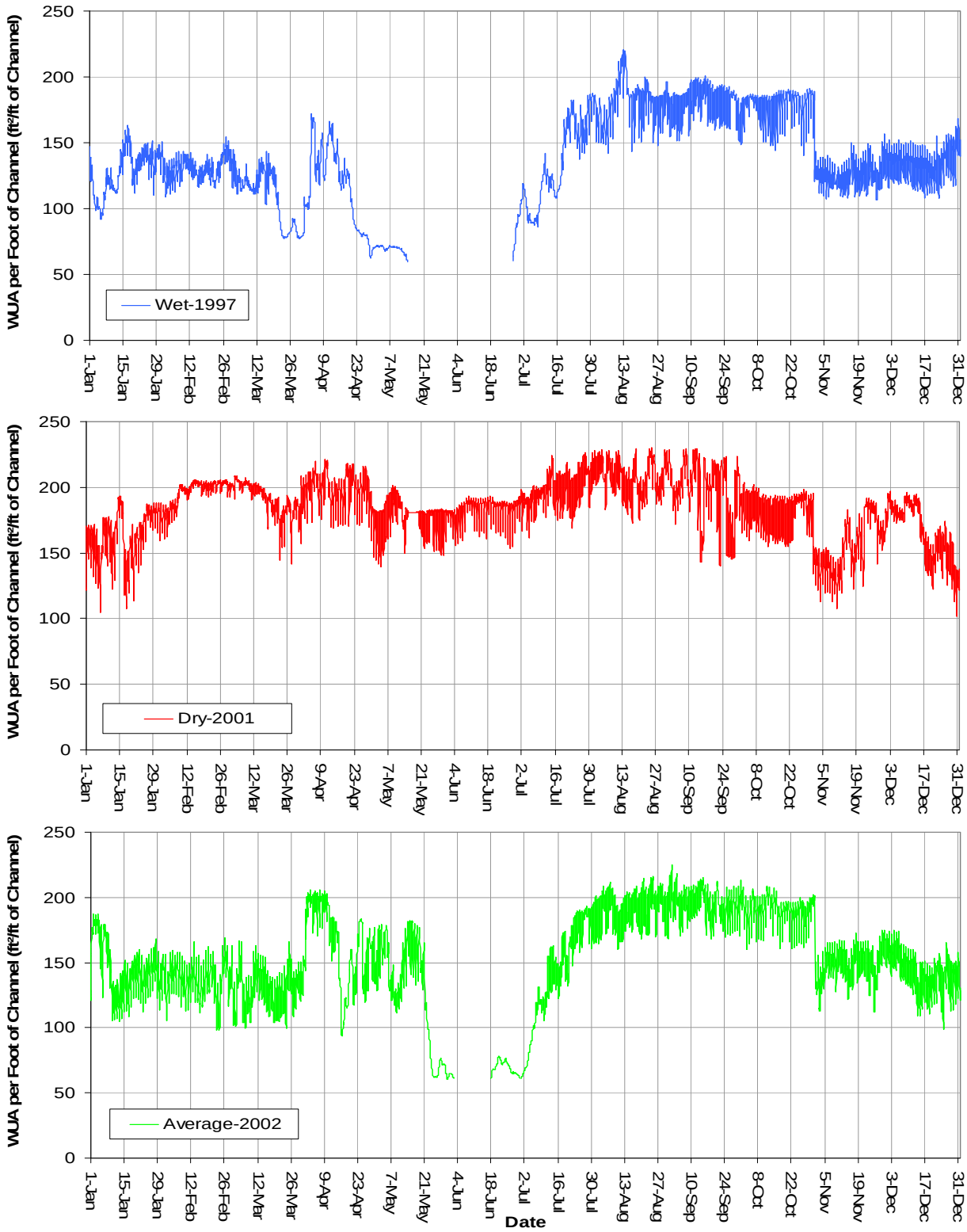


**Figure A-31.** Annual WUA for juvenile bull trout in the Upper Reservoir Reach during the three representative years.

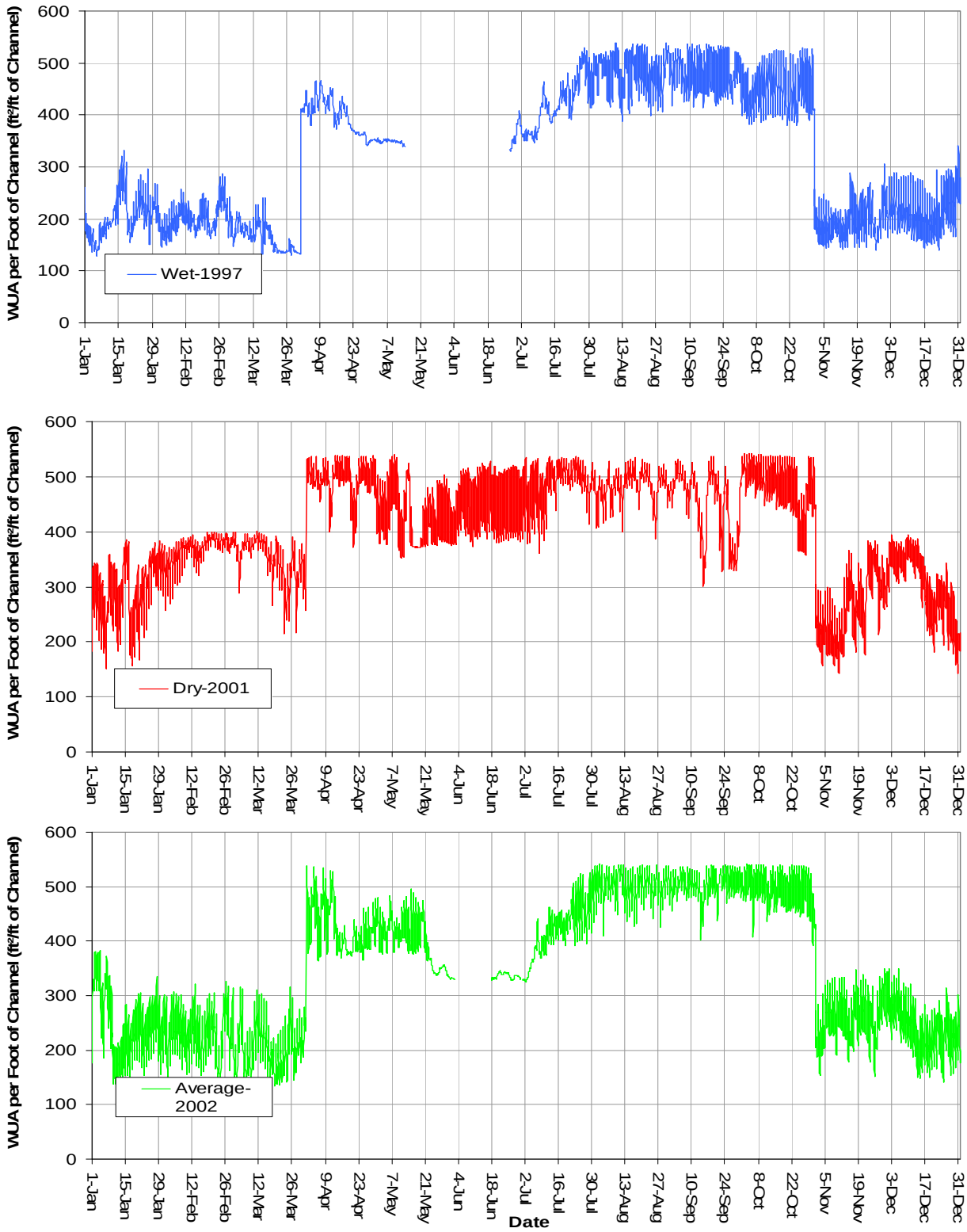


**Figure A-32.** Annual WUA for adult bull trout in the Upper Reservoir Reach during the three representative years.

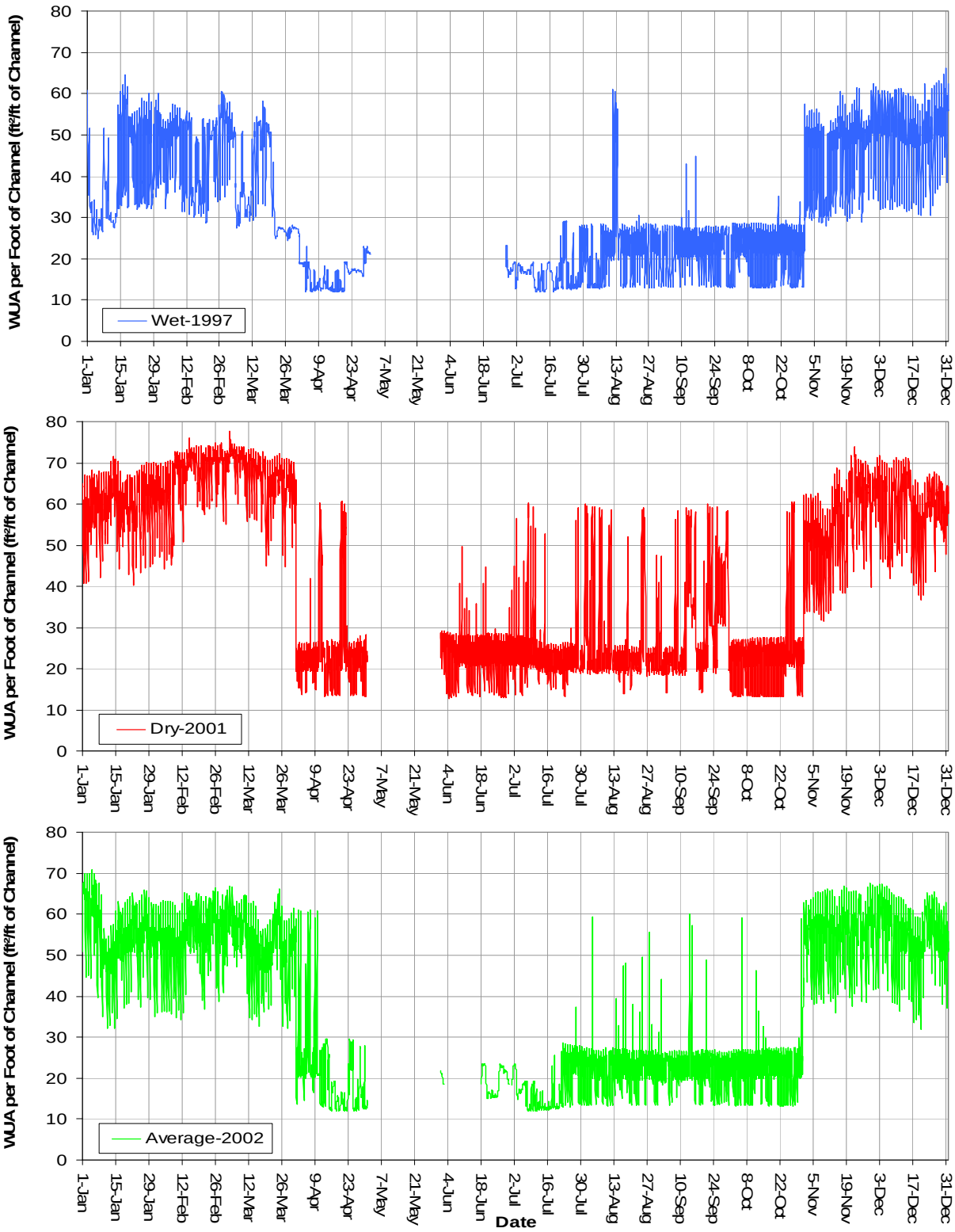


**Figure A-33.** Annual WUA for fry cutthroat trout in the Upper Reservoir Reach during the three representative years.

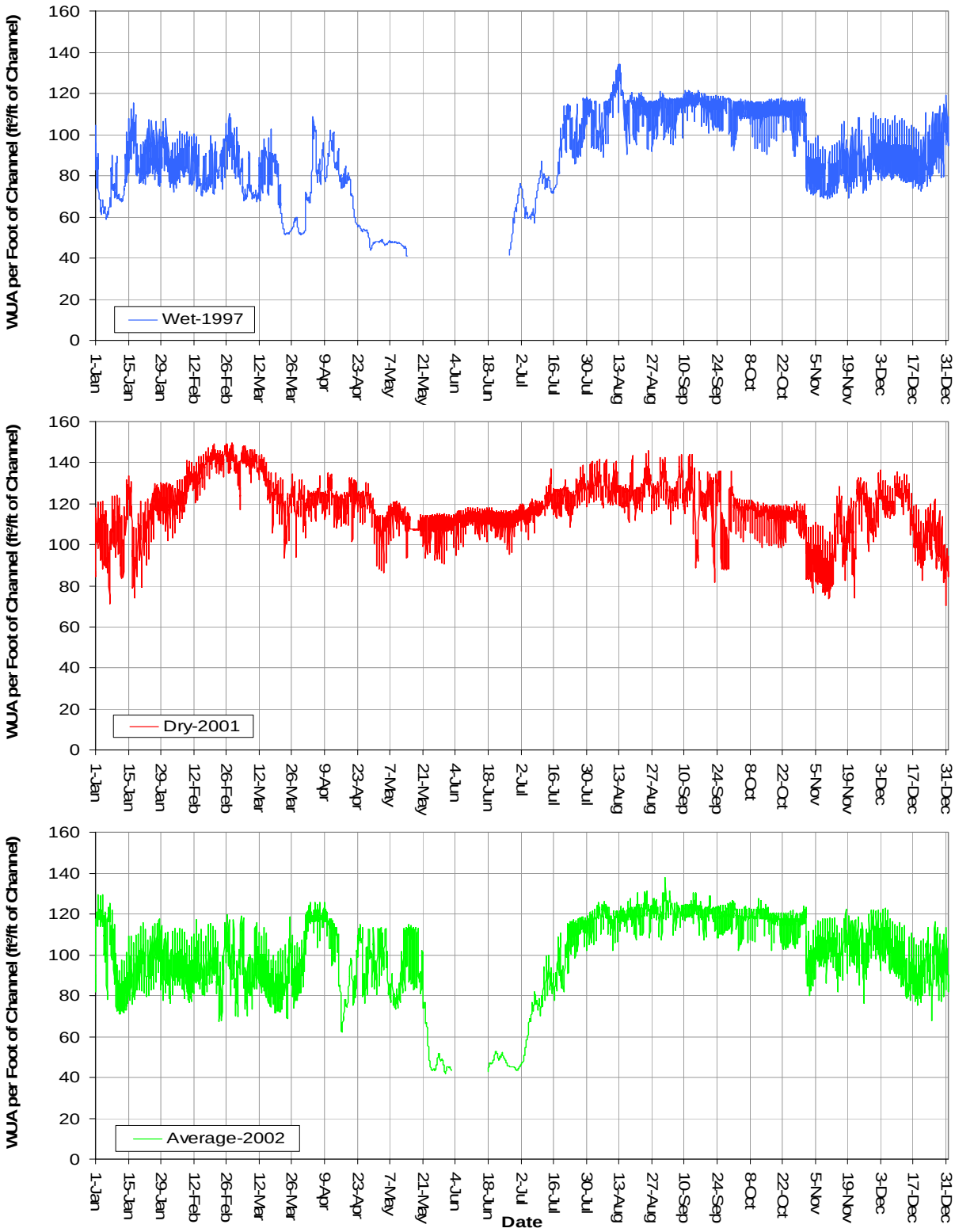


**Figure A-34.** Annual WUA for juvenile cutthroat trout in the Upper Reservoir Reach during the three representative years.

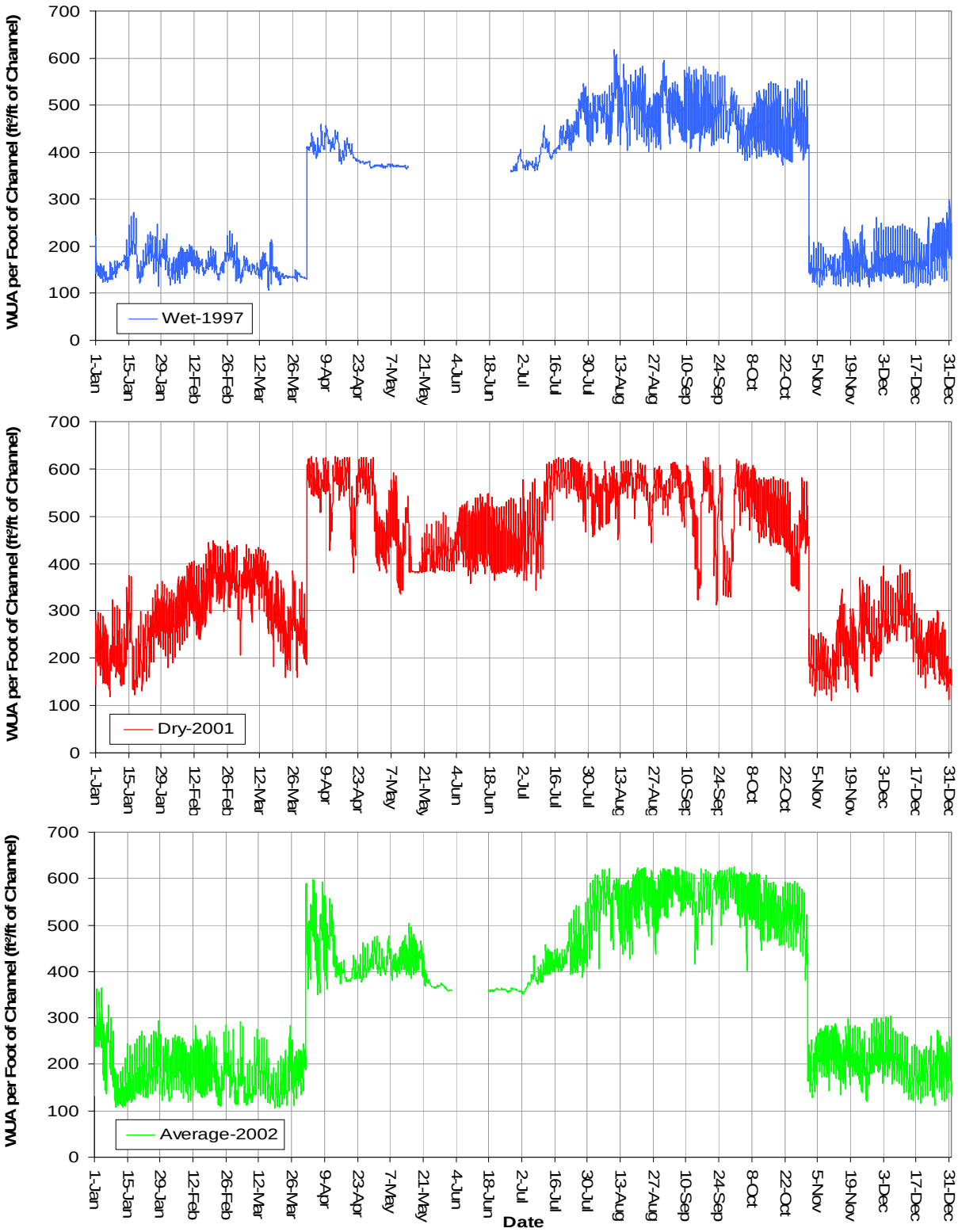


**Figure A-35.** Annual WUA for adult cutthroat trout in the Upper Reservoir Reach during the three representative years.

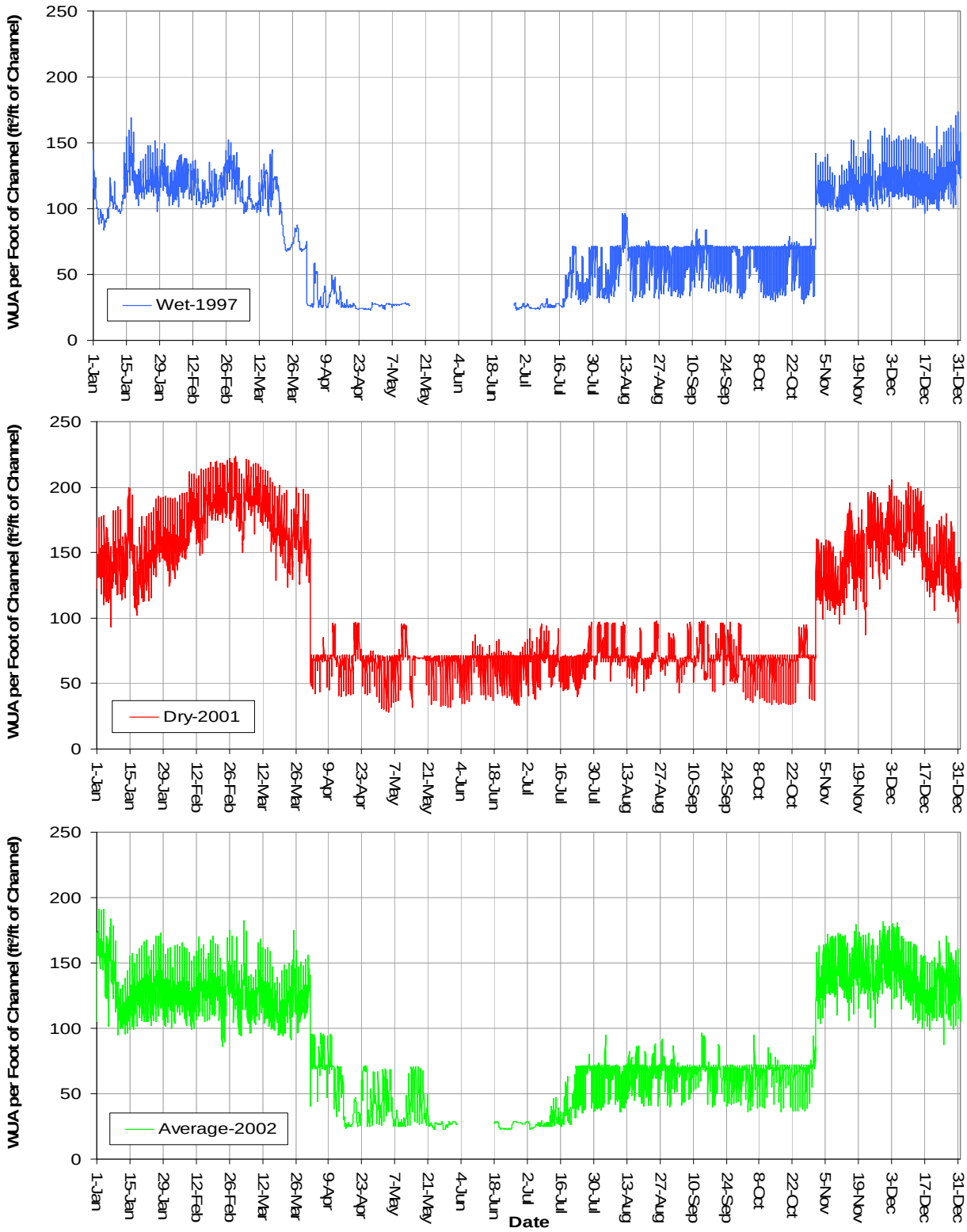


**Figure A-36.** Annual WUA for fry and juvenile cyprinids in the Upper Reservoir Reach during the three representative years.

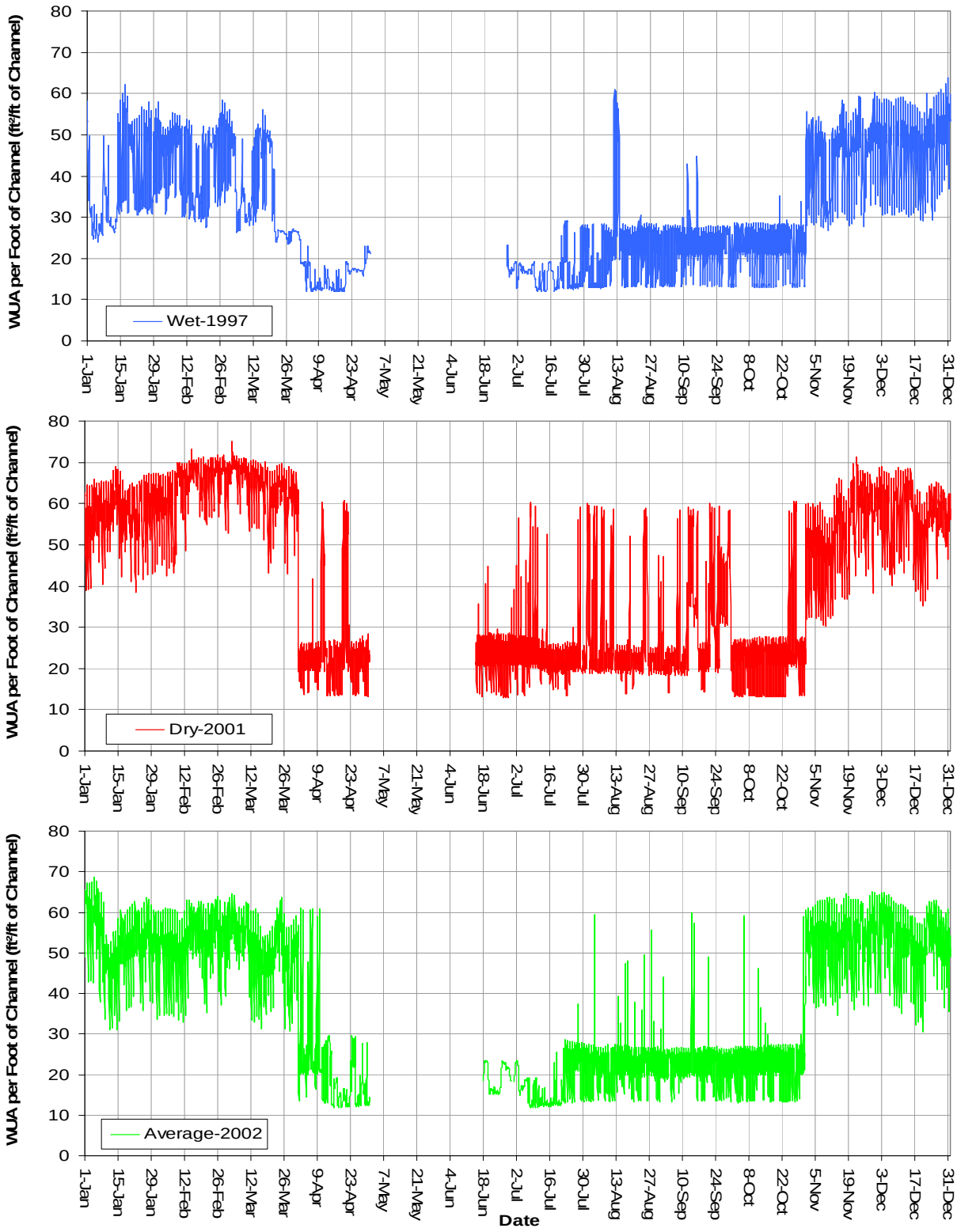


**Figure A-37.** Annual WUA for fry redband trout in the Upper Reservoir Reach during the three representative years.

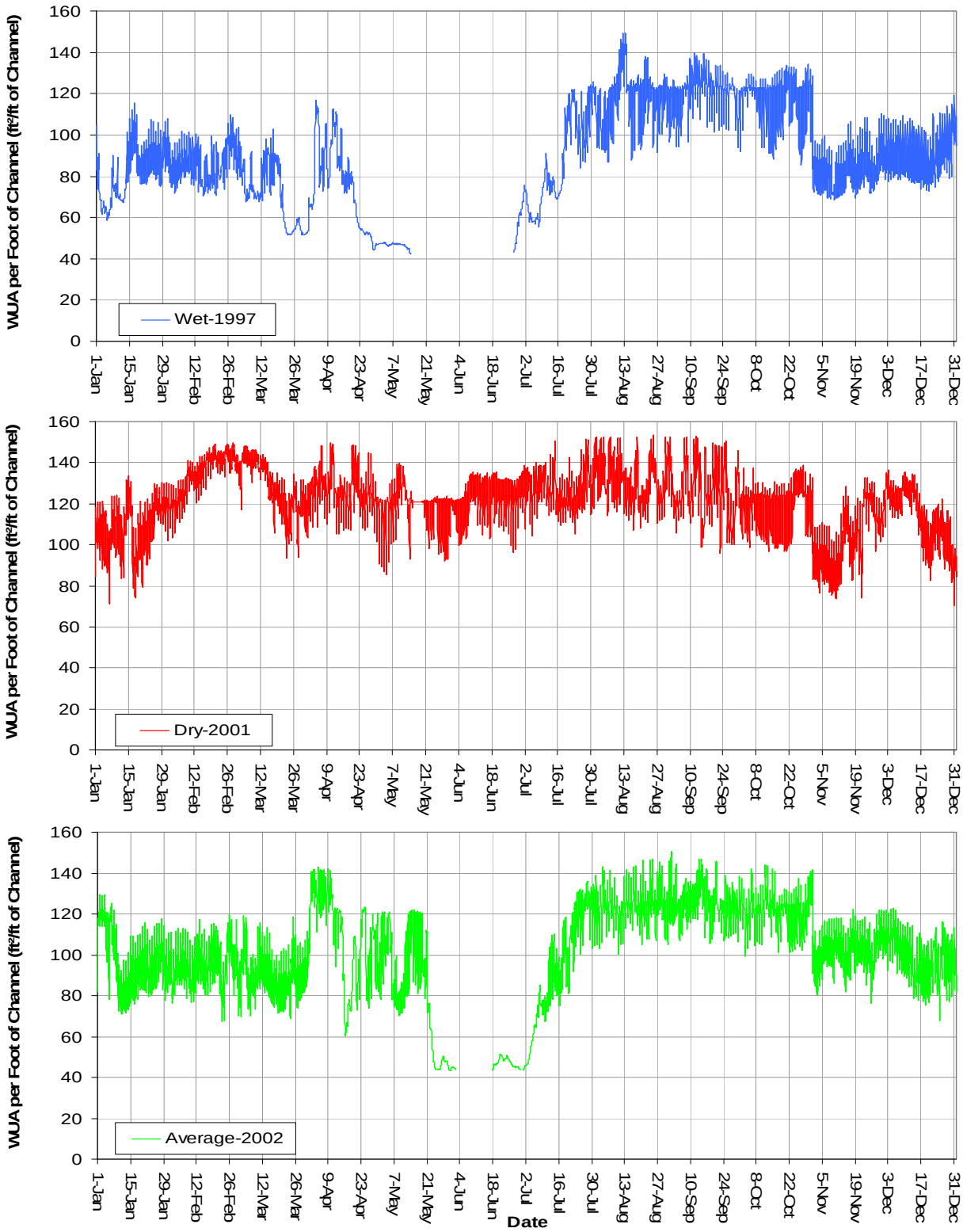


**Figure A-38.** Annual WUA for juvenile redband trout in the Upper Reservoir Reach during the three representative years.

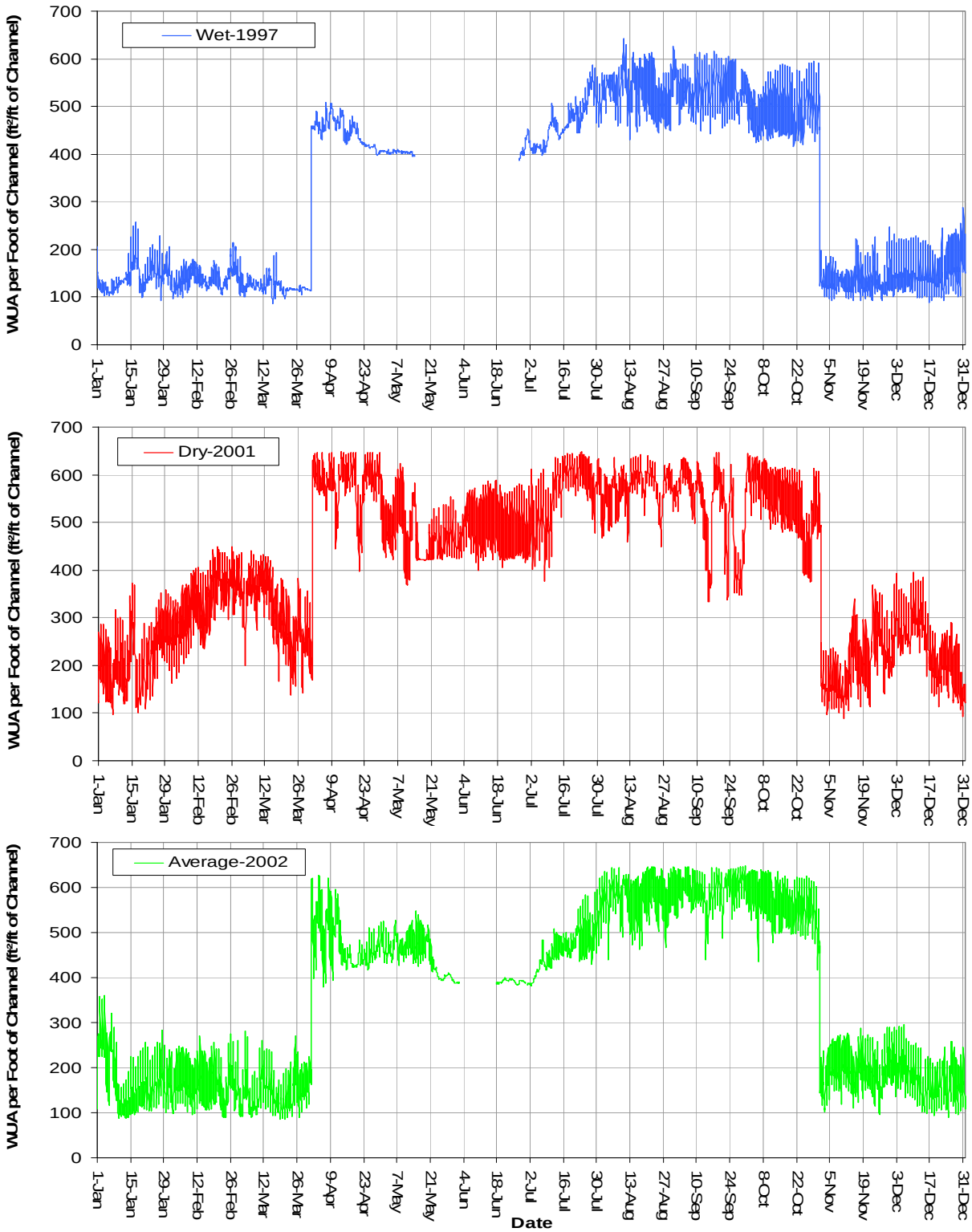


**Figure A-39.** Annual WUA for adult redband trout in the Upper Reservoir Reach during the three representative years.

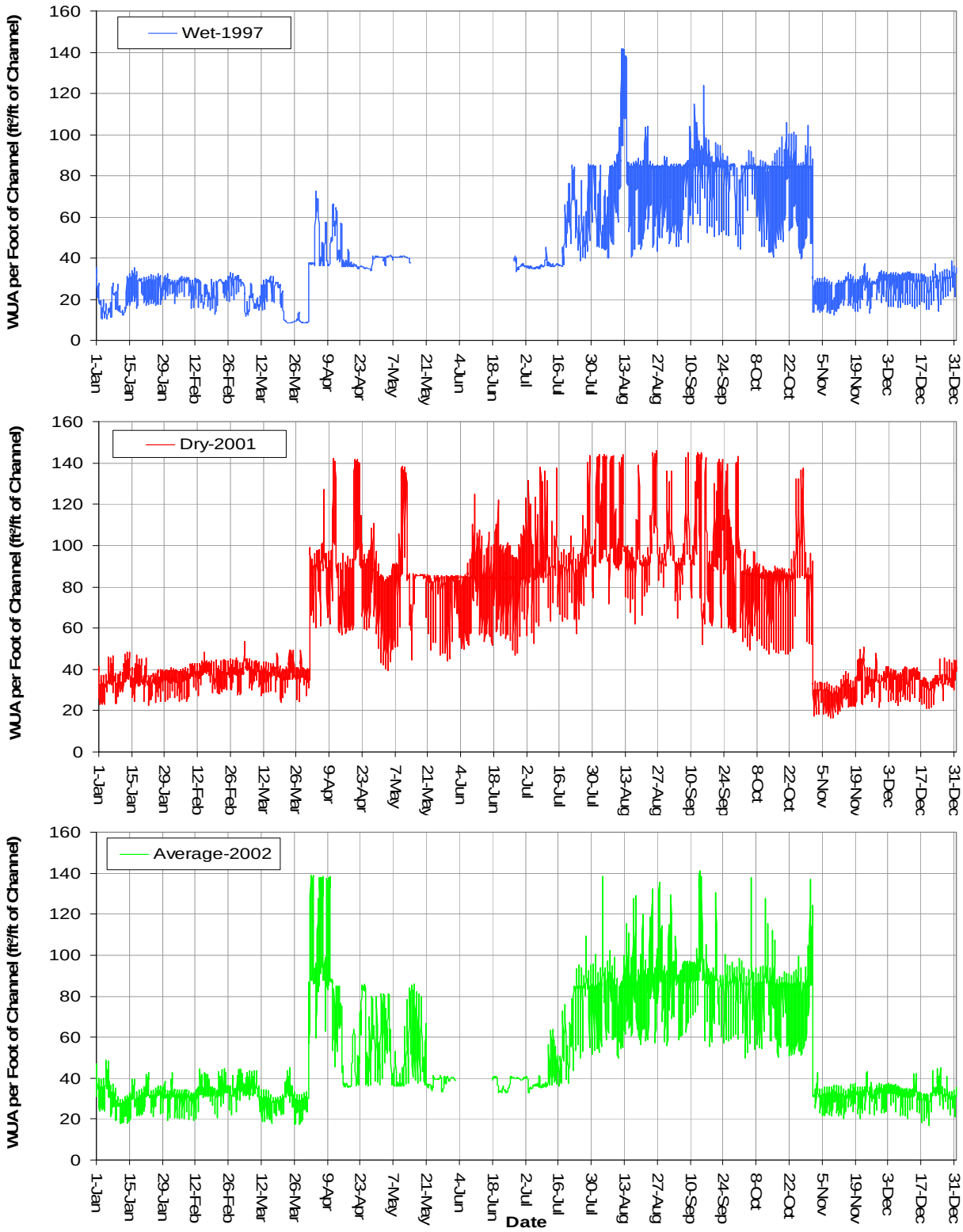


**Figure A-40.** Annual WUA for fry smallmouth bass in the Upper Reservoir Reach during the three representative years.

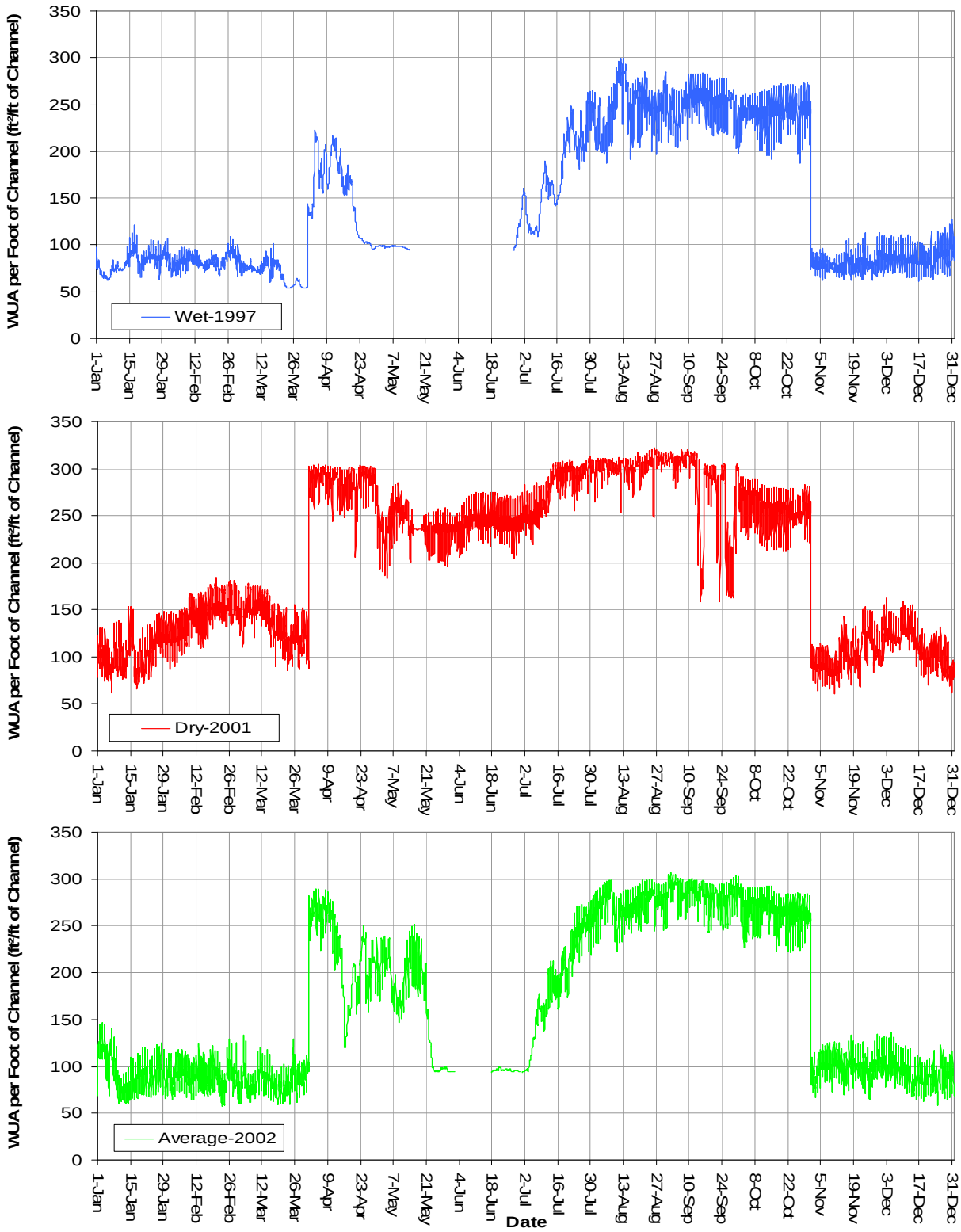


**Figure A-41.** Annual WUA for juvenile smallmouth bass in the Upper Reservoir Reach during the three representative years.

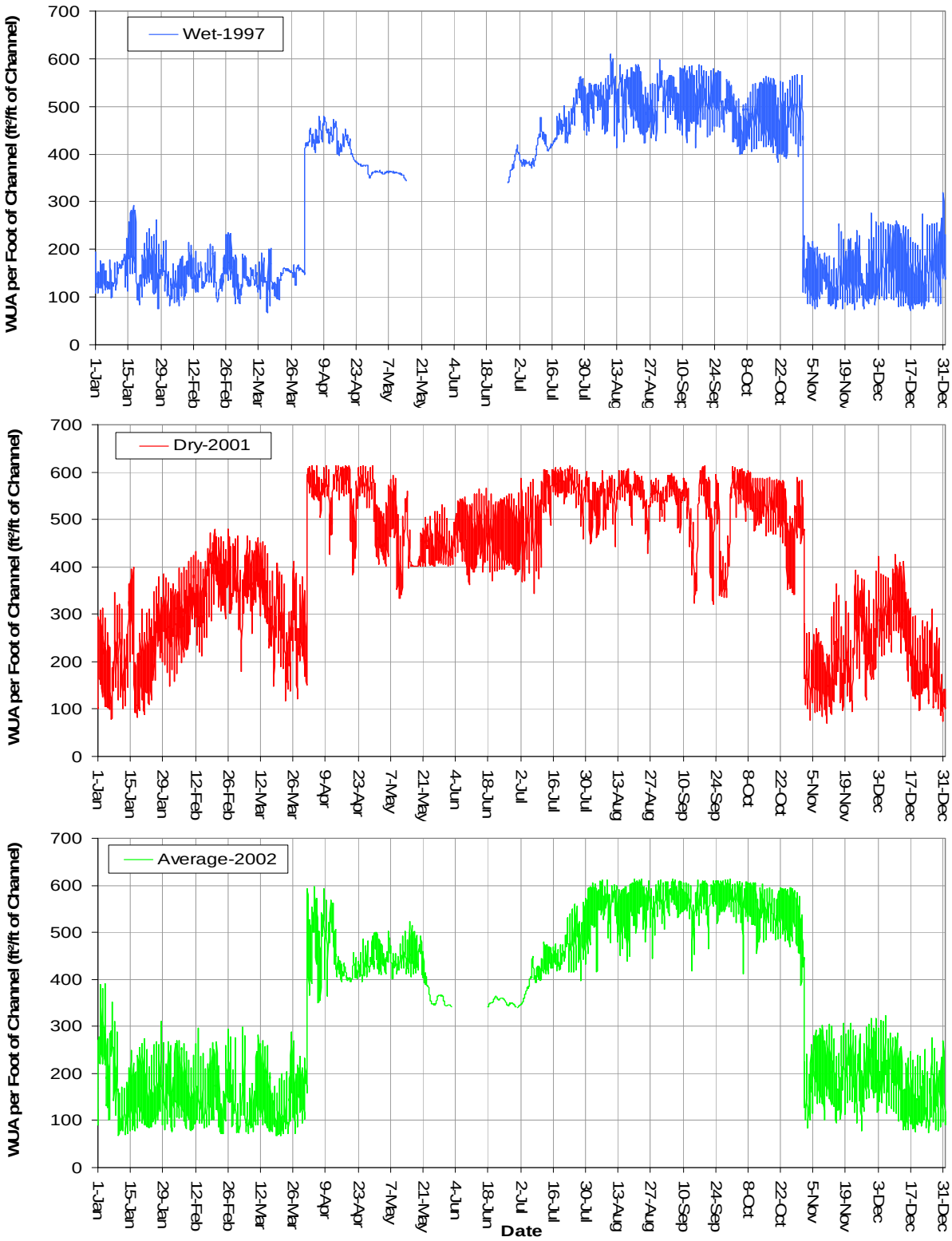


**Figure A-42.** Annual WUA for adult smallmouth bass in the Upper Reservoir Reach during the three representative years.

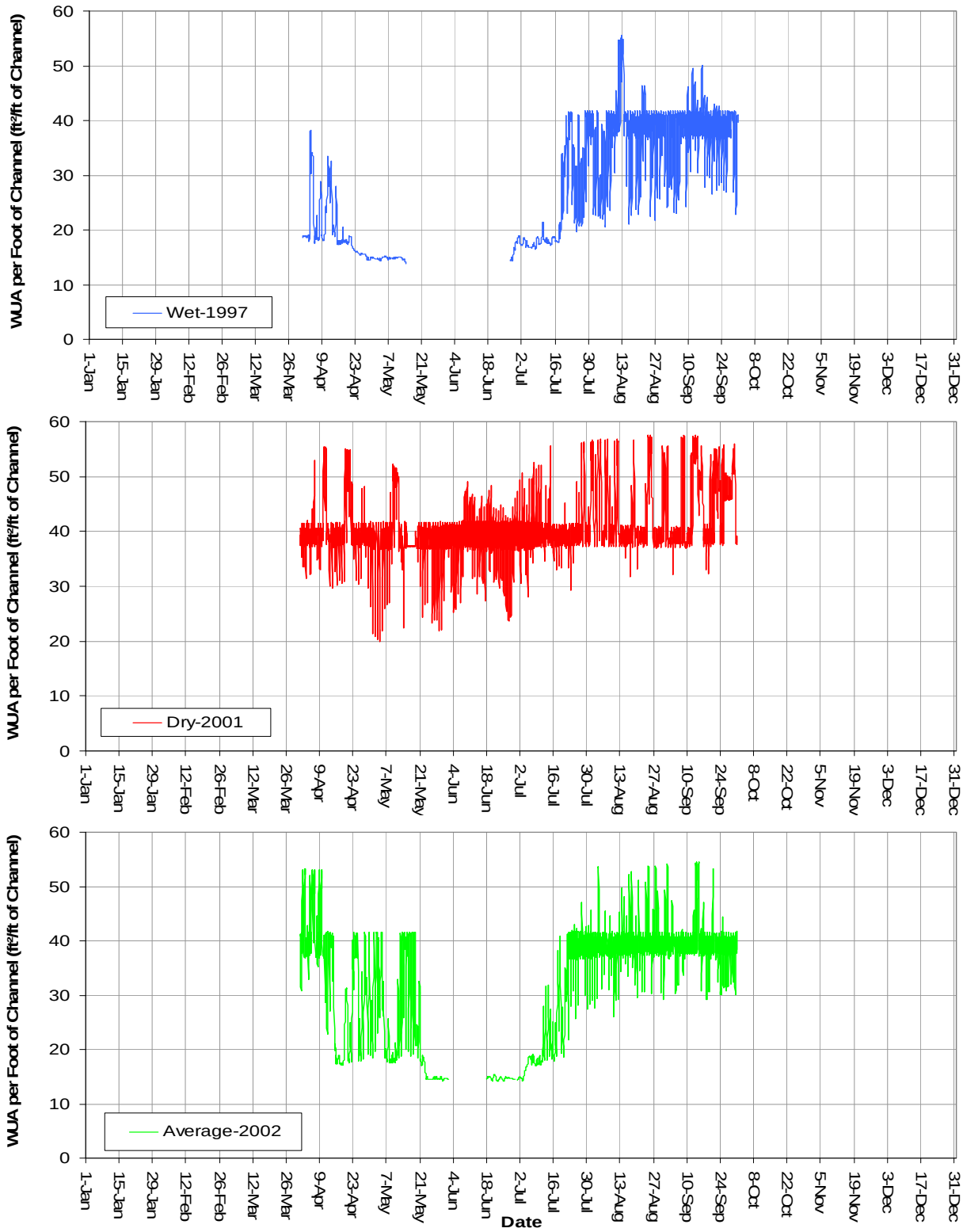


**Figure A-43.** Annual WUA for fry whitefish in the Upper Reservoir Reach during the three representative years.

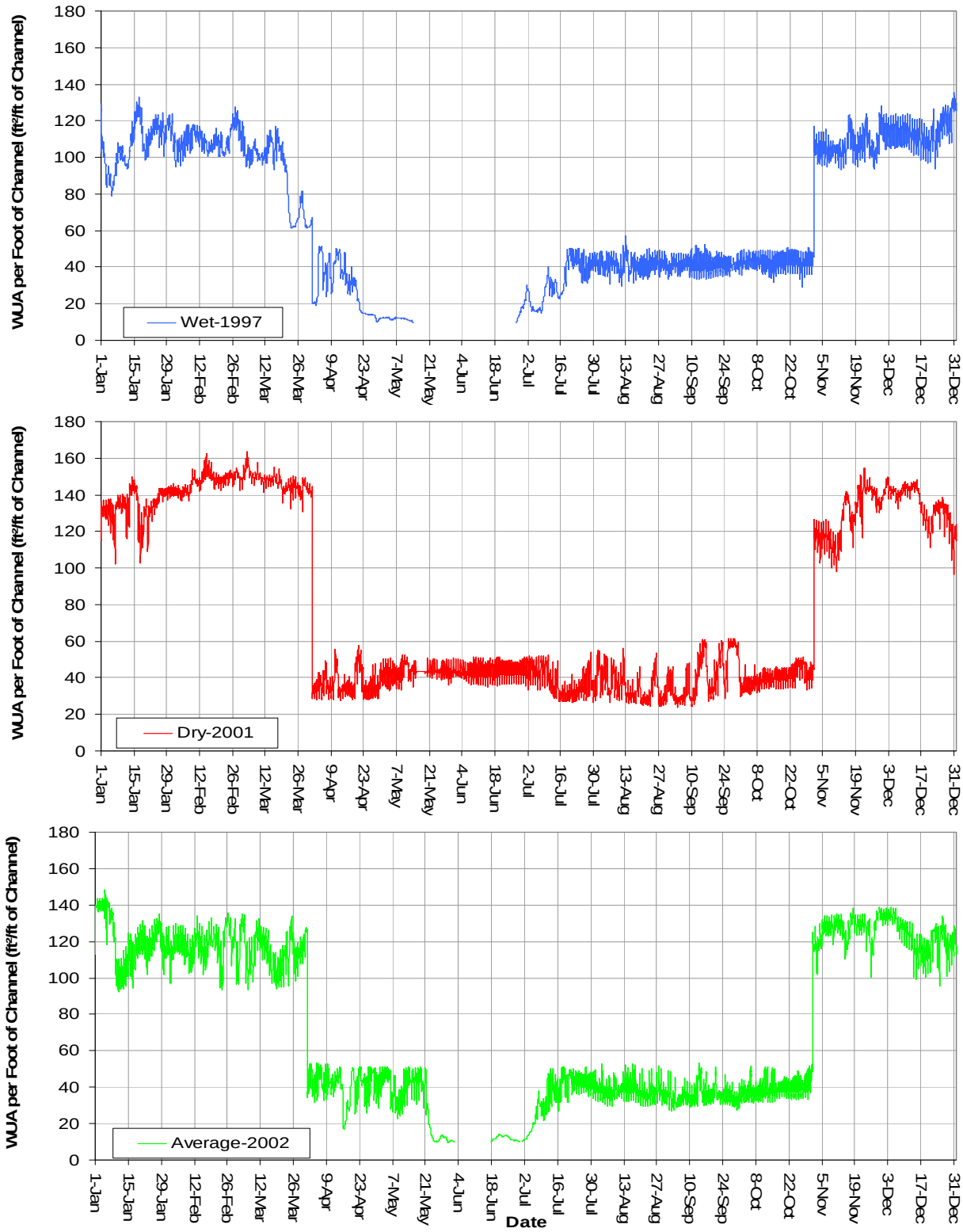


**Figure A-44.** Annual WUA for juvenile whitefish in the Upper Reservoir Reach during the three representative years.

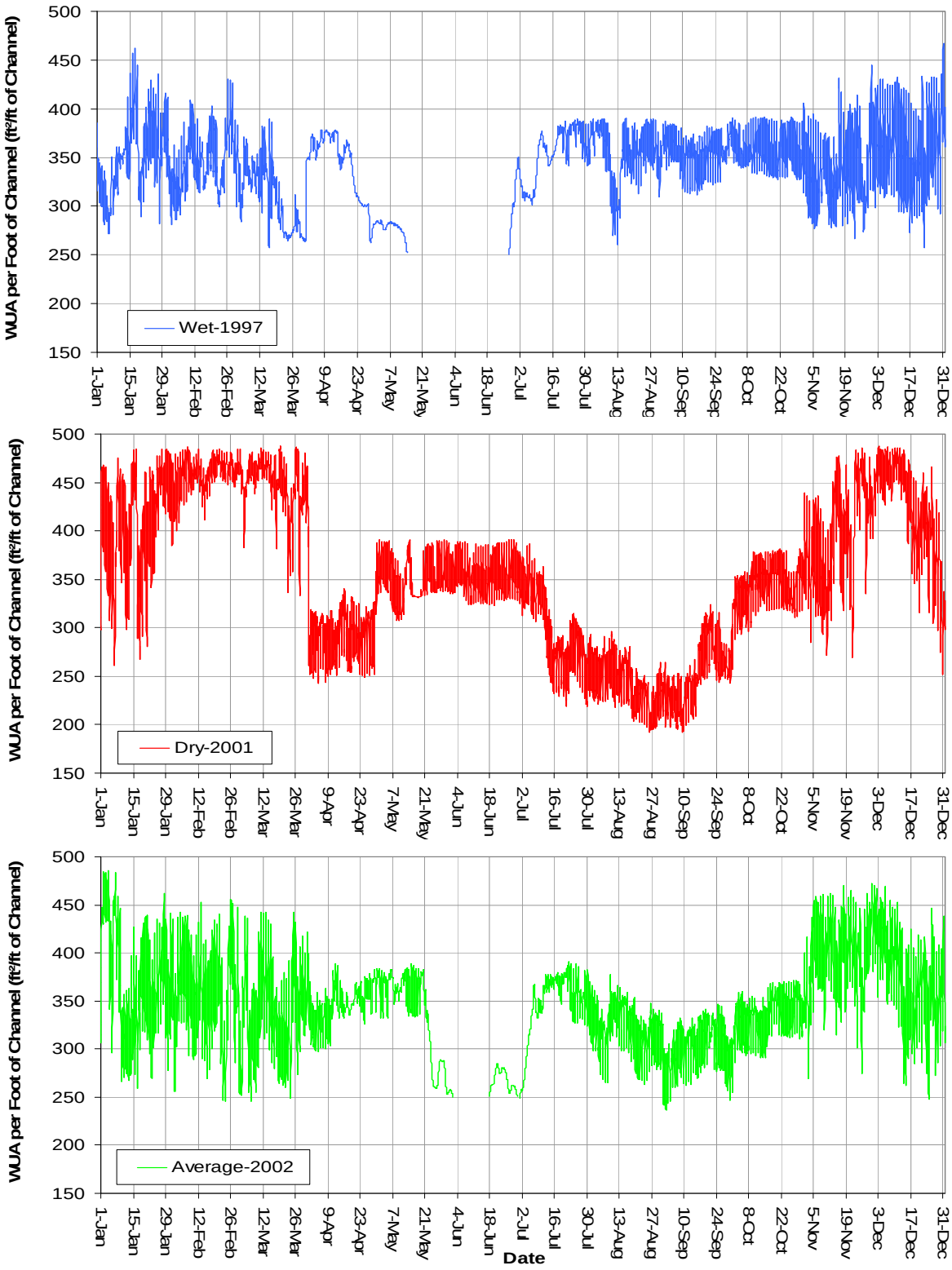


**Figure A-45.** Annual WUA for adult whitefish in the Upper Reservoir Reach during the three representative years.

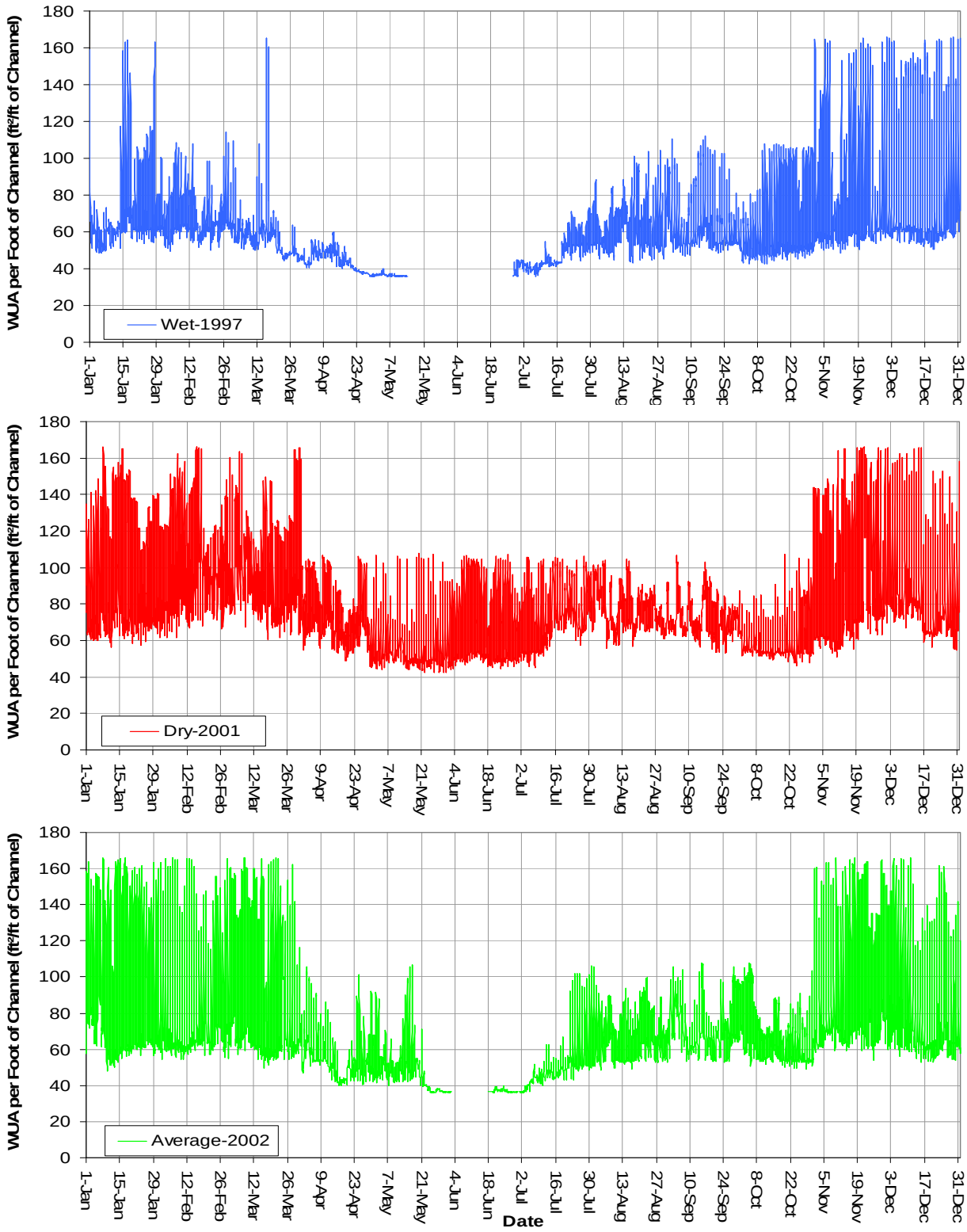


**Figure A-46.** Annual WUA for juvenile bull trout in the Tailrace Reach during the three representative years.

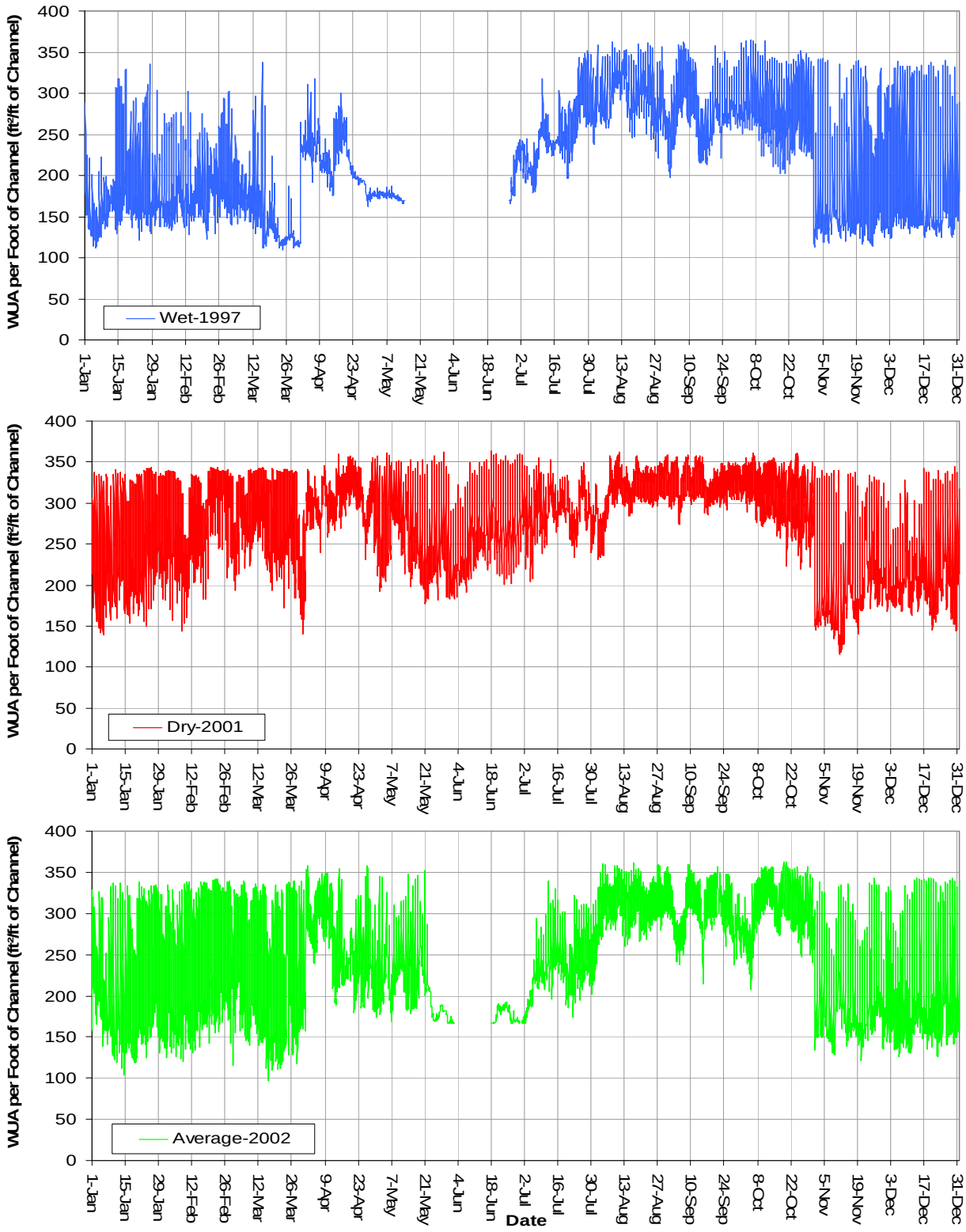


**Figure A-47.** Annual WUA for adult bull trout in the Tailrace Reach during the three representative years.

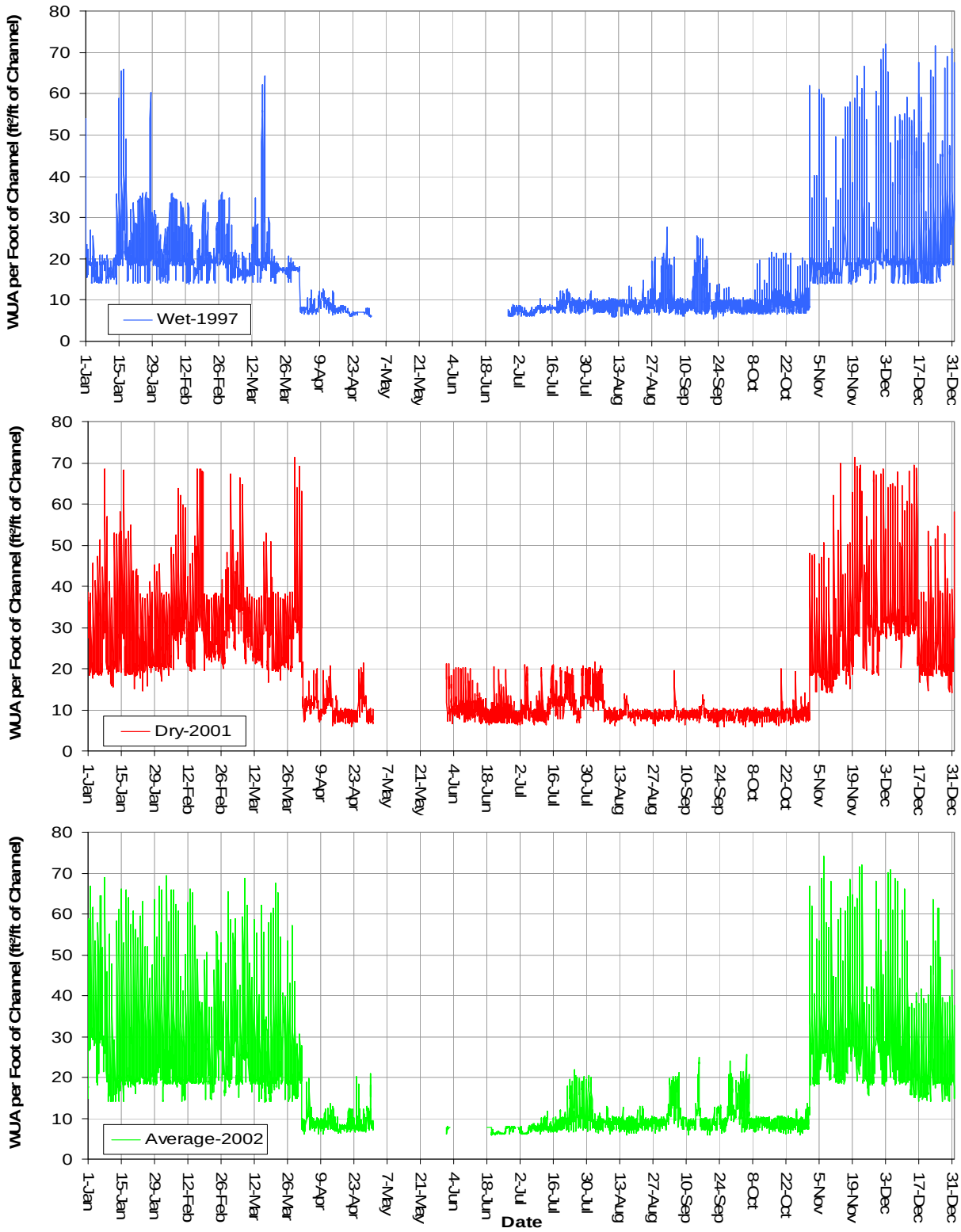


**Figure A-48.** Annual WUA for fry cutthroat trout in the Tailrace Reach during the three representative years.

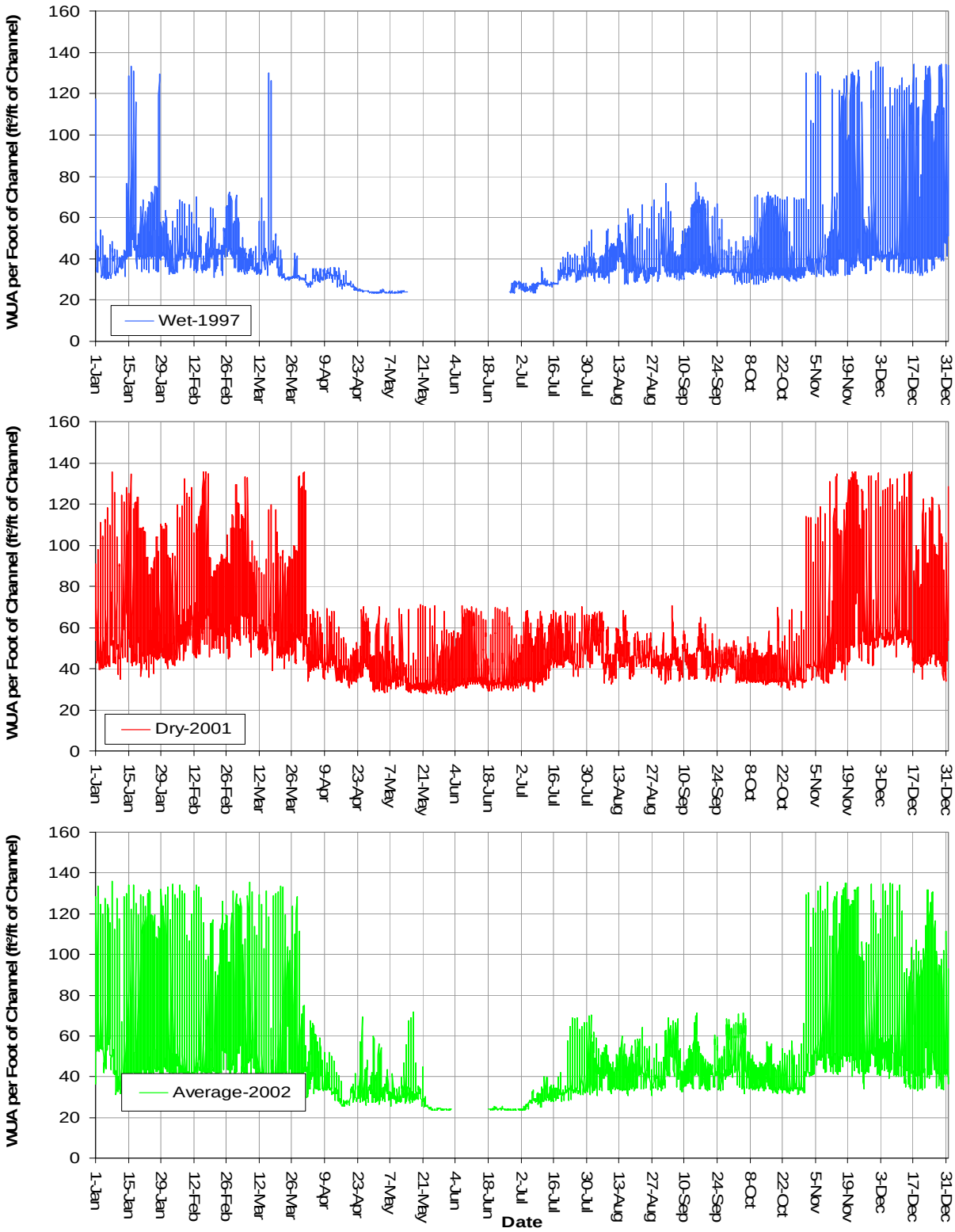


**Figure A-49.** Annual WUA for juvenile cutthroat trout in the Tailrace Reach during the three representative years.

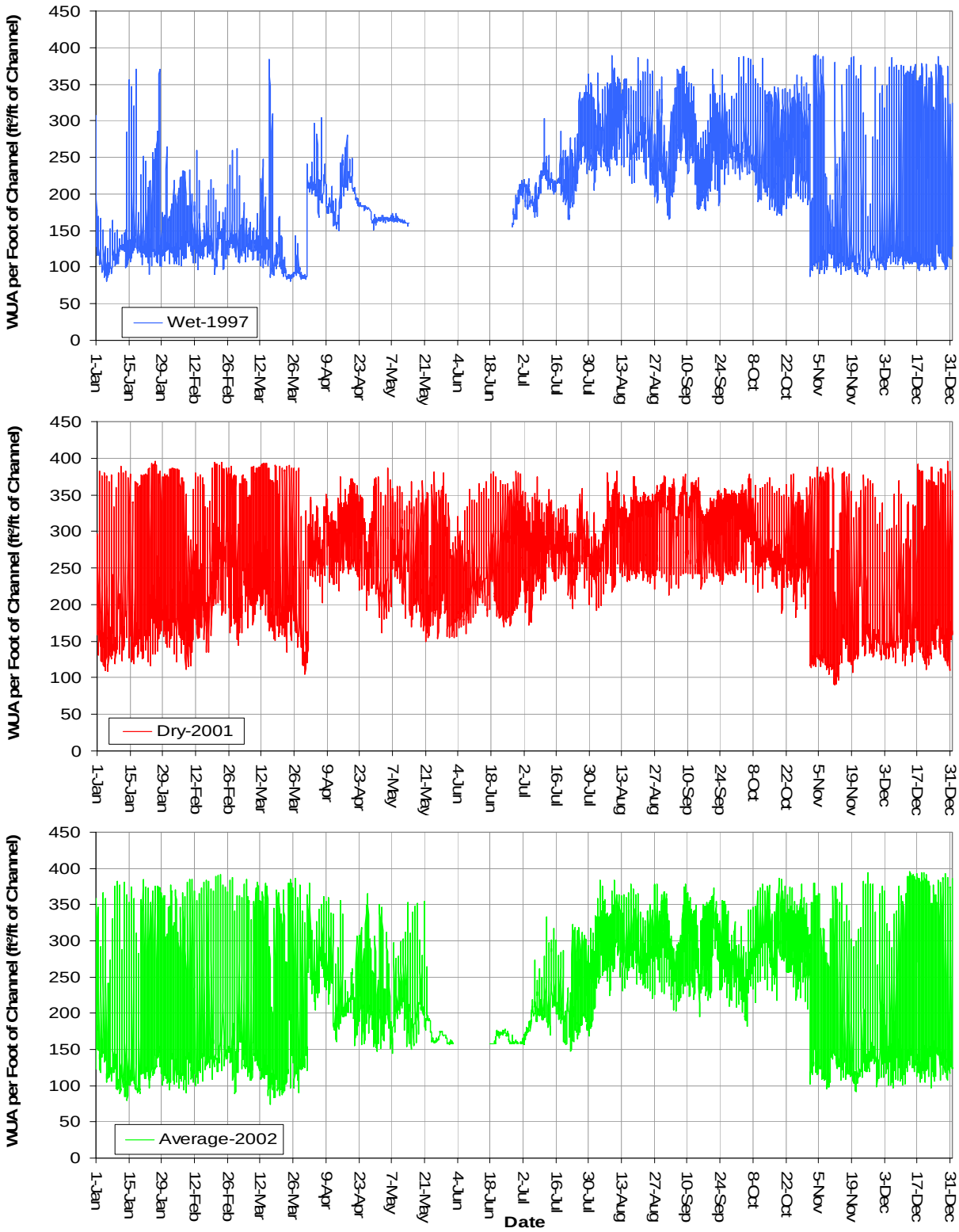


**Figure A-50.** Annual WUA for adult cutthroat trout in the Tailrace Reach during the three representative years.

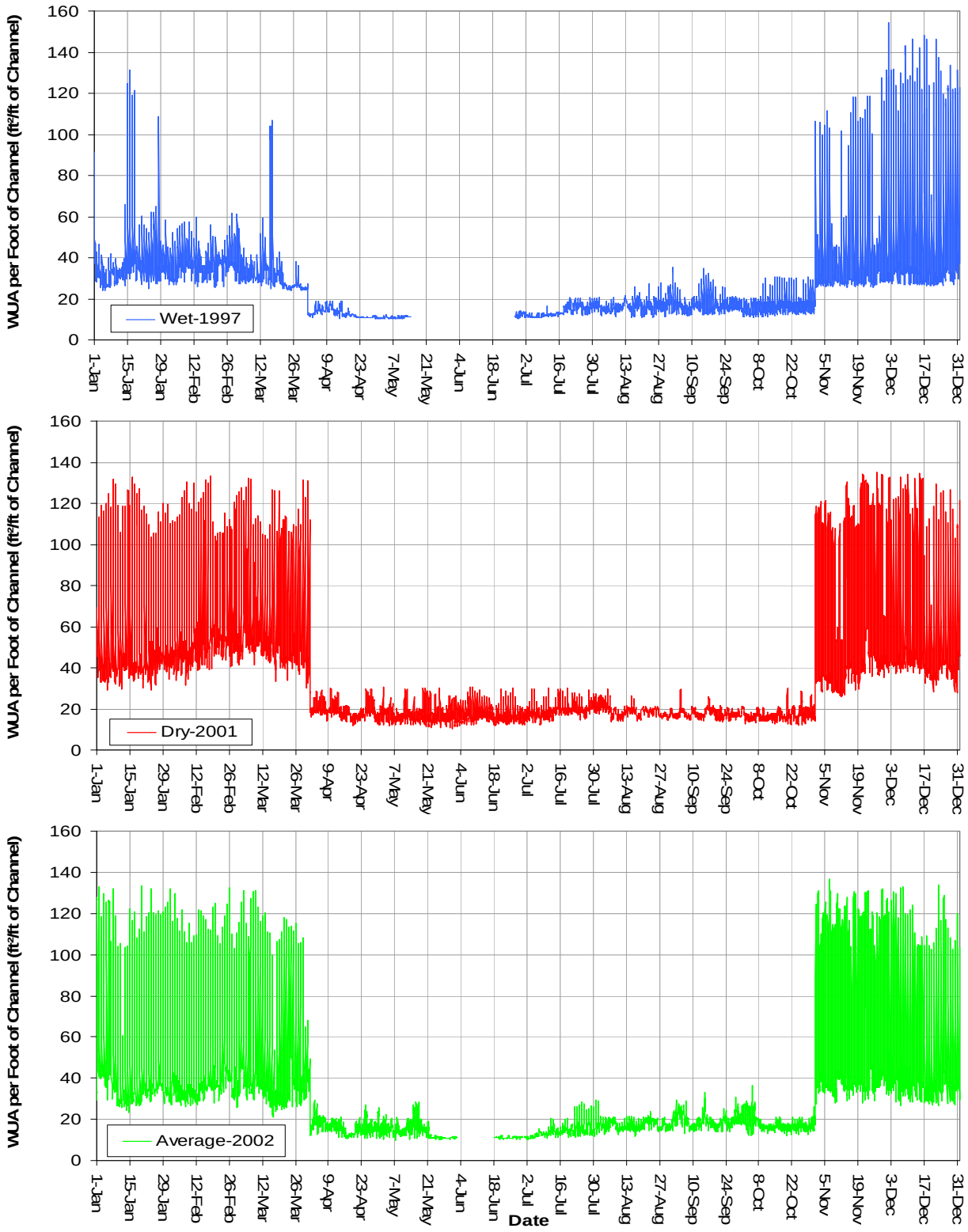


**Figure A-51.** Annual WUA for fry and juvenile cyprinids in the Tailrace Reach during the three representative years.

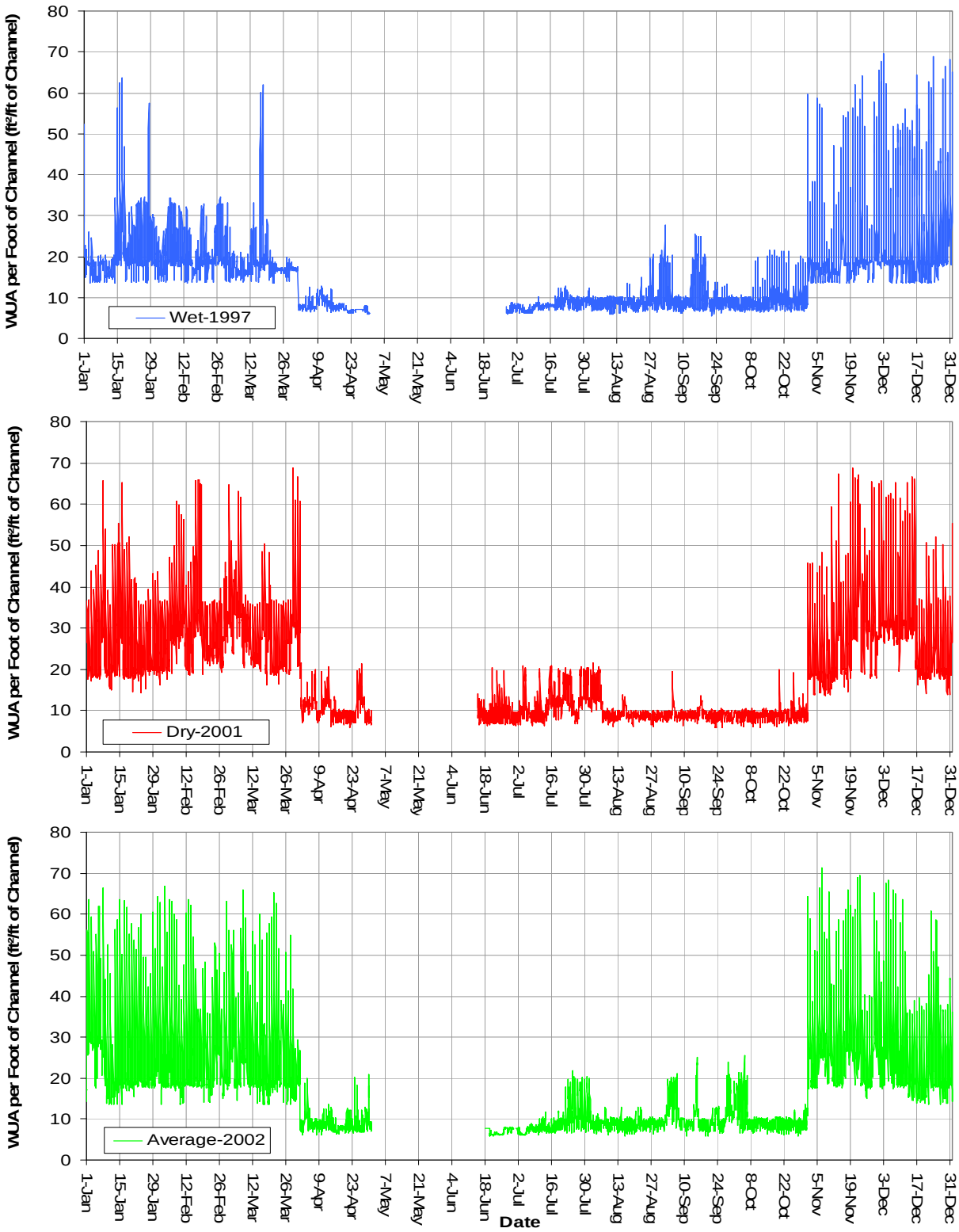


**Figure A-52.** Annual WUA for fry redband trout in the Tailrace Reach during the three representative years.

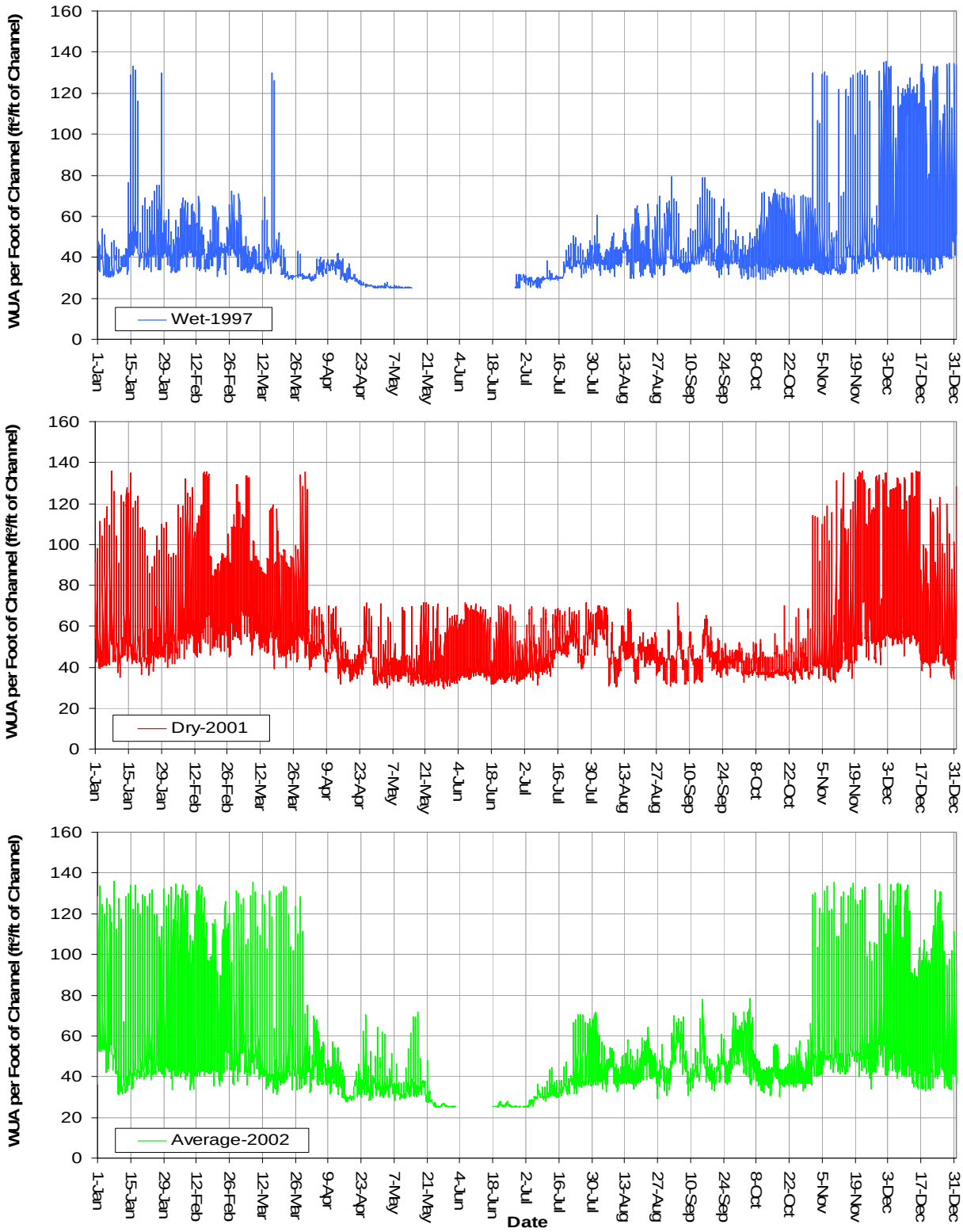


**Figure A-53.** Annual WUA for juvenile redband trout in the Tailrace Reach during the three representative years.

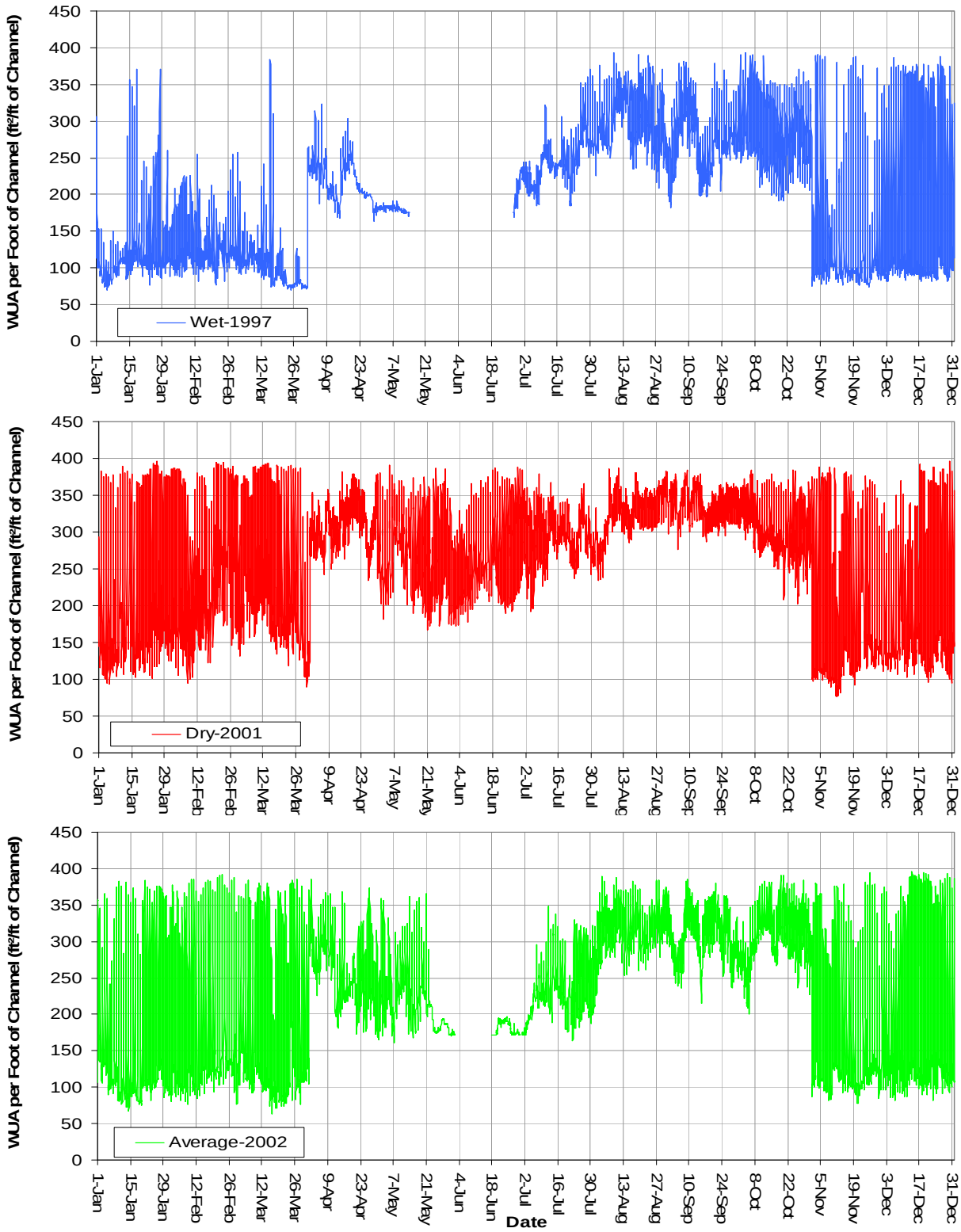


**Figure A-54.** Annual WUA for adult redband trout in the Tailrace Reach during the three representative years.

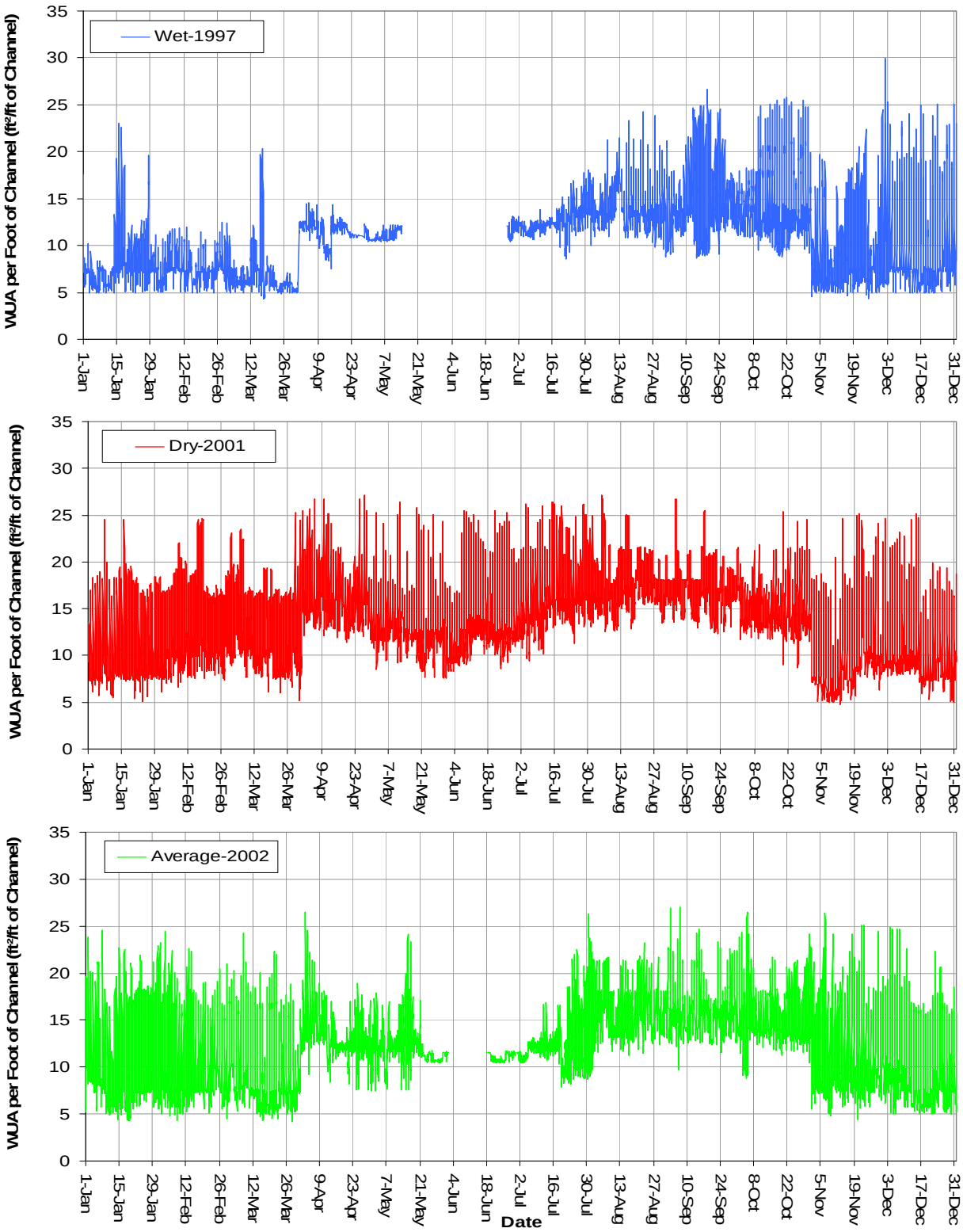


**Figure A-55.** Annual WUA for fry smallmouth bass in the Tailrace Reach during the three representative years.

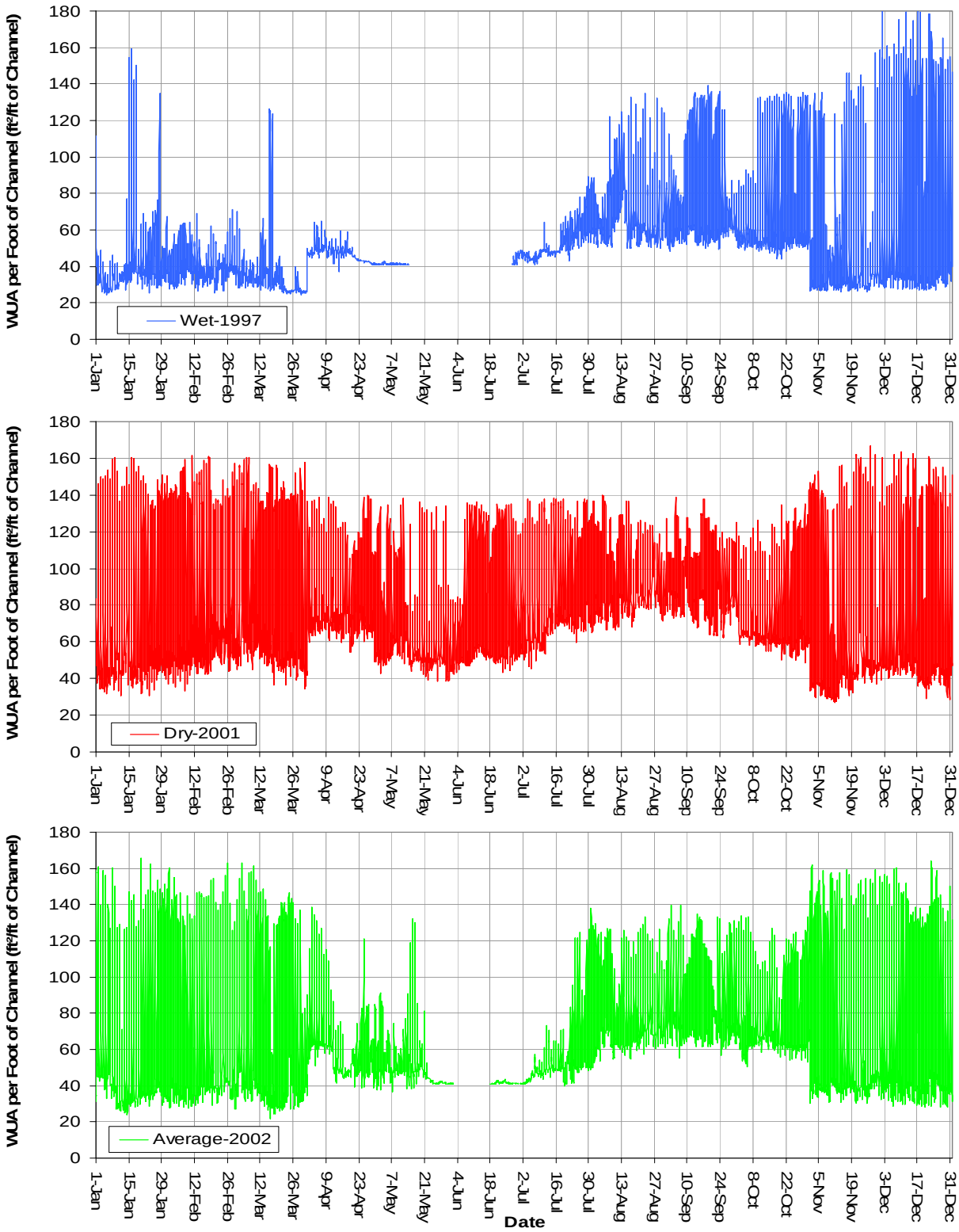


**Figure A-56.** Annual WUA for juvenile smallmouth bass in the Tailrace Reach during the three representative years.

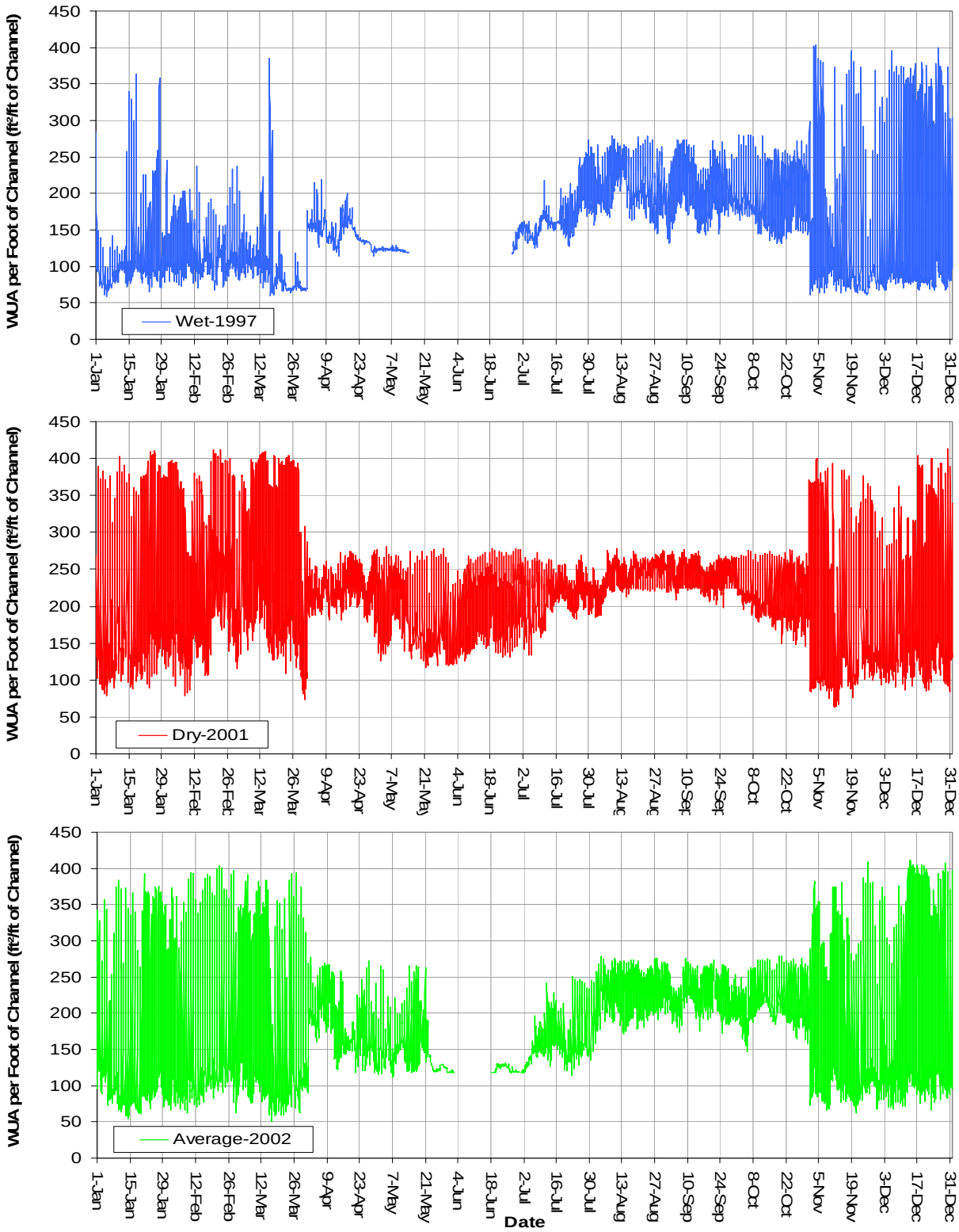


**Figure A-57.** Annual WUA for adult smallmouth bass in the Tailrace Reach during the three representative years.

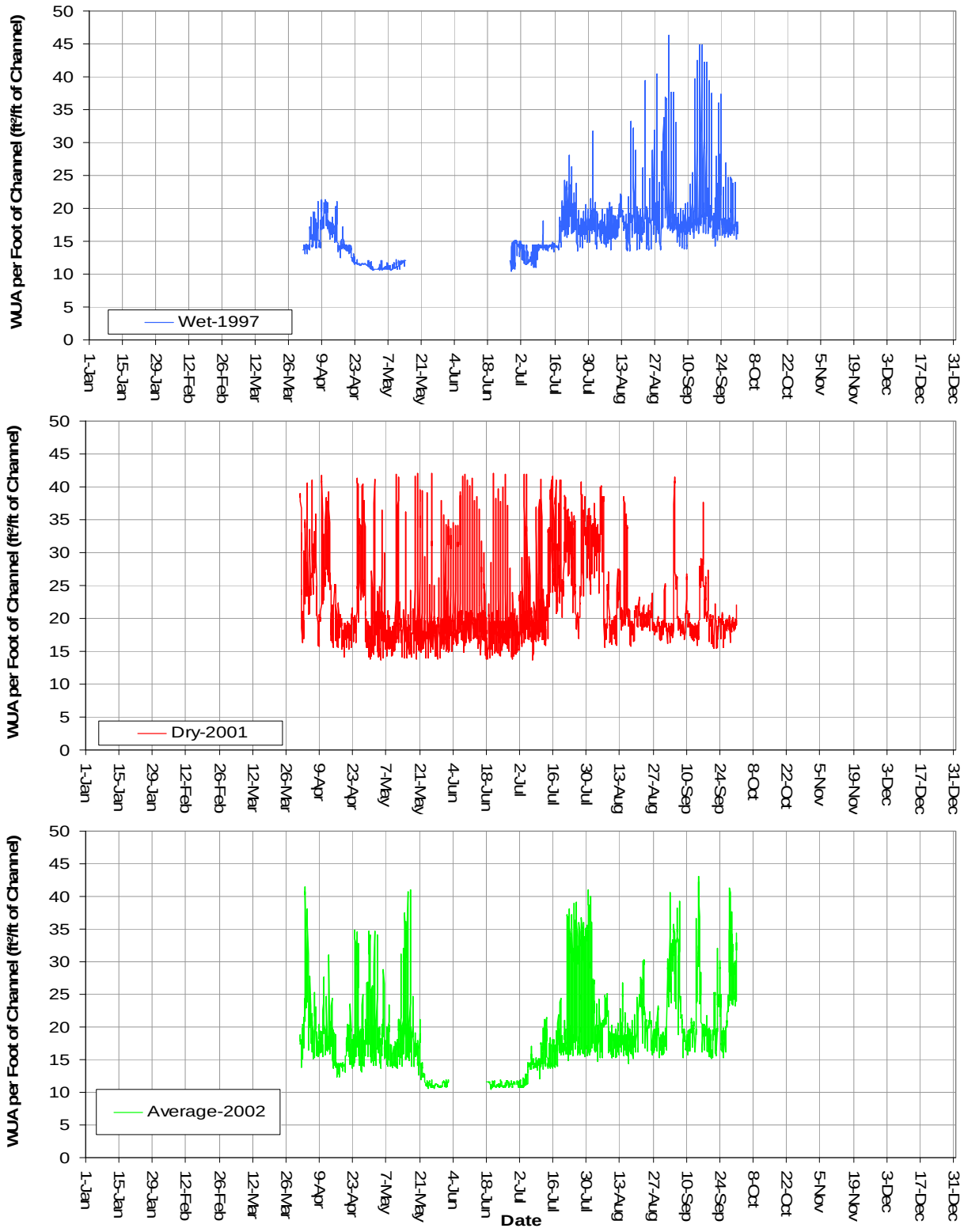


**Figure A-58.** Annual WUA for fry whitefish in the Tailrace Reach during the three representative years.

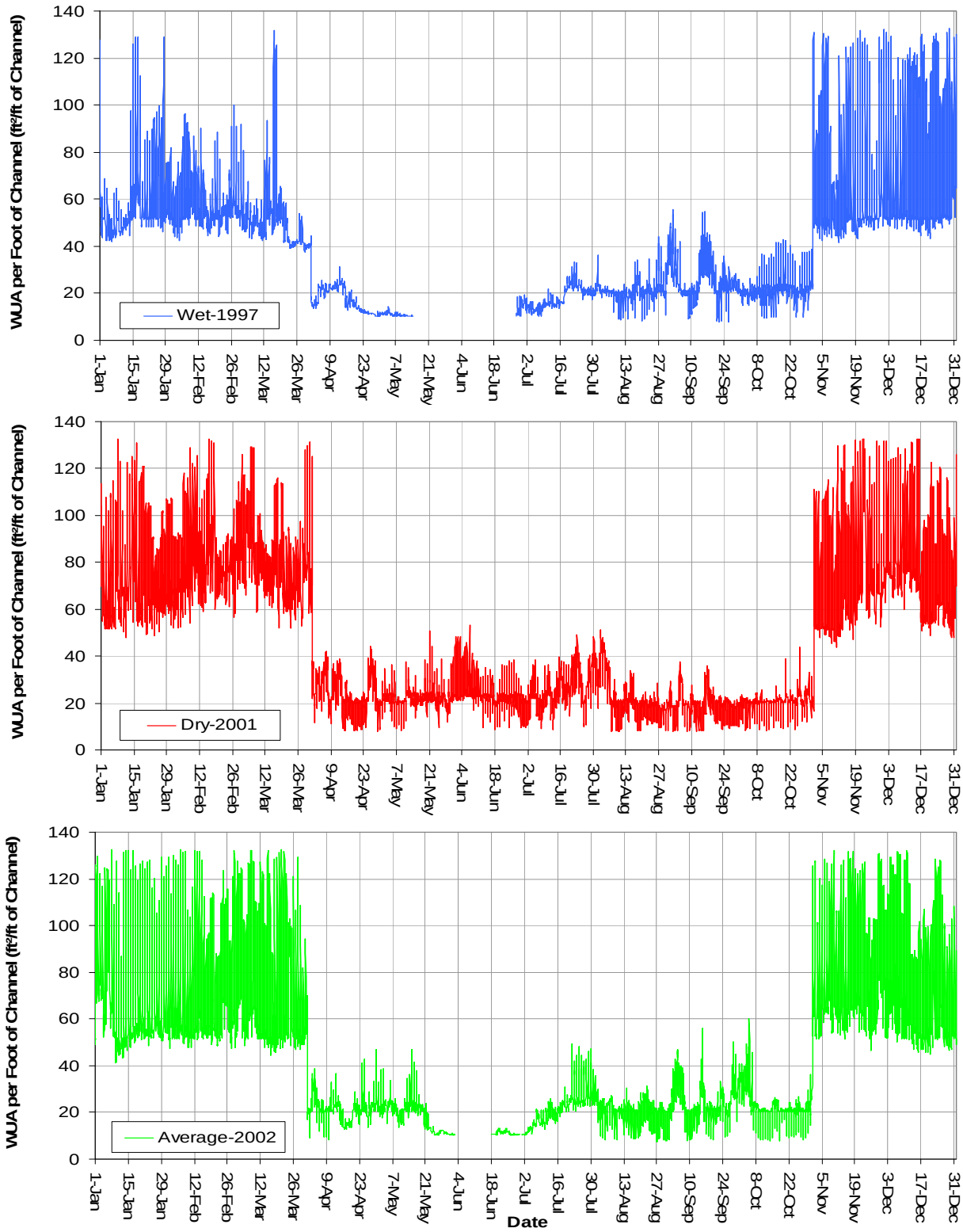


**Figure A-59.** Annual WUA for juvenile whitefish in the Tailrace Reach during the three representative years.

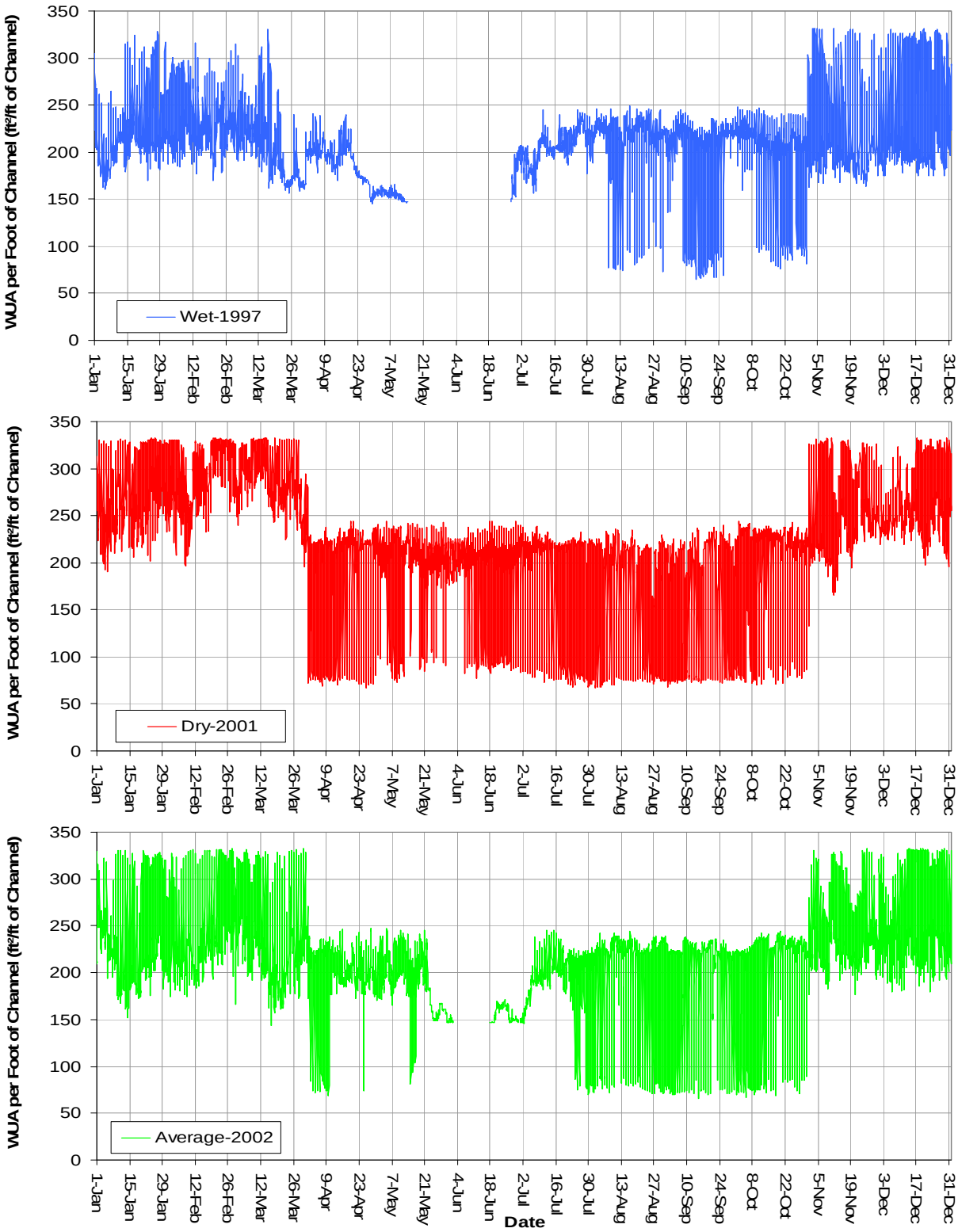


**Figure A-60.** Annual WUA for adult whitefish in the Tailrace Reach during the three representative years.

# Attachment B: Fish Habitat Weighted Useable Area (WUA)-Duration Curves

This attachment contains the following figures:

Figure B-1. WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-2. WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-3. WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-4. WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-5. WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-6. WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-7. WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-8. WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-9. WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-10. WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-11. WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-12. WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-13. WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-14. WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-15. WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.
Figure B-16. WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-17. WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-18. WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-19. WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-20. WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-21. WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-22. WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

Figure B-23. WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-24. WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-25. WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-26. WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-27. WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-28. WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-29. WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-30. WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.
Figure B-31. WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-32. WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-33. WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-34. WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-35. WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-36. WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-37. WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-38. WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-39. WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-40. WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-41. WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-42. WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-43. WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-44. WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.
Figure B-45. WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

Figure B-46. WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-47. WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-48. WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-49. WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-50. WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-51. WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-52. WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-53. WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-54. WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-55. WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-56. WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-57. WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-58. WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-59. WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.
Figure B-60. WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

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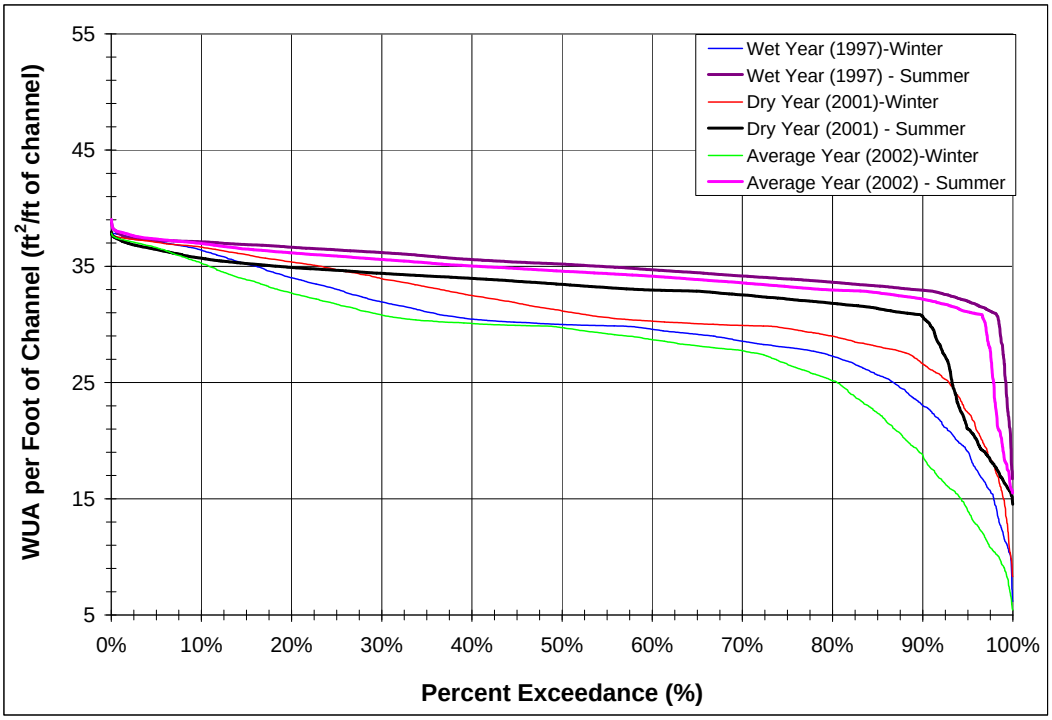


**Figure B-1.** WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

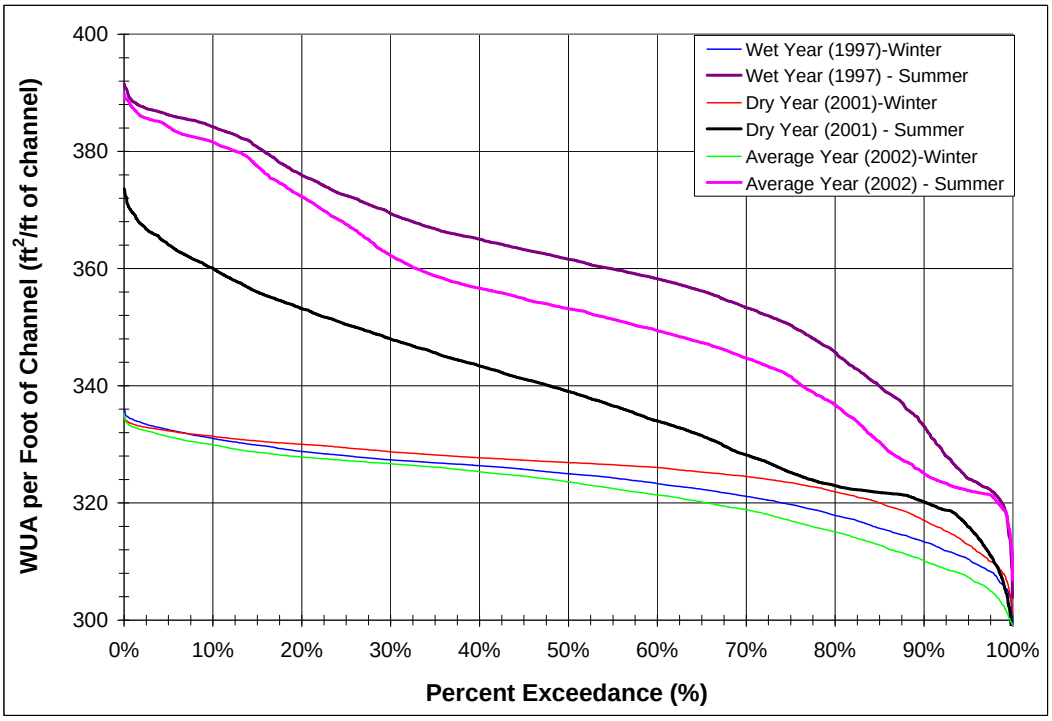


**Figure B-2.** WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

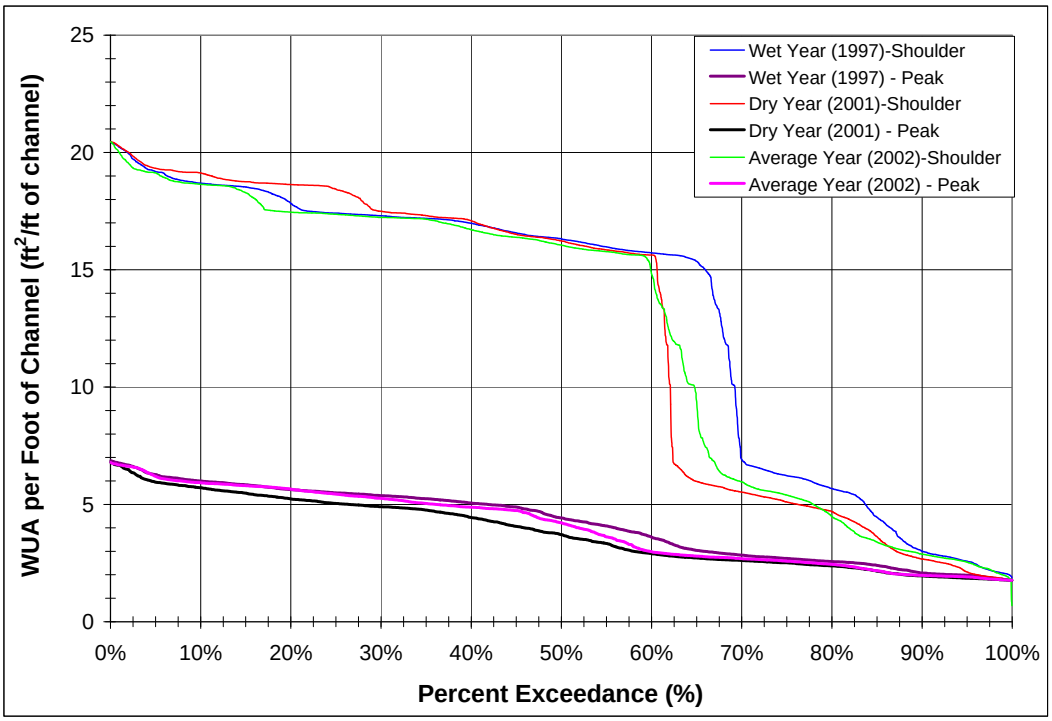


**Figure B-3.** WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

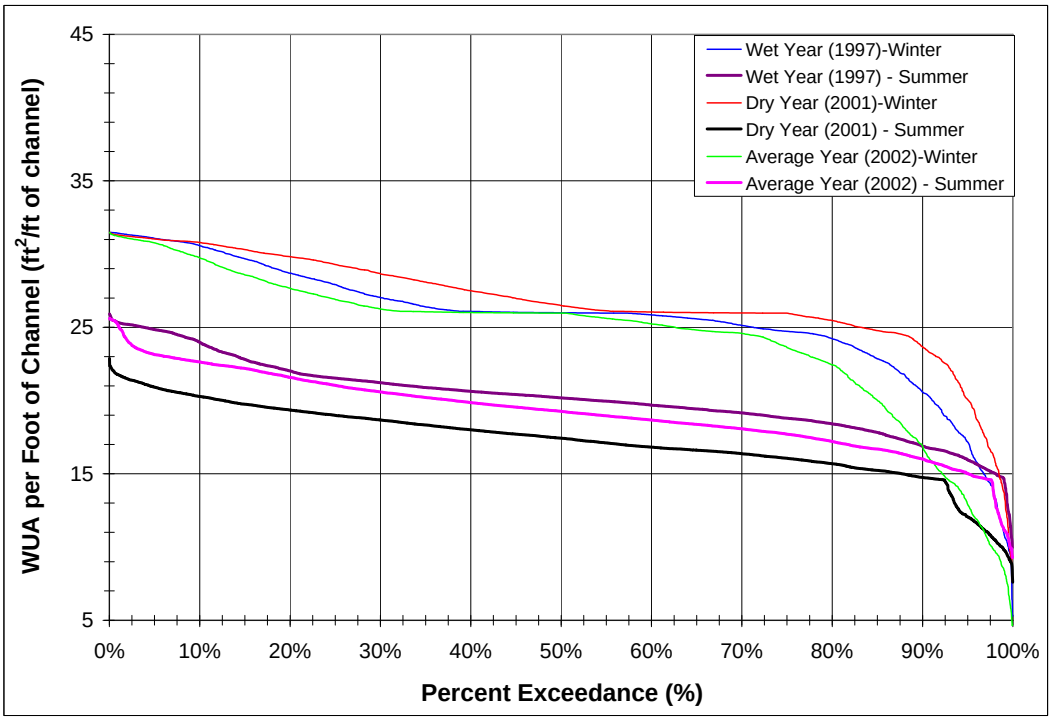


**Figure B-4.** WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

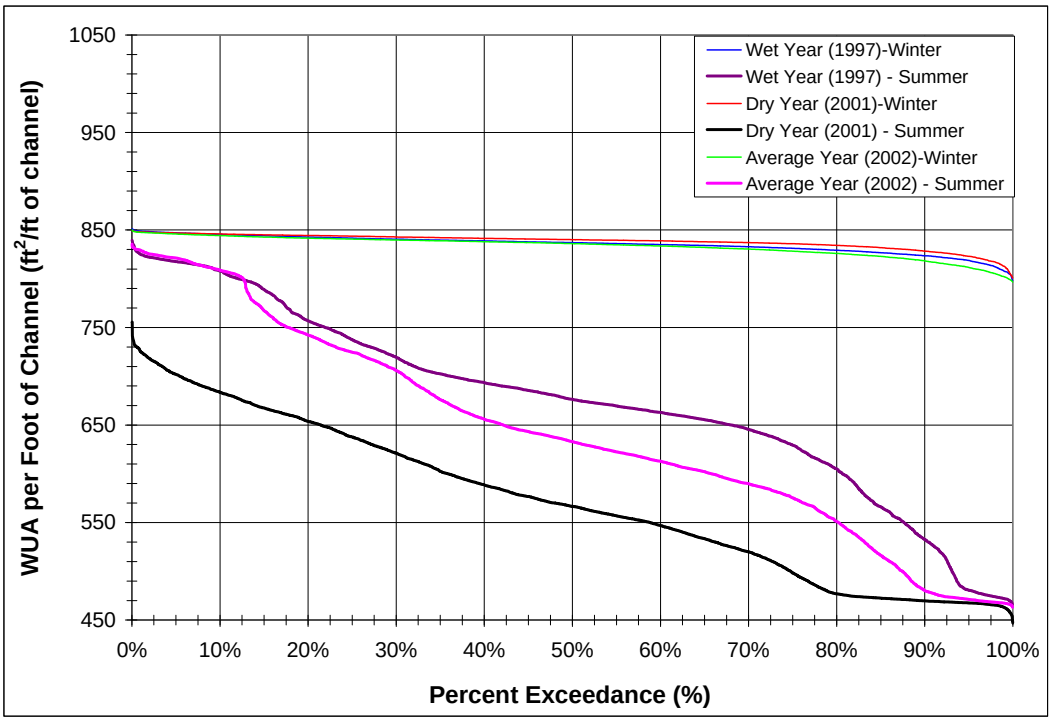


**Figure B-5.** WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

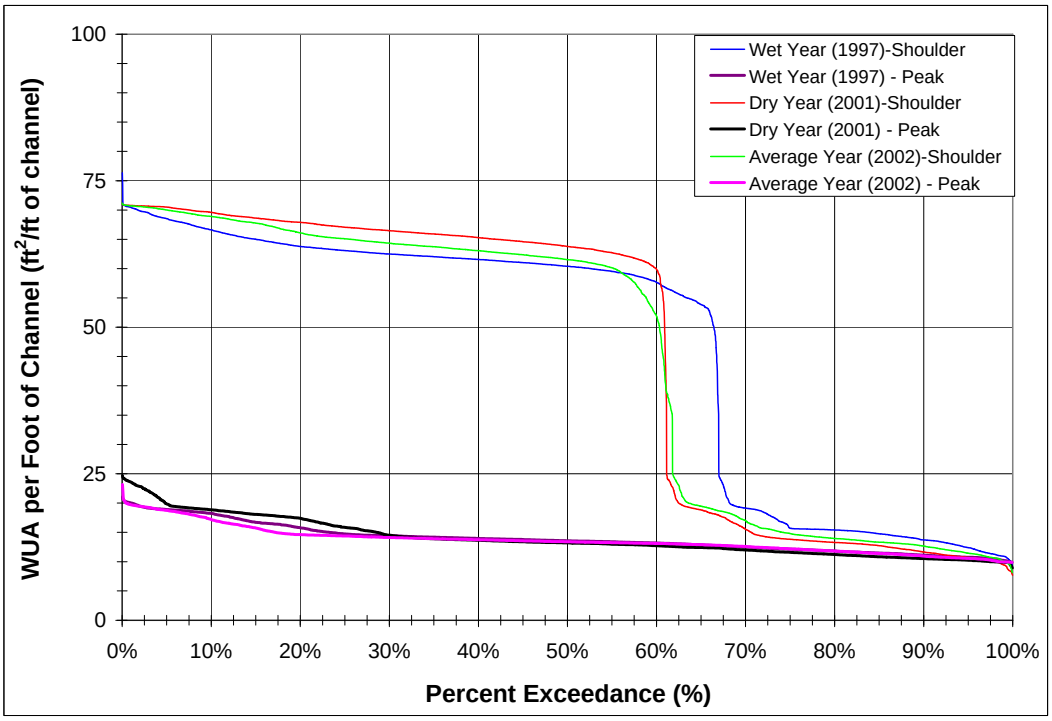


**Figure B-6.** WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

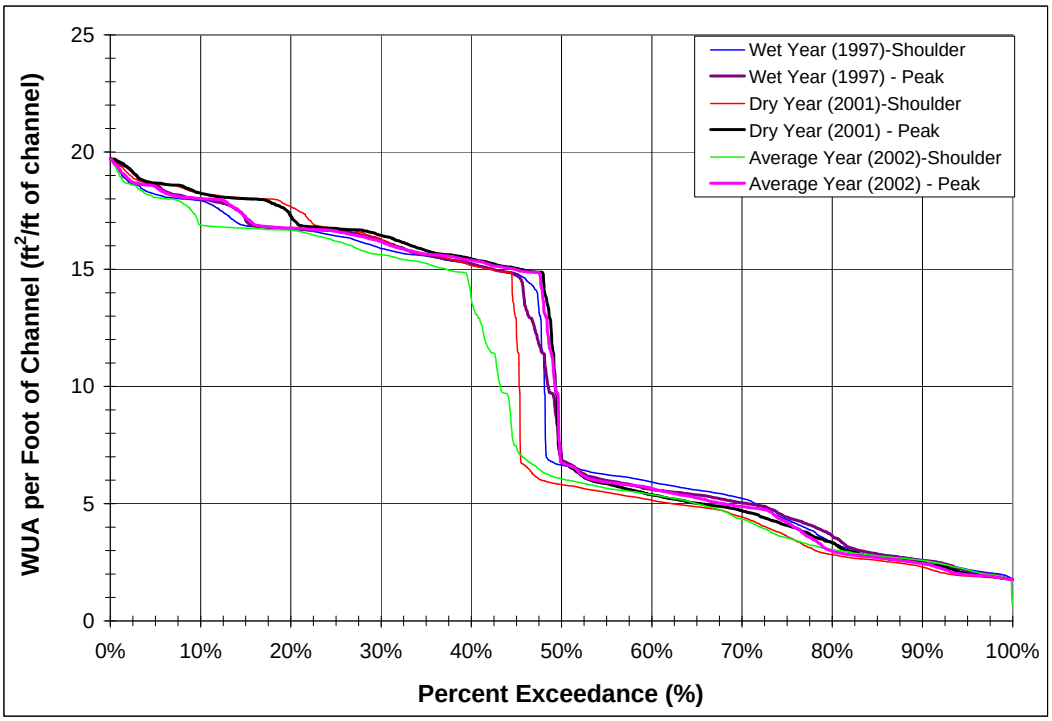


**Figure B-7.** WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

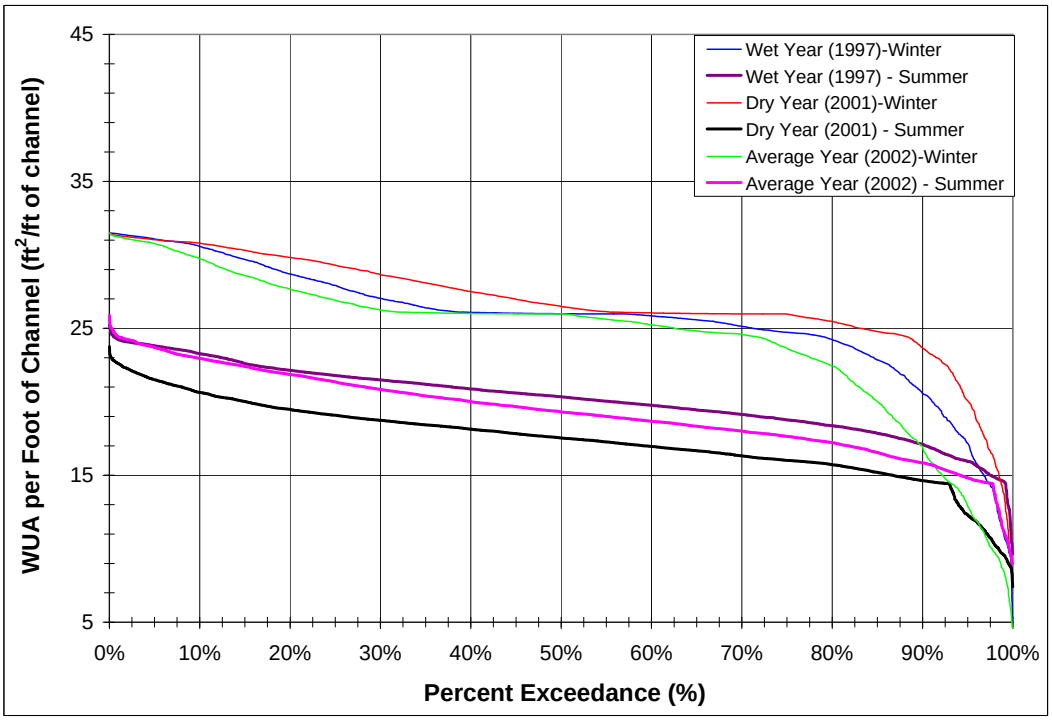


**Figure B-8.** WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

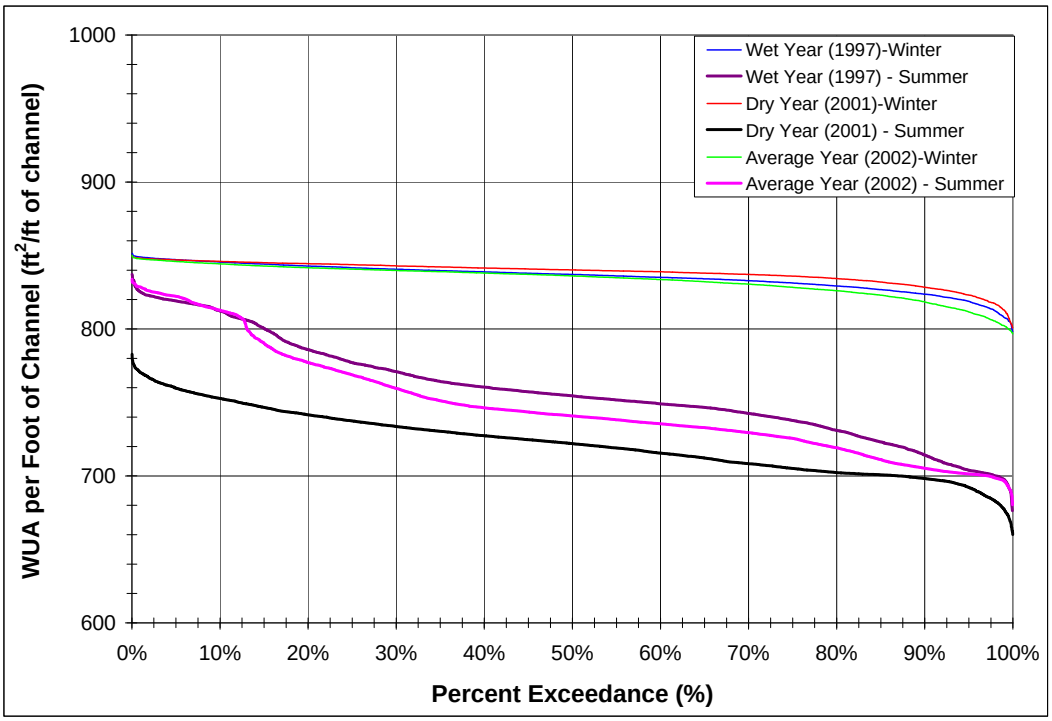


**Figure B-9.** WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

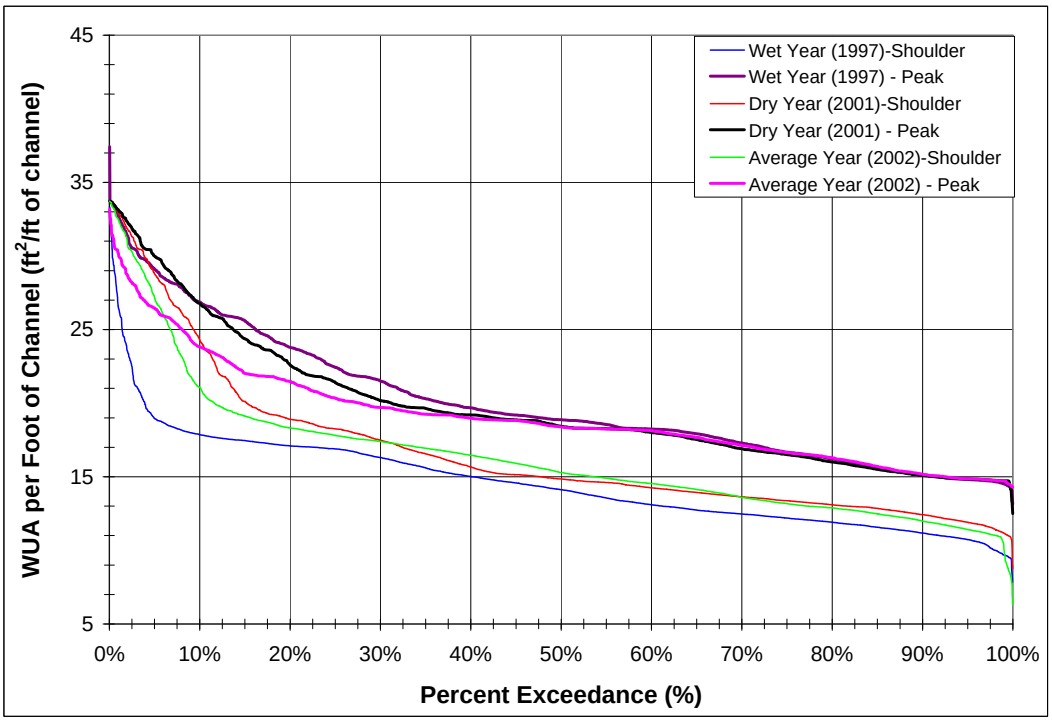


**Figure B-10.** WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

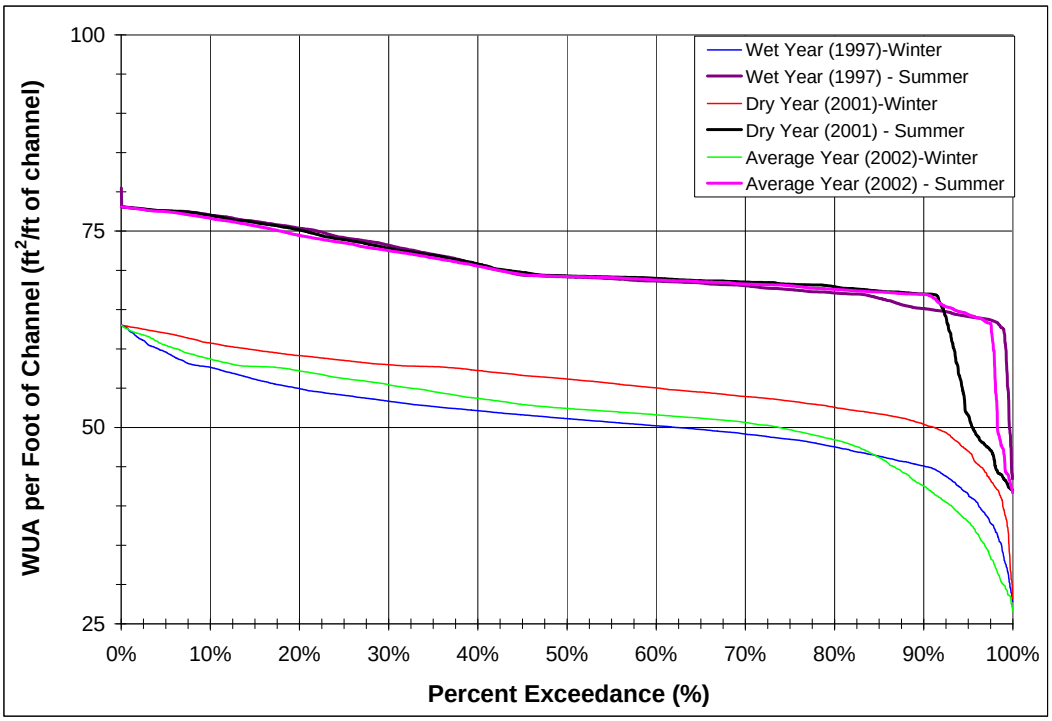


**Figure B-11.** WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

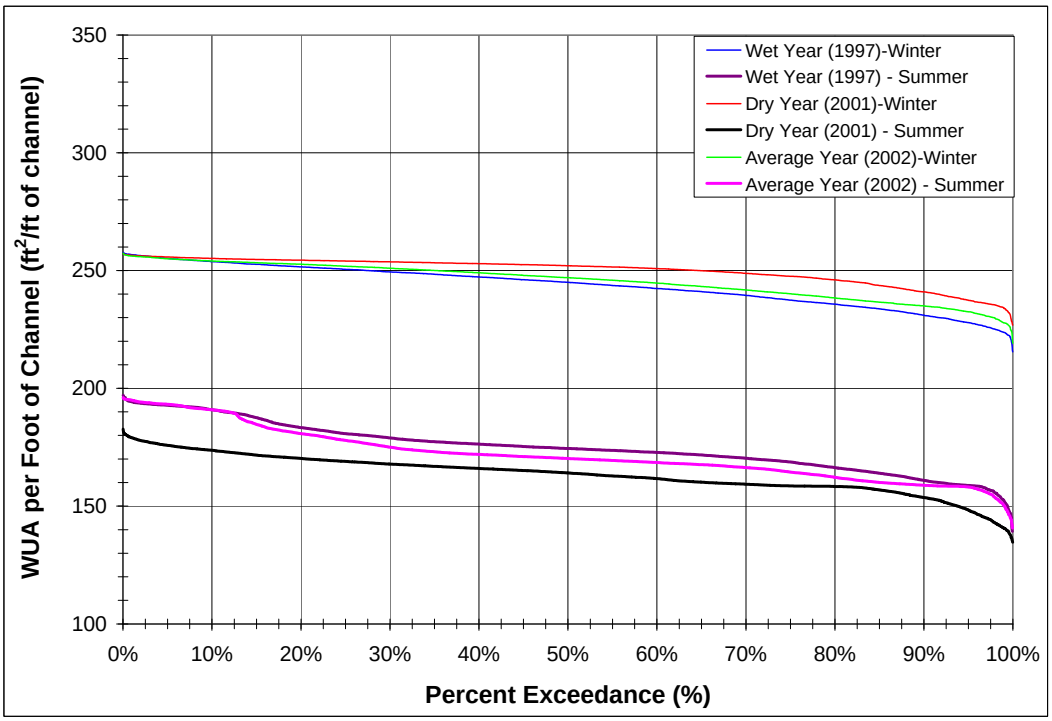


**Figure B-12.** WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

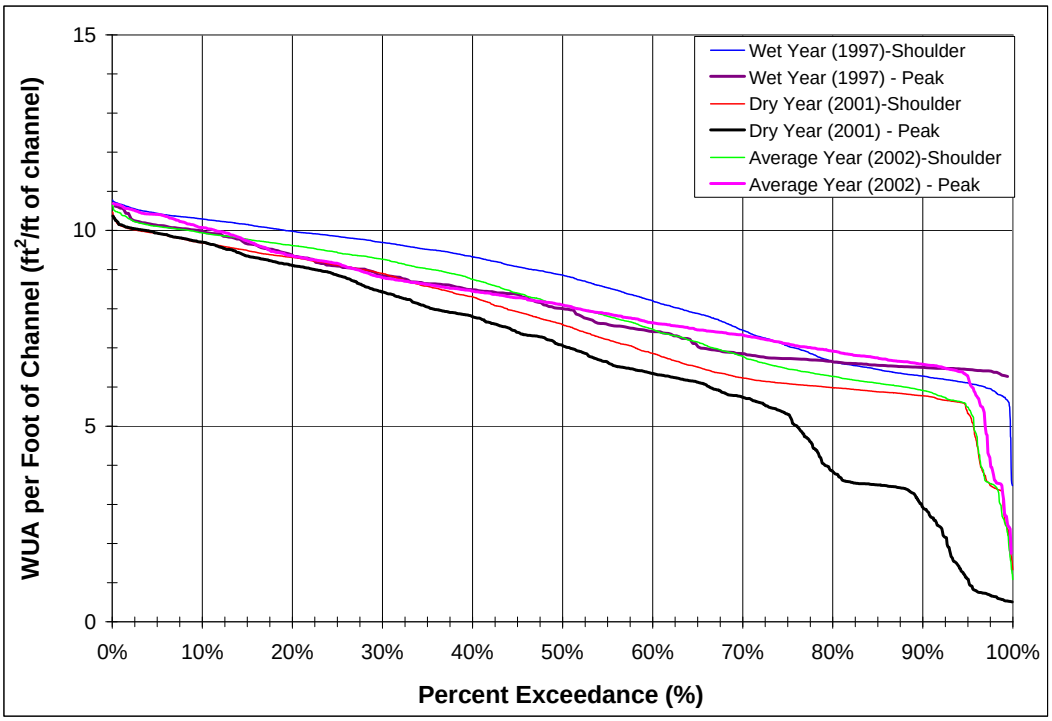


**Figure B-13.** WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

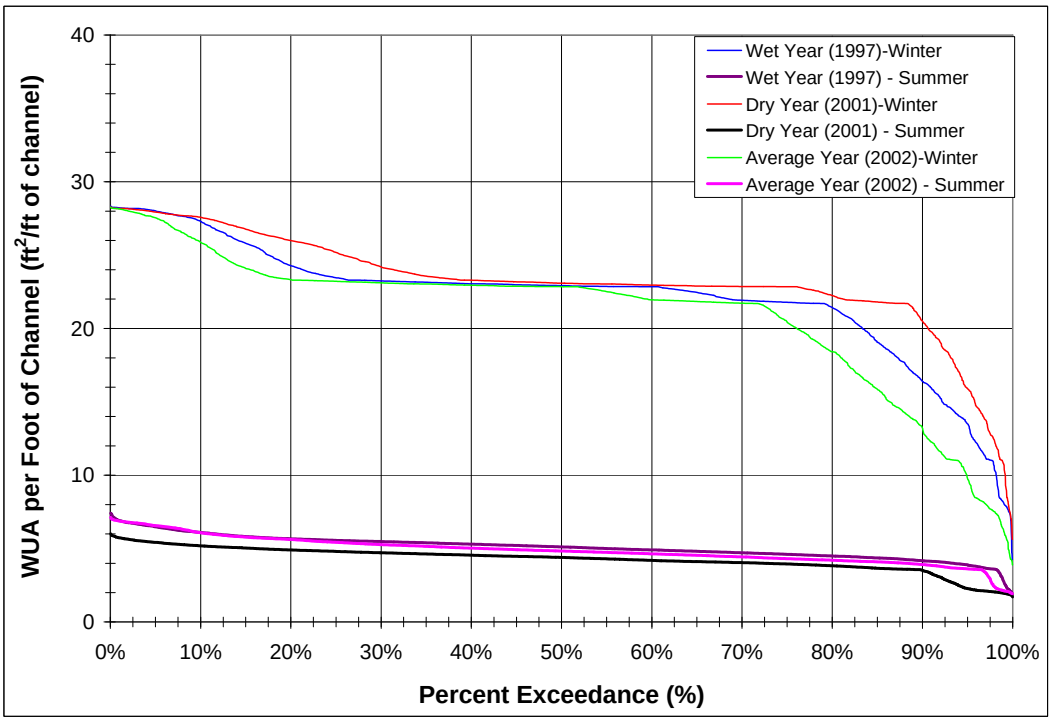


**Figure B-14.** WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

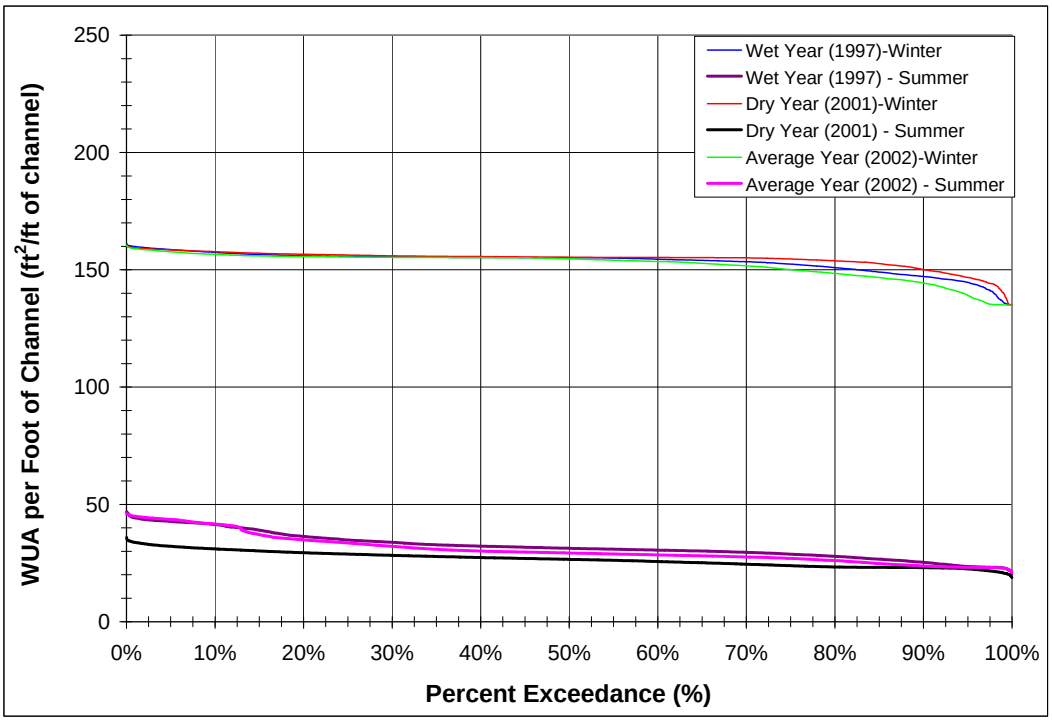


**Figure B-15.** WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Forebay Reach.

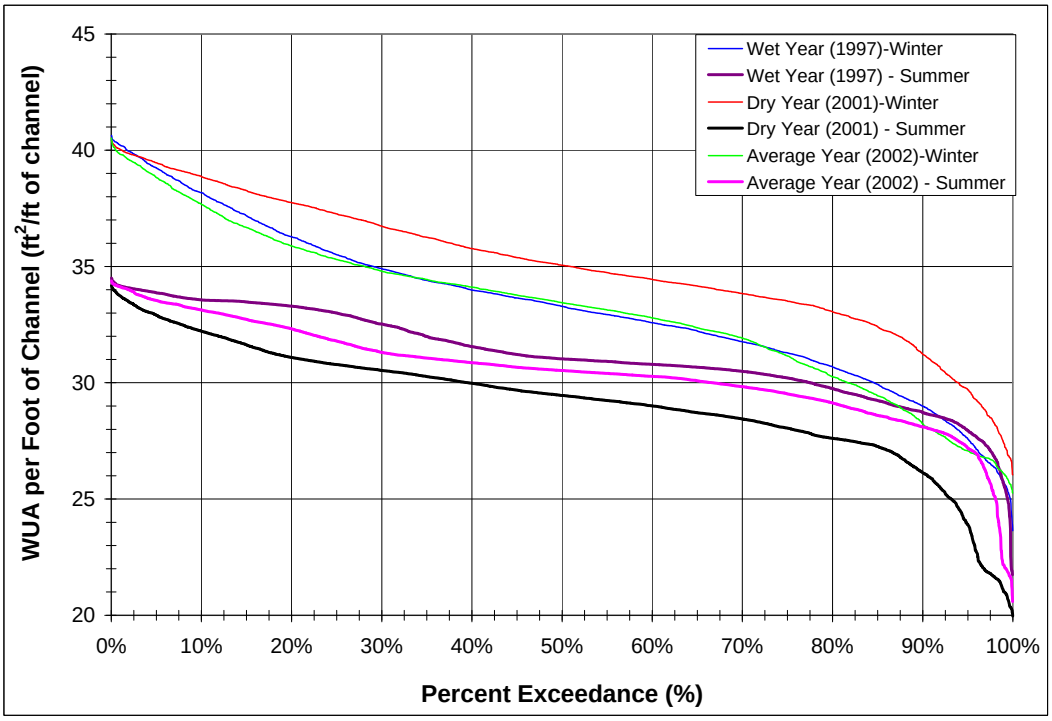


**Figure B-16.** WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

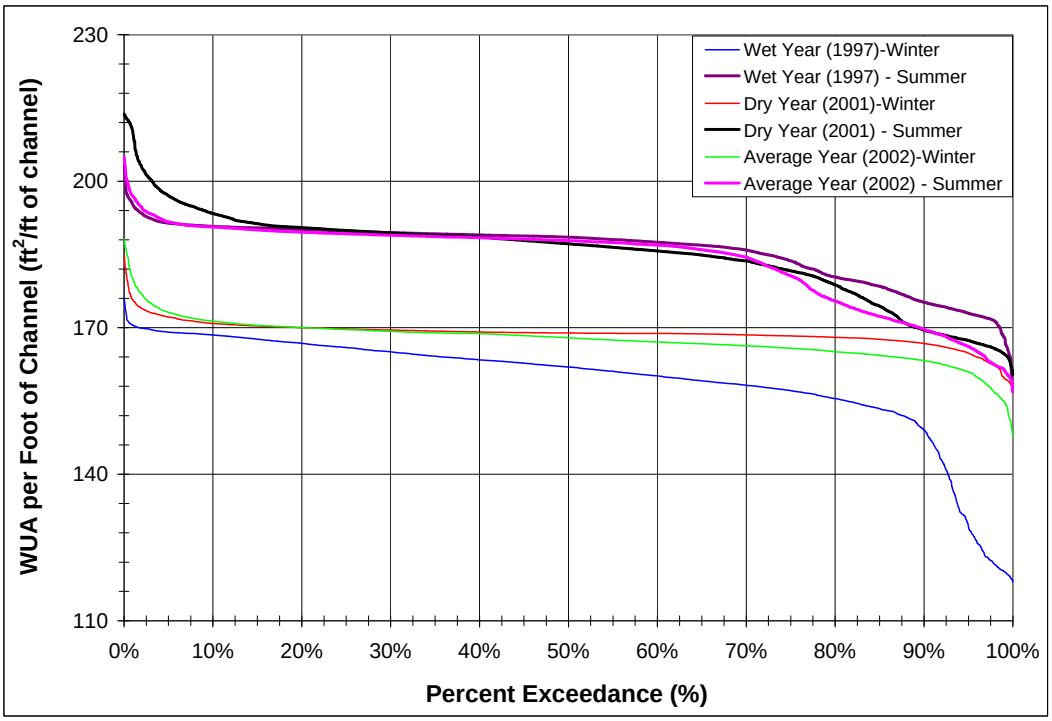


**Figure B-17.** WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

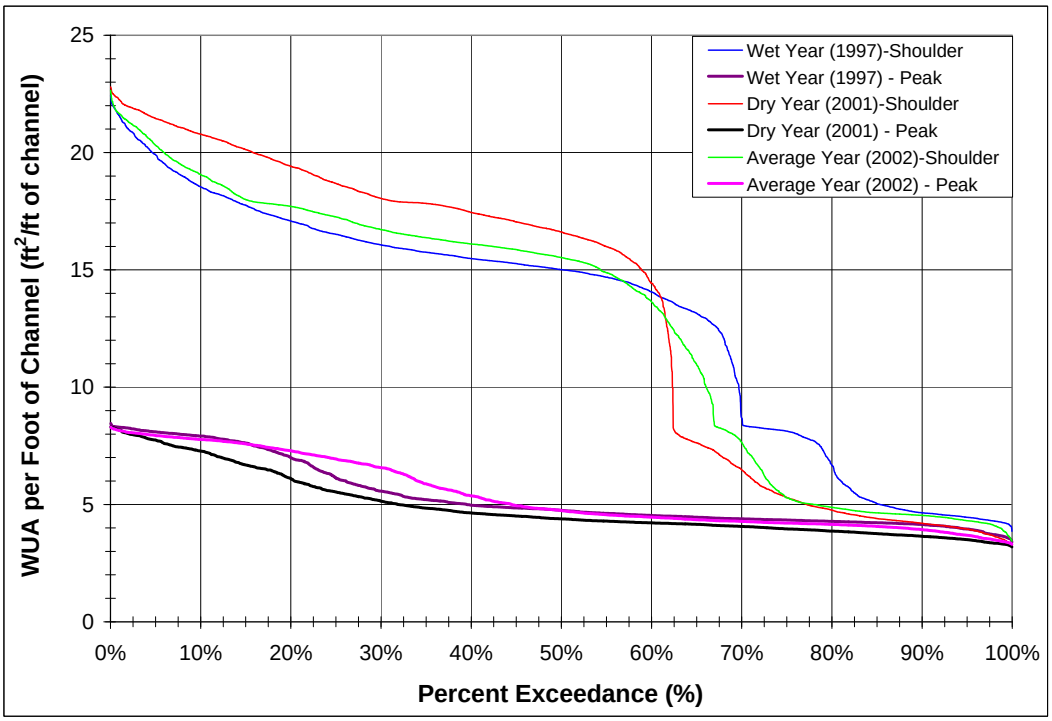


**Figure B-18.** WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

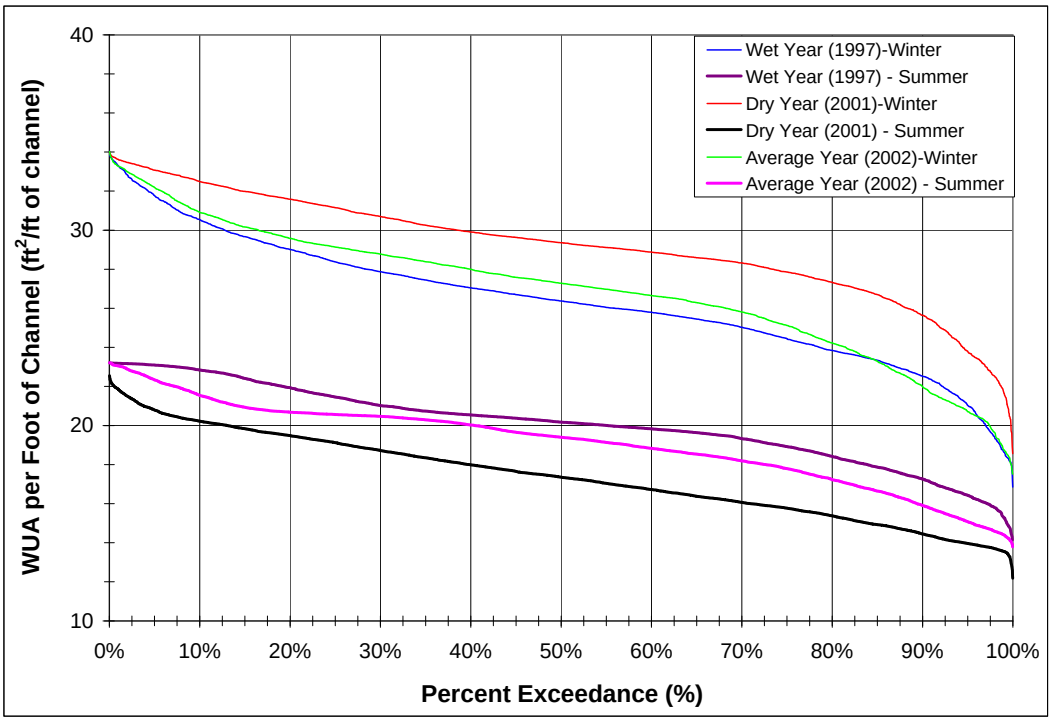


**Figure B-19.** WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

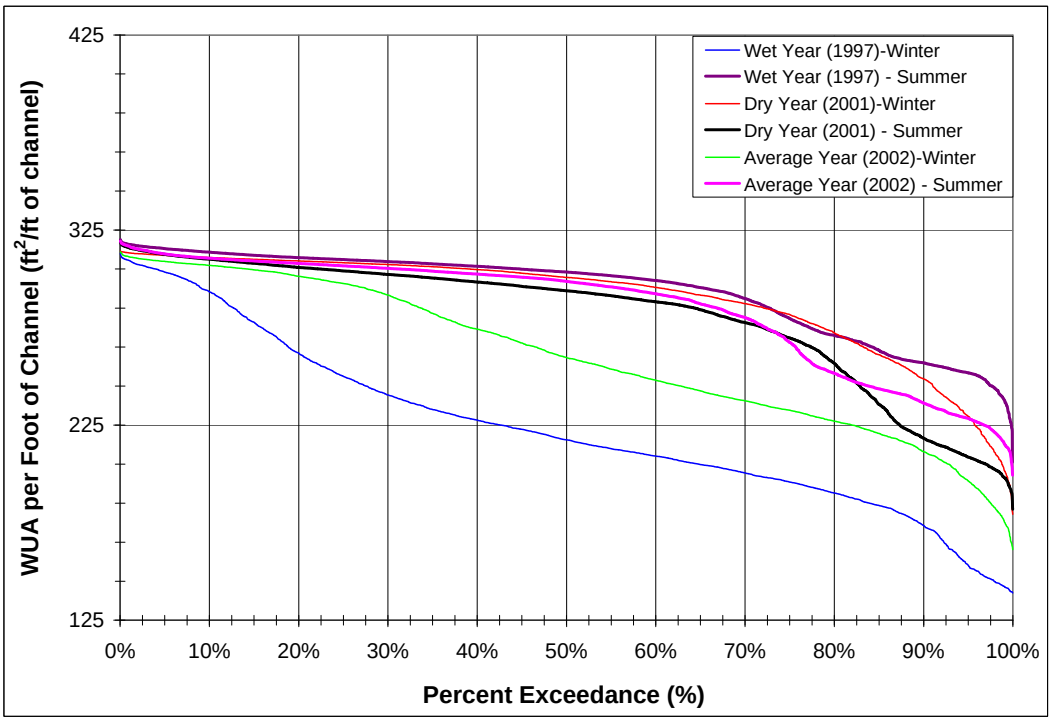


**Figure B-20.** WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

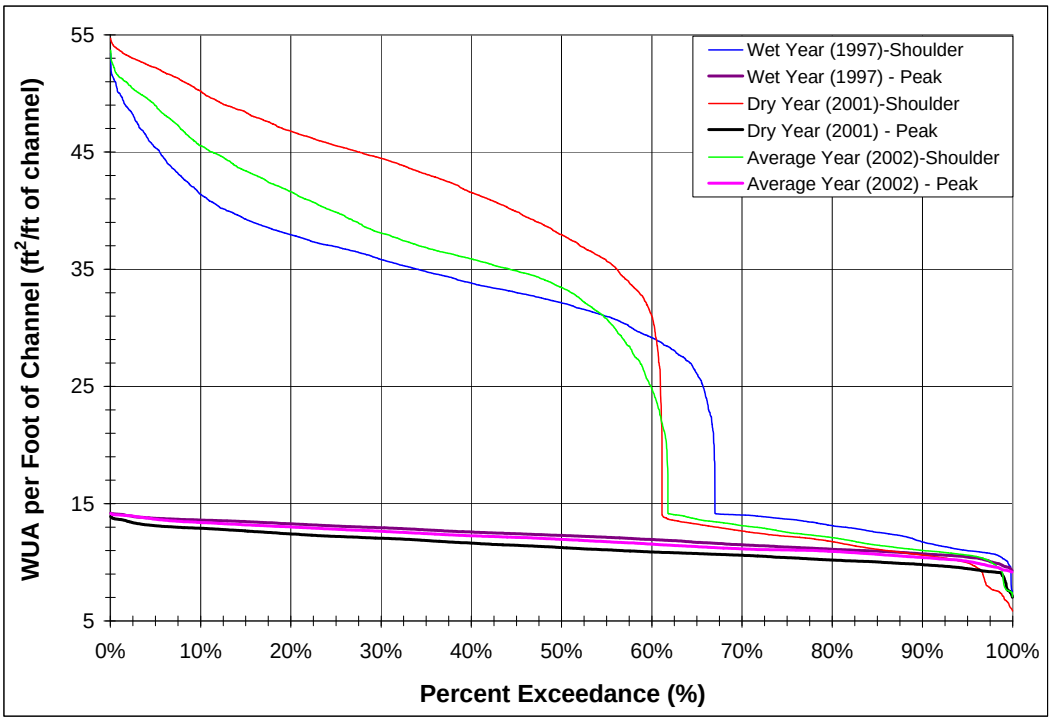


**Figure B-21.** WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

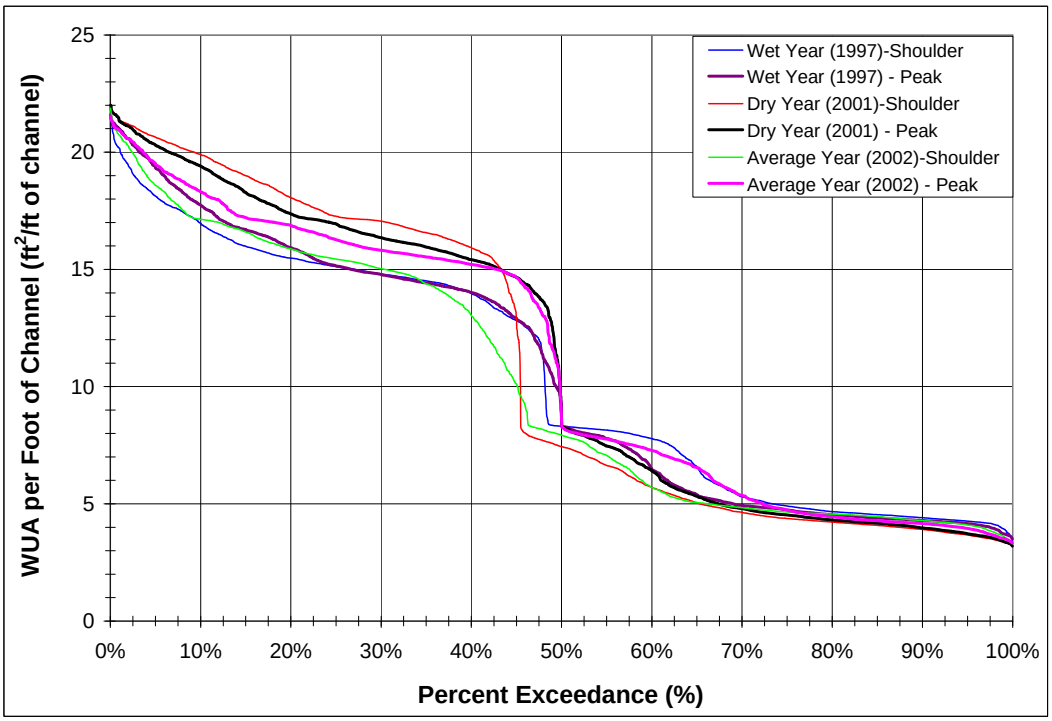


**Figure B-22.** WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

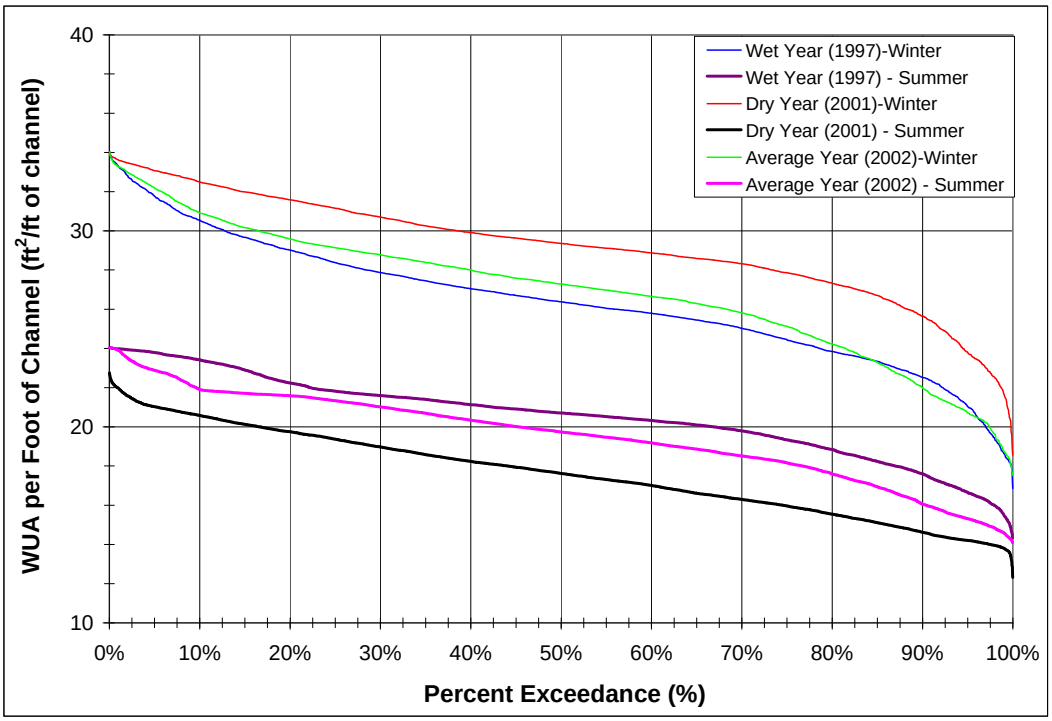


**Figure B-23.** WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

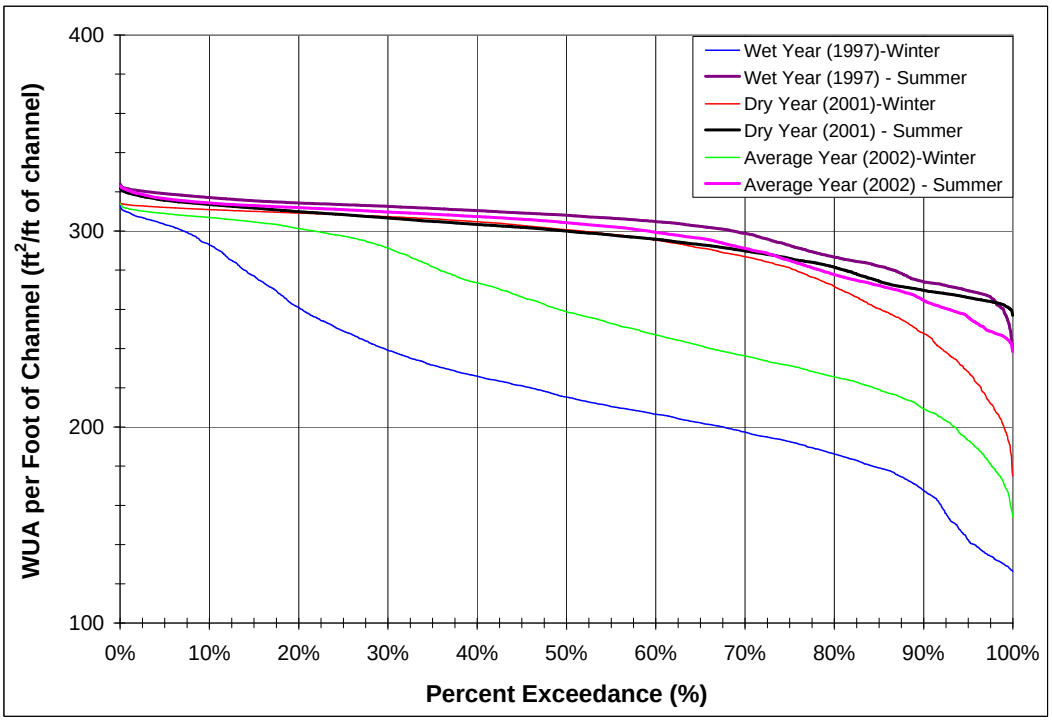


**Figure B-24.** WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

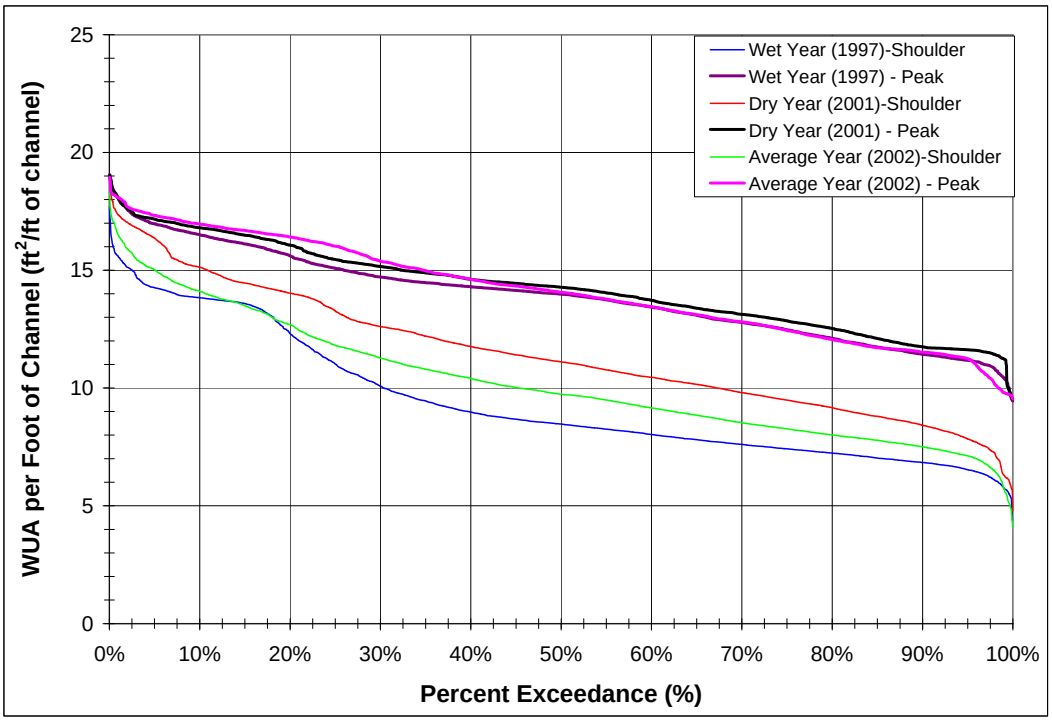


**Figure B-25.** WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

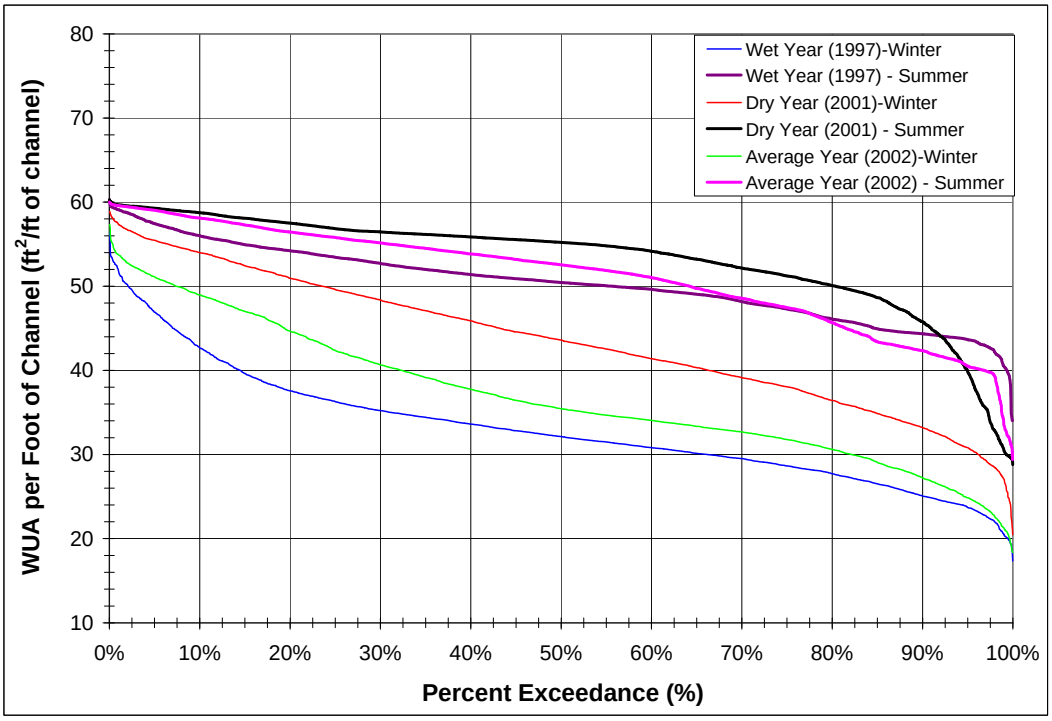


**Figure B-26.** WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

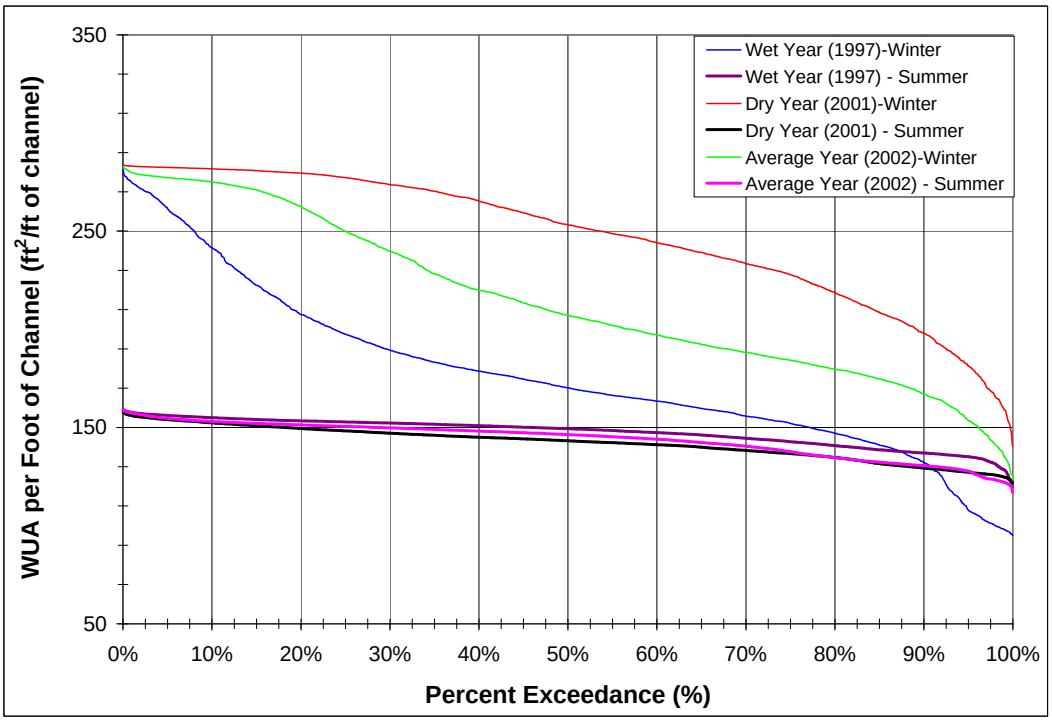


**Figure B-27.** WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

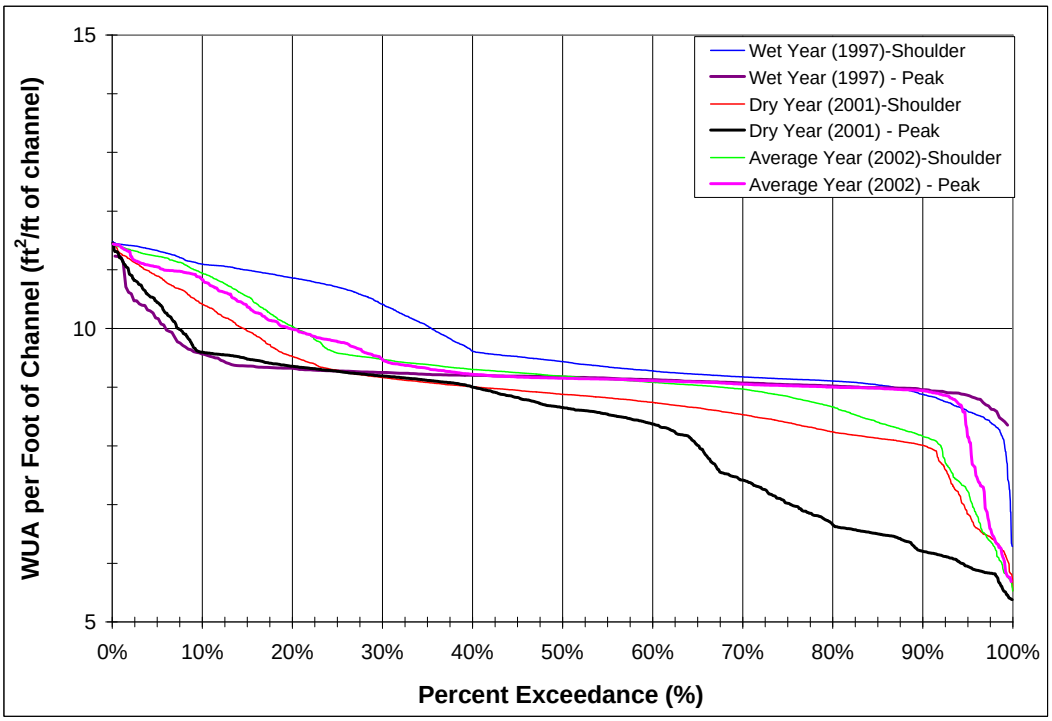


**Figure B-28.** WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

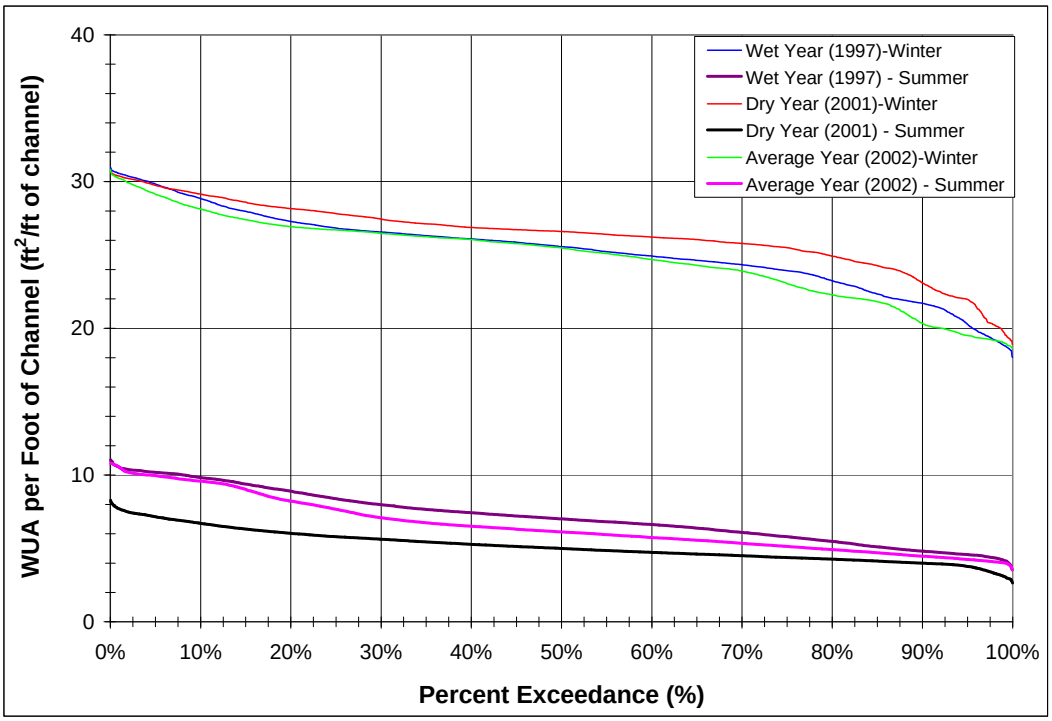


**Figure B-29.** WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

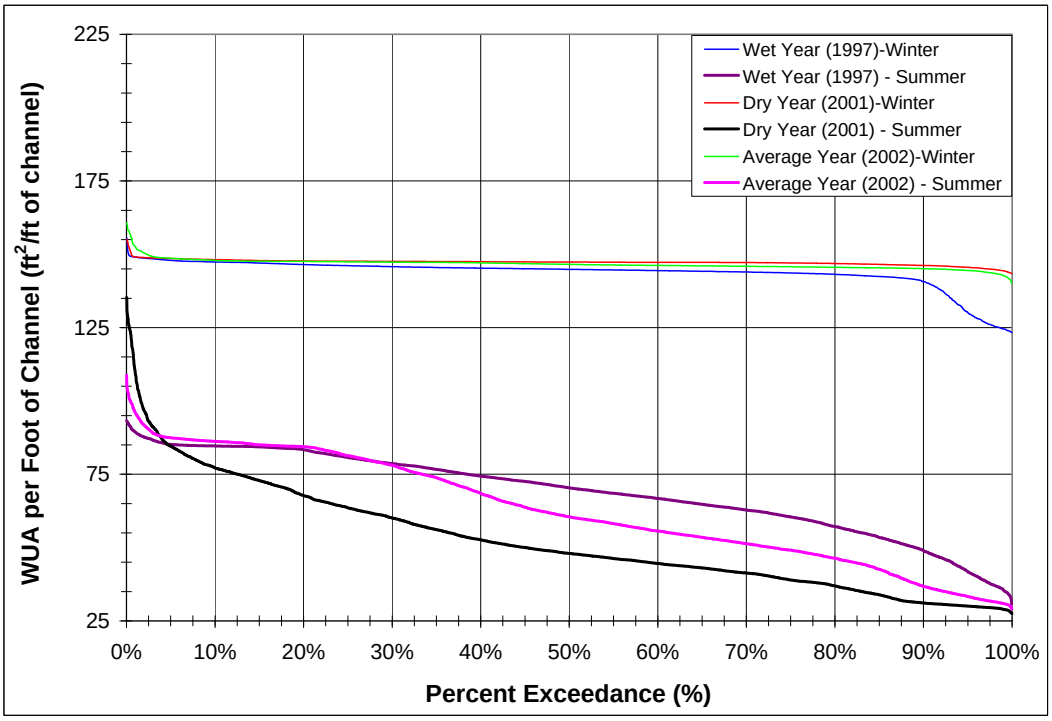


**Figure B-30.** WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Canyon Reach.

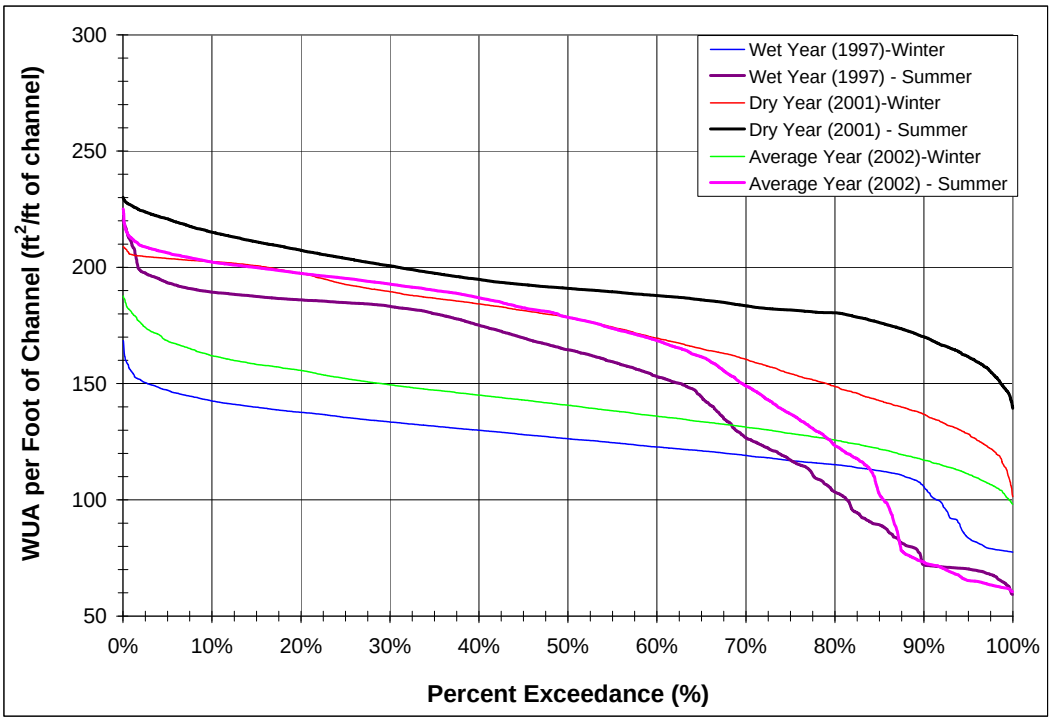


**Figure B-31.** WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

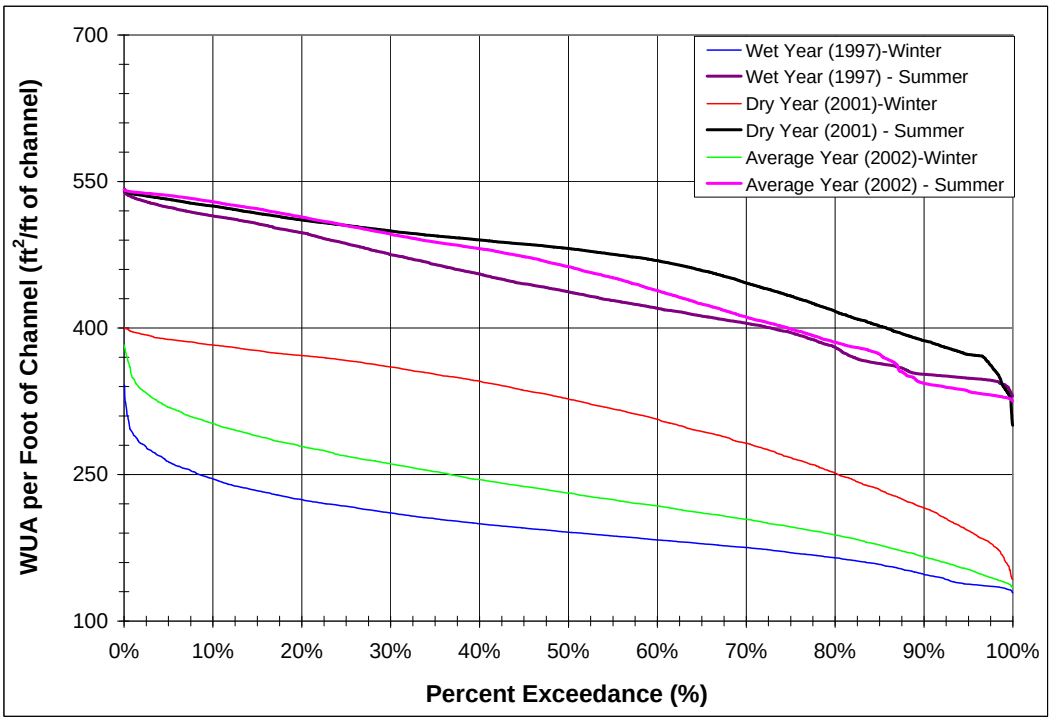


**Figure B-32.** WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

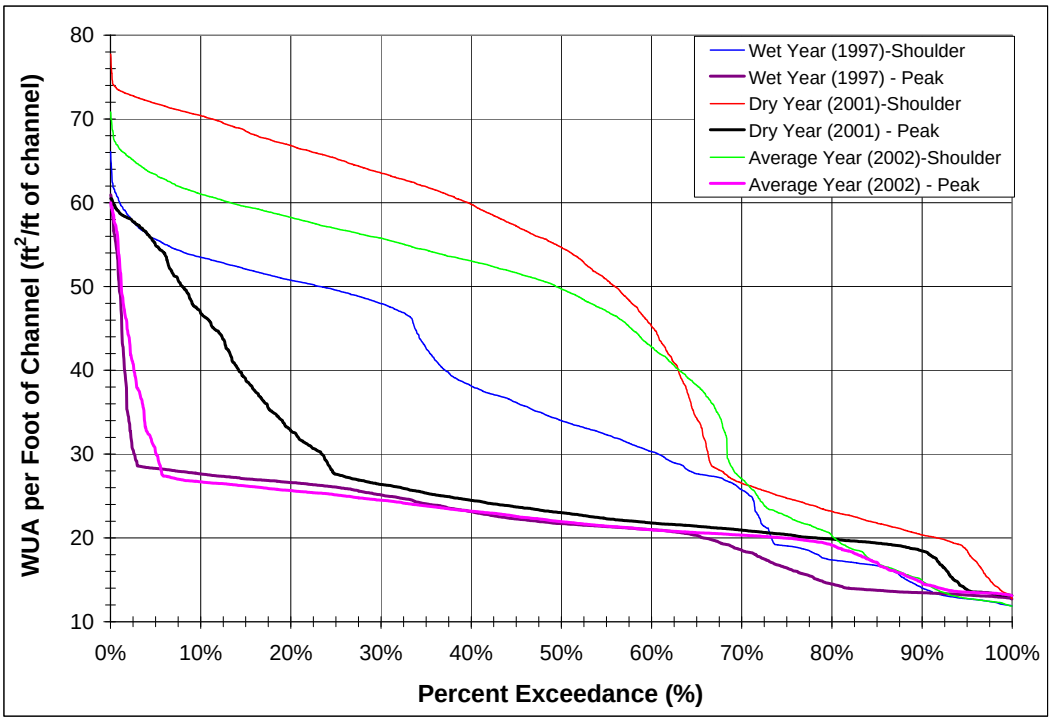


**Figure B-33.** WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

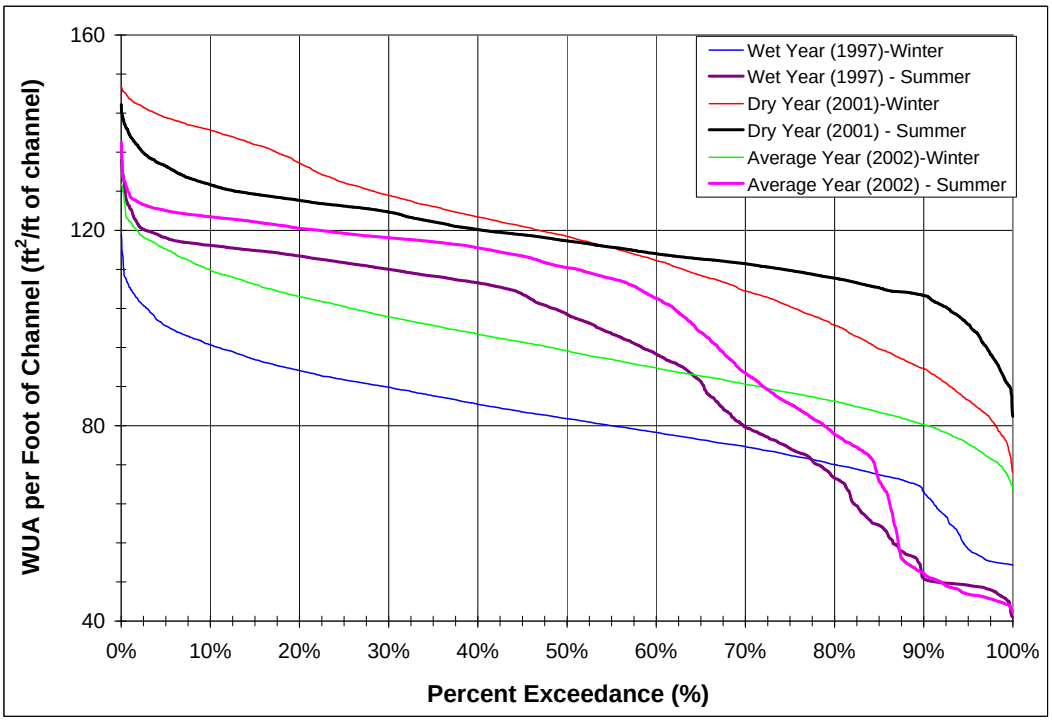


**Figure B-34.** WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

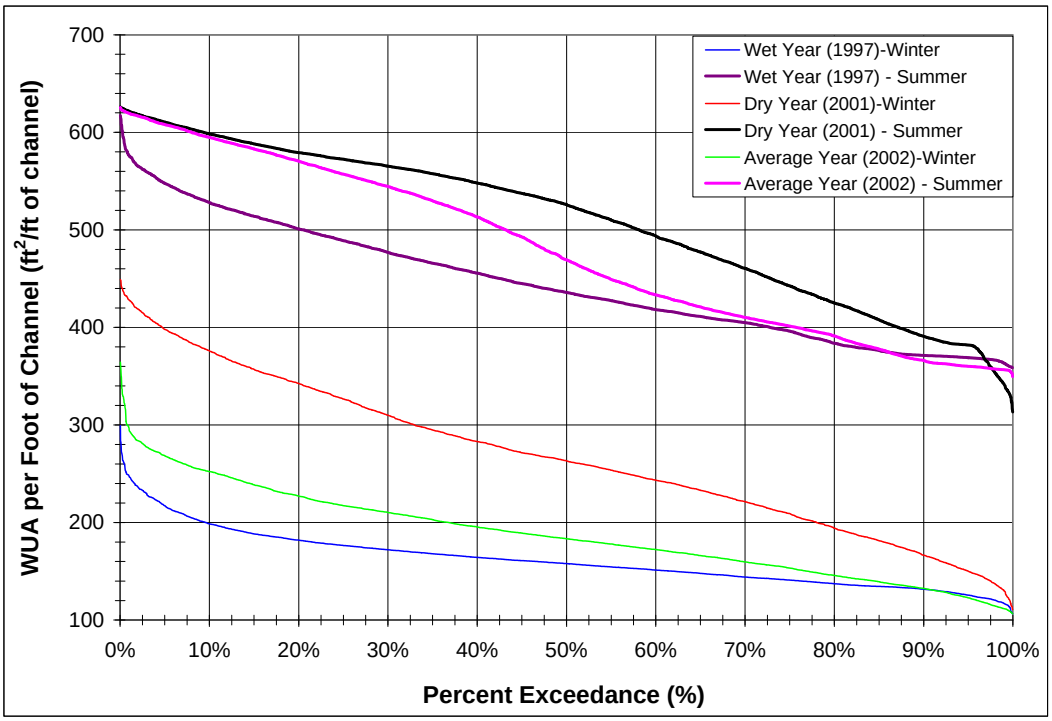


**Figure B-35.** WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

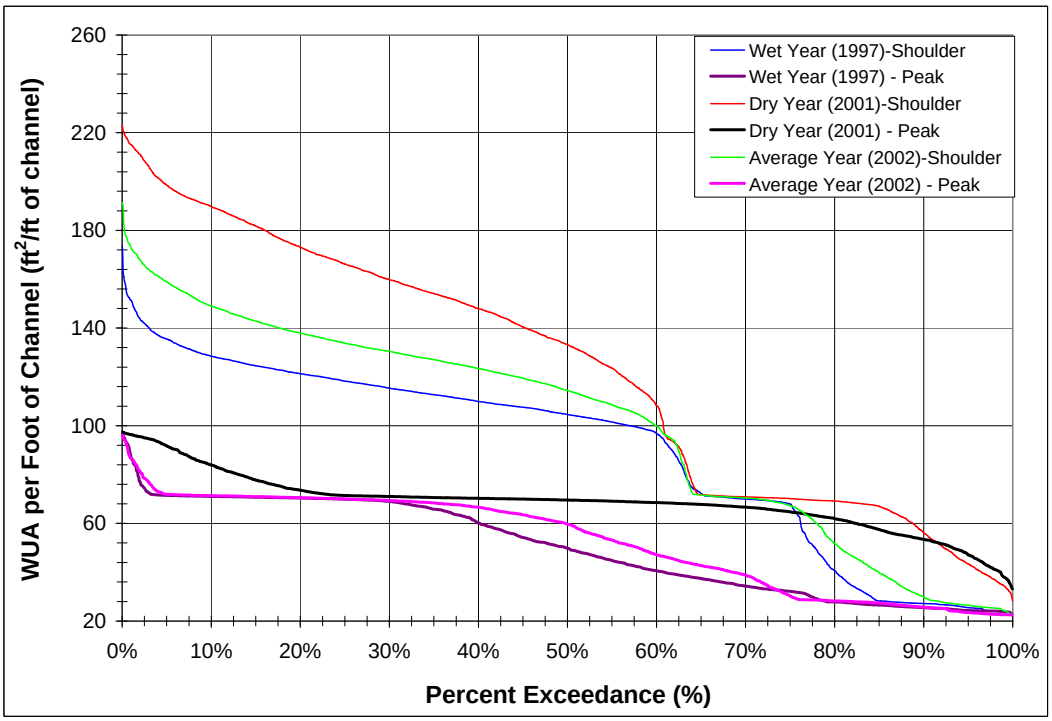


**Figure B-36.** WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

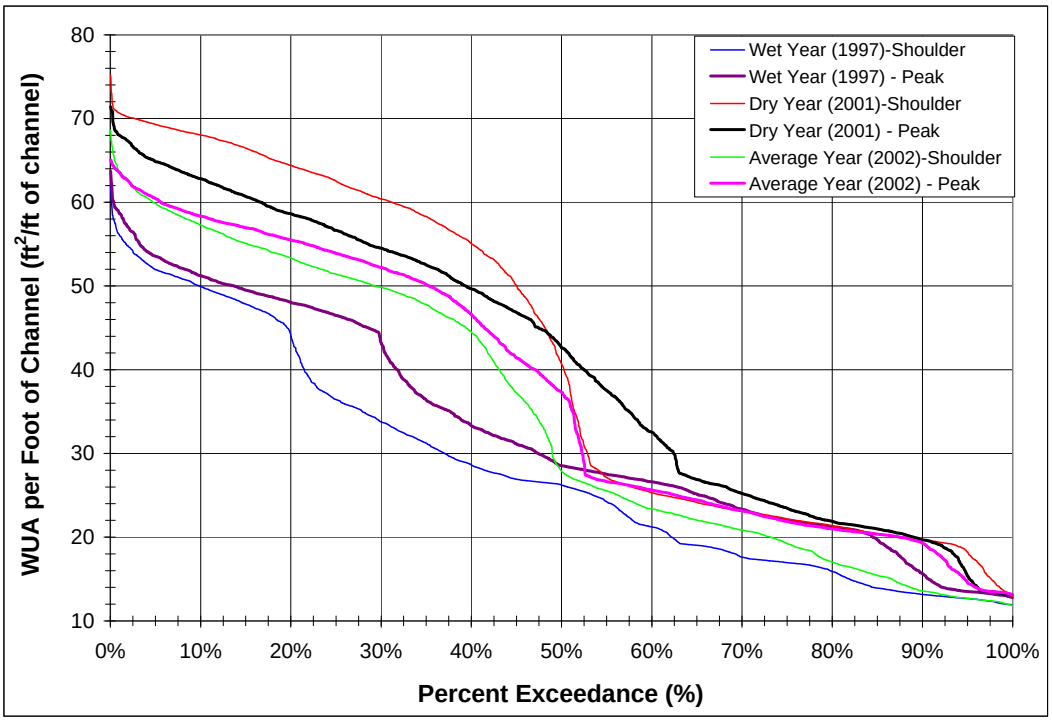


**Figure B-37.** WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

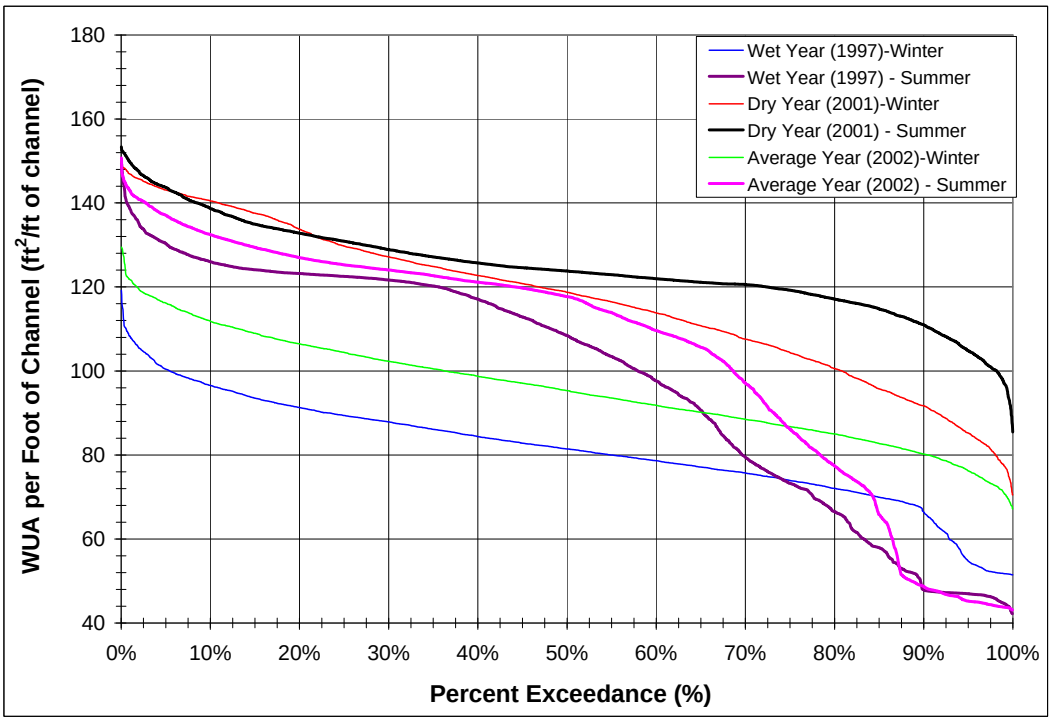


**Figure B-38.** WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

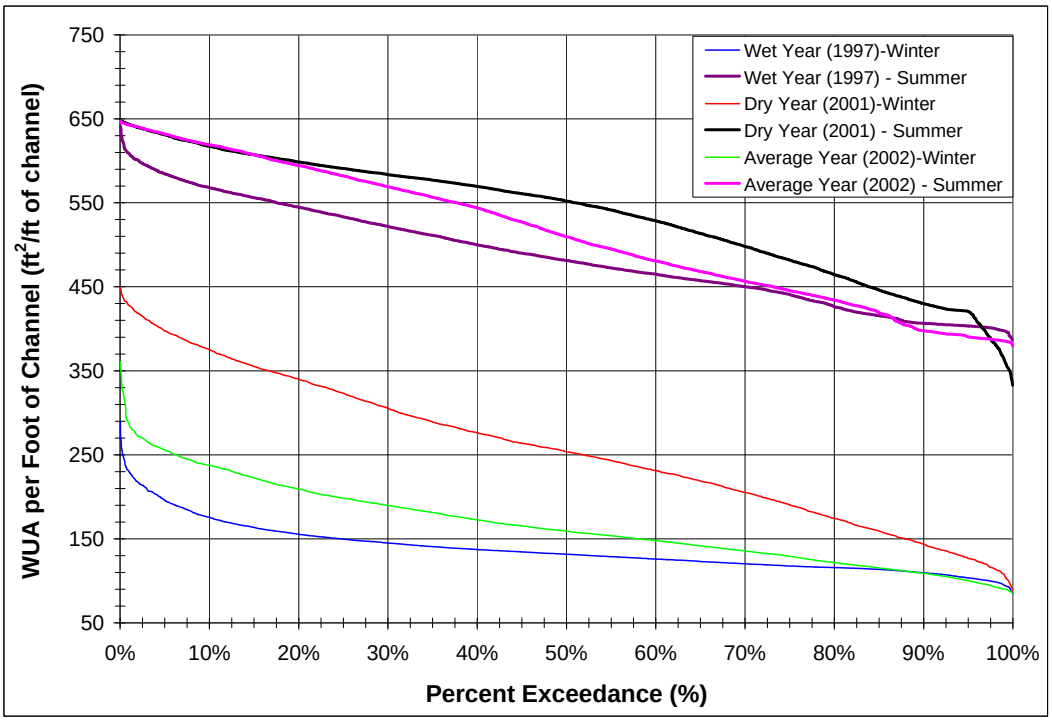


**Figure B-39.** WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

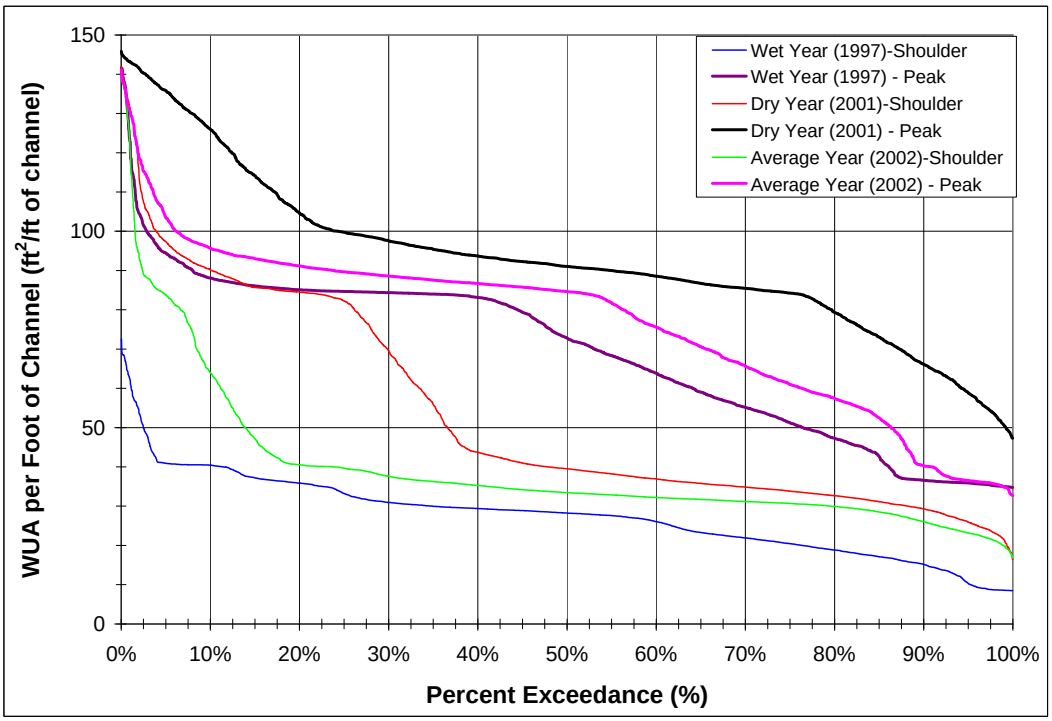


**Figure B-40.** WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

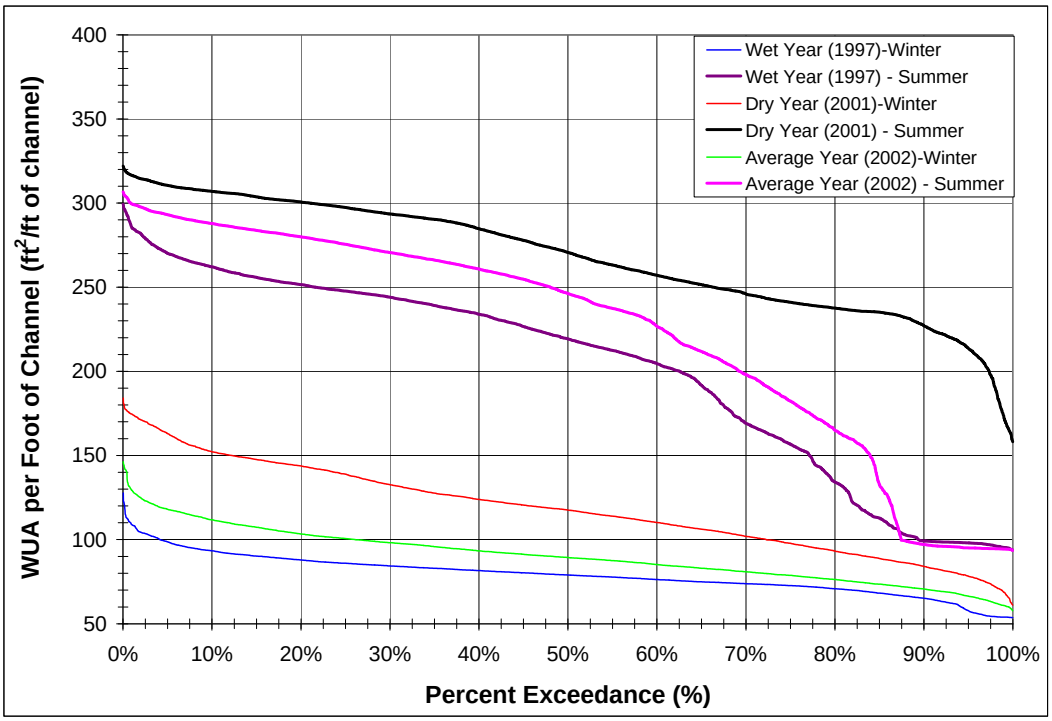


**Figure B-41.** WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

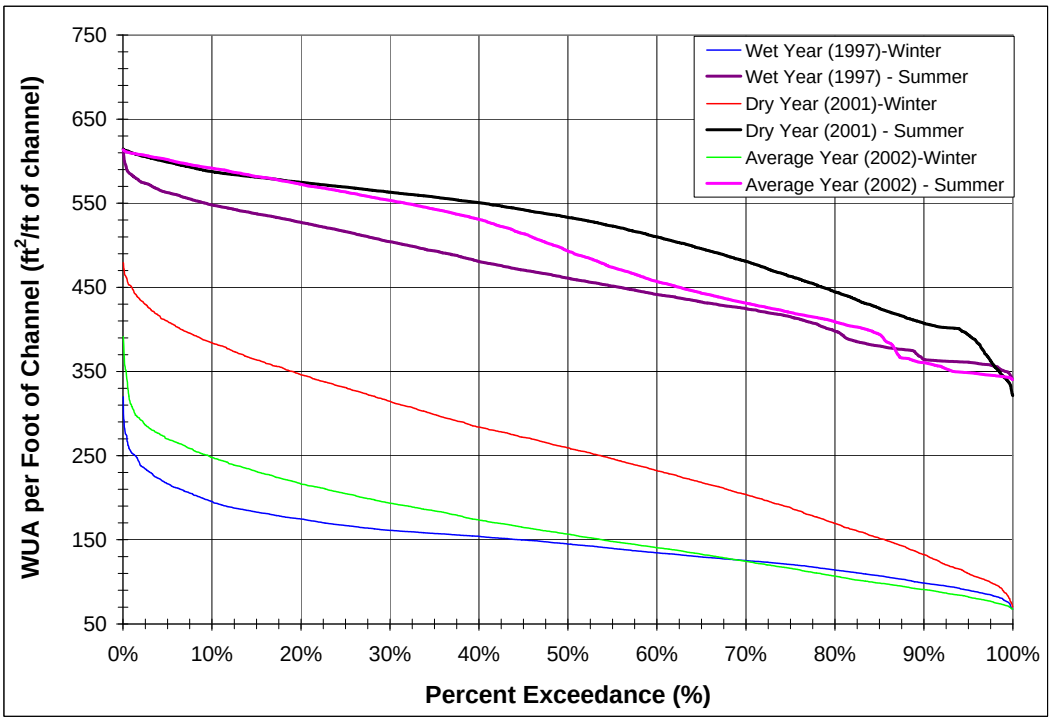


**Figure B-42.** WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

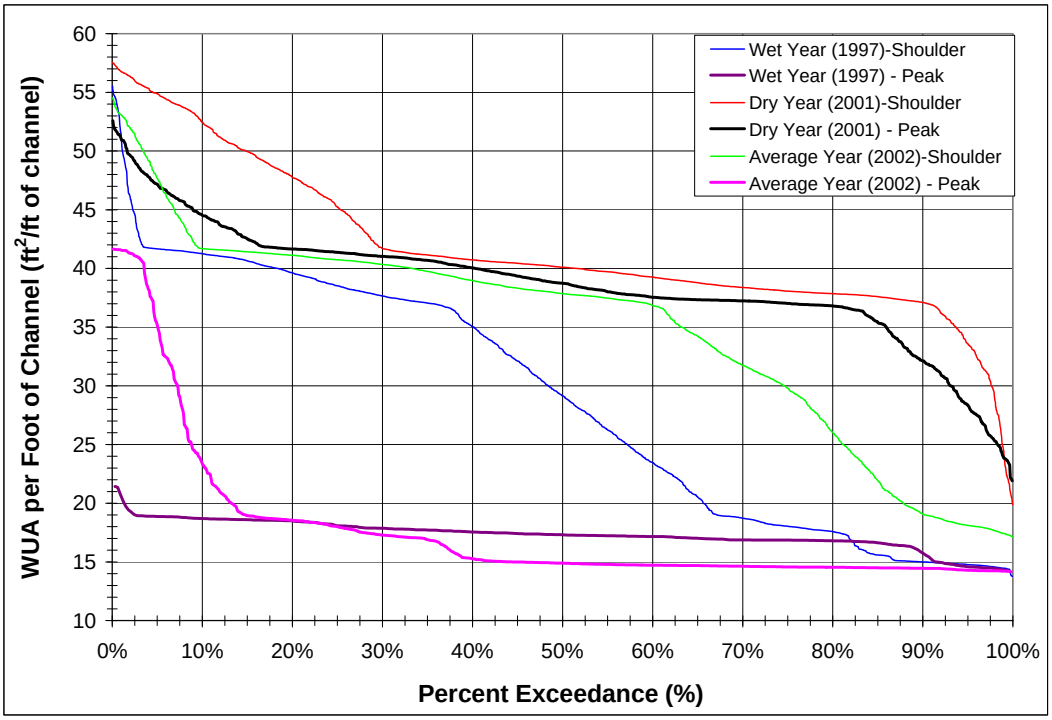


**Figure B-43.** WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

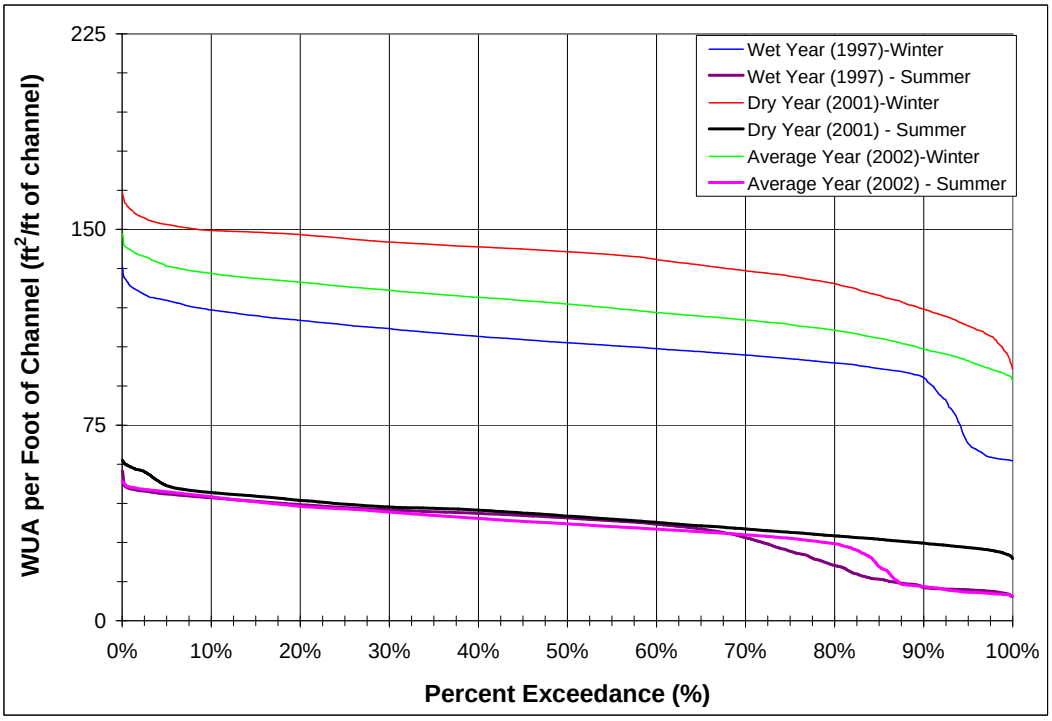


**Figure B-44.** WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

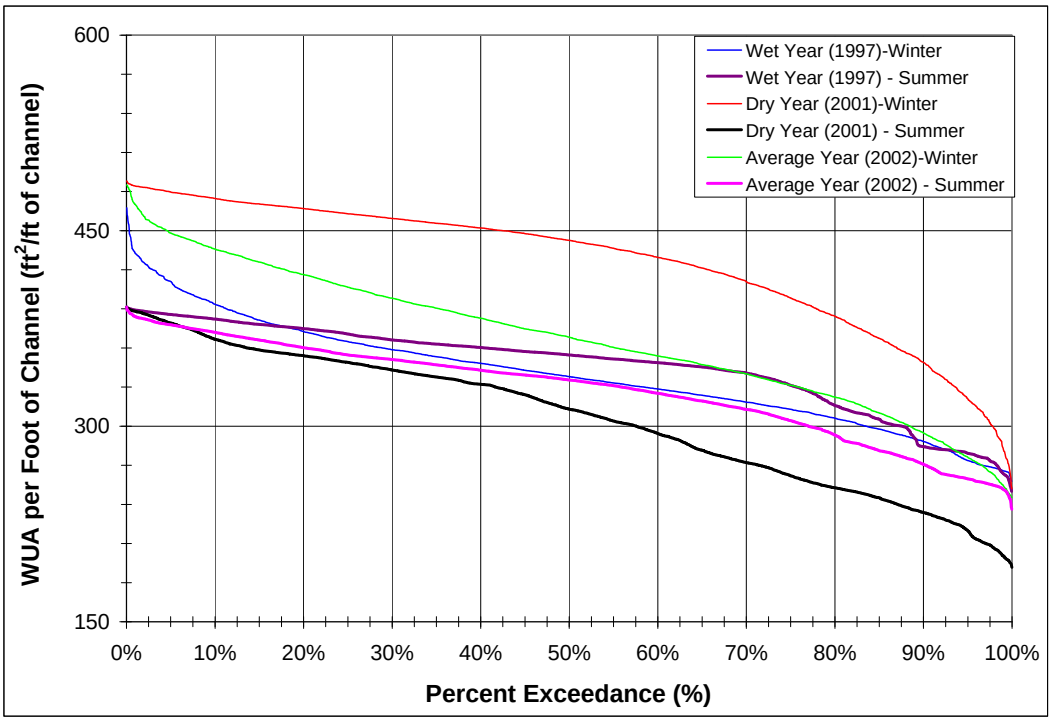


**Figure B-45.** WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Upper Reach.

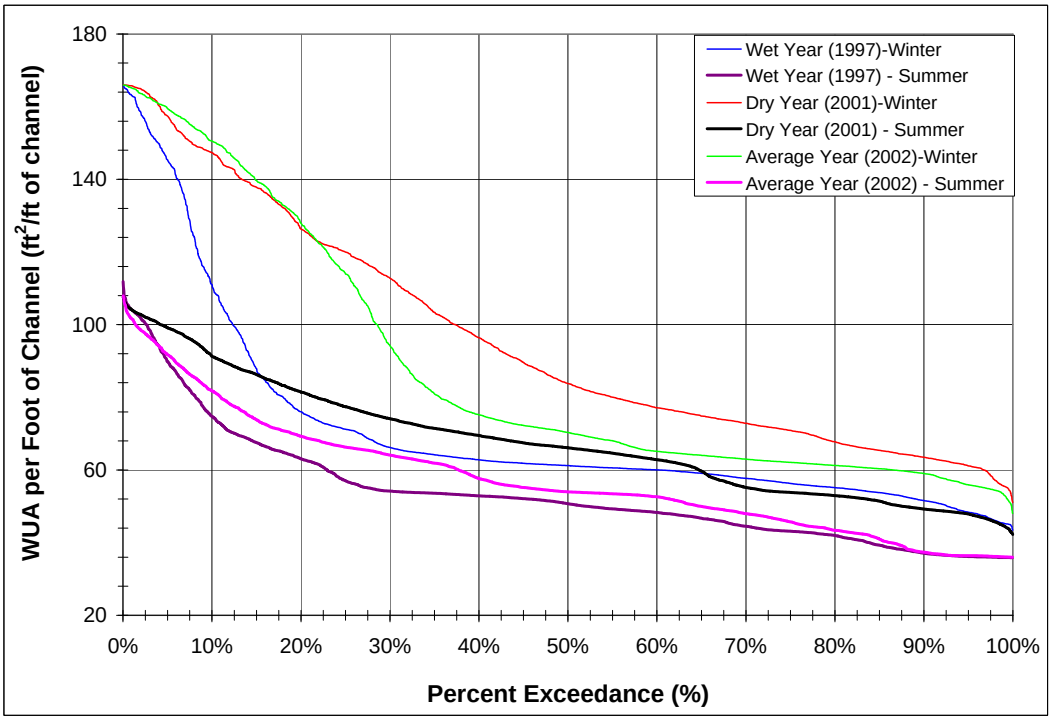


**Figure B-46.** WUA duration curves for juvenile bull trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

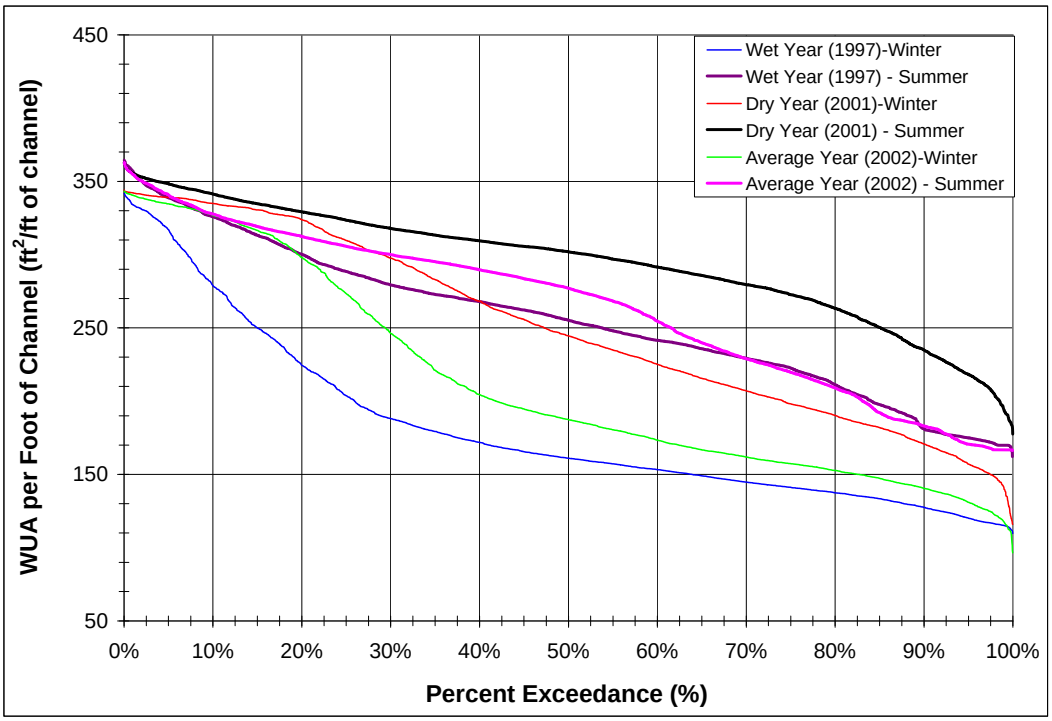


**Figure B-47.** WUA duration curves for adult bull trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

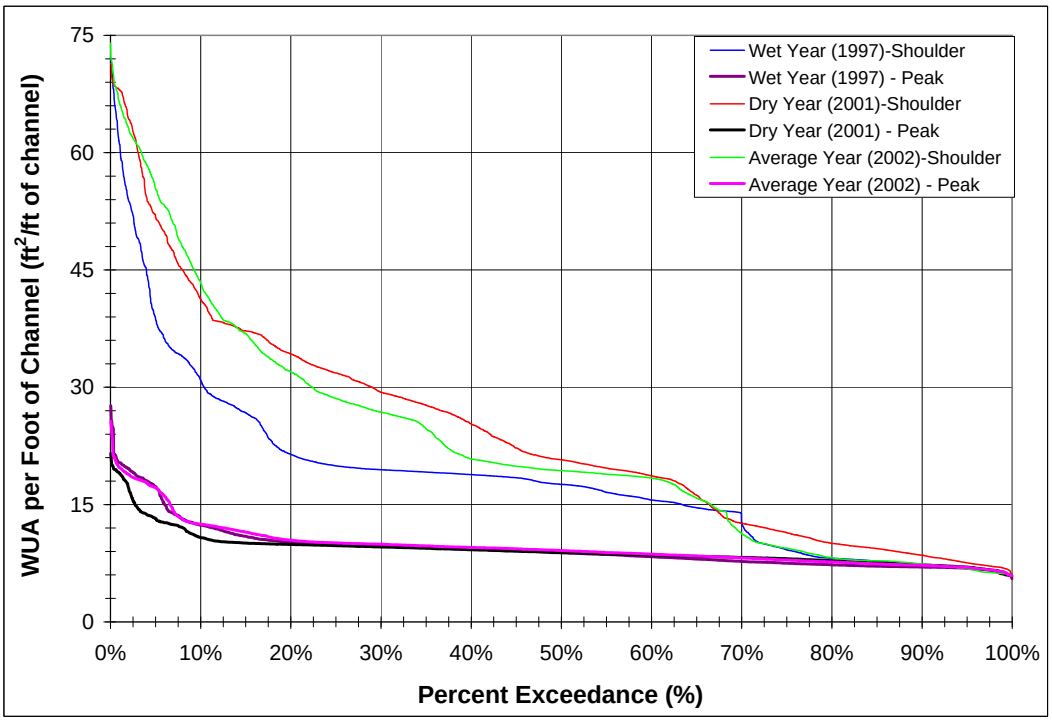


**Figure B-48.** WUA duration curves for cutthroat trout fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

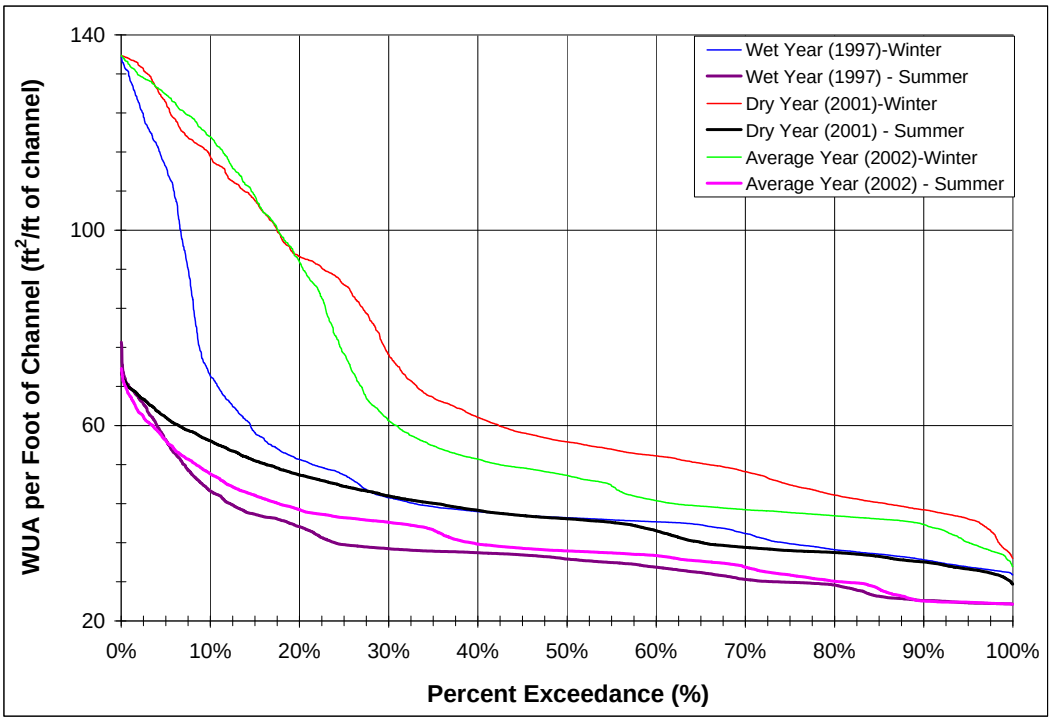


**Figure B-49.** WUA duration curves for juvenile cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

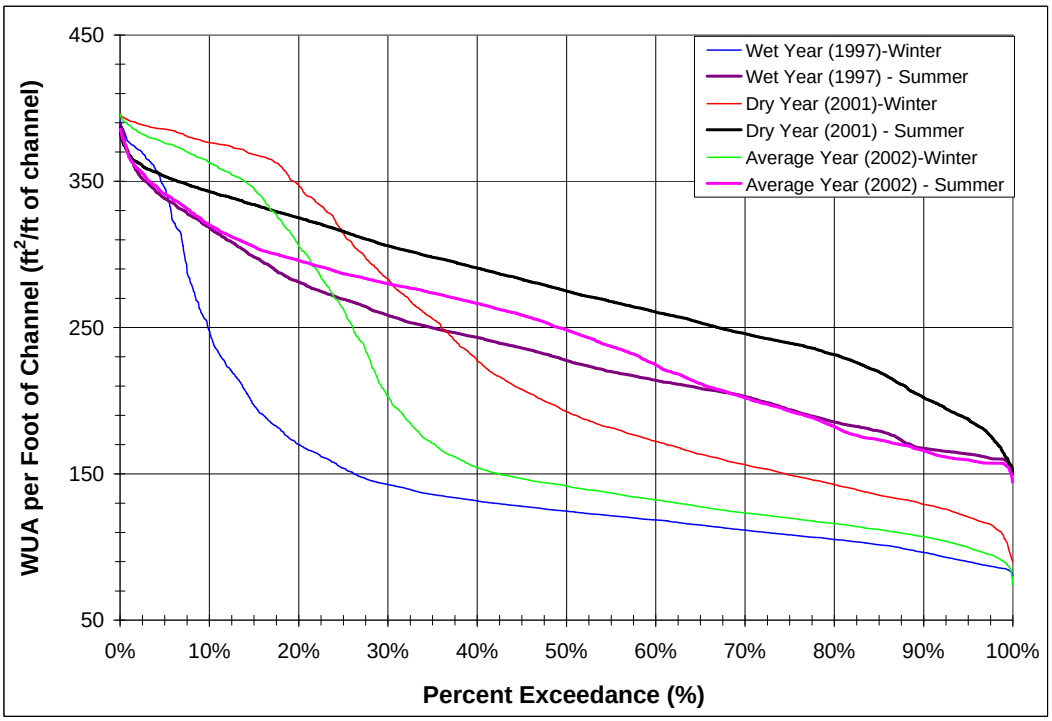


**Figure B-50.** WUA duration curves for adult cutthroat trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

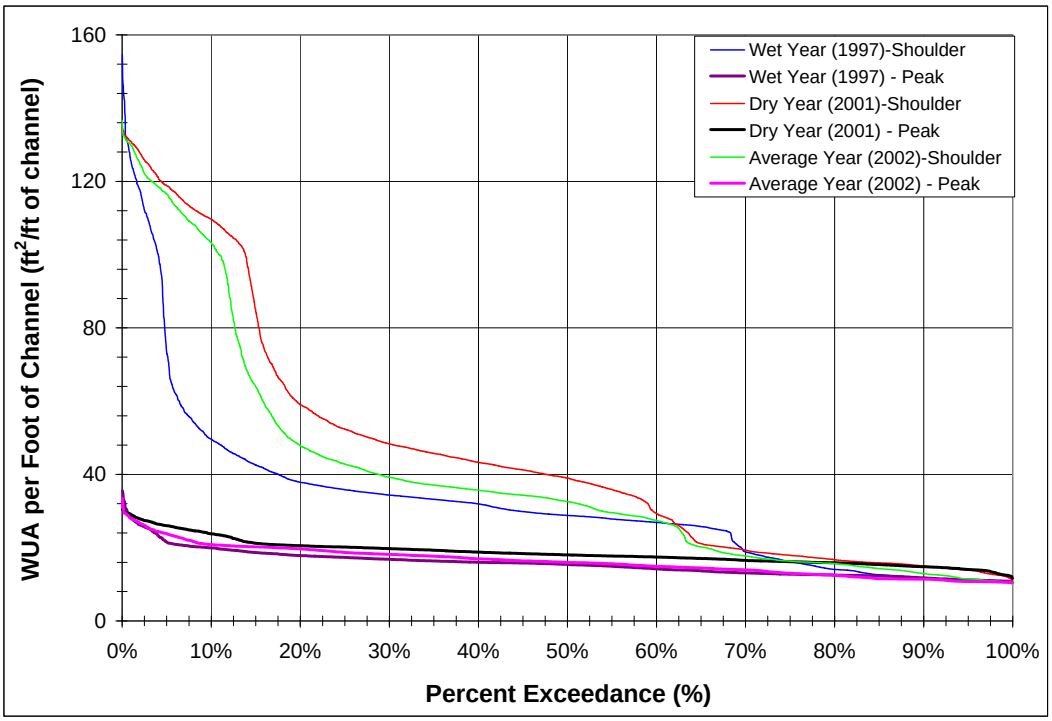


**Figure B-51.** WUA duration curves for cyprinid forage juveniles and fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

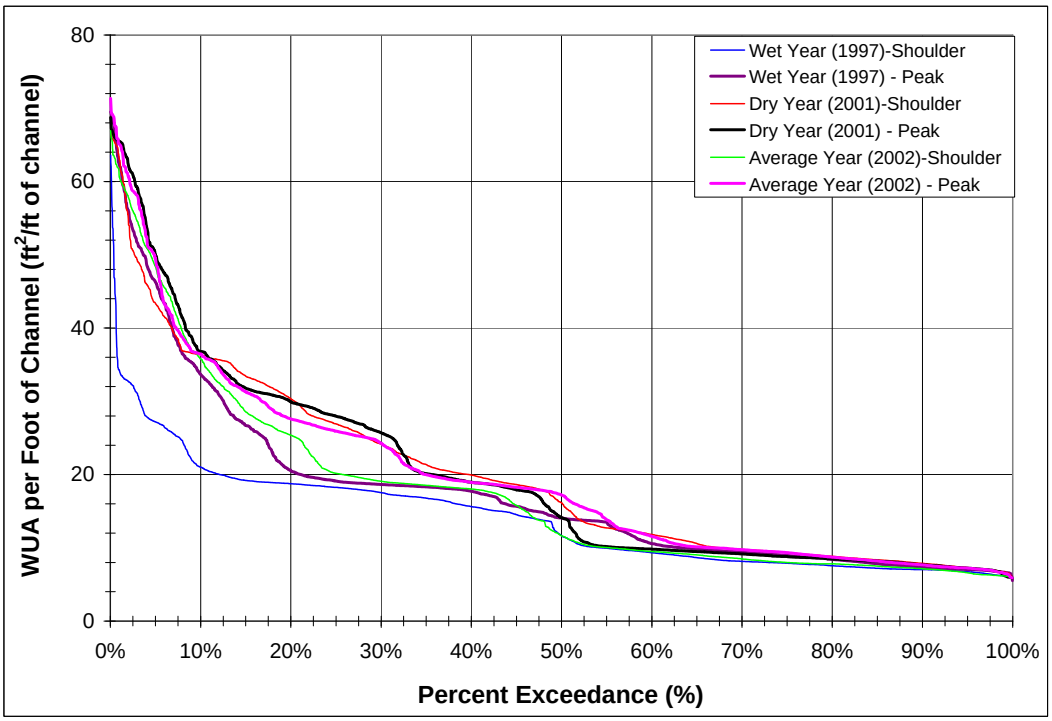


**Figure B-52.** WUA duration curves for redband trout fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

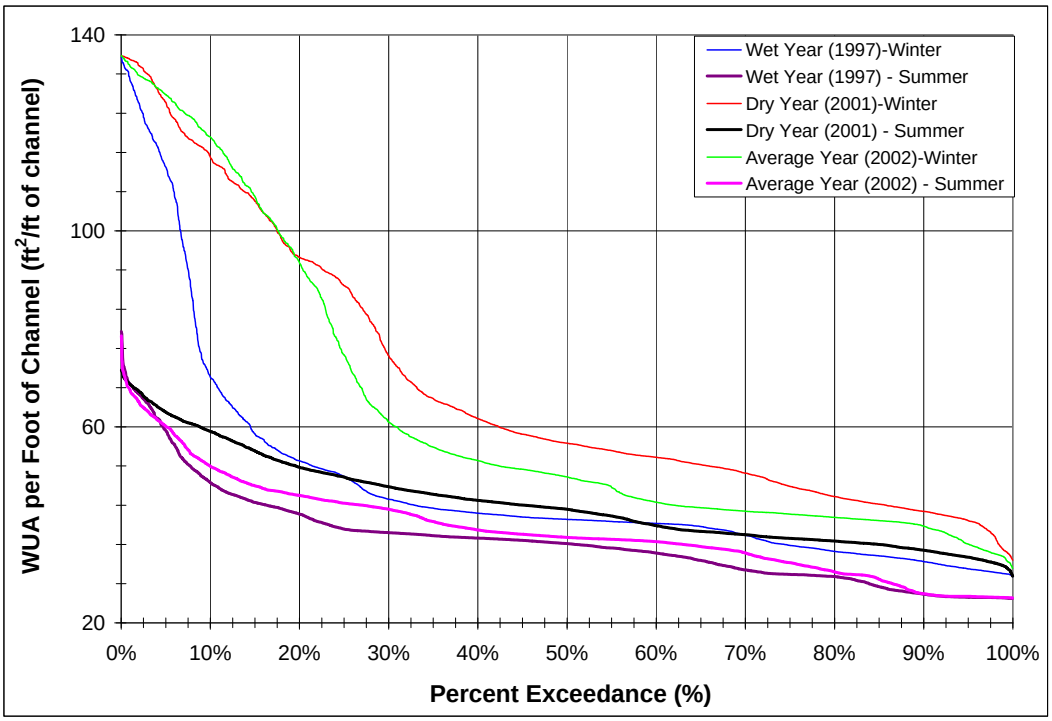


**Figure B-53.** WUA duration curves for juvenile redband trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

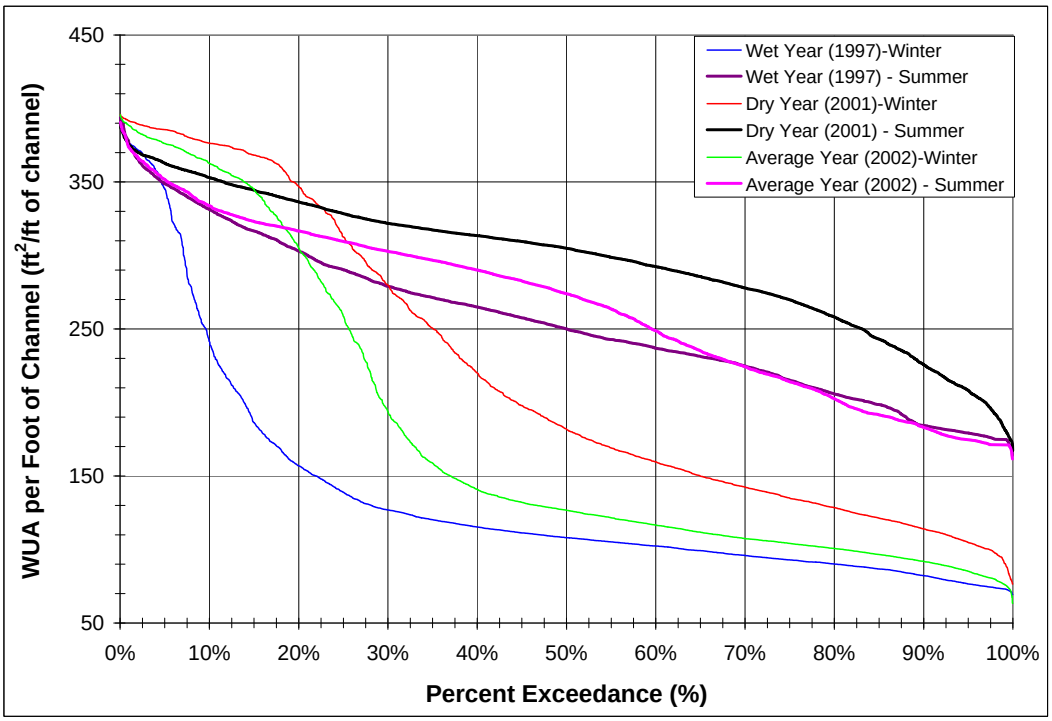


**Figure B-54.** WUA duration curves for adult redband trout during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

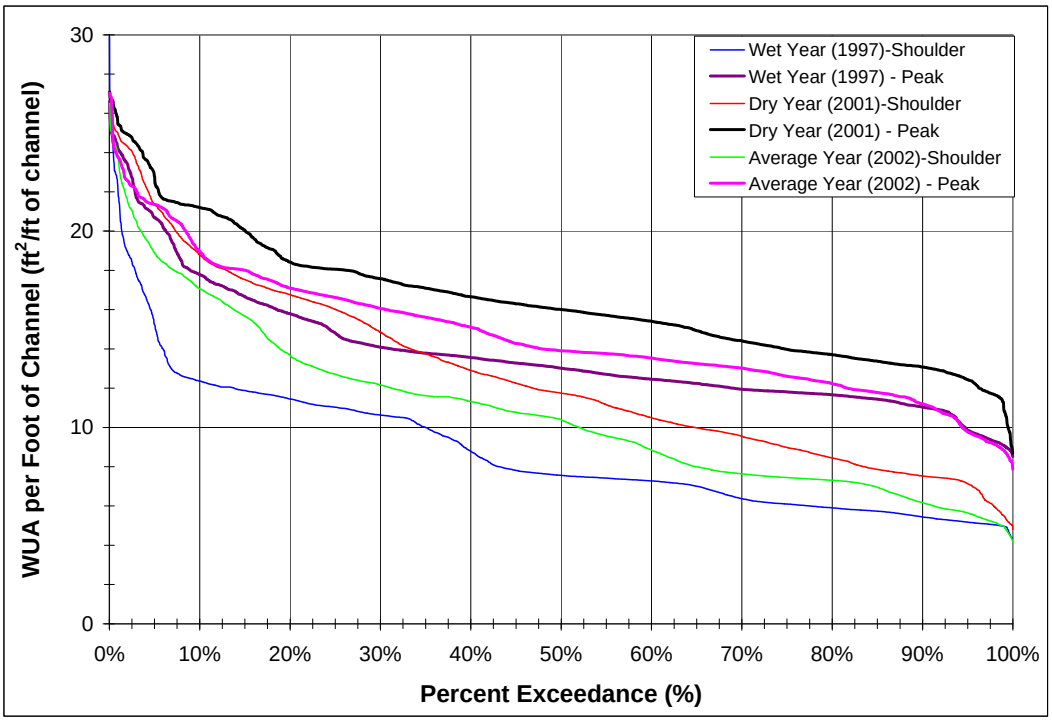


**Figure B-55.** WUA duration curves for smallmouth bass fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

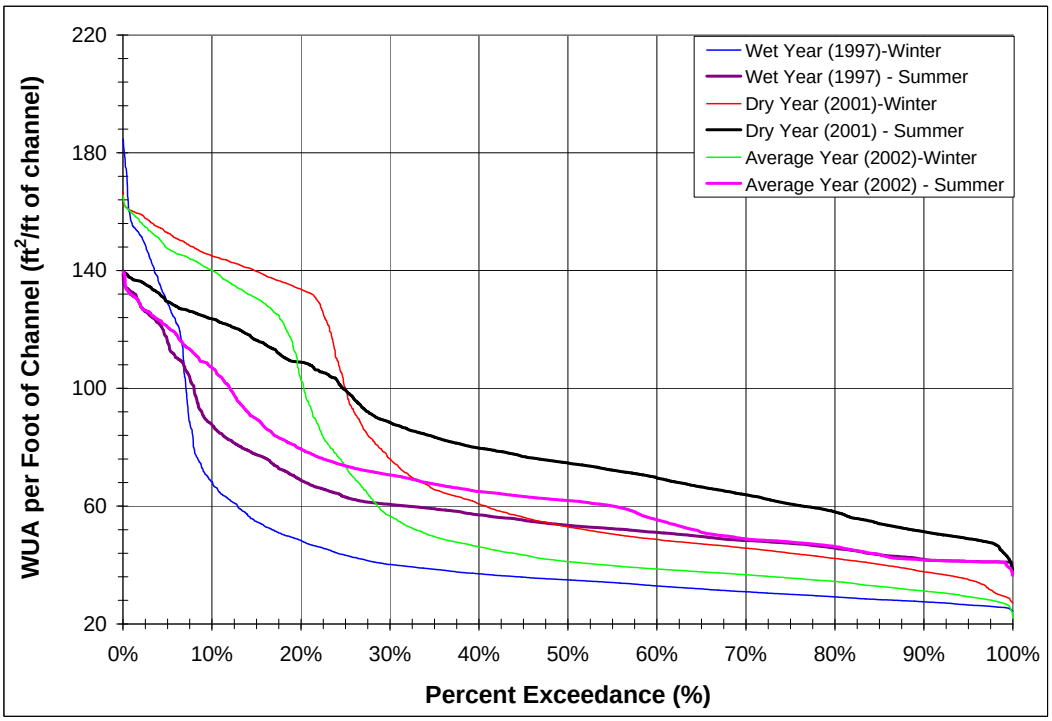


**Figure B-56.** WUA duration curves for juvenile smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

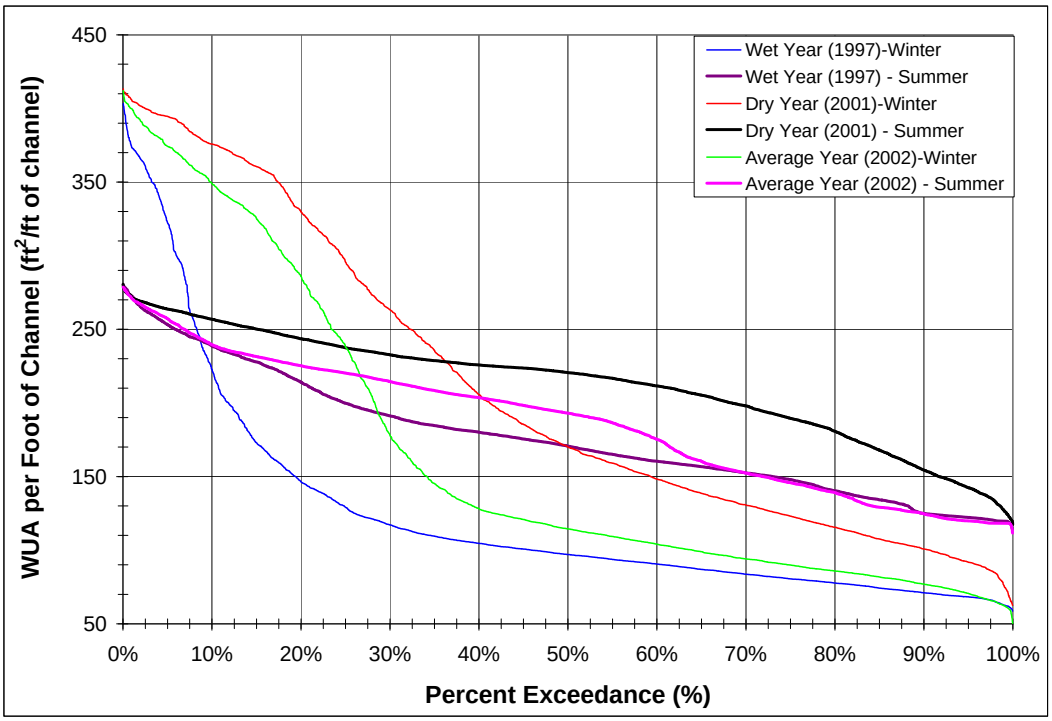


**Figure B-57.** WUA duration curves for adult smallmouth bass during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

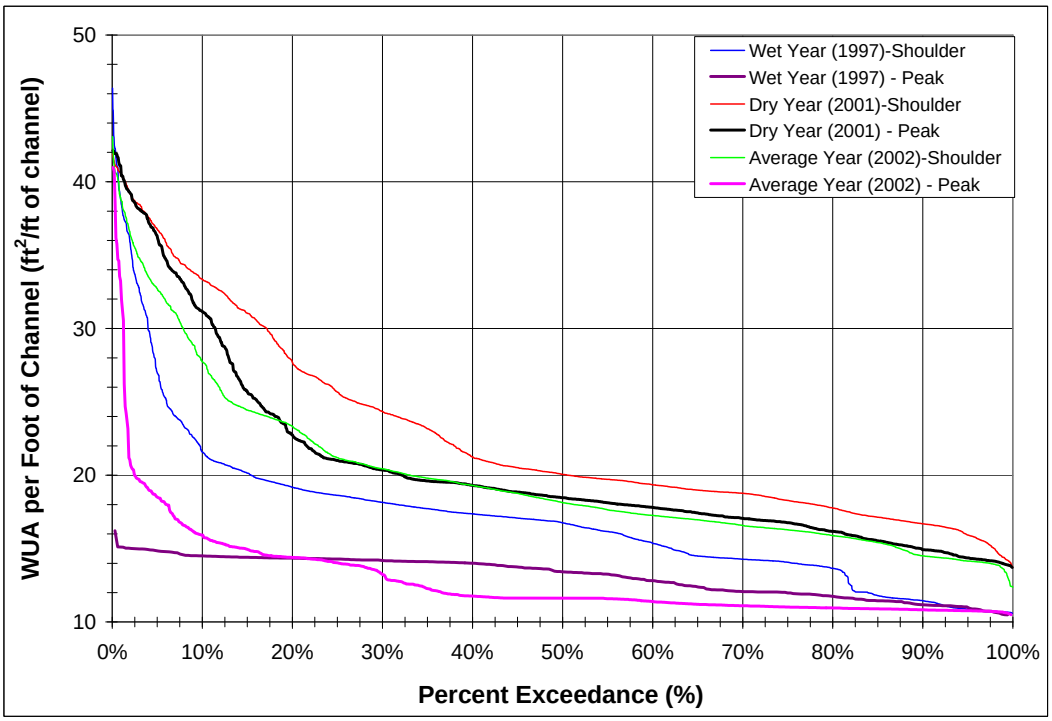


**Figure B-58.** WUA duration curves for whitefish fry during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

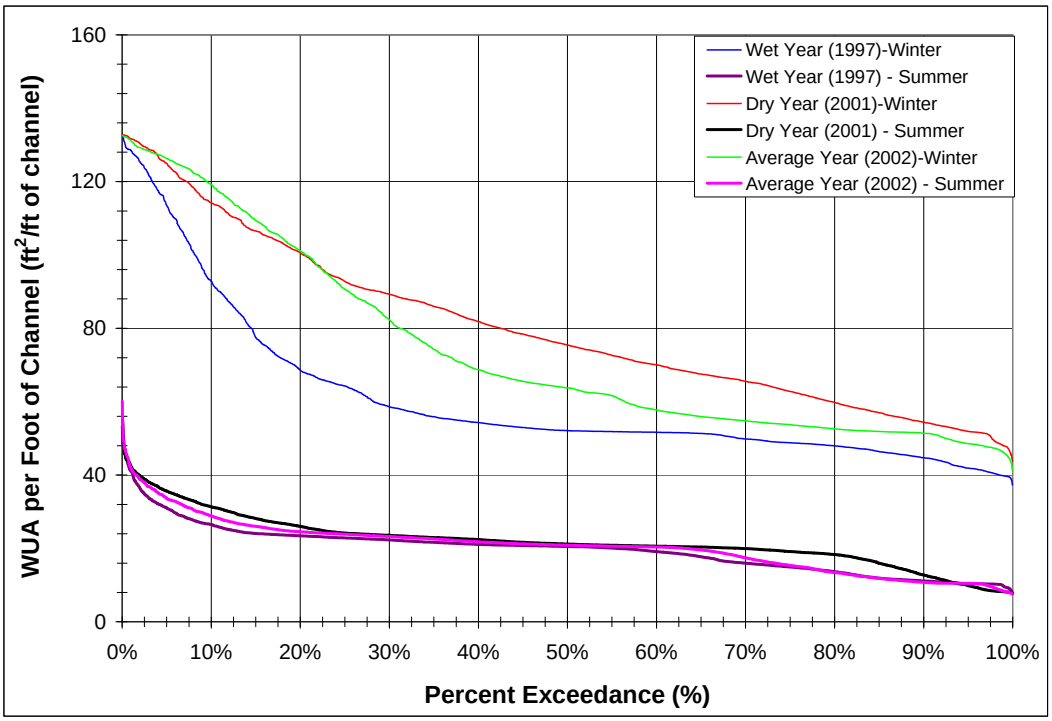


**Figure B-59.** WUA duration curves for juvenile whitefish during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

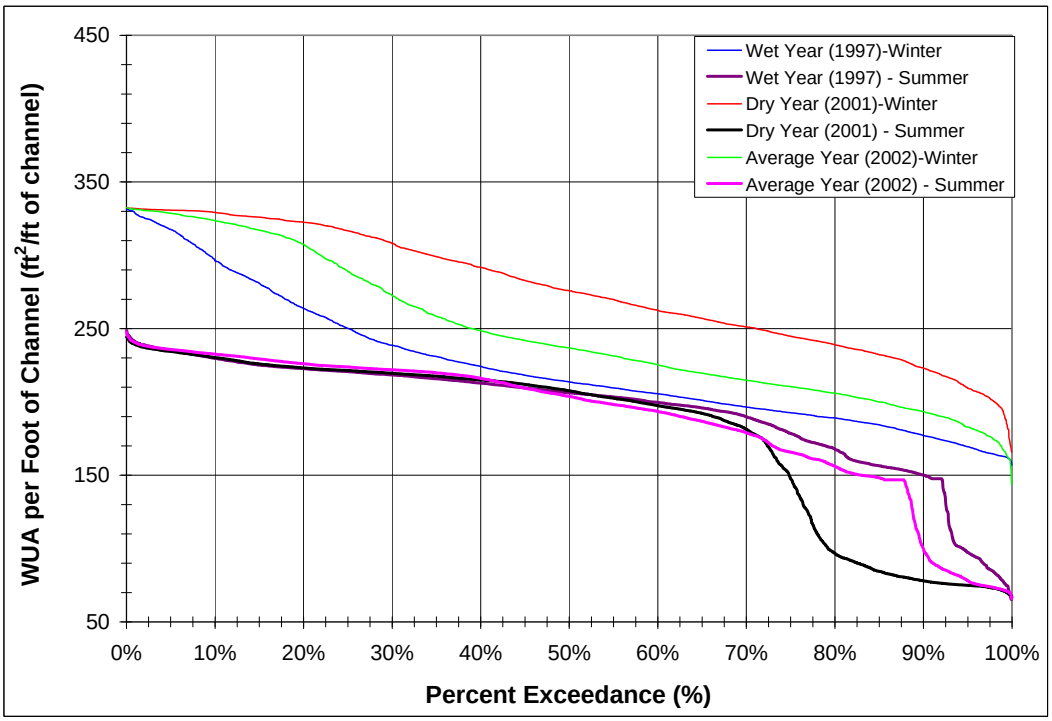


**Figure B-60.** WUA duration curves for adult whitefish during representative wet (1997), dry (2001), and average (2002) years in the Tailrace Reach.

# Attachment C: Figures of Spawning and Incubation Model Output

This attachment contains the following figures:

Figure C-1. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-05.
Figure C-2. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-10.
Figure C-3. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-11.
Figure C-4. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-23.
Figure C-5. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-24.
Figure C-6. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect TR-15.
Figure C-7. Potential and effective spawning and incubation widths for mountain whitefish at habitat transect TR-16.
Figure C-8. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect C-06.
Figure C-9. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect C-07.
Figure C-10. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-05.
Figure C-11. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-06.
Figure C-12. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-07.
Figure C-13. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-10.
Figure C-14. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-16.
Figure C-15. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-17.
Figure C-16. Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-21.

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Note: Each figure in this attachment includes model output for three representative years: wet (1997), dry (2001), and average (2002). The representative wet year output is the top of the three plots, the representative dry year output is in the middle, and the representative average year output is shown in the bottom plot. Each plot illustrates the potential spawning index width (PSI), effective spawning index width (ESI), hourly water surface elevation in the Pend Oreille River at the specified habitat transect (WSE), and the lowest water surface elevation during the period of incubation (WSEesi).

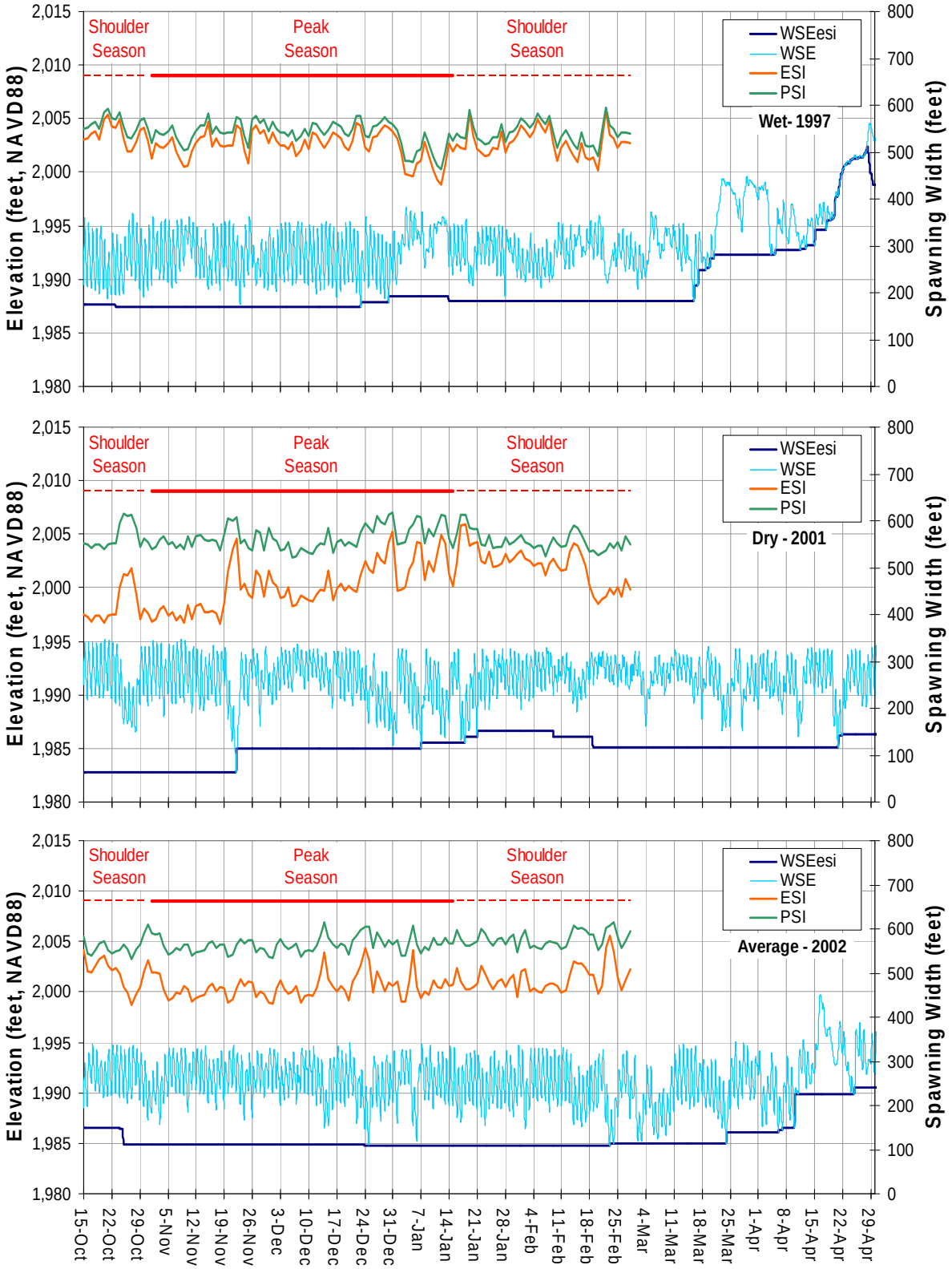


**Figure C-1.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-05.

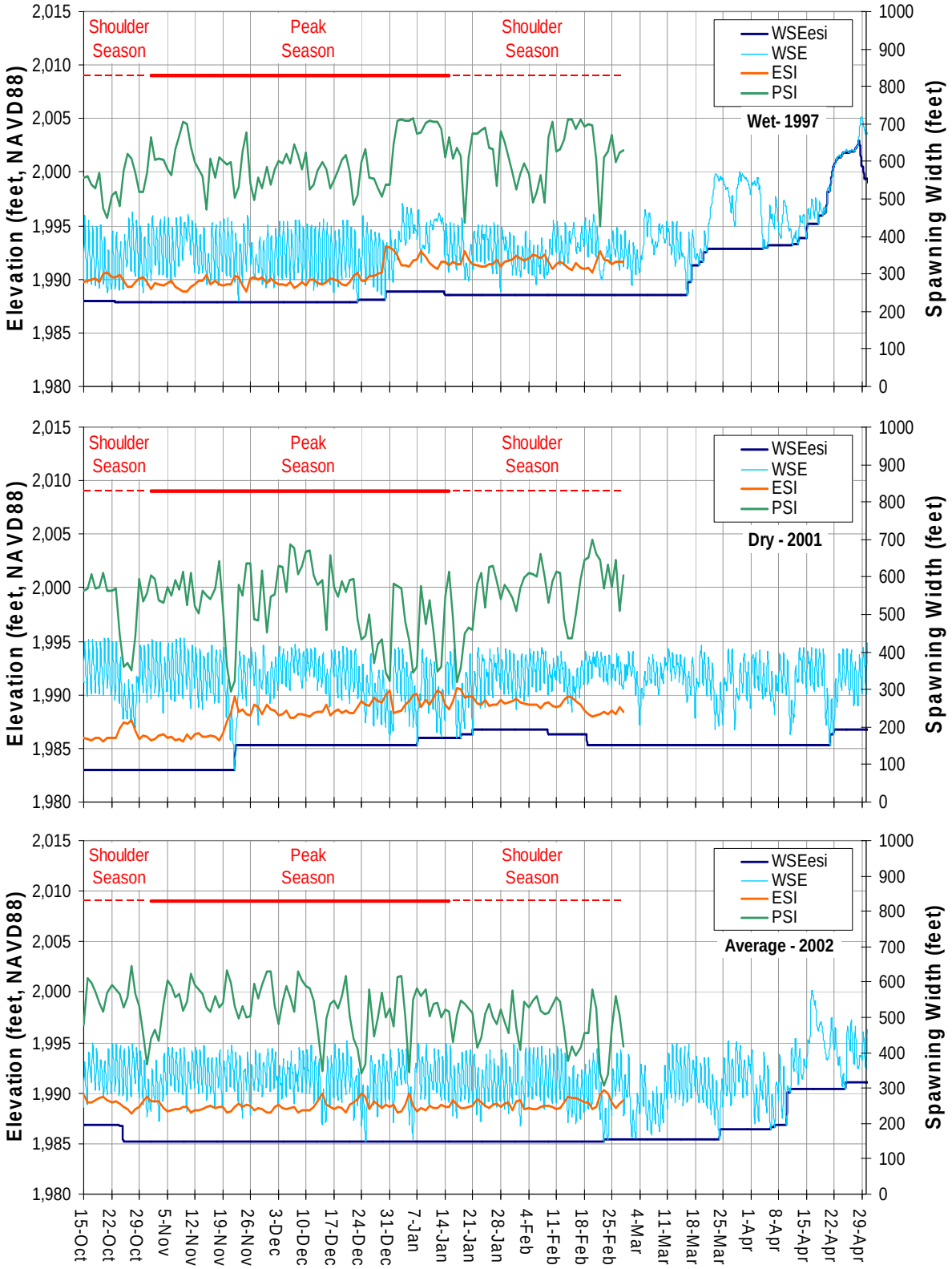


**Figure C-2.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-10.

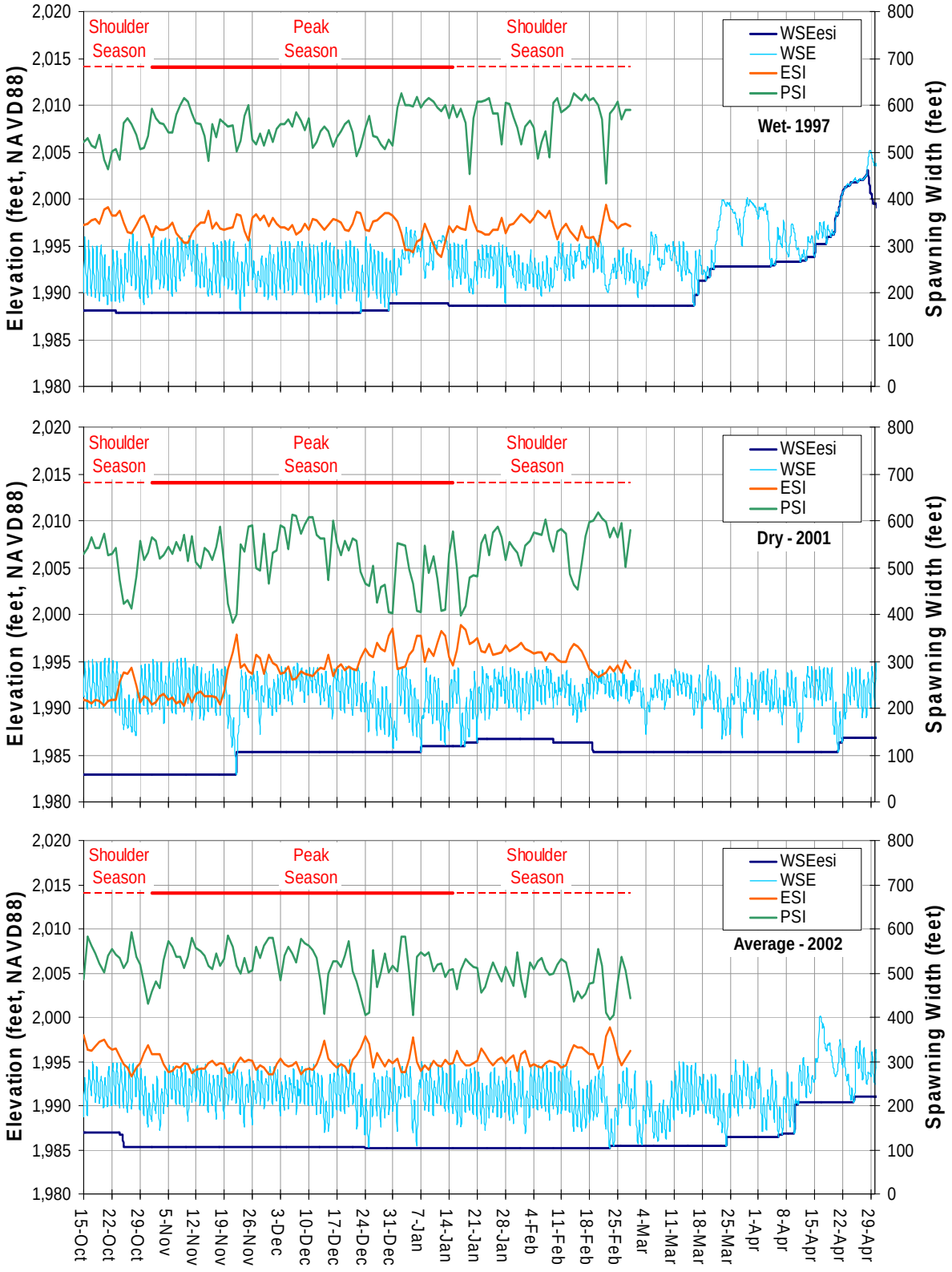


**Figure C-3.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-11.

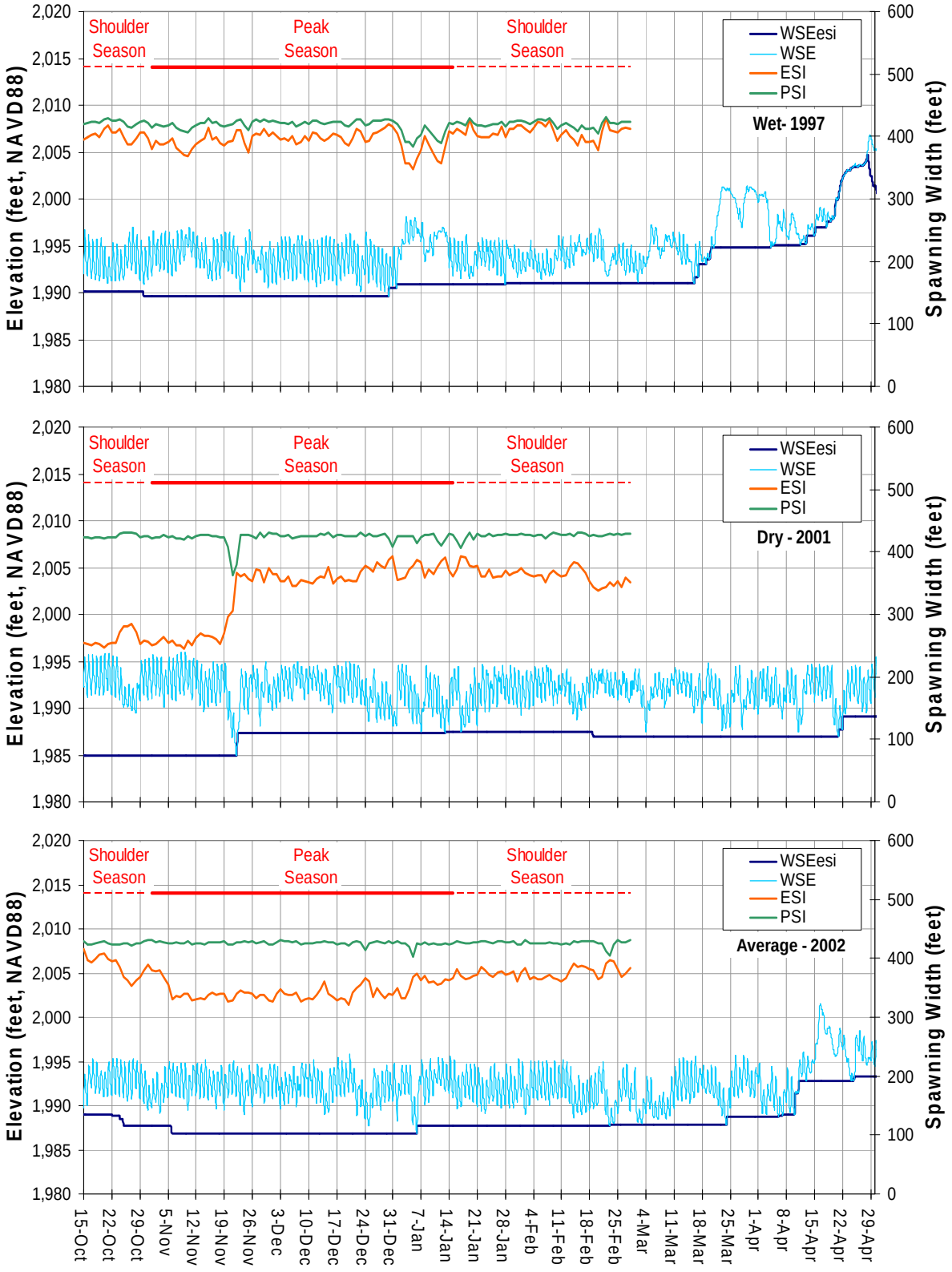


**Figure C-4.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-23.

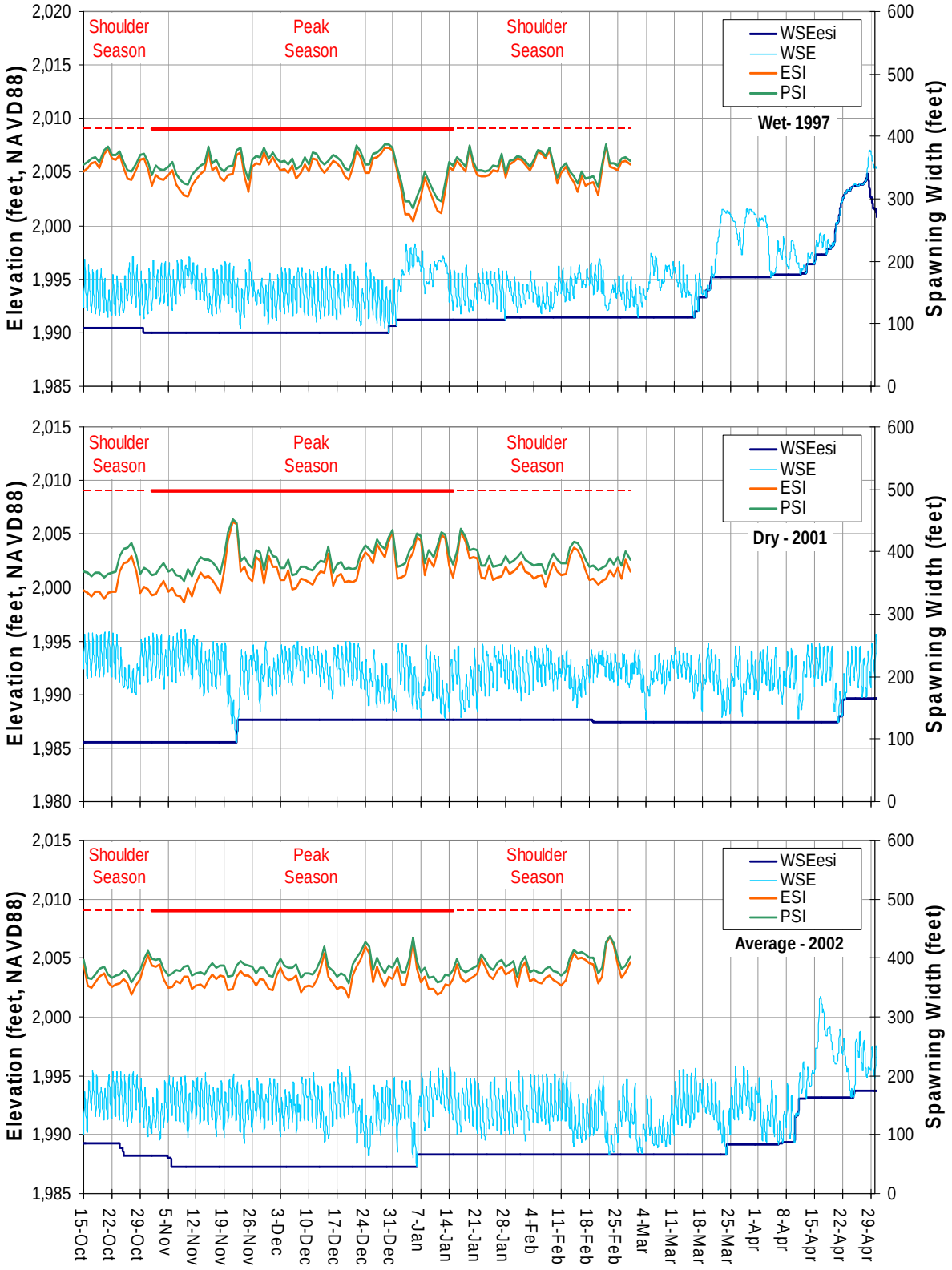


**Figure C-5.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect U-24.

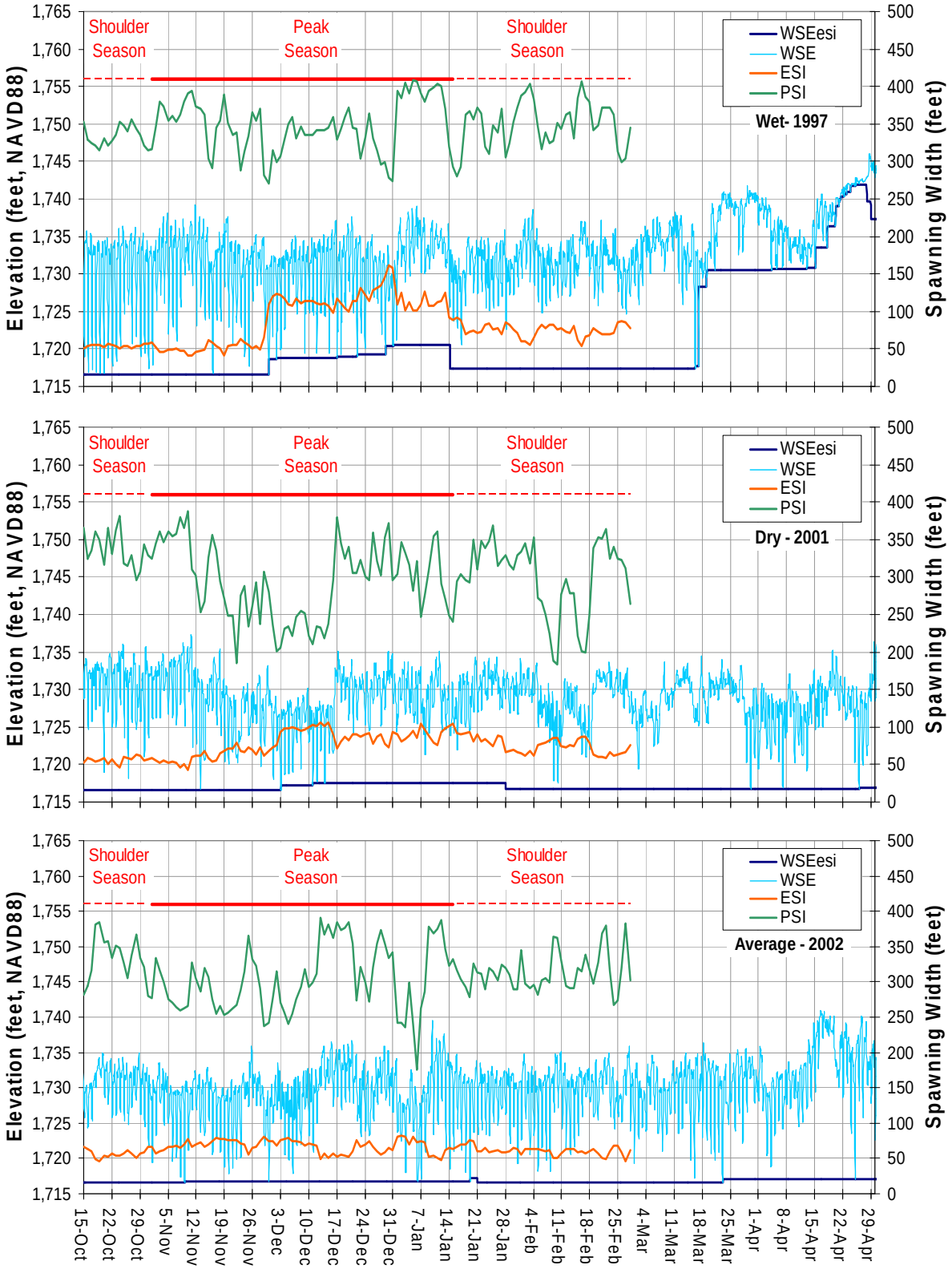


**Figure C-6.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect TR-15.

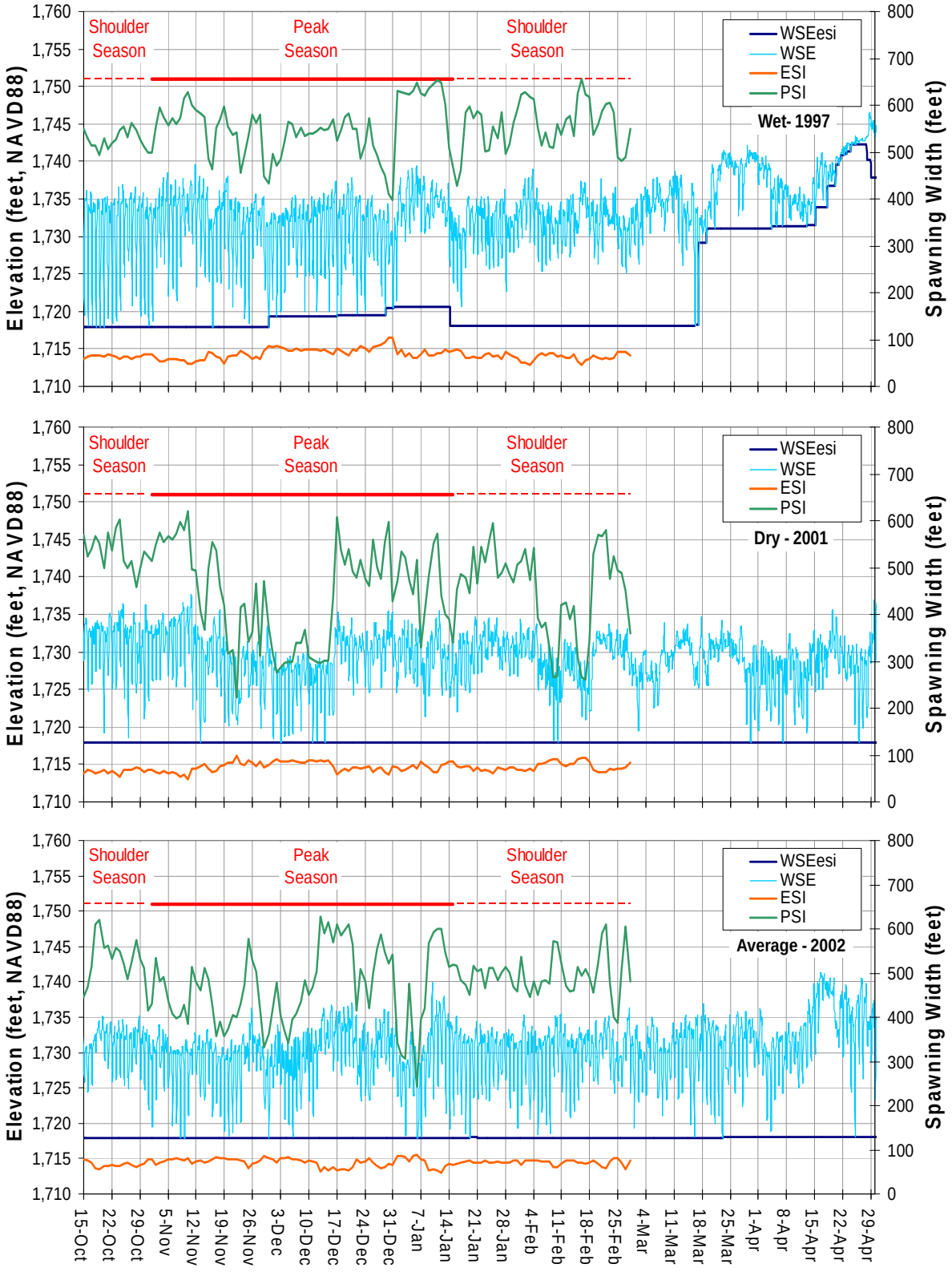


**Figure C-7.** Potential and effective spawning and incubation widths for mountain whitefish at habitat transect TR-16.

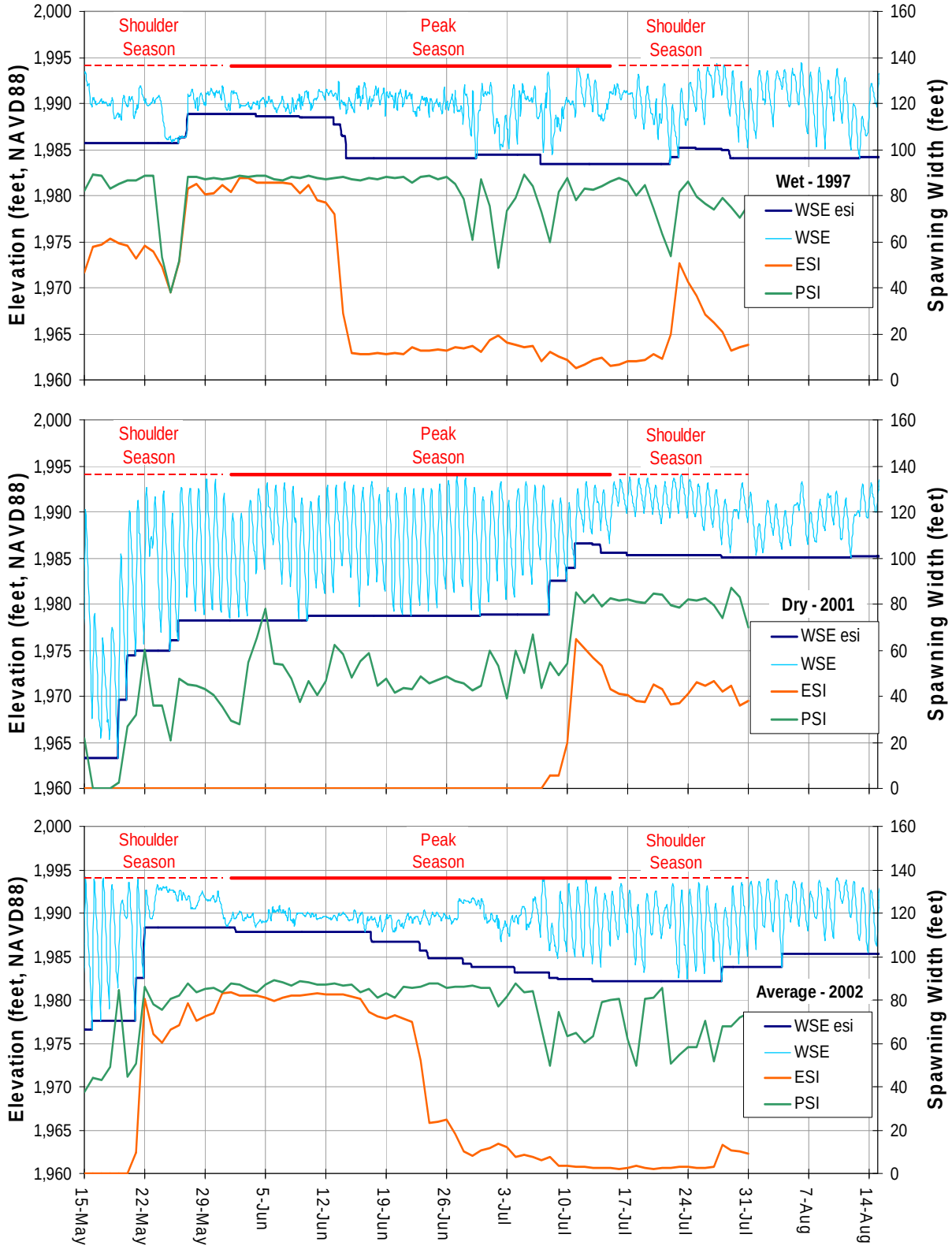


**Figure C-8.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect C-06.

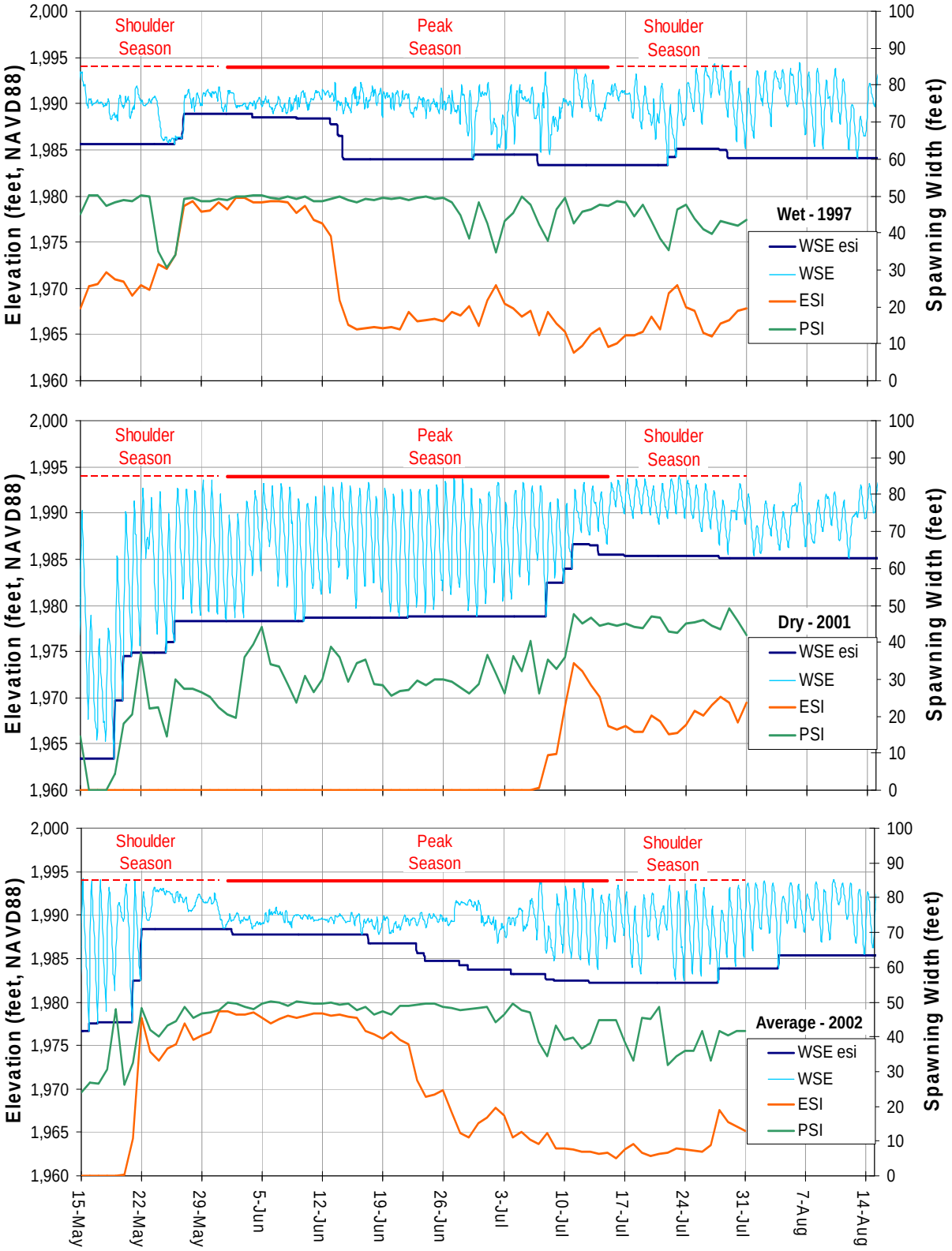


**Figure C-9.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect C-07.

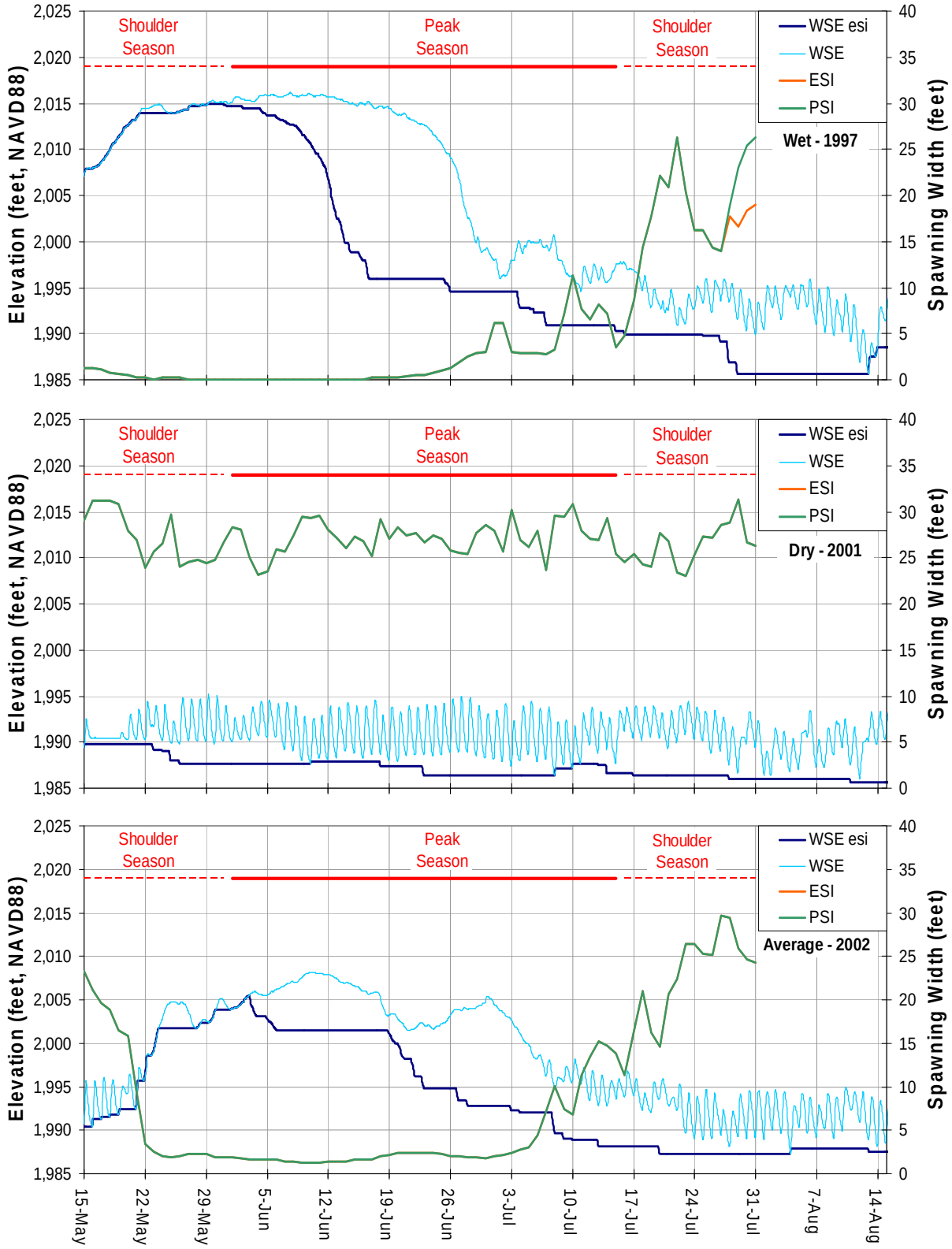


**Figure C-10.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-05.

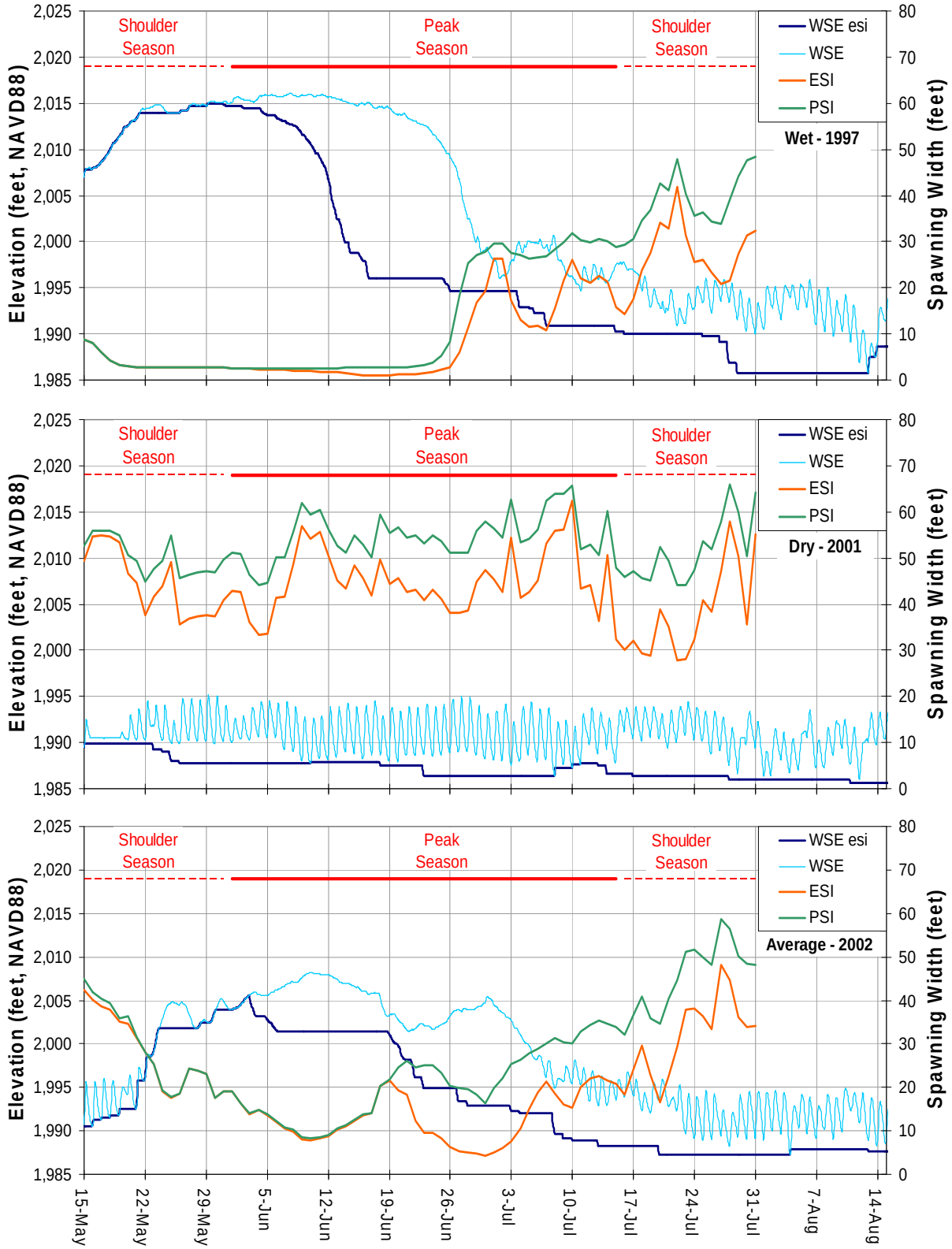


**Figure C-11.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-06.

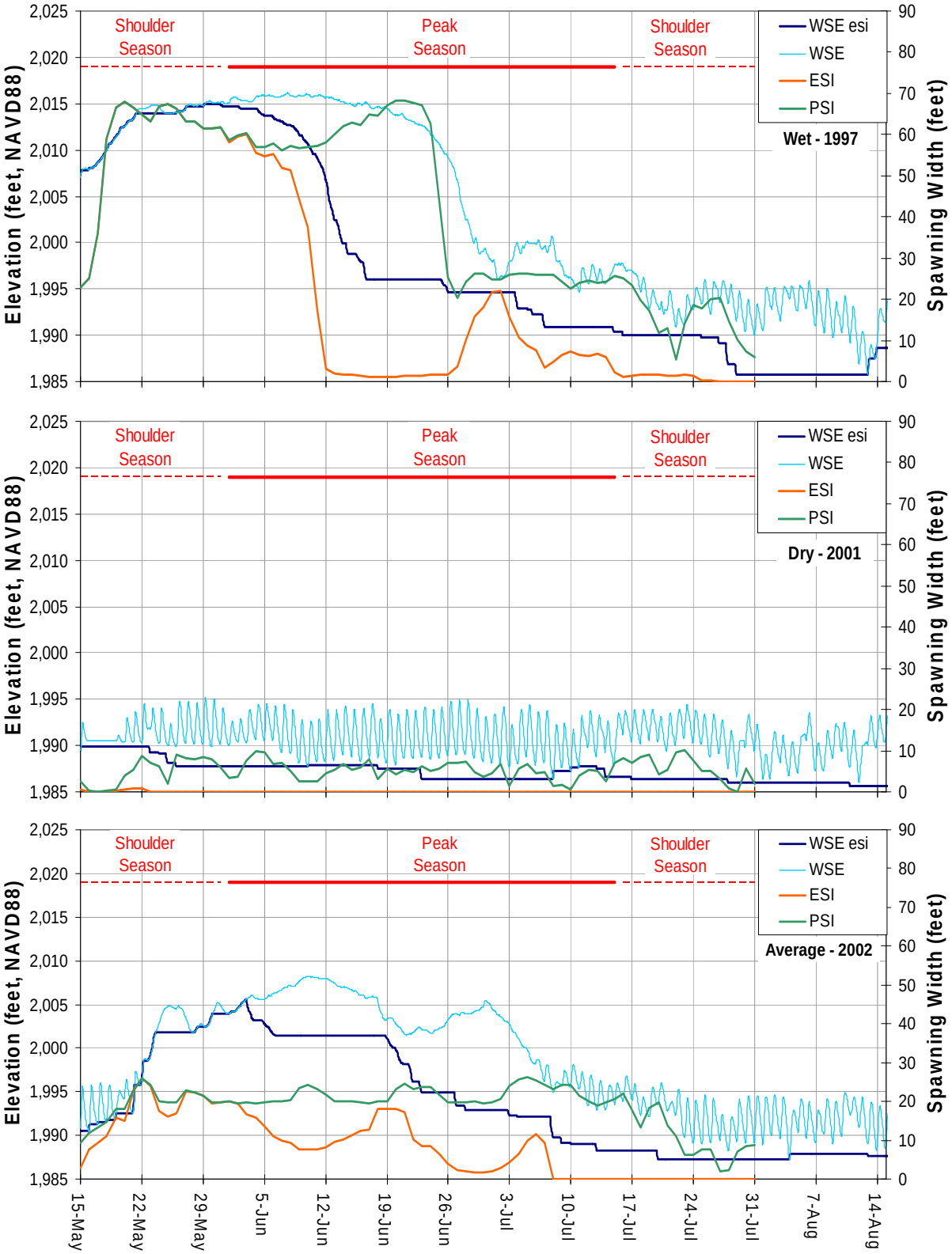


**Figure C-12.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-07.

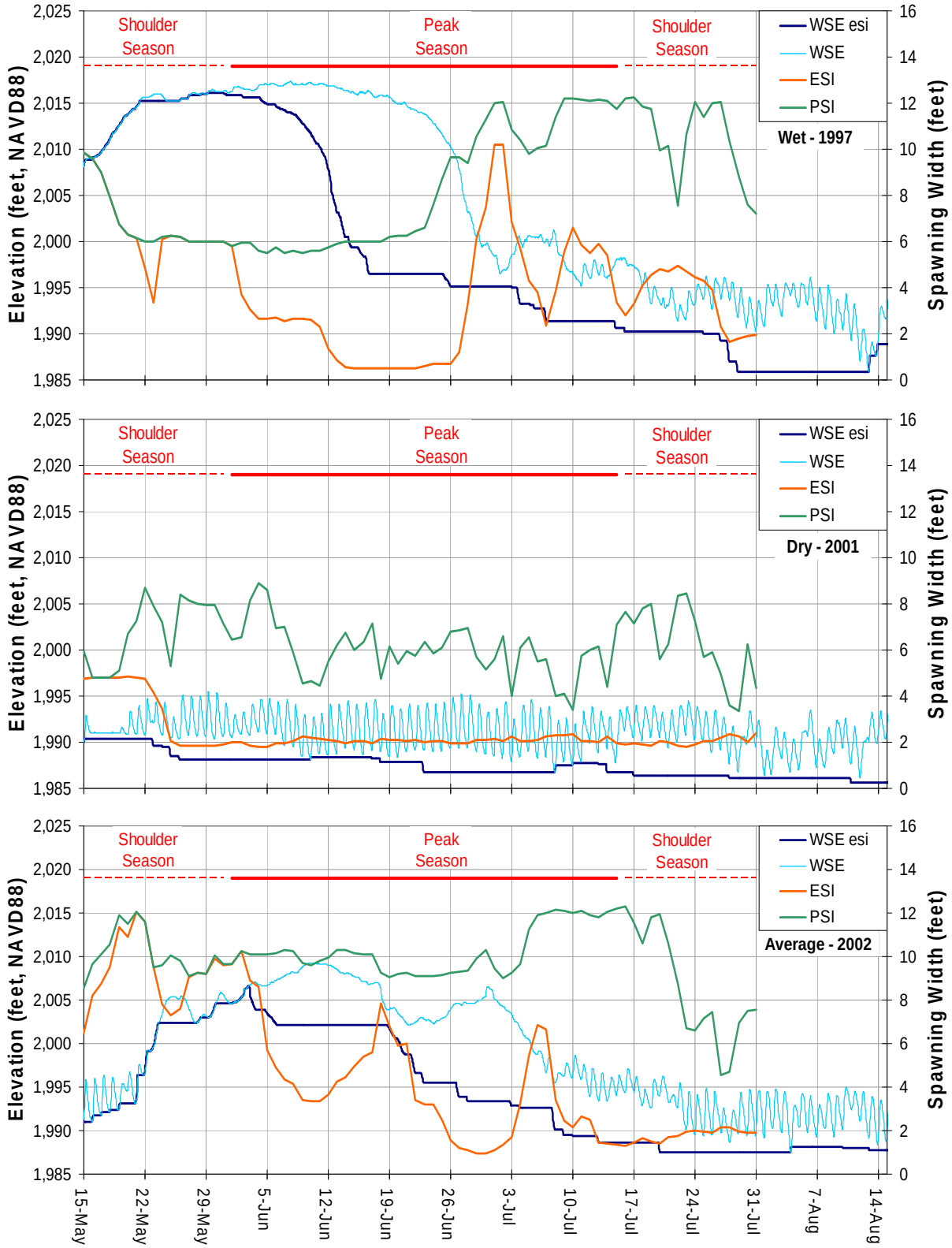


**Figure C-13.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-10.

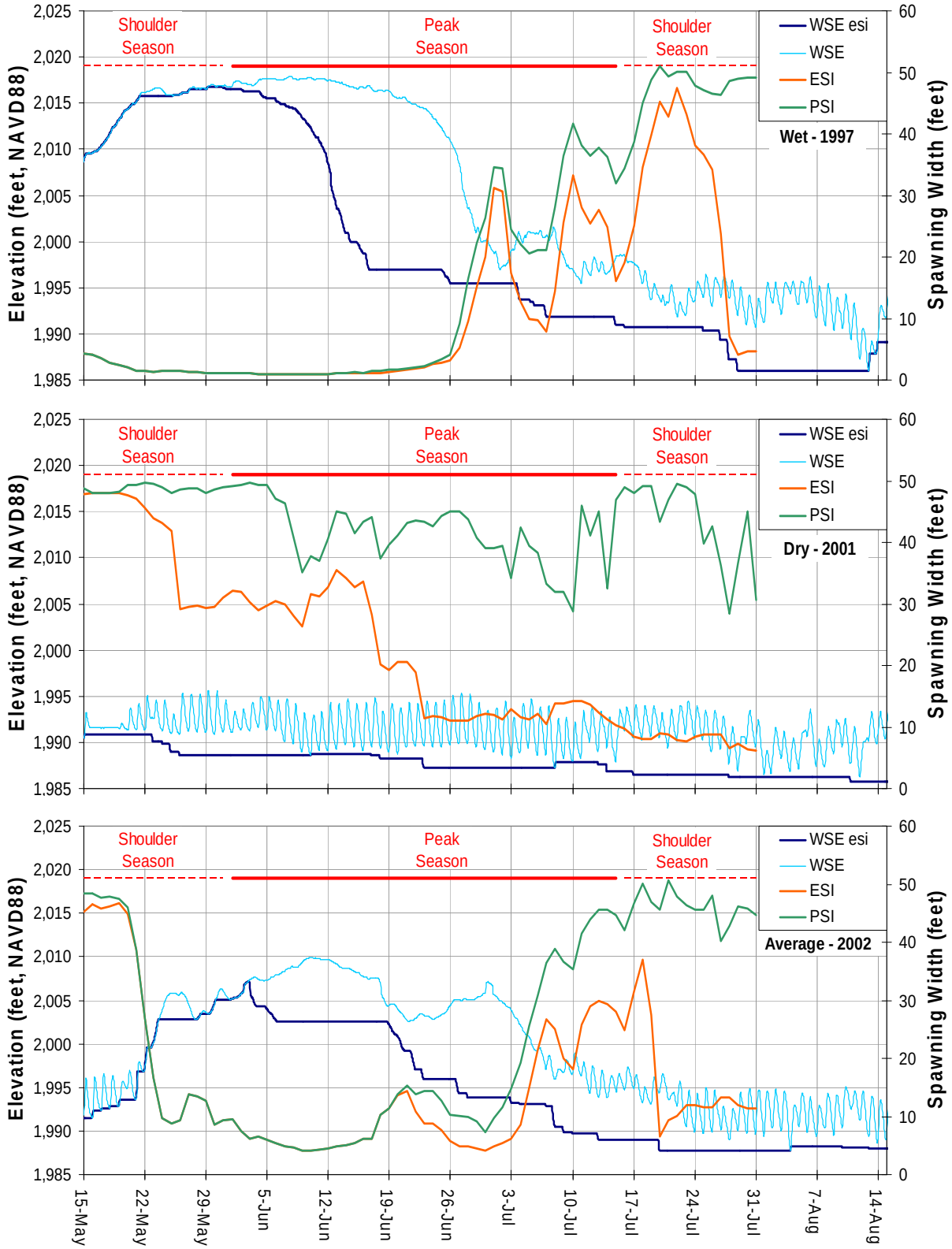


**Figure C-14.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-16.

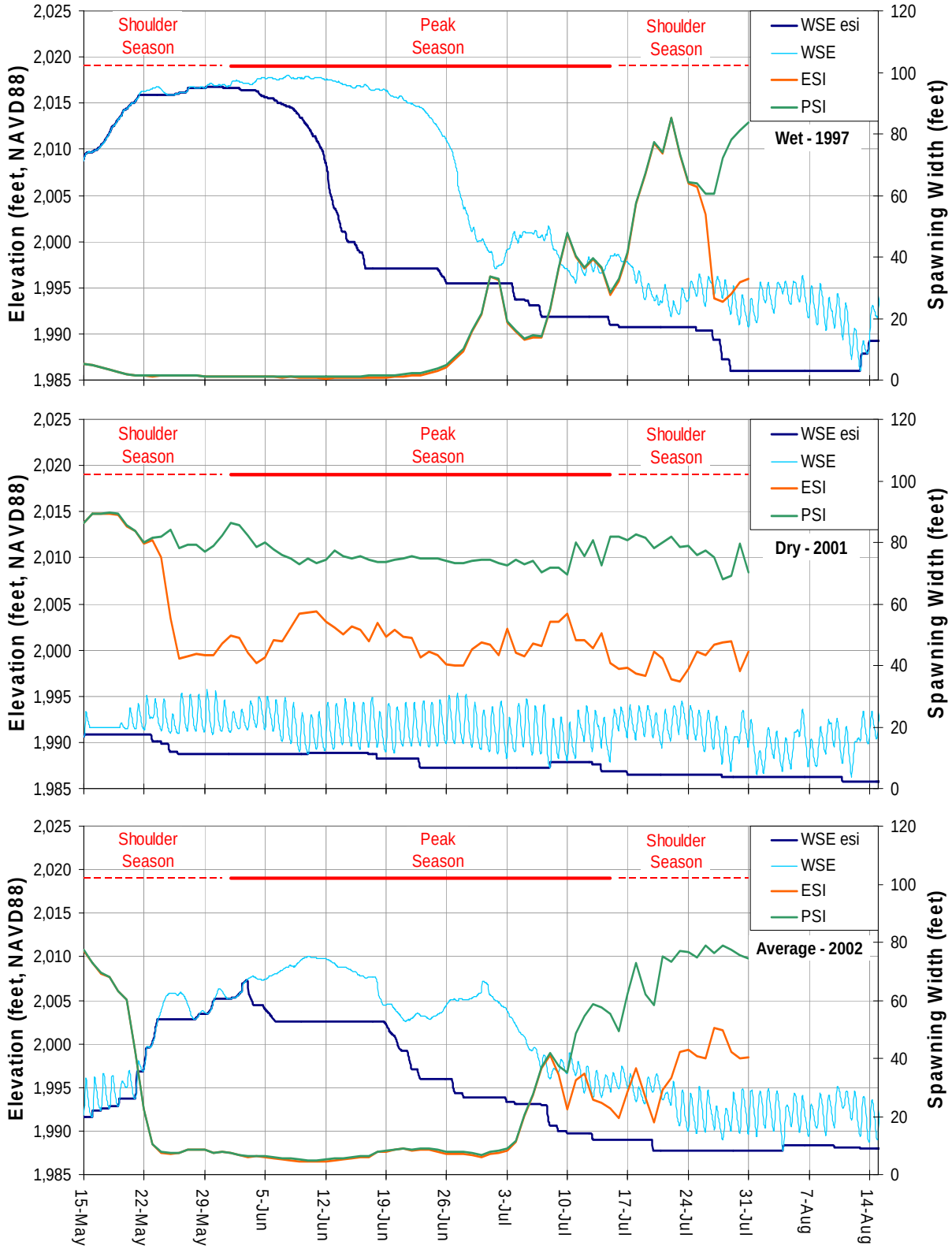


**Figure C-15.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-17.

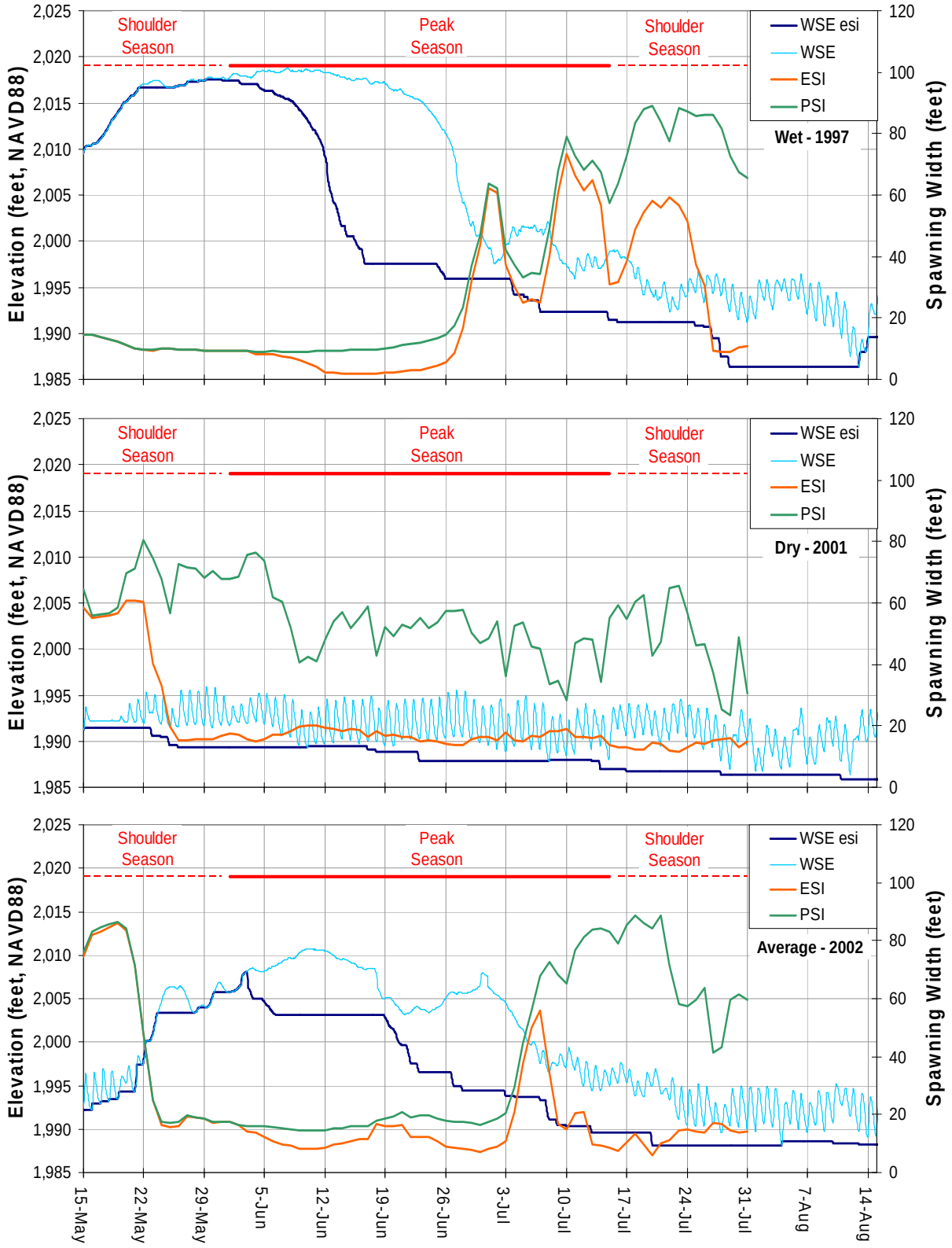


**Figure C-16.** Potential and effective spawning and incubation widths for smallmouth bass at habitat transect U-21.

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