Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7
Mainstem Aquatic Habitat Modeling Study
Interim Report

Prepared for
Seattle City Light

Prepared by
Tetra Tech
(Bill Fullerton, John Knutzen, Harry Gibbons, Jay Smith,
Rob Plotnikoff, Jennifer O'Neal, Shannon Brattebo,
Darlene Siegel, Chris James, and Trish Gross)
Thomas R. Payne and Associates
(Tom Payne, Mark Allen, Tom Gast, and Tim Salamunovich)
Golder Associates Inc.
(Dana Schmidt and Brad Hildebrand)
and
Terrapin Environmental
(Eddie Cupp and Ryan McNee)

March 2008

TABLE OF CONTENTS

Appendices

List of Tables

List of Figures

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

1 INTRODUCTION

Study No. 7, Mainstem Aquatic Habitat Modeling, 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 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 interim report for the 2007 study efforts of the Mainstem Aquatic Habitat Modeling Study.

The Mainstem Aquatic Habitat Modeling Study represents the integration of the efforts being 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 has been 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 range of conditions associated with operations scenarios will then be assessed and their effects determined.

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. 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.

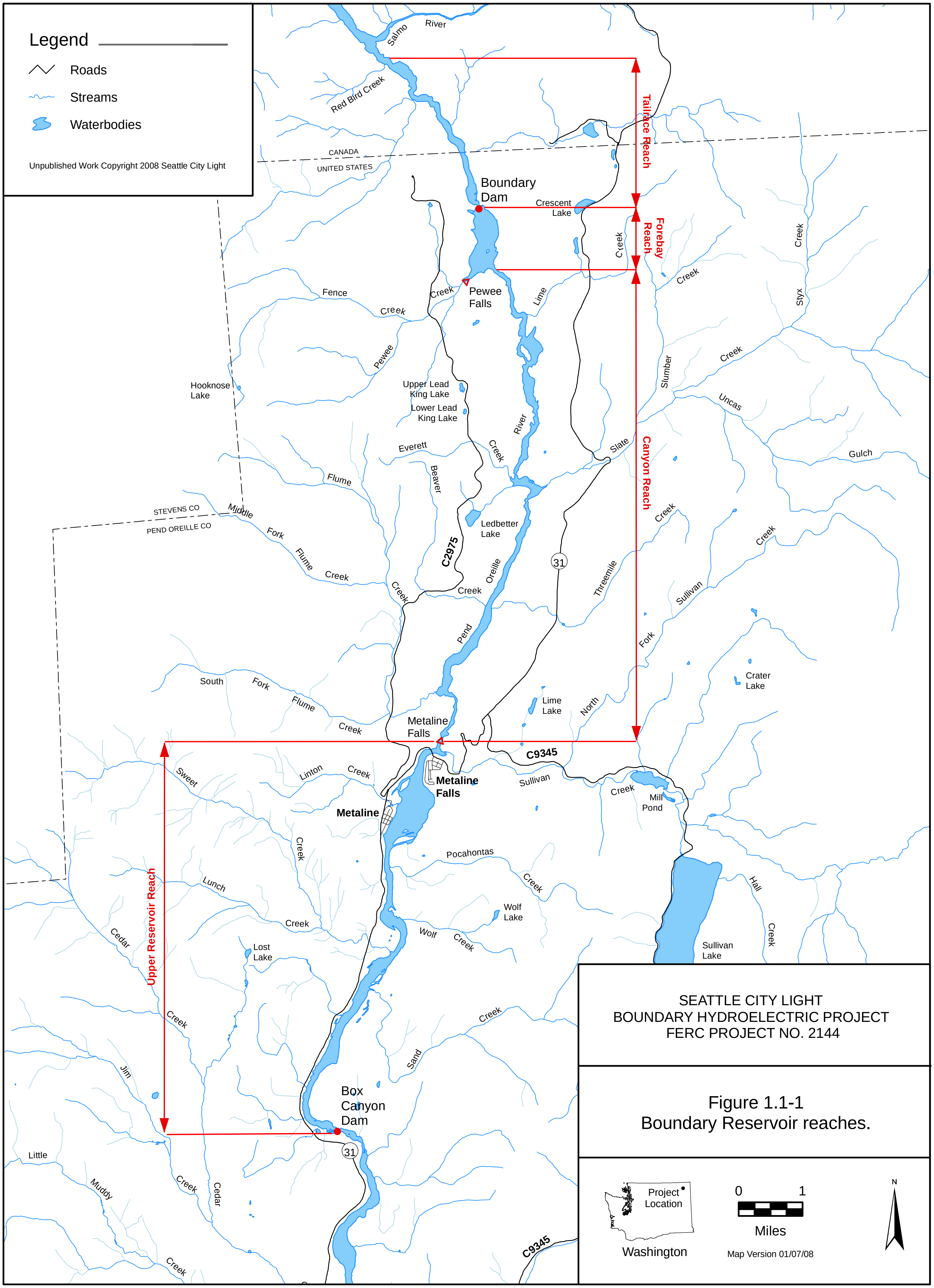
Fluctuations in the water surface elevation of the Boundary Reservoir forebay occurs in response to inflow fluctuations at Box Canyon Dam and the Project operations. The resulting water surface elevation fluctuations in the Project forebay extend upstream but attenuate, or dampen, as they travel from 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 rapid changes in downstream pool surface 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 tailwater 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 that contribute to primary production and provide unique habitat for some aquatic species or lifestages. 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 lifestages, may be found in both zones.

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 benthic macroinvertebrates (BMI) are reduced (Fisher and LaVoy 1972; Ward 1992).



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 1.1-1
Boundary Reservoir reaches.

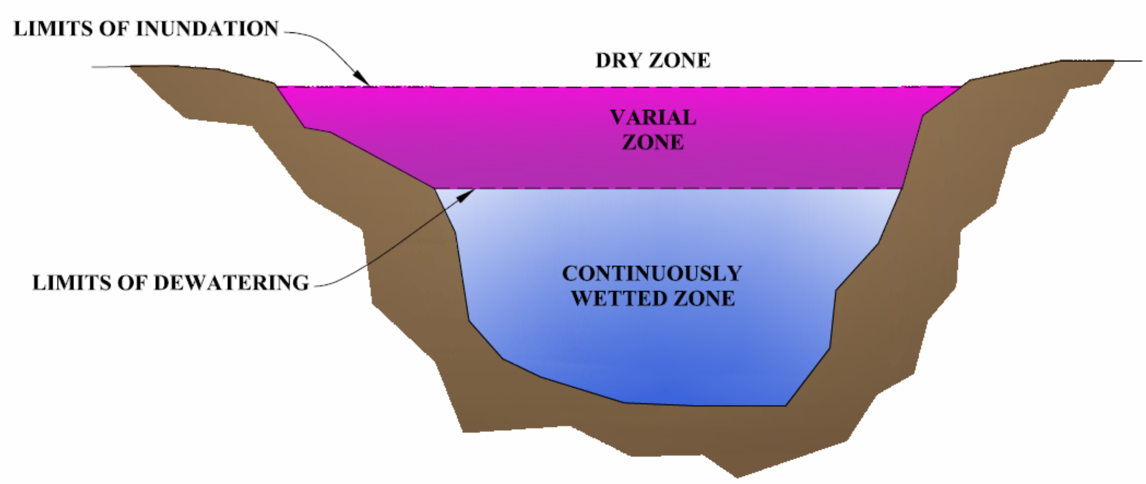


Figure 1.1-2. Example cross section of a hypothetical channel margin that depicts extent of varial zone as defined by maximum range in water surface elevation fluctuations.

The mainstem physical habitat model is the core tool that will be used for assessing effects on aquatic habitat of operations scenarios at the Boundary 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 the 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 will be used to compare the effects of operations scenarios. The number, location, and placement of transects was coordinated with relicensing participants. The mainstem physical habitat model will estimate 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 will incorporate spatial representation of entire channel and shoreline areas between transects.

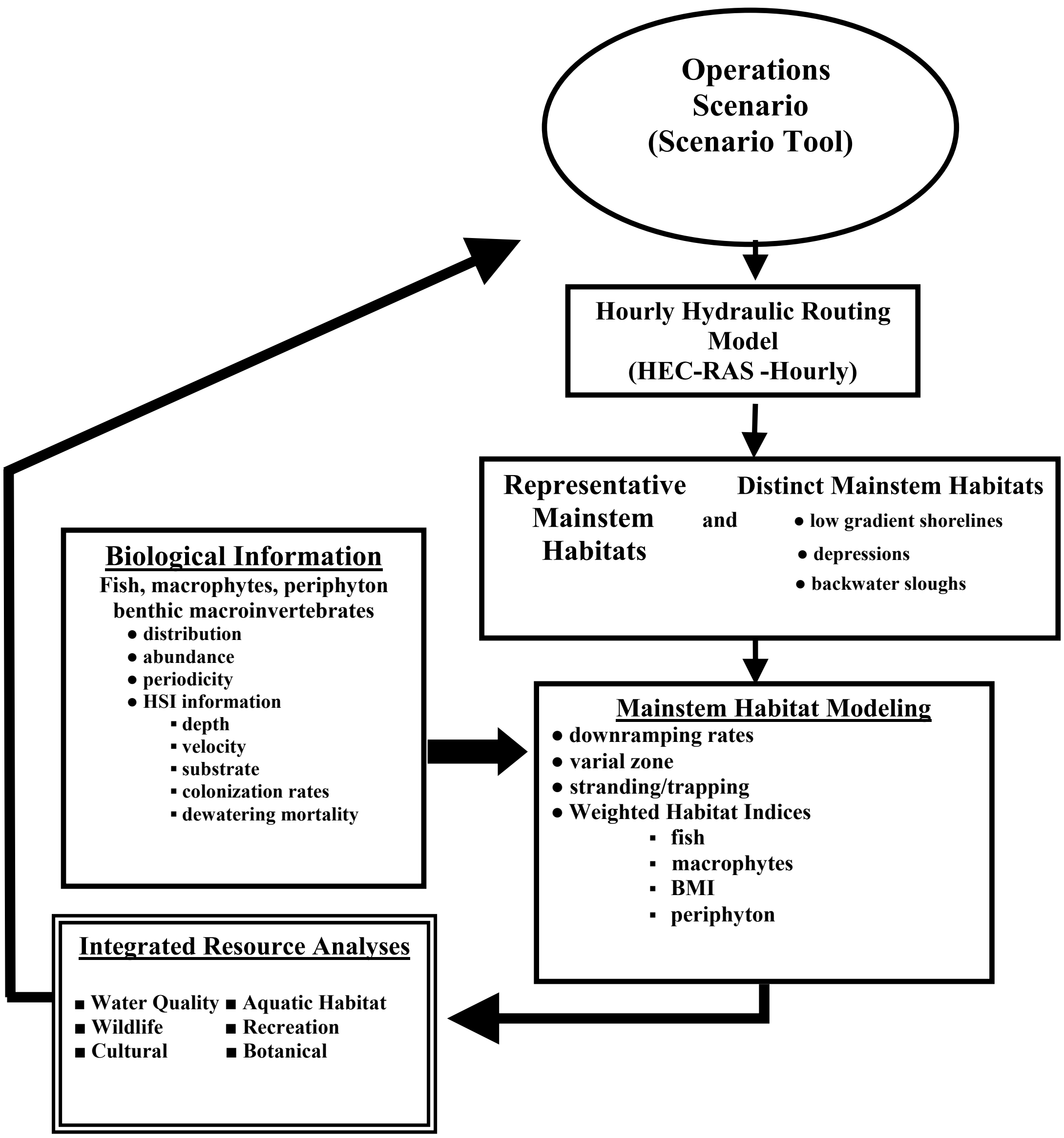


Figure 1.1-3. Conceptual workflow for the Mainstem Aquatic Habitat Modeling Study.

1.2. Study Components

The Mainstem Aquatic Habitat Modeling Study is divided into five components or substudies, described as follows.

- *Habitat Mapping* (Study 7.1). This study component inventories and maps several aspects of current aquatic habitat conditions in Boundary Reservoir. The results were originally intended to be used for selecting the location and weighting of transects in the mainstem physical habitat model. The original approach followed that typically used for riverine conditions; however, because the study area is dominated by reservoir conditions much of the time, an alternative approach was applied in selecting transect locations and weighting of transects. Use of the alternative procedure to select and weight transects was coordinated with and agreed upon by the Relicensing Participants. Due to the use of the alternative procedure, some of the habitat mapping information originally identified in Study 7.1 was not required and therefore was not developed including channel typing, wetted width calculation and wetted surface area calculation.

- *Hydraulic Routing Model* (Study 7.2). The hydraulic routing model has been developed from bathymetric data collected in 2006 and 2007 and is being used to translate output from the Scenario Tool (hourly Boundary Dam outflow and forebay water surface elevations) to water surface elevations and mean channel velocity at each of the transects in the mainstem physical habitat model on an hourly basis.
- *Physical Habitat Model Development* (Study 7.3). This study component involves collection of the habitat transect information, development of the modeling routines, integration of the modeling routines with the hydraulic routing model (including calibration and determination of mean column velocities), and the application of the modeling routines to produce the indices that will be used to evaluate existing Project effects and operations scenarios. Within this effort, the various indices of Project effects on mainstem aquatic habitats will be summarized and tabulated to allow relative comparison of the effects of existing Project operations to operations scenarios.
- *Habitat Suitability Indices Development* [1] (Study 7.4). The results of these study efforts are depth, velocity, substrate, cover, colonization and dewatering Habitat Suitability Indices (HSI) for selected fish species and life stages, macrophytes, periphyton, and benthic macroinvertebrates. Suitability is an index value from 0.0 to 1.0, where 1.0 is optimal. HSI information is being used to translate physical characteristics for operations scenarios to an index of the amount of potential habitat that is suitable for the selected species.
- *Stranding and Trapping Field Surveys* (Study 7.5). This effort was originally included as part of the Fish HSI effort in Study 7.4. However, this effort was made its own substudy because of the complexity of the analysis. Further, the development of the stranding and trapping modeling approach evolved from a transect-based to a

[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.

spatial analysis integrating the hydraulic routing model with GIS-based bathymetry. The results of this study will provide information to develop and improve the factors used to describe the influences of operations scenarios on the potential for stranding and trapping.

Because of the division of the Study 7 effort into substudies, this report has been organized so that the major sections presenting information pertaining to the specific substudies have subsections dedicated to each of the five substudies. The major sections with materials presented by substudies are Section 4 Methods, Section 5 Preliminary Results, Section 6 Summary, and Section 7 Variances. The subsections presenting information pertaining to Study 7.1 end in 1, those for Study 7.2 end in 2, and so on through Study 7.5.

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 may also have objectives beyond support of the mainstem aquatic habitat model and include:

- *Scenario Tool* (see ISR Introduction [Attachment 1]). The Scenario Tool 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 hydraulic routing model.
- *Tributary Delta Habitats in Boundary Reservoir* (Study 8, SCL 2008e). This study involves 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 are being developed. The tributary delta models utilize the results of the hydraulic routing model (Study 7.2) to determine water surface elevation fluctuations at the mouths of the tributaries. Study 8 (SCL 2008e) also considers 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, SCL 2008e). The study is being 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 will also delineate zones of sediment erosion and accumulation in the Boundary Reservoir portion of the Pend Oreille River.
- *Fish Distribution, Timing, and Abundance Study* (Study 9, SCL 2008f). This study provides biological information on fish distribution, abundance, and periodicity in Boundary Reservoir using passive and active sampling methods and biotelemetry.

The following subsections provide further descriptions of each of the five Study 7 components.

1.2.1. Habitat Mapping

The Habitat Mapping (Study 7.1) effort originally involved inventorying and mapping habitat characteristics within the study area including channel typing, wetted width and wetted surface areas, large woody debris (LWD) mapping, aquatic vegetation mapping and compilation of angler interviews. These results were to be used to select locations and weight transects. However, because of reservoir conditions created much of the time for most of the study area, an alternative approach was employed in selecting transect locations and weighting of transects. The mapping information that is used in other components of Study 7 is still presented in this effort. The original approach followed that typically used for riverine conditions; however, because the study area is dominated by reservoir conditions much of the time, an alternative approach was applied in selecting transect locations and weighting of transects. The alternative approach utilized the high resolution bathymetry and aerial photographs to divide the study area into geomorphically similar segments. Due to the use of the alternative procedure, some of the habitat mapping information originally identified in Study 7.1 was not required and therefore was not developed including channel typing, wetted width calculation, and wetted surface area calculation. Other portions of the habitat mapping effort were retained because they support other aspects of the relicensing effort.

The Habitat Mapping effort is now primarily being conducted to provide documentation of the distribution and characteristics of major habitat parameters within Boundary Reservoir and some channel typing information for the tailrace region from the U.S.-Canada border to Redbird Creek in British Columbia. Included in the effort are angler interviews, which provide local knowledge on fish distribution and potential spawning area information within the reservoir. The information being developed will be useful during other analyses being conducted as part of modeling process, such as stranding and trapping, varial zone analysis, as well as fish distribution and abundance analysis. The LWD and aquatic vegetation mapping were also retained. The aquatic vegetation mapping is important to several efforts including the stranding and trapping analysis.

Descriptions of the methods for performing the Habitat Mapping effort are presented in Section 4.1. Results for the Habitat Mapping effort are presented in Section 5.1. Section 6.1 summarizes the current status of the Habitat Mapping substudy, with variances and recommendations presented in Section 7.1.

1.2.2. Hydraulic Routing Model

The Hydraulic Routing Model, Study 7.2, is being used to translate output from the Scenario Tool to water surface elevations, flow rate and mean column velocity at each of the transects in the mainstem physical habitat model on an hourly basis. A one-dimensional unsteady flow hydraulic routing software is being 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. The results of 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.

The application of the unsteady flow hydraulic model is 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. A one-dimensional unsteady flow hydraulic routing model is being used to analyze the translation and attenuation of these waves and to quantify the spatial variability in the flow rate upstream and downstream of the Project.

Descriptions of the methods for conducting the Hydraulic Routing Model Study are presented in Section 4.2. Results to date of the Hydraulic Routing Model Study are presented in Section 5.2. Section 6.2 summarizes the current status of the Hydraulic Routing Modeling Study with any variances and recommendations presented in Section 7.2.

1.2.3. Physical Habitat Model Development

Physical Habitat Model Development involves creating the core structure of the mainstem aquatic habitat model. It uses the information or technical analyses performed in other study components as a basis for developing the model structure (e.g., Stranding and Trapping Field Studies) or as part of internal model processes (e.g., Hydraulic Routing and HSI curves). The mainstem physical habitat modeling effort involves collection and analysis of data, development of a variety of models, and application of these models to quantify existing Project effects and assess operations scenarios.

The combination of the Scenario Tool and the hydraulic routing model, which in tandem determine the hourly water surface elevations and flow rates throughout the study area, is the foundation on which the mainstem physical habitat models are based. The hydraulic information, represented by either water surface elevations and flow rates or velocity and depth distributions across a transect, along with other characteristics describing the physical habitat conditions, are utilized in the suite of mainstem habitat modeling efforts to produce the indices to evaluate existing Project effects and assess operations scenarios. The modeling efforts that will be conducted are listed below:

- Determination of downramping rates
- Identification of critical downramping pool elevation
- Macrophyte composite suitability index and weighted useable area (WUA)
- Periphyton composite suitability index and WUA
- BMI composite suitability index and WUA
- Fish stranding and trapping potential
- WUA for fish species and lifestages of interest

Within this effort, the various indices of Project effects on mainstem aquatic habitats will be summarized and tabulated to allow ready comparison of existing Project effects to operations scenarios. Each indicator of environmental effect will be tallied separately, and the relative effects of operations scenarios on various aquatic resources may be determined.

The Physical Habitat Model Development methods are presented in Section 4.3. Results of the efforts conducted to date are presented in Section 5.3. Section 6.3 summarizes the current status of Study 7.3 effort with any variances and recommendations presented in Section 7.3.

1.2.4. Habitat Suitability Indices Development

The efforts in this study provide information for the Physical Habitat Modeling Development (Study 7.3). The Habitat Suitability Indices Development (Study 7.4) provides depth, velocity, substrate, cover, colonization, and dewatering HSI for selected fish species and life stages, macrophytes, periphyton, and benthic macroinvertebrates. The HSI results will be used in the mainstem physical model to translate physical characteristics present for different operations scenarios to indices representing the potential habitat that is suitable for the selected species. HSIs will be applied to describe the response of each biological group to depth, velocity, and substrate conditions, and in some cases, inundation and dewatering.

Fish species, macrophytes, periphyton, and BMI are included in the mainstem physical habitat model in the form of Habitat Suitability Curves (HSC) and HSI to estimate habitat suitability for operations scenarios. Literature-based HSC and HSI are being supplemented by site-specific information developed through field studies. Project operations may affect flows and reservoir pool water surface elevations, and the frequency and duration of inundation and dewatering of shoreline areas. Therefore HSIs for several species not only incorporate depth, velocity and substrate information, but also include HSIs relating colonization and mortality to inundation and dewatering, respectively. The response of each these biological groups to operations scenarios will be evaluated through the mainstem physical habitat model based on the effects of each operations scenario on the physical conditions represented by depth, velocity, substrate, duration of inundation, and duration of dewatering. The combination of the Scenario Tool providing input to the Hydraulic Routing Model (Study 7.2) will create the physical conditions associated with each of the operations scenarios.

As each HSI effort involved its own development process, including field data collection efforts, they are presented separately in the main body of this report. Each of the HSI efforts has a separate appendix which serves as a stand-alone report documenting the development of the HSIs for the particular biological group. This approach has been taken since the development of each HSI is a significant effort with much of it being conducted in 2007. The preparation of the separate reports for each HSI, which are now included as appendices, allowed for efficient early review of these important components of the Mainstem Physical Habitat Modeling Study. The detailed development of the Fish HSIs is presented in Appendix 1a, with Fish Periodicity information presented in Appendix 1b. Appendix 2 documents the development of the Macrophyte HSI. The Periphyton HSI is presented in Appendix 3 and the Benthic Macroinvertebrate HSI in Appendix 4. Within the main body of this report, the material for the HSIs is a summary of the information in the appendices with reference to the appropriate appendix for detailed information.

1.2.4.1. Fish HSI

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. The fish assemblage of the Boundary Reservoir and tailrace includes a variety of native and non-native species. Dominant species by number captured in 2007 in all gears include largescale sucker, yellow perch, smallmouth bass, and peamouth. However, some native salmonids including bull trout, westslope cutthroat trout, redband rainbow trout (tailrace), and mountain whitefish are present in generally very low abundance in the mainstem. The mainstem physical habitat model analysis will use curves (HSI) of habitat preference for various physical conditions (depth, velocity, and substrate) to estimate quantity of suitable habitat for fish with changes in flow and water elevation associated with each operations scenario. The curves of habitat preference are being developed for the life stages of selected (target) fish species based on literature and field studies.

Fish HSI variables are utilized in the instream flow modeling of Boundary Reservoir and tailrace by incorporating physical parameters that are commonly associated with habitat quality for fish. Fish HSI are developed for each species and each life stage of interest. The HSI variables are 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. Such information will be used to evaluate potential effects of different operations scenarios on fish habitat.

The principal HSI variables will describe the relative suitability of water depth, mean column water velocity, and bottom substrate type for each target species and life stage. Additional physical habitat parameters that are being measured include instream cover, presence of velocity shear zones, and distance to bank. Continuing analysis will determine if, and how, any of these additional variables can be used to improve the fish habitat model for the Project area. An additional component of fish HSI is periodicity, which describes the time periods when each target species and life stage is present in the Project area. The periodicity information will be used to determine the temporal periods when fish HSI curves are applied in the fish habitat modeling, and to assess the periods when spawning and fry life-stages are susceptible to stranding and trapping from Project operations.

Section 4.4.1 provides a summary description of the Fish HSI development methods. A summary of the results of the efforts conducted to date are presented in Section 5.4.1. Section 6.4.1 summarizes the current status of the development of the Fish HSI with any variances and recommendations presented in Section 7.4.1. Appendix 1a provides the complete details on the development of the Fish HSI and Appendix 1b documents the development of the fish periodicity tables.

1.2.4.2. Macrophyte HSI

The aquatic macrophytes comprise a diverse assemblage of macroscopic flora that has 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.

Since macrophytes are affected by changes in water surface elevations, and specifically inundation and dewatering, the HSIs for macrophytes include the effects of the duration of inundation and the duration of dewatering on habitat suitability. Incorporation of inundation and dewatering is in addition to the usual HSI considerations of depth, velocity, and substrate. In the mainstem habitat modeling effort, evaluation of the potential effects of operations scenarios on macrophytes is primarily included in the varial zone analysis.

Section 4.4.2 summarizes the Macrophyte HSI development methods. A summary of the results of the efforts conducted to date is presented in Section 5.4.2. Section 6.4.2 summarizes the current status of the development of the Macrophyte HSI with any variances and recommendations presented in Section 7.4.2. The full details of the Macrophyte HSI development are presented in Appendix 2.

1.2.4.3. Periphyton HSI

The periphyton and benthic macroinvertebrate are groups of organisms which 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 including both hard substrate and soft substrate sampling. 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 have been provided with their own subsections throughout this report

Periphyton is a complex matrix of algae, bacteria and other microorganisms; the algae are the primary producers that are the focus of this study effort. Periphyton live on the benthic substrate of a waterbody, or on structures or organisms resting on or attached to the bottom such as logs, rocks, or rooted plants. Primary production 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.

In the Mainstem Physical Habitat Modeling Study, evaluation of the effects of operations scenarios on periphyton is primarily performed in the varial zone analysis. To incorporate periphyton into the mainstem physical habitat model, an HSI is being developed to assist in evaluating the response of periphyton to various reservoir operational scenarios. Specifically the scenarios include cyclic water surface elevation and flow fluctuations that may change physical parameters that periphyton are exposed to, such as, depth, velocity, and duration of inundation and dewatering. The mathematical model used for developing HSI curves for periphyton is based upon a literature review concerning the species' habitat requirements and preferences. The field studies are being performed to refine the curves for the specific conditions encountered in the study area.

Section 4.4.3 summarizes the Periphyton HSI development methods. A summary of the Periphyton HSI results for the efforts conducted to date is presented in Section 5.4.3. Section 6.4.3 summarizes the current status of the development of the Periphyton HSI with any variances and recommendations presented in Section 7.4.3. Appendix 3 provides the details on the development of the Periphyton HSI.

1.2.4.4. Benthic Macroinvertebrate HSI

The primary objective of this effort is to develop a BMI HSI to help assess the effects of operations scenarios on aquatic productivity. As with periphyton, the HSI needs to incorporate depth, velocity, and substrate, as well as the duration of inundation and dewatering, which greatly influence habitat suitability. The initial models for the BMI HSI development were based on literature review, with field studies being conducted to refine the curves. In terms of the field studies, three sample areas were selected to represent a high fluctuation area (Lower Boundary Reservoir), a lower fluctuation area (Upper Boundary Reservoir), and a control area (Box Canyon Reservoir). The BMI HSI development effort includes six primary tasks necessary to develop accurate and comprehensive HSI, including previously mentioned literature-based component and field data collection, and efforts directed toward final validation of HSI information for Boundary Reservoir.

The BMI HSI development methods are summarized in Section 4.4.4. Section 5.4.4 summarizes results of the BMI HSI development efforts conducted to date. Section 6.4.4 summarizes the current status of the development of the BMI HSI with any variances and recommendations presented in Section 7.4.4. A complete presentation of the development of the BMI HSI is presented in Appendix 4.

1.2.5. Stranding and Trapping Field Surveys

This effort was originally included as part of the Fish HSI effort in Study 7.4. However, as the development of the stranding and trapping modeling approach evolved from a transect-based approach to a spatial analysis integrating the hydraulic model and GIS analysis of the bathymetry, this effort became a separate sub-study. This study will provide information for factors used in modeling, such as site characteristics that influence the potential for fish mortality during stranding and trapping events. These factors include depth of potential trapping sites, areas that drain into the trapping basin (i.e., contributing basin areas), the presence of macrophyte cover, and duration of dewatering. The field surveys also verify physical information developed from the bathymetric surveys. Secondary information, such as water temperature, which is not directly incorporated into the factors but will help in defining them, is also being collected. During the Stranding and Trapping Field Surveys, information describing the presence of stranded and trapped fish and mortality is being collected. The information on mortality is essential to properly defining the stranding and trapping factors.

The development of the stranding and trapping factors and the modeling effort are part of Study 7.3. The stranding and trapping analysis effort is closely related to the varial zone analysis, but is included as its own separate modeling effort in the Physical Habitat Modeling study component. Whereas the varial zone modeling is a transect-based effort, the stranding and trapping effort uses GIS-based spatial analysis to translate the water surface elevation fluctuations from the hydraulic routing model to changes in stranding and trapping potential.

The Stranding and Trapping Field Survey methods are summarized in Section 4.5. Section 5.5 summarizes results of the stranding and trapping field surveys conducted in 2007. Section 6.5 summarizes the current status of stranding and trapping field investigations with any variances and recommendations presented in Section 7.5.

2 STUDY OBJECTIVES

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

1. Select transects to measure and model mainstem Pend Oreille River habitat types (Studies 7.1 and 7.2).
2. 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 (Study 7.2).
3. Develop new, or modify existing, HSIs for selected target species and lifestages (Study 7.4).
4. 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 include (but are not necessarily limited to [Study 7.3]):
    - 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
5. Conduct a variety of post-processing comparative analyses derived from the output metrics estimated under the Mainstem Physical Habitat Model (Study 7.3) to identify the effects of operations scenarios. These include (but are not necessarily limited to):
    - downramping rates
    - juvenile fish stranding and trapping
    - fish nest viability
    - macrophyte distribution and abundance
    - distribution and abundance of periphyton and benthic macroinvertebrates

3 STUDY AREA

Two levels of study areas are defined for the Mainstem Aquatic Habitat Modeling effort. There is a detailed study area for which the potential effects of operations scenarios on biological indices will be evaluated. There is also a larger study area required to conduct the Hydraulic Routing Model Study in order to accurately model the water surface elevation and flow fluctuations resulting from 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 operations scenarios and extends to the confluence with Red Bird Creek.

The study area is divided into the following four reaches (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 – 19.4)
- Forebay Reach — Downstream end of Z-Canyon to Boundary Dam (PRM 19.4 – 17.0)
- Tailrace Reach — Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0 – 13.1)

The effects of operations scenarios on aquatic habitats below Boundary Dam are influenced by Seven Mile Project operations. At low Seven Mile Reservoir pool levels, riverine habitat is present in the Pend Oreille River downstream to the confluence with Red Bird Creek. At high Seven Mile Reservoir pool levels, the riverine habitat above the Red Bird Creek confluence becomes reservoir habitat. The Mainstem Aquatic Habitat Modeling effort includes collecting data on up to 3.9 miles of the Pend Oreille River channel exposed for low Seven Mile Reservoir pool levels and performing modeling the Tailrace Reach similar to the three reaches above Boundary Dam.

In addition to the detailed study reach described above, the hydraulic routing model will extend an additional 7.1 miles downstream to Seven Mile Dam at PRM 6.0. This is 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 13.1. The hydraulic routing model will be used to determine hourly water surface elevations and flow conditions in the Tailrace Reach based on Seven Mile forebay elevations and inflows from the Boundary Project.

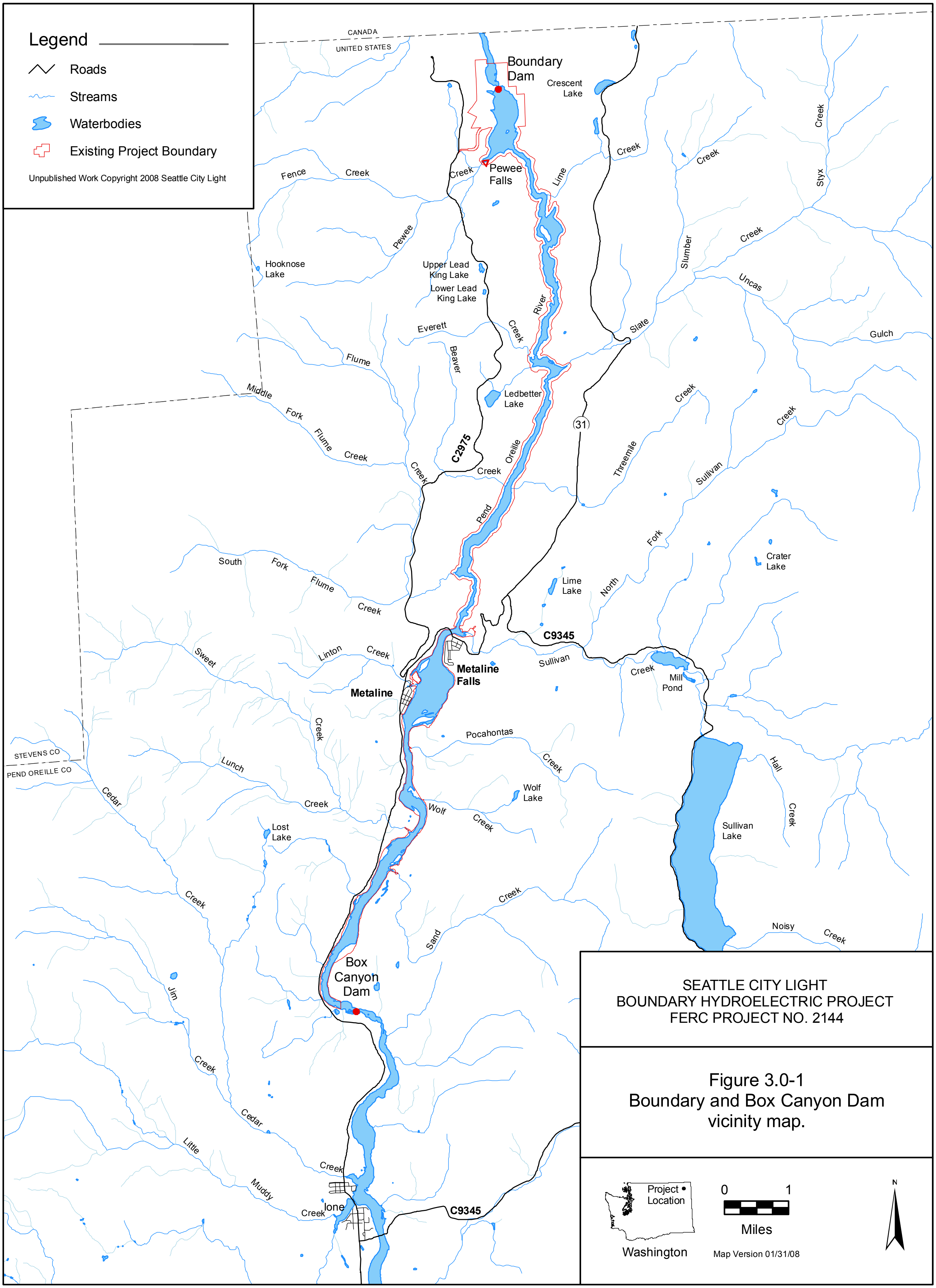


Figure 3.0-1
Boundary and Box Canyon Dam vicinity map.

4 METHODS

As noted previously, the Mainstem Aquatic Habitat Modeling Study consists of five primary components: Habitat Mapping, Hydraulic Routing Model, Physical Habitat Model Development, Habitat Suitability Indices Development, and Stranding and Trapping Field Surveys. The methods for each of these components are presented in this section. In the case of the HSI development study components, these efforts are summarized in this section, with complete methods presented in their corresponding appendices, which serve as stand-alone reports. These study sections and their corresponding appendices are:

- Section 4.4.1 Fish HSI/Appendix 1
- Section 4.4.2 Macrophyte HSI/Appendix 2
- Section 4.4.3 Periphyton HSI/Appendix 3
- Section 4.4.4 Benthic Macroinvertebrate HSI/Appendix 4

4.1. Habitat Mapping

The Mainstem Aquatic Habitat Model will be used to evaluate the effects of operations scenarios on aquatic habitats and biota in the Pend Oreille River. An initial task was to select transects. The RSP methods (SCL 2007a) for selecting these transects envisioned that specific habitat mapping methods would be needed to select location and number of transects. But because of changes in the manner in which habitat transects were determined, the purpose of the Habitat Mapping study component has changed from that described in the RSP. The main purpose of the Habitat Mapping component as described in the RSP was to determine distribution of major and distinct habitat features in the study area to aid selection of representative transects for the Mainstem Physical Habitat Model and assign weighting to each selected transect. The study area habitat conditions extend from Box Canyon Dam to the confluence with Red Bird Creek in British Columbia. The final method of transect selection is described in Section 4.3.1.

The Habitat Mapping retains some of its initial purposes but is not now required for selection of transects in Boundary Reservoir. It primarily provides documentation of major habitat parameters, distribution, and characteristics within Boundary Reservoir and some channel typing information for the tailrace region from Boundary Dam to Redbird Creek in British Columbia. Additionally, results from angler interviews are presented to help provide local knowledge on fish distribution and potential spawning area information within the reservoir. The information provided will be useful during other analyses being conducted as part of the modeling process, such as stranding and trapping, varial zone analysis, and fish distribution and abundance analysis.

Seven tasks were to be performed for Habitat Mapping. These tasks included:

- Task 1—Channel Typing
- Task 2—Wetted Width Calculations
- Task 3—Wetted Surface Area Calculation
- Task 4—LWD Mapping
- Task 5—Aquatic Vegetation Mapping
- Task 6—Angler Interviews
- Task 7—Data Compilation

Most of Task 1 and all of Tasks 2 and 3 were not performed due to a change in the approach used to select transect locations. Several other tasks were modified as a result of the change in transect selection approach and are discussed further in this section.

4.1.1. Channel Typing

The Pend Oreille River between Box Canyon Dam and the U.S.–Canadian border was divided 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.

The Canadian portion of the Tailrace Reach transects were 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 bathymetry 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.

4.1.2. Wetted Width Calculations

Wetted width was initially envisioned in the RSP to be one of several reach characteristics that were to be used to describe channel morphology. Due to changes in the methodology used to determine the habitat transect locations, the calculation of wetted width within the study area was not necessary and was therefore not conducted. The final method of habitat transect selection is described in Section 4.3.1.

4.1.3. Wetted Surface Area Calculations

Wetted surface area was initially envisioned in the RSP to be one of several reach characteristics that were to be used to describe channel morphology. Due to changes in the methodology used to determine the habitat transect locations, the calculation of wetted surface area was not necessary and was therefore not conducted. The final method of habitat transect selection is described in Section 4.3.1.

4.1.4. LWD Mapping

LWD mapping was accomplished as part of Study 10, Large Woody Debris Management Study Final Report (SCL 2008g). Data collected from Study 10 have been incorporated into this study for habitat mapping purposes.

Mapping of LWD along the Boundary Reservoir shoreline was accomplished by conducting a field survey of the shoreline for existing LWD. The entire shoreline of the Boundary Dam

Reservoir was surveyed from August 20 to 24, 2007. A complete census of all observable LWD was made during this field survey. The Global Positioning System (GPS) data layers were used to locate areas with high probability of LWD deposition. Additionally, the locations of all other observations of LWD were recorded during field surveys. Observations were made during very low water surface elevations (below elevation 1,974 feet NAVD 88 [1,970 feet NGVD 29][2] as measured at Boundary Dam Control Room), which allowed for observation of much of the submerged shoreline LWD in the lower Boundary Reservoir. Much of this wood would not have been observable at higher water surface elevations. Due to low inflow from Box Canyon Dam, there was also significant drawdown in the Upper Reservoir, allowing for improved counts of LWD along the shoreline. LWD was enumerated in both reservoir sections approximately from the vegetation line to the visible water depth.

Each piece of wood was counted and classified to size class using categories defined by Peck et al. (2003) and shown in Table 4.1-1. Where possible, information on decay class of wood was collected and determined using methods from Robison and Beschta (1990) and Hedman et al. (1996). Table 4.1-2 shows the criteria used for each decay class ranging from I to V—the least decayed to the most decayed. The decay class indicates the length of time that the piece has been in the reservoir, and the table is arranged in terms of increasing residence time in the reservoir. The presence of Decay Class I generally indicates new recruitment of LWD along the reservoir while later classes indicate more stable pieces.

Table 4.1-1. Size classes for LWD.

Diameter Large End	Short Length	Medium Length	Long Length
4 in < 12 in	Length 5 ft < 17 ft	Length 17 < 50 ft	Length > 50 ft
12 in < 24 in	Length 5 ft < 17 ft	Length 17 < 50 ft	Length > 50 ft
24 in < 32 in	Length 5 ft < 17 ft	Length 17 < 50 ft	Length > 50 ft
> 32 in	Length 5 ft < 17 ft	Length 17 < 50 ft	Length > 50 ft

Source: Peck et al. 2003

Table 4.1-2. Decay class criteria.

Decay Class	Bark	Twigs	Texture	Shape	Wood Color
I	Intact	Present	Intact	Round	Original Color
II	Intact	Absent	Intact	Round	Original Color
III	Trace	Absent	Smooth: some surface abrasion	Round	Darkening
IV	Absent	Absent	Abrasion: some holes and openings	Round to oval	Dark
V	Absent	Absent	Vesicular: many holes and openings	Irregular	Dark

Source: Robison and Beschta 1990

[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). Although some other relicensing studies may round the conversion to 4 feet, the Project forebay elevations are monitored with precision of 0.01 foot and the hydraulic routing model provides output to the same level of precision — rounding of output, if appropriate, will be performed after application of the actual conversion factor of 4.03 feet.

The location of each piece or group of pieces of wood was documented using GPS. GPS files were uploaded into GIS and a LWD location data layer was created for use in habitat mapping. Elevation of LWD locations was estimated by overlaying the GPS locations on the topography and bathymetry of the Boundary Reservoir using GIS. These elevations can be compared to water surface elevations to predict when a piece of wood will be inundated.

4.1.5. Aquatic Vegetation 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 recommended work to be performed in 2008. The work to be performed in 2008 is being recommended to provide information that was found to be necessary to support application of the stranding and trapping modeling effort (Section 4.3.9)

4.1.5.1. 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 100 m 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.

4.1.5.2. 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 is recommended in 2008. The updated macrophyte data from 2008 will be used to support the study of potential for stranding and trapping of fish (Studies 7.3 and 7.5). Additionally, the final bathymetry was not available at the time of the 2007 mapping effort. The final bathymetry will be reviewed to determine if there are any features likely to contain macrophytes that were not identifiable in the earlier versions of the mapping. The features will include the potential fish stranding and trapping areas identified from the GIS-based analysis. These areas will be visited and any macrophytes mapped. The mapping will be 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. In addition, the mapping effort will be coordinated with the Stranding and Trapping Field Surveys (Study 7.5) to incorporate any additional small localized macrophyte beds that are identified during the 2008 stranding and trapping surveys.

4.1.6. Angler Interviews

Angler interviews were conducted primarily to assist in identifying specific areas and seasons supporting spawning, concentrated game fish use, and fish stranding and trapping areas. The interviews were not part of a systematic creel census to determine effort and catch rates by anglers. Instead local anglers most familiar with the Project area fisheries and history of the region were sought out to obtain more specific information on locations of areas noted above. Anglers identified by their peers as most knowledgeable of Project area fisheries were the primary persons interviewed. These anglers were requested to recollect their past fishing experiences and observations. Prospective respondents were also identified at the Bassin' Assassin' Fishing Tournament sponsored by the Western Star and held in early May 2007.

All interviews began with the interviewer describing the purpose of the interview. The interviewer guided the discussions to obtain available information and knowledge on the key target species and other important sport fish species. The respondent was asked to share their information on their familiarity or past observations of four main categories:

- Areas that fish were observed spawning or where “ripe” fish were captured
- Areas where fish were observed trapped within isolated pools or stranded along shorelines
- Seasonal changes in the distribution of the species they targeted
- Fish concentration areas as determined either visually or by increased catch rates

All interviews were conducted in person with maps available during the interview. Anglers were asked to specify areas discussed and if possible, show the areas on the map. The angler was asked to be as specific as possible regarding the habitat conditions (such as substrate, depths, and vegetative cover) associated with the referenced areas. Because the information was based on the anglers' memory, the exact location, events, and timeframe likely had various levels of accuracy and precision.

4.1.7. Data Compilation

This task originally involved compilation of the information developed in the first six elements of the habitat mapping and using this information to decide upon representative transects and assist in the development of the transect weighting for habitat WUA calculations. However, since the approach was altered to have each transect selected so as to represent the mainstem conditions halfway between the next upstream and the next downstream task, this effort is not being performed. Data developed in Study 7.1 that are used in other efforts has been made available to those efforts. For instance, the stranding and trapping effort will utilize the macrophyte mapping.

4.2. Hydraulic Routing Model

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 Dam and in the reach downstream of Boundary Dam between Boundary Dam and Seven Mile Dam. The results of the hydraulic model will be used to support the analysis of potential impacts of operations scenarios on aquatic habitats in the Pend Oreille River between Box Canyon and Seven Mile Dam.

The need for an unsteady flow hydraulic model is necessitated by the 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 Boundary forebay travel upstream through the Pend Oreille River to as far upstream as Box Canyon Dam, and flow fluctuations originating in the Boundary tailrace travel downstream to as far as just south of the confluence with the Salmo River. The unsteady flow hydraulic routing model will be used to analyze the translation and attenuation of these waves and to quantify the spatial variability in the flow rate upstream and downstream of the Boundary Dam.

The methods summarized in the following subsections, and discussed in detail in Appendix 5, 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.

Section 4.2.1 briefly describes the methods used to construct the hydraulic model and Section 4.2.2 presents a brief discussion of the approach used for model calibration. The potential need for a separate seasonal model is described in Section 4.2.3. Finally, the relationship of the hydraulic routing model to the other models in the study is presented in Section 4.2.4. A more detailed presentation of these topics is documented as a stand-alone Interim Report, which is included as Appendix 5.

4.2.1. Hydraulic Routing Model Construction

Version 4.0 (Beta) 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 2006). 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.

Two separate hydraulic routing models will be required for this study. A hydraulic model of the reach upstream of Boundary Dam (upstream routing model) will be 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 (downstream routing model) will be used to analyze the translation and attenuation of flood waves 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, is due to the presence of Boundary Dam. The HEC-RAS modeling software is a purely hydraulic modeling tool that does not have the capabilities to model dam operations. Therefore, a separate model or software is needed to provide the “link” between the upstream and downstream hydraulic models. The

Scenario Tool is designed specifically to simulate operations scenarios, and will therefore function as the "link" between the two hydraulic models by providing boundary condition information to each hydraulic model.

The upstream hydraulic model was developed in 2007; however, the downstream hydraulic model has not yet been developed. Development of the downstream hydraulic model was delayed until 2008 due to the unavailability of the final bathymetric data downstream of Boundary Dam, which was completed in December 2007.

The basic data and information necessary for the development of the upstream and downstream hydraulic routing models are 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 the hydraulic models. The specific data and information that were used to construct the upstream hydraulic routing model and that will be used to construct the downstream hydraulic routing model include 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.
- 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. 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. The data are available at only one gaging station in the project area, as summarized in Table 4.2-2 and Figure 4.2-1.
- 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 1-hour time intervals) in the Seven-Mile Dam forebay, obtained from BC Hydro.

Development of the hydraulic routing models will continue in 2008 as new data and new information become available. Additional data that are expected include the following:

- Detailed cross section surveys at each habitat transect location
- Continuous pressure transducer data collected in 2008
- Continuous USGS gage data collected in 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

Notes:
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 gaging station 12398600 is a total dissolved gas (TDG) monitoring station and does not provide direct measurement of flow rate.
2 USGS gaging station 12396500 comprises a primary station and an auxiliary station.

4.2.2. Hydraulic Routing Model Calibration

The downstream hydraulic routing model will be calibrated using the post-processed water surface elevation data from the pressure transducers installed downstream of Boundary Dam for the 13-month period between September 2006 and September 2007. The pressure transducer data will be available in 15-minute resolution and will be converted to Pacific Standard Time (PST). Since this is a future work effort to be conducted in 2008, the remainder of the discussion in this section will focus on the calibration methodology for the upstream hydraulic routing model, which was a work effort conducted in 2007.

The upstream hydraulic routing model was calibrated to the post-processed water surface elevation data from the five pressure transducer installations upstream of Boundary Dam and water surface elevation data reported at the USGS Gage Station 12396500 for the 13-month period between September 2006 and September 2007. All data were available in 15-minute resolution and were converted to PST. All water surface elevation data were either provided or converted to NAVD 88 vertical datum.

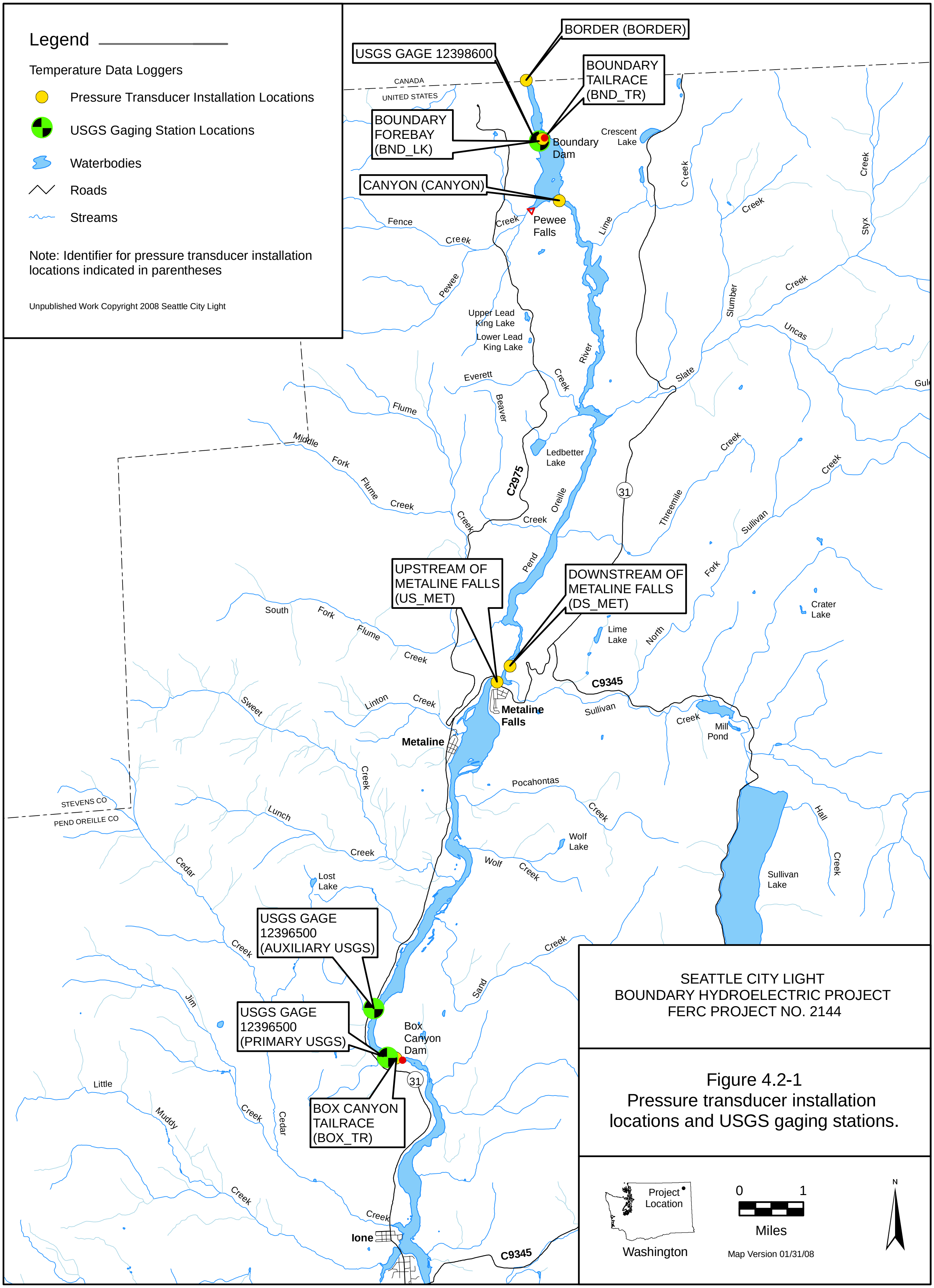


Figure 4.2-1
Pressure transducer installation locations and USGS gaging stations.

The calibration of the upstream hydraulic routing model 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 the parameters, selection of the historical time periods for the calibration, determination of an acceptable error range for the calibration, and execution of the calibration.

Phase Two included selection of the historical time periods for the verification, determination of an acceptable error range for the verification, and then execution of the verification. The second phase also included refinement of the calibration parameters in the event that the verification results were outside of the acceptable error range.

Phase Three included an execution of the verified model for the 13-month data collection period and a reporting of the error range for the 13-month data collection period.

Calibration of the upstream hydraulic model will continue as additional data are available, which includes, but is not limited to, the following:

- Water surface elevations surveyed by TRPA at the habitat transect locations during May, July, and August 2007 (see Section 4.3.4).
- Water surface elevation data from the pressure transducers and from the USGS gaging station collected subsequent to September 2007.

4.2.2.1. Upstream Hydraulic Routing Model 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 13-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 the 13-month record. A matrix comprising six specific portions of the 13-month record was developed using unique combinations of the following forebay conditions and Box Canyon outflow conditions:

- High Pool Conditions—conditions where 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 where 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 where outflow from Box Canyon Dam was greater than 40,000 cfs as recorded at USGS Gage 12396500.
- Moderate Flow Conditions—conditions where outflow from Box Canyon Dam was approximately 20,000 cfs.
- Low Flow Conditions—conditions where outflow from Box Canyon Dam was less than 10,000 cfs.

Table 4.2-3 presents the matrix and summarizes the identified time periods that were used for the calibration of the upstream hydraulic model. 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).

Table 4.2-3. Calibration periods for upstream hydraulic routing model.

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

Notes:
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, 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 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 pre-defined acceptable error range. The pre-defined error range for absolute error was specified at a nominal value of 0.75 foot. The pre-defined error range for RMSE for a single calibration location within a single calibration period was specified as 0.50 foot.

4.2.2.2. Upstream Hydraulic Routing Model Calibration – Phases Two and Three

Verification of the model calibration was conducted using a separate set of time periods from the 13-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 4.2-4 summarizes the time periods used for the model verification. The time period identified as Var_Var in Table 4.2-4 is representative of a wide range of pool and flow conditions and covers both a Hi_Mod and a Lo_Mod condition

Table 4.2-4. Verification periods for upstream hydraulic routing model.

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. Simulated water surface elevation hydrographs were compared against the observed hydrographs at each of the six calibration locations. Absolute maximum error and RMSE were computed. The verification was deemed successful if the verification model results were within the pre-defined error ranges defined originally for the calibration step. If this was not the case, 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 13-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. Evaluate Need for Separate Seasonal Models

The presence of macrophyte beds in the Upper Reservoir Reach may contribute to the need to develop separate seasonal hydraulic models. During the period of most robust growth of macrophytes, June through September, the density of the growth has the potential to sufficiently 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 proposed methodology for evaluating this need is included in Appendix 5.

4.2.4. Model Documentation and Executable Model

The calibrated hydraulic routing model will be used integrally with several other models 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.

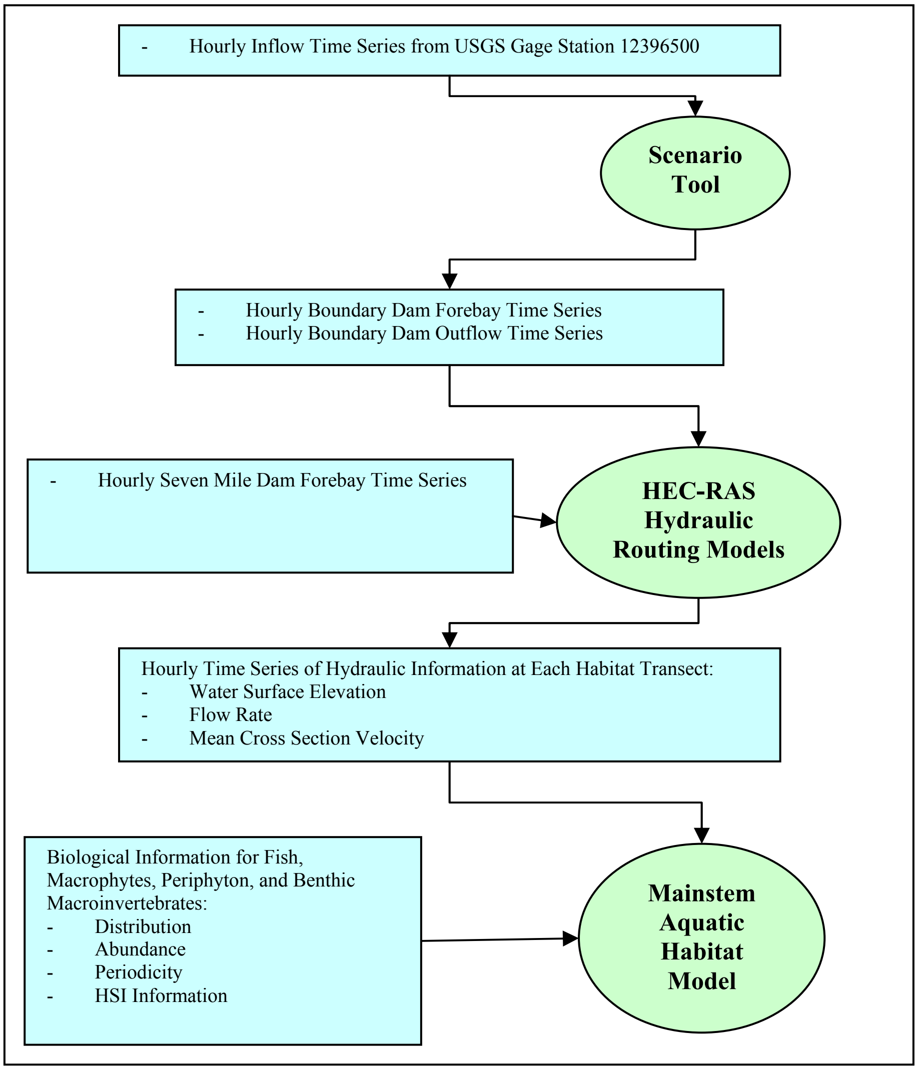


Figure 4.2-2. Conceptual model framework for Study 7.

The Scenario Tool is an Excel®-based hydroelectric operations tool tailored to the requirements of relicensing for the Boundary Dam Project (CddHoward Consulting 2006). 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 2000 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 Scenario Tool 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.

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.

4.3. Physical Habitat Model Development

This section presents the methods associated with the development and application of the Physical Habitat Model portion of the Mainstem Aquatic Habitat Modeling effort. This includes twelve tasks that range from selecting the mainstem habitat transect locations and performing the transect measurements to developing the individual modeling components and performing the application of the models. Much of the information has been presented at previous relicensing participant and Fish and Aquatics Workgroup meetings including those held on April 24, June 7, July 24, and October 17, 2007.

The Physical Habitat Model study component (Study 7.3) will take results of the hydraulic routing model, representing changes in flow conditions associated with operations scenarios, and generate a variety of indices reflecting habitat conditions within the mainstem of the Pend Oreille River. This will be accomplished through a suite of modeling and post-processing efforts that in combination constitute the physical habitat model component of the Mainstem Aquatic Habitat Model. The hydraulic information from the routing model, represented by either water surface elevations and flow rates or velocity and depth distributions across transects, along with other characteristics describing the physical habitat conditions, are used in the physical habitat modeling effort to produce the indices that will be used to evaluate the existing Project effects and operations scenarios. The modeling efforts being developed and applied in Study 7.3 include:

- Determination of downramping rates
- Identification of critical downramping pool elevation
- Calculation of macrophyte composite suitability index and WUA
- Calculation of periphyton composite suitability index and WUA
- Calculation of BMI composite suitability index and WUA
- Analysis of fish stranding and trapping potential
- Determination of habitat (WUA) for fish species and lifestages of interest

The first six items concentrate on conditions associated with the area influenced by water surface elevation fluctuations that result in inundation and dewatering of the channel margins or reservoir shoreline. This is the area referred to as the varial zone. The seventh item reflects habitat conditions across the entire river channel or reservoir. In addition to the development and application of the physical habitat modeling components, Study 7.3 effort involves integration of the hydraulic routing model and the physical habitat modeling routine, collection of the habitat transect information, and integration of the transect level velocity distributions with the hydraulic routing model.

Besides the tasks within Study 7.3, the Physical Habitat Model Development effort draws from the information or technical analyses performed in other Study 7 components as a basis for developing the model and applying the model. Study 7.1 provides information on a variety of physical characteristics that influence the modeling and also assist in identifying habitat transect locations. The combination of the Scenario Tool and the hydraulic routing model (Study 7.2), which in tandem determine the hourly water surface elevations and flow rates throughout the study area, form the foundation on which the physical habitat models are based. Study 7.4 provides the HSI that are critical for the quantification of habitat conditions resulting from each operations scenario. Study 7.5, Stranding and Trapping Field Surveys, provides the information to help formulate the modeling procedure for stranding and trapping and the factors used to reflect the influence of physical conditions on the potential for stranding and trapping.

4.3.1. 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 Section 4.2, Hydraulic Routing Model) 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; recon-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.–Canadian border. The number and locations of the Canadian Tailrace transects were approved at the July 24, 2007 Fish and Aquatics workgroup meeting.

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 is better accomplished through inspection of that data. The large scale of the reservoir enables sections of generally homogenous cross section to be selected. Rather than stratify each reach into mesohabitat types, each segment is represented by one transect, thus representing entire reaches. This avoids 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 are short enough to allow for a coherent response to the flow changes to be represented by one transect. In the physical habitat simulation, each transect will be weighted in the proportion of the segment length that it represents to the entire reach length.

4.3.2. Relicensing Participant Site Visit

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 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.

4.3.3. Substrate and Aquatic Vegetation Characterization

Substrate and aquatic vegetation were mapped and characterized along habitat transects to a depth of 50 feet below the full 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 riverwide aquatic vegetation mapping, the two study components were executed independently. The approach used during the riverwide aquatic vegetation mapping is presented in Section 4.1.5.

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 4.3-1 and codes for substrate types associated with aquatic habitat in Table 4.3-2.

Table 4.3-1. 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 4.3-2. Codes for substrate types.

Code	Description
1[1]	Silt, clay, or organics
2	Sand
3	Small gravel (0.25-1.25cm)
4	Medium gravel (1.25-3.75cm)
5	Large gravel (3.75-7.5cm)
6	Small cobble (7.5-15cm)
7	Large cobble (15-30cm)
8	Boulder (>30cm)
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 equal suitability of all deep substrate types must be considered when evaluating model results if any spawning curves are not depth-limited.

To support the objectives of Study 7.4.2 and the overall habitat model when aquatic plants were observed along a transect (Code 6 from Table 4.3-1), additional descriptive and density data were recorded (Table 4.3-3) and (Table 4.3-4). 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 4.3-3. 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 4.3-4. 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.

4.3.4. 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]) 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 will be measured for high flow, high pool (Seven Mile Reservoir) conditions, as well as high, middle, and low flow with low pool conditions for the Tailrace Reach transects on the U.S. side of the border (Table 4.3-5). 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.

Transect bottom profile data were collected concurrently with the velocity data using a TRDI 1200 kHz Rio Grande acoustic Doppler current profiler (ADCP), an Airmar 6^0 235 kHz digital depth transducer, and a Trimble Pathfinder Pro XRS submeter GPS with Omnistar correction. In areas of heavy macrophyte growth, hand-held electromagnetic velocity meters were used to collect velocity data. As a supplement to these target flows and pool water surface elevations, additional measurements of velocity patterns were obtained in early May in areas where heavy macrophyte growth was anticipated. This was done to allow accurate velocity simulation for macrophyte seasonal growth conditions, as well as outside the seasonal growth period.

Table 4.3-5. 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 Box Canyon Dam to Metaline Falls	34.5 to 26.8	7.7	24	High pool: 40,000 cfs Low pool: 40,000 cfs 20,000 cfs 10,000 cfs
Canyon Metaline Falls to Canyon mouth	26.8 to 18.0	8.8	20	High pool: 40,000 cfs
Forebay Canyon mouth to Boundary Dam	18.0 to 17.0	1.0	5	High pool: 40,000 cfs
Tailrace Boundary Dam to US/Canadian Border	17.0 to 16.0	1.0	6	High pool: 40,000 cfs Low pool: 40,000 cfs 20,000 cfs 10,000 cfs
US/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.

4.3.4.1. Hydraulic Data Collection

Field data collection and data recording generally followed the guidelines established in the 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.

4.3.4.2. 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 reasonable. 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 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, mini-meters in shallow, slower waters as recommended in the U.S. Geological Survey techniques manual (Rantz 1982). Each day all mechanical meters were inspected. Pivot pins were replaced if significant wear was noted, pin clearances adjusted, and the meters 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.

4.3.4.3. Velocity Measurements

Techniques for measuring discharge have evolved in recent years with the advent of ADCP. The USGS has been using ADCPs to 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. With the addition of smaller units, tethered small boat platforms and improved software, ADCPs can be used to measure almost any size stream or channel.

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 66 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 only accurately measure 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 66 feet) were not taken. This occurred in the transects within the Canyon and Forebay reaches.

A sub-meter accurate GPS with 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 to the laptop's hard drive and copied to a USB flash drive daily.

For those sections of a transect that could not be readily measured using the ADCP such as shallow areas (<1 foot) and edge cells near the shore, 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. 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 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.

4.3.4.4. Extrapolation of Velocity Measurements

For those transects that had cell depths greater than 50 feet, it was necessary to develop a method to estimate the mean column velocity for those cells of the transect with depths greater than 50 feet. The method essentially applies a factor to the measured mean column velocity for the upper 50 feet and is an adaptation of algorithms used internally in the ADCP and information presented in Simpson and Oltmann (1993). For those cells with depths less than or equal to 50 feet, the mean column velocities determined by the ADCP were not adjusted. The algorithm used to compute the mean column velocity for cells greater than 50 feet in depth is as follows:

$$V_{meancell} = V_{mean50} \times A \times \left(\frac{50}{D} \right)^{\frac{1}{B}}$$

Where:

$V_{mean\ cell}$	=	mean column velocity for entire depth of cell
$V_{mean\ 50}$	=	mean column velocity for upper 50 feet of cell as determined by ADCP
A	=	adjustment factor
D	=	depth of cell
B	=	adjustment factor

The ADCP fits the measured velocity data to a vertical velocity distribution using a power velocity distribution formula (Simpson and Oltmann 1993), specifically using a power function with a 1/6 exponent. This is based on the assumption that the magnitude of velocity attenuates with depth and that the velocity profile can be fit to a power function. The methodology used to estimate the mean column velocity for cells with depths greater than 50 feet is based on a similar set of assumptions.

The methodology is applied to each habitat transect with depths greater than 50 feet. The flow rate at the transect is first calculated using the measured mean column velocities in the upper 50 feet. The calculated flow rate is then compared with the "observed" flow rate at the time of the velocity measurements. The "observed" flow rate is based on the predicted flow rate from the calibrated hydraulic routing model. An iterative process is then used whereby the magnitudes of the two adjustment factors are changed until the calculated flow rate at the transect matches the "observed" flow rate at the time of the survey. The B adjustment factor is allowed to range between 2 and 10 as per Simpson and Oltmann (1993). If acceptable results cannot be achieved with this range, then the B factor is set to 6 and the A factor is adjusted until the results are acceptable. This process is repeated for each habitat transect, with the result being a unique pair values for the A and B adjustment factors for each habitat transect.

Figure 4.3-1 graphically illustrates the results of applying this methodology to habitat transect C2. The velocities at this transect were measured in May 2007 during high flow conditions. As seen in this figure, the mean column velocities for those cells with depths less than 50 feet were unchanged. For those cells with depths greater than 50 feet, the mean column velocity was reduced by as much as 20 percent. As would be expected, those cells with the greatest depths result in mean column velocities with the largest adjustments.

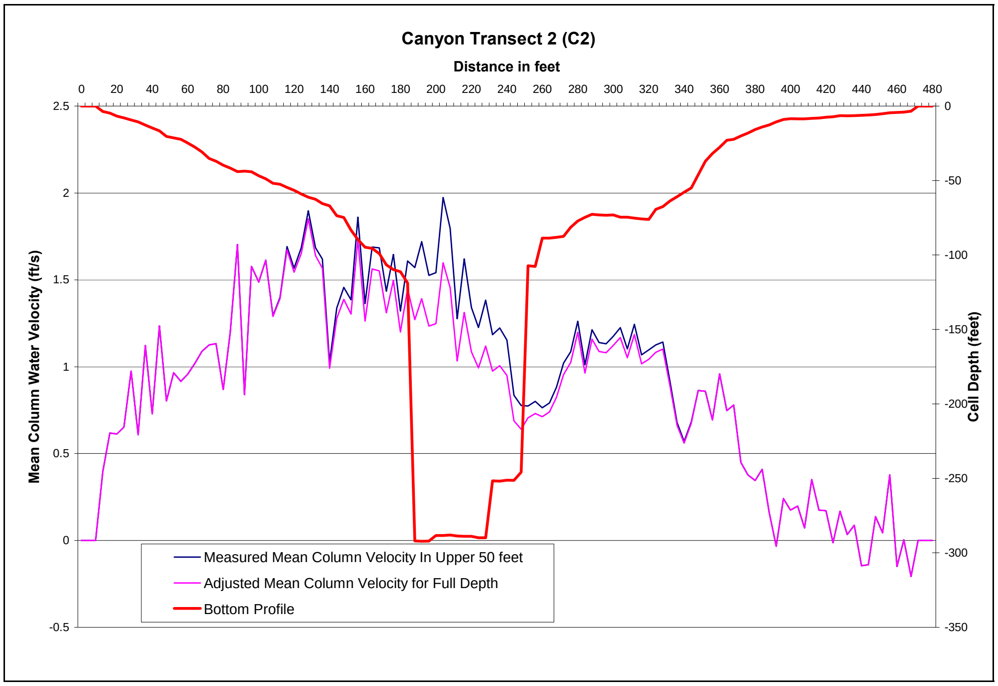


Figure 4.3-1. Example of mean column velocity adjustments for habitat transects.

4.3.5. Develop Cross-Sectional Profiles

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.

4.3.6. Hydraulic Model Integration

Cross-section geometry collected during the ADCP transect data collection effort will be incorporated into the hydraulic routing models. The ADCP collected transect geometry will replace the DTM derived cross-section geometry at the habitat transect locations only. Those cross sections in the hydraulic routing model that are not co-located with a habitat transect will remain as DTM derived cross sections.

For each habitat transect, the left and right end points will be geospatially located within ArcGIS using the GPS coordinates determined in the field survey of the end points and will be overlaid onto the DTM. The portion of the DTM-derived cross section between these two endpoints will be removed from the hydraulic routing model and replaced with the ADCP-derived geometry.

During the operations scenario evaluation, the hydraulic routing model will be used to determine the flow rate, the water surface elevation, and cross-sectional mean velocity at each of habitat transects for specific hourly operational conditions. The hydraulic routing model will export this hydraulic output in either Microsoft Excel® format or HEC Data Storage System (HEC-DSS) format for subsequent input into the habitat model.

4.3.7. Calibrate Hydraulic Model

The hydraulic routing model must be calibrated to not only the observed water surface elevations as described in Section 4.2, but must also be calibrated to the horizontal velocity distributions that were measured during the ADCP data collection periods summarized in Section 4.3.4. Initially, it was thought that this velocity calibration would occur internally within the HEC-RAS hydraulic routing models, using horizontally variable values for the Manning's roughness coefficient. However, for several reasons, this approach is no longer being considered. Instead the calibration will occur using the hydraulic subroutines in the RHABSIM physical habitat model, a commercial version of the Physical Habitat Simulation (PHABSIM) computer models.

The primary reason for not using HEC-RAS for calibrating to the observed horizontal velocity distributions is due to the internal limitations of the software. HEC-RAS only allows for the subdivision of a cross section to a maximum of 45 computational cells. For the upstream hydraulic routing model, the top width of the flow during high pool-high flow conditions ranges between 125 feet and 3,100 feet, with an average value of 760 feet. Therefore, assuming a maximum of 45 computational cells, the width of the computational cells would be as high as 70 feet. This was felt to be too coarse of a resolution for habitat modeling. Secondly, the output of the horizontal velocity distribution in HEC-RAS is not in a format that can readily be transferred or read by other models. This provides a significant limitation in regards to using HEC-RAS to provide velocity output for use in other models or programs.

Therefore, it is proposed that the calibration to the observed horizontal velocity distributions be conducted using the hydraulic modeling capabilities within the habitat model itself. For this approach, the calibrated HEC-RAS hydraulic routing model will be used to determine the flow rates and water surface elevations at each habitat transect for each of the velocity data collection time periods. This hydraulic model output will be input into the RHABSIM model, and the hydraulic algorithms in RHABSIM (specifically the VELSIM algorithm) will be used to allocate the total flow across each transect and to calibrate to the observed horizontal velocity distributions.

RHABSIM offers several methods to calibrate to observed velocity data, depending upon the number of velocity data sets that are available for calibration. For the Boundary Project, the number of available velocity data sets is summarized below for each of the five reaches in the study area:

- Upper Reservoir Reach—4 velocity data sets
- Canyon Reach—1 velocity data set
- Forebay Reach—1 velocity data set
- Tailrace Reach—4 velocity data sets
- Below Border Reach—1 velocity data set

Velocity calibration will proceed differently depending on whether four velocity data sets are available (multiple sets) or one velocity data set is available (single). The two calibration scenarios are summarized in the following subsections.

4.3.7.1. Calibration with a Single Velocity Data Set

Velocity calibration for those transects for which only one set of velocity data is available will proceed using Manning's equation and the measured velocities associated with the single flow condition. This approach uses Manning's roughness coefficient as the sole calibration parameter. An initial solution of Manning's equation is used to obtain an estimated Manning's roughness coefficient value at each vertical along the transect using the following equation:

$$n_i = \left[1.486 \times (S_e)^{\frac{1}{2}} \times (d_i)^{\frac{2}{3}}\right] \times \frac{1}{v_i}$$

Where:

n_i = calibrated Manning's roughness coefficient value at vertical i
S_e = energy slope for transect
d_i = depth at vertical i
v_i = measured velocity at vertical i

The value for the energy slope (Se) at each transect will be determined from the calibrated hydraulic model. The values for the depth and the velocity at each vertical will be obtained from the ADCP field data. In the above equation, the depth (d_i) variable has been substituted for the hydraulic radius in the original form of the Manning's equation.

The product associated with this calibration effort will be a set of horizontally variable Manning's roughness coefficient values for each transect (a single value for each cell) for the single velocity data set. The calibrated roughness coefficient values are then used for simulating any other combination of discharge and water surface elevation. The simulated velocity patterns and flow rates derived using the calibrated roughness coefficient values are reviewed for internal consistency and stable behavior over the range of discharges and water surface elevations. The simulated velocity patterns are adjusted using an internal Velocity Adjustment Factor (VAF) so that the simulated flow rate at the transect is equal to the expected flow rate at the transect.

4.3.7.2. Calibration with Multiple Velocity Data Sets

Velocity calibration for those transects for which multiple sets of velocity data are available will proceed using one of two possible methods. The final determination as to which method will be used will be a function of how well each of the methods reproduces the observed conditions and/or the methods preferred by consulting relicensing participants, including the Washington departments of Ecology and Fisheries and Wildlife. The two methods are summarized as follows:

- Velocity Regression Method
- Discreet Use of Multiple Data Sets Method

Using the velocity regression method, the measured velocities for each cell of each transect will first be plotted as a function of the measured flow rate. The velocities for the three low pool hydrologic conditions will be used in the regression. The program uses a log-log plot and fits a linear trend line through the data points of velocity against discharge. Figure 4.3-2 is an example plot for the measured cell velocities at Transect U-22 at the 200-foot station offset. This figure shows the measured cell velocity for each of three low pool hydrologic conditions that were measured. A linear trend line is shown fit through the data. Consideration will be given to including the cell velocity associated with the fourth field measured condition (the high pool, high flow condition) in the regression analysis. In the upstream portion of the Upper Reservoir Reach, including this value may not significantly impact the regression analysis. However, for those transects closer to Metaline Falls, which experience a greater backwater effect from Boundary Dam during high pool conditions, the inclusion of this fourth data point may significantly affect the regression analysis and may require that the three-point regression be replaced with a regression analysis using all four points.

The velocities predicted from the regression line will then replace the actual measured velocities from the three (or four) field conditions. For sample points with only two velocity measurements (edge cells only wetted at higher discharges), velocities would be predicted with a two-point regression. Water's edge stations with only one velocity measurement are simulated using the single velocity set calibration approach described in Section 4.3.7.1. The final step is to review the simulated velocities for other combinations of discharge and water surface elevation for stable behavior and reasonable velocity prediction. Simulated velocity patterns are adjusted using an internal VAF, as described previously in Section 4.3.7.1.

The alternative method that is being considered for calibrating cell velocity using the multiple data sets is to treat each velocity calibration data set as an independent data set for modeling purposes. In other words, using the highest observed velocity data to simulate at all flows higher than the highest measured flow, the lowest observed velocity set to simulate flows lower than the lowest measured flow, and user judgement for flows between the two. This approach results in using each of the velocity calibration data sets within a user defined range of flow rate or stage.

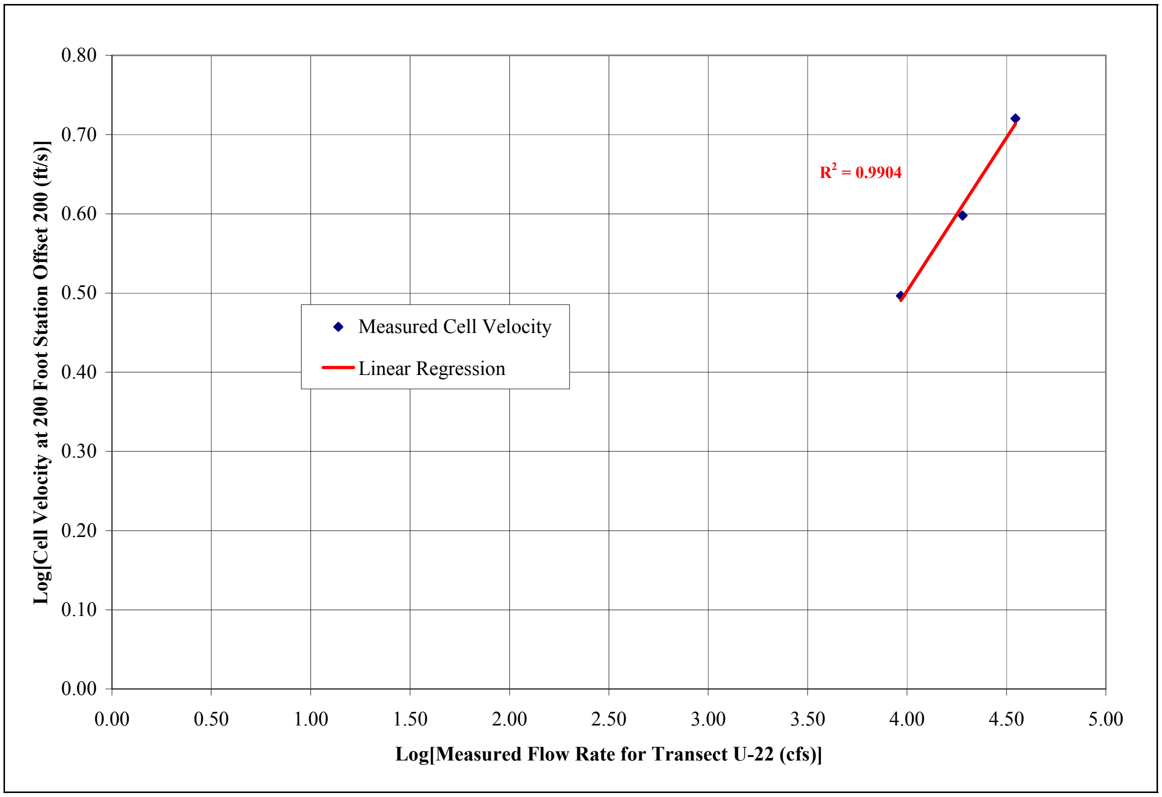


Figure 4.3-2. Velocity regression for cell velocities at transect U-22 and 200-foot station offset.

Using each of the velocity data sets as an independent calibration data set, RHABSIM will be used to calibrate the horizontal velocity distribution using the Manning's roughness coefficient method as was described above for the single velocity data set (Section 4.3.7.1). The result of this calibration effort will be a set of horizontally variable Manning's roughness coefficient values for each transect for each velocity data set. The final step of this process would be to define the range of flow rate (or water surface elevation) for which each calibrated data set is applicable. The ranges will be defined such that they will be continuous and cover the entire range of expected operating conditions.

4.3.8. Downramping Analysis

The downramping analysis is one of several tools being 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. The downramping analysis calculates reductions in reservoir water surface elevation over time. Washington State Instream Flow Guidelines assume that faster rates of water surface elevation drops are correlated to increased risk of stranding of aquatic organisms (WDFW and Ecology 2004; Hunter 1992). The downramping analysis is closely related to the stranding and trapping analysis (Section 4.3.9) and the varial zone analysis (Section 4.3.10) since all three efforts are directed toward evaluating the potential influences of mainstem water surface elevation fluctuations on aquatic habitat. The stranding and trapping and varial zone analyses evaluate the magnitude of water surface elevation fluctuations by calculating changes in area, while the downramping analysis evaluates the rate of water surface elevation fluctuations.

4.3.8.1. General Approach

Because the entire study area can be influenced by backwater from operations scenarios, conducting the downramping analysis will vary somewhat from the typical riverine-based downramping analysis. In standard Washington State instream flow studies, a critical flow is used to identify the conditions where ramping rates are applied. In typical river systems, the amount of exposed channel bed increases as the river stage drops, and the rate of exposure increases rapidly when the toe of the bank begins to be exposed. The critical flow identifies that flow volume where the rate of channel bed exposure begins to increase. Ramping rates are applied when flows drop below some level where the rate of channel exposure becomes high; thus downramping rate constraints do not typically apply at high flows. Once the elevation of increasing channel bed exposure is identified, a river flow associated with that elevation is calculated and identified as the critical flow.

Identifying a critical flow at the Boundary Project is more complicated than a standard riverine system because of the influence of downstream controls represented by Boundary Dam for the Upper, Canyon, and Forebay reaches and by Seven Mile Dam for the Tailrace reach. As a result of the backwater conditions created by the downstream water surface elevation controls, the rate of channel bed exposure for a given upstream inflow can vary substantially depending on the operating water surface elevation at the downstream control. Likewise, the rate of channel bed exposure for a given operating water surface elevation can vary substantially depending on the upstream inflow. Therefore it was proposed and agreed upon at the June 7, 2007 Fish and Aquatics Workgroup meeting that the downramping analysis for Boundary Dam be performed with the intent of identifying "critical downramping conditions." The critical downramping conditions, as defined at the Workgroup meeting, are the "range of pool elevations and flow volume where large areas of the river bed or reservoir shoreline contain characteristics likely to contribute to fish stranding and/or trapping." The critical downramping conditions concept accounts for influence of both the flow volume and the downstream pool elevation on determining the actual water surface elevation at any point in the study area.

4.3.8.2. Details of Downramping Analysis

To conduct the downramping analysis, two primary steps will be performed. The first will be to develop information to support the identification of the critical downramping conditions. The second will be to evaluate the frequency at which operations scenarios result in exceedance of specific downramping rates, during combinations of forebay pool elevation and flow volume representing critical downramping conditions.

4.3.8.2.1. Development of the Critical Downramping Conditions

Identifying the critical downramping condition will require a combined application of the hydraulic routing model and GIS analysis of the reservoir bathymetry. The hydraulic routing model will be applied to a range of forebay pool elevations and upstream inflows (outflows from Box Canyon Dam) to determine water surface elevations throughout the study area. To develop this information, the routing model will be executed in steady state mode (constant flow rate and constant downstream elevation). From this information, a matrix of water surface elevations at each mainstem habitat transect will be developed from a combination of forebay pool elevation and upstream inflow. The range of elevations and upstream inflow is still being developed, but for each habitat transect, it is currently anticipated that there will be approximately 200 elevations determined (20 forebay pool elevations by 10 upstream inflows).

From the hydraulic routing model and the GIS application, each transect will have a matrix with water surface elevations as a function of forebay pool elevation and inflow, and a table with the total area of channel bed identified at 1-foot intervals. This will provide the information to identify elevation ranges that are most critical at a cross section in terms of contributing to a potential for exposed streambed area when the combination of forebay pool elevation and inflow produce the given water surface elevation. By reviewing the two tables in tandem, the critical downramping conditions can be identified for each transect. By reviewing the results for all transects, the critical downramping conditions can be generalized by reaches.

4.3.8.2.2. Development of Downramping Rates

The results from the runs of the hydraulic routing model for each operations scenario will be post-processed to determine ramping rates at each mainstem habitat transect within the study area. The downramping rates will be determined for conditions in which the water surface elevation is falling based on the difference in hourly water surface elevations. For each mainstem habitat transect, the number of hours with downramping rates exceeding 1, 2, 4, 6, and 12 inches per hour associated with each operations scenario will be calculated for selected hydrologic periods by reach. The number of hours of downramping exceeding each criterion will be calculated by month and by annual total for each of the mainstem habitat transects. The number of hours of downramping exceeding each criterion will be calculated as a reach-averaged, transect-weighted total for the entire study area from Box Canyon Dam downstream to Red Bird Creek and for the four mainstem Pend Oreille reaches (Upper Reservoir Reach, Canyon Reach, Forebay Reach, and Tailrace Reach).

A second set of tables showing the quantification of the hours exceeding each criterion will be produced. This set of tables will quantify the hours of operation that exceed the downramping criterion during periods when critical downramping conditions exist.

4.3.9. Stranding and Trapping Analysis

The purpose of this analysis is to develop indices that provide a relative quantification between operations scenarios of the potential for stranding and trapping of aquatic organisms. The analysis will cover the range of conditions encountered for operations scenarios as opposed to only analyzing extreme conditions, though extreme conditions will be incorporated if they occur for a given operations scenario. The procedure is not intended to estimate actual fish mortality from stranding and trapping.

The methods to perform the field surveys to support the stranding and trapping analyses are presented in Section 4.5. An outline of the general approach was presented to the relicensing participants at the June 7, 2007 Fish and Aquatics Workgroup meeting in Spokane. This section provides details beyond those presented at the Workgroup meeting. The factors described in this section and used in application of the stranding and trapping modeling procedure will be coordinated with the Relicensing Participants at a meeting planned for the September 2008 timeframe.

4.3.9.1. General Approach

The approach to the stranding and trapping analysis has been formulated to be similar to other analyses involving water surface elevation fluctuations in the varial zone. These other analyses include the evaluation of indices for macrophytes, BMI, and periphyton. As with the other indices, the stranding and trapping indices will utilize results of the Scenario Tool and the hydraulic routing model to determine the water surface elevation on an hourly basis to evaluate conditions throughout the mainstem habitat modeling study area. In each of the other varial zone analyses, indices representing the influence of reservoir water surface elevation fluctuations are developed based on evaluation of the duration of inundation or dewatering, as well as other variables. These indices are computed on an hourly basis, weighted by area, and summed over time.

The stranding and trapping analysis follows a similar approach; however, there are two differences. First, the stranding and trapping analysis will only 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 areas. Secondly, stranding and trapping indices will not be treated as values that are summed on an hourly basis. Stranding and trapping will be viewed as a series of events or cycles. Therefore, the results will be computed at the end of a cycle based on the duration of the cycle, then these results will summed over the series of cycles. A cycle will be considered to start when a stranding area becomes dewatered or a trapping area becomes disconnected from the mainstem. A cycle will be considered to end when a stranding area becomes inundated or a trapping area becomes reconnected to the mainstem. Each cycle will be 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 occur over many days. The distinction between discrete hourly values for the macrophyte, periphyton and BMI versus a single value per cycle for stranding and trapping is made, since 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.

In the stranding and trapping analysis, ramping rate was not incorporated as a factor in the calculation of the indices. Strong relationships between ramping rate and incidence of stranding and trapping are not consistently demonstrated in previous studies (Higgins and Bradford 1996; R.W. Beck and Associates 1989). Ramping rates are being determined for operations scenarios as part of the downramping analysis (see Section 7.4.8) including the exceedance of specific hourly rates ranging from 1 inch per hour to 12 inches per hour.

In conducting the evaluation of stranding and trapping potential, periodicity for each of the fish species of interest will be an important factor. The potential for stranding and trapping of a specific species of interest will depend 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 initial results for the development of the periodicity table are presented in Section 5.4.1. The results of fish distribution studies (Study 9, SCL 2008f) may also assist in evaluating the results of the stranding and trapping analysis by indicating areas in which species of interest may be more abundant. Since the stranding and trapping indices can be calculated at each cross section location within the hydraulic routing model, there will be a high level of spatial resolution to the indices. This will help in evaluating and interpreting the results of the stranding and trapping indices developed.

4.3.9.2. Formulation of Stranding and Trapping Indices

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 will be 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 will assist in developing the ratings for several of these factors. The following paragraphs present the two indices, their factors, initial estimates for factor ratings, and how the field surveys will be utilized to support development of the factors.

4.3.9.2.1. Trapping

The trapping index is presented first since its formulation has more factors than the stranding index and covers the concepts that are also proposed for stranding. The following equation is proposed for computing the trapping index:

$$TI = A_T * B_T * T_{T(D)} * C_T$$

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

Figure 4.3-3 provides a conceptual sketch of a trapping area, both in plan and section view which will help in defining several of the above factors.

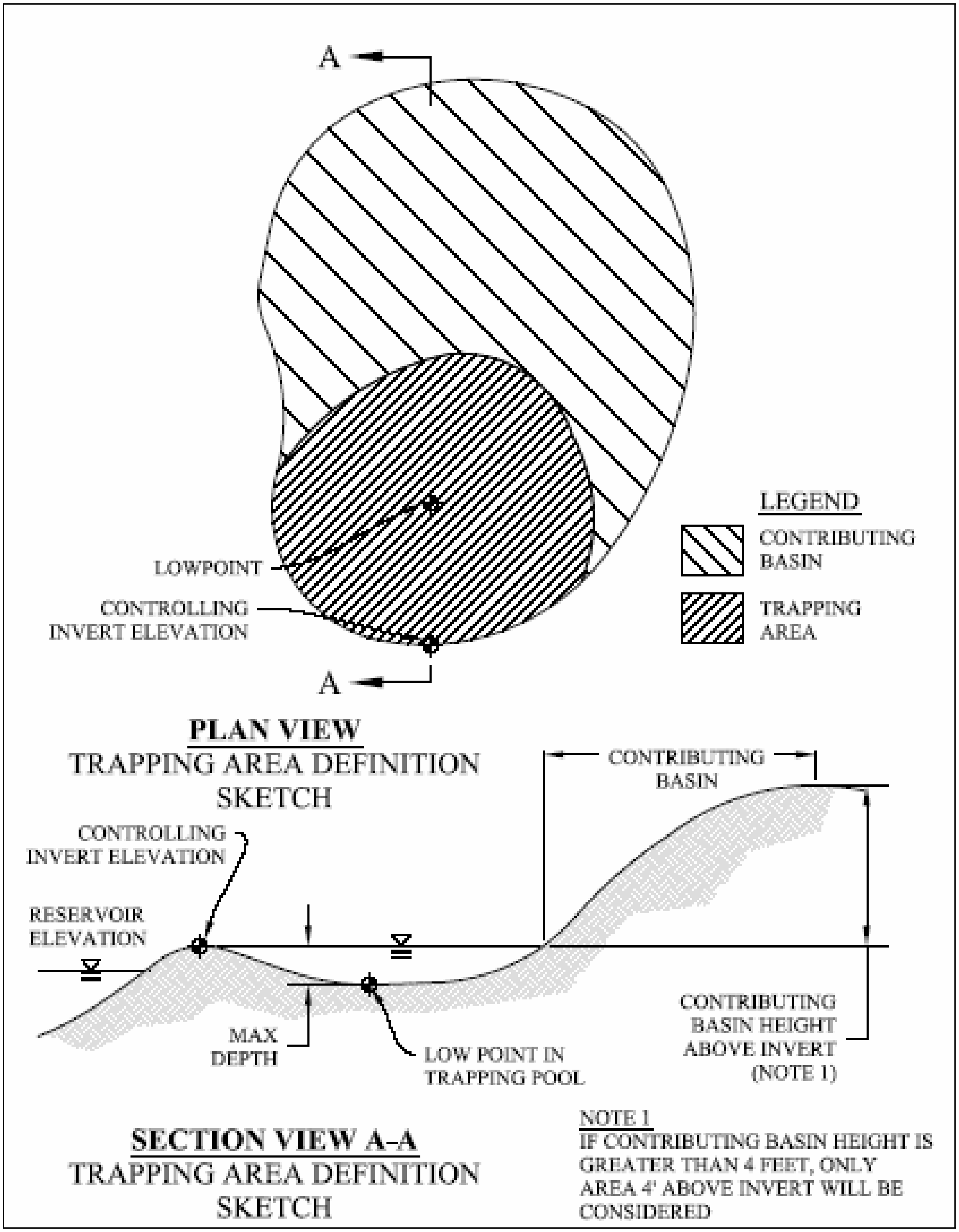


Figure 4.3-3. Conceptual sketch of trapping area, plan and section views.

TI Trapping Index

The trapping index will be calculated once for each trapping event. The index only needs to be calculated once per trapping event since 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 during the event. The time interval will be the total time between disconnection of the trapping site and reconnection to the mainstem. It will also be assumed that once the trapping area is reconnected, it instantly reaches its full potential for trapping; that is, the fish population is replenished. This assumption is conservative in that a species of interest may require some time (days to weeks) to recolonize trapping or stranding 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.

The TI will be calculated for each individual trapping depression. Consequently, the factors on the right hand side of the equation will be defined for individual trapping pools. Each pool will have an effective elevation assigned to its outlet, which will allow for determination of the time periods it is disconnected based on application of the hourly elevations available from the routing model cross section closest to controlling water surface for the trapping pool outlet.

A_T Trapping Area

The trapping area factor is the actual area of the depression in square feet. GIS tools will be used to identify each depression and determine its area and several other parameters (see Section 4.9.3.3). 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 will be 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 invert. Currently it is proposed that 0.5 foot be added to the outlet invert elevation if macrophytes are present. This is based on initial observations in 2007 of trapping areas with macrophytes present at the outlet, which will be further reviewed based on the 2008 observations. Additionally, a marginal depth of 0.1 foot for clear outlets is proposed to be added to the GIS derived 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, will be determined from the bathymetry utilizing GIS analysis tools. The trapping area will be based on the area below the effective outlet elevation. Depressions with areas of less than 100 square feet will not be considered in the trapping analysis.

B_T Contributing Basin Factor

This factor accounts for the area that drains into the trapping basin 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. It is proposed that this factor will 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 will be set equal to the ratio of the contributing area divided by the trapping area. If the ratio is above 3.0, the factor will be set to a maximum 3.0. The resulting contributing basin factors are provided in Table 4.3-6.

Table 4.3-6. Initially proposed values for contributing basin area factor (B_T) 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 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, since 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 4.0 feet, there is recognition that the contributing basin concept has limits both laterally and vertically.

Validation or adjustment of the contributing basin factor will be attempted by reviewing results of trapping surveys along with tabulated values of the trapping areas and the contributing basin factors. Within the limitations of the available data, trends indicating relatively larger numbers or density of fish as indicated by catch per unit of effort for live fish, or actual estimates of counts for dead fish, trapped per unit area, in areas with large contributing basins would support application of this factor. However, a variety of factors may affect fish density in trapping pools besides the size of the contributing basin. For example, the natural variability of fish distribution and abundance independent of 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.

$T_{T(D)}$ Duration of Trapping Factor

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, three separate curves will be provided to determine the factor. Each curve will represent the increase in mortality as the time period passes for a range of maximum pool depths. Different curves based on depth ranges were considered since it was reasoned that the shallower depressions would result in mortality in a shorter period than deeper depressions. This is primarily because the shallower depressions will dewater quicker (all other factors equal), change temperature more rapidly, and oxygen will be depleted more rapidly. The other process contributing to mortality is predation, with the trapped fish being easier prey in shallower depths. This may be the most significant process at initial disconnection from the mainstem until predators become satiated.

Pool depths will be divided into categories of less than 1 foot, 1 to 2 feet, and greater than 2 feet. An initially proposed base relationship for the 2-foot condition was developed. This relationship was assumed to be linear, such that the duration of trapping factor proportionately increases with the length of time a pool is disconnected from the mainstem. Based on professional judgement the vast majority of fish trapped during the summer in a 2-foot deep pool will die within 2 days. It is not yet clear whether the mortality rate may be higher in the initial hours, or at the end of the 48-hour period. Further investigations involving review and interpretation of the data as well as review of literature will be pursued to determine whether the initially assumed relationship is the most appropriate. The initially developed relationships for both summer and winter conditions are presented in Figure 4.3-4. The summer conditions relationship is presented in tabular form in Table 4.3-7. As shown in this table, for pool depths greater than 2 feet, full mortality is reached in 48 hours, full mortality is reached in 36 hours for pool depths between 1 and 2 feet, and full mortality is reached in 24 hours for pool depths less than one foot.

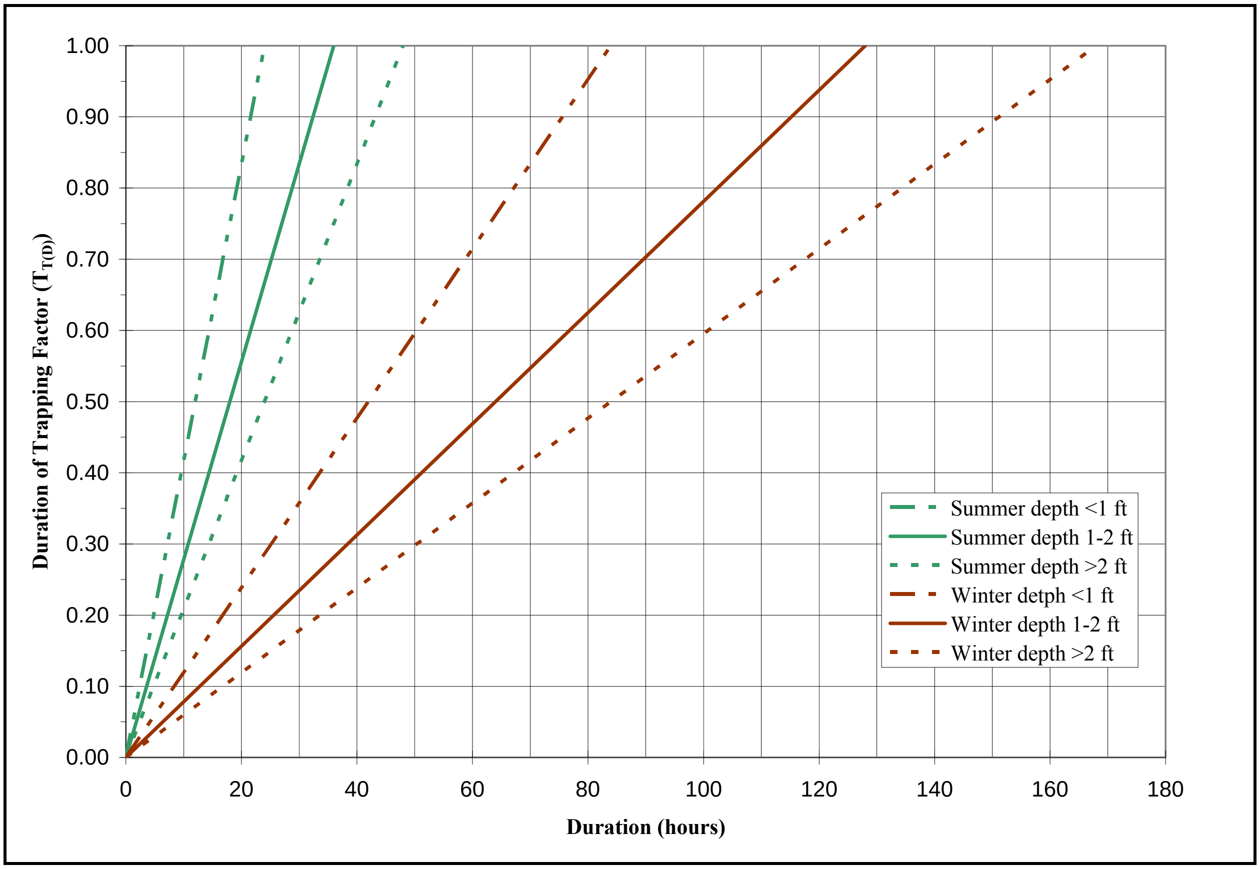


Figure 4.3-4. Initially proposed relationship for duration of trapping factor ($T_{T(D)}$) for summer and winter conditions in the trapping analysis.

Table 4.3-7. Initially proposed values for duration of trapping factor ($T_{T(D)}$) for summer conditions in the trapping analysis.

Depth > 2 feet		Depth 1 to 2 feet		Depth < 1 foot	
Hours	**$T_{T(D)}$**	**Hours**	**$T_{T(D)}$**	**Hours**	**$T_{T(D)}$**
0	0.0	0	0.0	0	0.0
12	0.25	9	0.25	6	0.25
24	0.50	18	0.50	12	0.50
36	0.75	27	0.75	18	0.75
48	1.0	36	1.0	24	1.0

For winter months, the "greater than 2 feet curve" was adjusted to have a 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 ratios. The resulting duration of trapping factors for winter conditions are shown in Figure 4.3-4 and listed in Table 4.3-8.

Table 4.3-8. Initially proposed values for duration of trapping factor ($T_{T(D)}$) for winter conditions in the trapping analysis.

Depth > 2 feet		Depth 1 to 2 feet		Depth < 1 foot	
Hours	**$T_{T(D)}$**	**Hours**	**$T_{T(D)}$**	**Hours**	**$T_{T(D)}$**
0	0.0	0	0.0	0	0.0
42	0.25	32	0.25	21	0.25
84	0.50	64	0.50	42	0.50
126	0.75	96	0.75	63	0.75
168	1.0	128	1.0	84	1.0

Further refinement of the initially proposed factors will be performed utilizing the results of the 2007 and 2008 stranding and trapping surveys. The duration that each pool surveyed in the field has been disconnected from the mainstem will be estimated based on application of the hydraulic routing model and the outlet invert elevation. To address the depth ranges, GIS will be used to determine the maximum depth of each trapping pool. Since the surveys will be taken over a range of seasons, it will be possible to separate winter and summer conditions. The duration of disconnection from the mainstem, the maximum pool depth and the seasonal period, along with the estimates of the proportion of fish that have died in each pool surveyed will form the primary means of refining the initial relationships. To have potential information on other factors possibly contributing to fish mortality, the approximate maximum pool water depth at the time of the survey, substrate characteristics, and pool water temperature will all be recorded, and notes will be made of any signs of predation.

C_T Cover Factor

The cover factor represents the influence of cover on the potential for trapping of fish in disconnected depressions. A variety of factors had been initially considered and discussed for application in determining this factor including macrophytes, LWD, and coarse substrate. Ultimately, it was decided for the initial proposed factors that only macrophytes would be considered. LWD was excluded because its occurrence is relatively rare compared to macrophytes and is a secondary influence. Substrate was not considered because there is little very large substrate (greater than 6 inches). These assumptions can be revisited if 2008 data collection indicates that substrate may be a significant factor. It was the opinion of the field crew members conducting the stranding and trapping surveys that the presence of macrophytes was the dominant cover factor influencing fish trapping.

The cover factors initially proposed for the trapping analysis to account for the presence of macrophytes are provided in Table 4.3-9.

Table 4.3-9. Initially proposed 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

The macrophyte factor will only be used during periods when the macrophytes are present. For other periods, the value will be 1.0.

These initially proposed factors are based on general observations from trapping events in 2007 and professional judgement. In 2008, the presence of macrophytes will be identified for each trapping site surveyed and categorized as: absent, less than 25 percent, 25 to 50 percent, 50 to 75 percent, and 75 to 100 percent. The percent coverage of macrophytes at each pool and the relative quantity of trapped fish will be reviewed to further refine the cover factors. In addition, to support this effort, a supplemental survey of macrophyte beds will be performed in the summer of 2008 (see Section 7.2), combined with the stranding and trapping survey notes, to provide the resolution necessary for determination of macrophyte coverage at potential stranding and trapping sites. This will allow for updating of the macrophyte map and use of GIS for development of the cover factor.

4.3.9.2.2. 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. The duration of trapping factor was omitted because it is assumed that the one 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 since fish can readily pass across the stranding areas and would not have a tendency to concentrate as is the case with the depressions of the trapping areas. Therefore, the area up gradient from the stranding location is 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 4.3-5 provides a conceptual sketch of a trapping area, both in plan and section view which will help in defining several of the above factors.

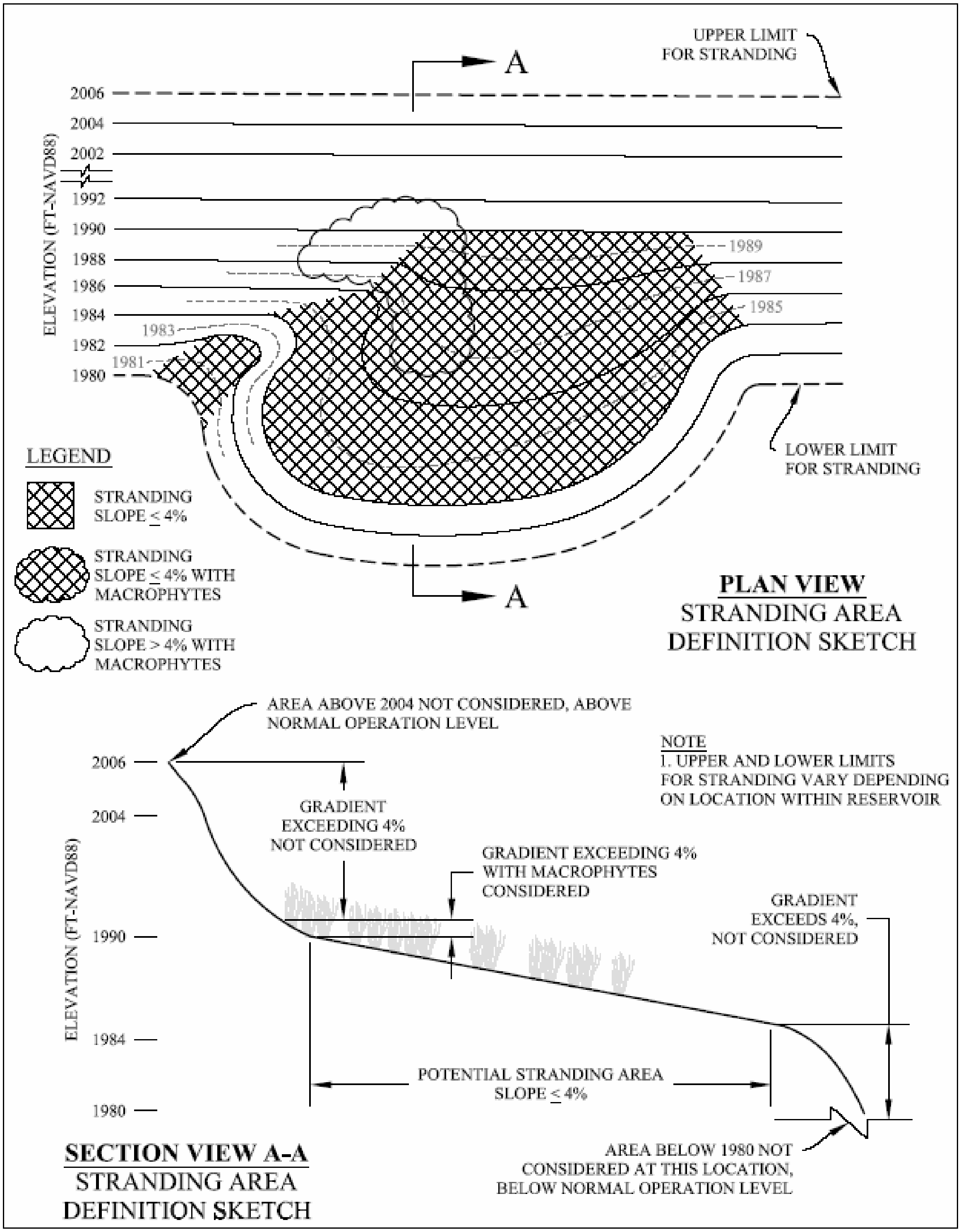


Figure 4.3-5. Conceptual sketch of stranding area, plan and section views.

SI Stranding Index

The stranding index will be calculated once for each stranding event. It was decided that there will not be a time component (duration) to stranding. It is 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 will also be assumed that once the stranding area is inundated again, it reaches its full potential for stranding; that is the fish population is replenished. Because of this assumption, it is not necessary to track potential residual fish from survival or model repopulation of the stranding area over time.

The SI will be calculated for each 1-foot elevation band. Elevation bands will be assigned to the nearest hydraulic routing modeling transect 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 will be defined for each 1-foot elevation band within the range of Project operations and for a distance halfway to the pervious cross section downstream and the next cross section upstream. There will be a set of elevation bands assigned to each hydraulic routing model cross section for the purpose of calculating the stranding index.

A_S Area of Stranding

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 will also be defined as areas with macrophytes regardless of slope. Inclusion of the macrophyte beds is based on field observations in 2007, which indicated that where macrophytes occurred there was likely to be stranding. Specific stranding zones will be defined at 1-foot of elevation so as to allow for tracking of dewatering of stranding areas as the water surface elevation rises and falls. Stranding areas will only be defined within the zone of water fluctuations expected for the potential range of reservoir water surface elevation fluctuations for a given operations scenario. The units for stranding areas will be square feet.

The stranding area within each elevation band will be determined from the bathymetry using GIS tools. It is proposed that sites of contiguous areas of 1,000 square feet or greater will be considered in this analysis. Setting the minimum stranding area at 1,000 square feet will eliminate 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 will help highlight the areas that pose the greatest stranding risk in Boundary Reservoir, the broad low gradient bars. 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 is assumed that the potential presence of fish in a stranding elevation band is directly proportional to the area of the elevation band.

C_S Cover Factor

The stranding cover factor represents the influence of aquatic macrophytes on the potential for stranding. In establishing the cover factor, if aquatic macrophytes are not present on a potential stranding slope of 4 percent or less, then this factor will be neutral and set to a value of 1.0. If aquatic macrophytes are present on a slope of greater than 4 percent, then the cover factor 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 factor 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. The proposed cover factors are listed below in Table 4.3-10.

Table 4.3-10. Initially proposed values for the cover factor (C_T) in the stranding analysis.

Gradient	Macrophytes Present?	Cover Factor
<= 4%	No	1.0
<= 4%	Yes	3.0
> 4%	Yes	2.0

Substrate was considered in development of the cover factor, but is currently not included. This is based on field observations indicating macrophytes are by far the most important factor and that typically, only the large cobble and larger substrate are considered to appreciably influence stranding. As with the trapping cover factor, this can be revisited if 2008 data collection indicates that substrate may be a significant factor. There are only a few locations in the project area where cobble or larger size substrate exists. Based on the observations in 2007, limited areas of such substrate may exist in the first mile below Box Canyon Dam along the irregular left bank bars, in the "Islands" area, and the right bank tailrace bar near the hydraulic control just upstream of the border.

In 2008, the presence of aquatic macrophytes will be identified for each stranding site surveyed. The presence or absence of macrophytes at surveyed stranding site, along with the gradient in the case where macrophytes are present, and the relative quantity of trapped fish will be reviewed to further refine the cover factors. In addition, to support this effort, a supplemental survey of macrophyte beds will be performed in the summer of 2008 (see Section 7.2), combined with the stranding and trapping survey notes, to provide the resolution necessary for determination of macrophyte coverage on potential stranding and trapping sites. This will allow for updating of the macrophyte map and use of GIS for development of the cover factor.

4.3.9.3. Stranding and Trapping GIS Map Development

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 is aiding field efforts in locating and characterizing areas where fish may become stranded or trapped during reduction in water surface elevations (see Section 4.5). The second is providing an accurate basis for characterizing the stranding and trapping areas. Use of the GIS system allows for the incorporation of both physical and biological conditions on a geographic basis to aid in the rating of the stranding and trapping areas. Information in addition to the bathymetry, for example the macrophyte mapping (see Section 5.1.3), 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 are developed from the mapping through application of the GIS tools.

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 LIDAR, were used to develop the maps for the two categories of areas, stranding and trapping. The overall elevation measurement points were on about 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. Based on detailed checks of the data against benchmarks and known elevations, the overall accuracy from the 3-foot center bathymetric surveys for each of the bathymetry points to true elevation was generally within about 0.3 to 0.5 foot.

The development of the potential stranding and trapping sites was performed for all areas that could potentially become inundated and then dewatered over the range of potential Project operations. High flow elevations that are only covered during spring freshet or floods were not included in this analysis, as water surface elevation changes at these reservoir elevations are not affected by existing Project operations. Therefore, the first step in the development of the potential stranding and trapping maps was to determine over what range of elevations these areas 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 indicate what ranges of elevation in what reservoir regions would become inundated and then dewatered (Figure 4.3-6). The model of reservoir elevation was run for constant low flow of 6,000 cfs and constant high flow of 55,000 cfs. The runs were done with the maximum and minimum forebay elevation that could occur for existing Project operations to indicate the upper and lower range of hydraulic effect of Project operations on elevations in Boundary Reservoir.

As shown in Figure 4.3-3, the upper reservoir above Metaline Falls has an elevation range that varies more than the lower reservoir. Water surface elevations in the upper reservoir continue to rise as flows exceed 55,000 cfs because of the effect of the Metaline Falls hydraulic control. Maximum water surface elevations in the Forebay and Canyon reaches are controlled by the use of spill gates and sluice gates at Boundary Dam. The upper reservoir was divided into three elevation ranges to account for the changes in elevations that would occur over the Project operation range:

- 2,003 to 1,982 feet NAVD 88 (1,999 to 1,978 feet NGVD 29) (Box Canyon Dam to near the USGS Auxiliary Gage; PRM 35.0 to 33.4)
- 2,002 to 1,981 feet NAVD 88 (1,998 to 1,977 feet NGVD 29) (just upstream of the USGS Auxiliary Gage to mouth of unnamed left bank creek; PRM 33.4 to 33.3)
- 2,001 to 1,980 feet NAVD 88 (1,997 to 1,978 feet NGVD 29) (mouth of unnamed left bank creek to Metaline Falls; PRM 33.3 to 26.8)

The lower reservoir has a similar elevation range from Metaline Falls to Boundary Dam, so for the entire region below Metaline Falls, the elevation range for map development was set for 1,996 to 1,974 feet NAVD 88 (1,992 to 1,970 feet NGVD 29).

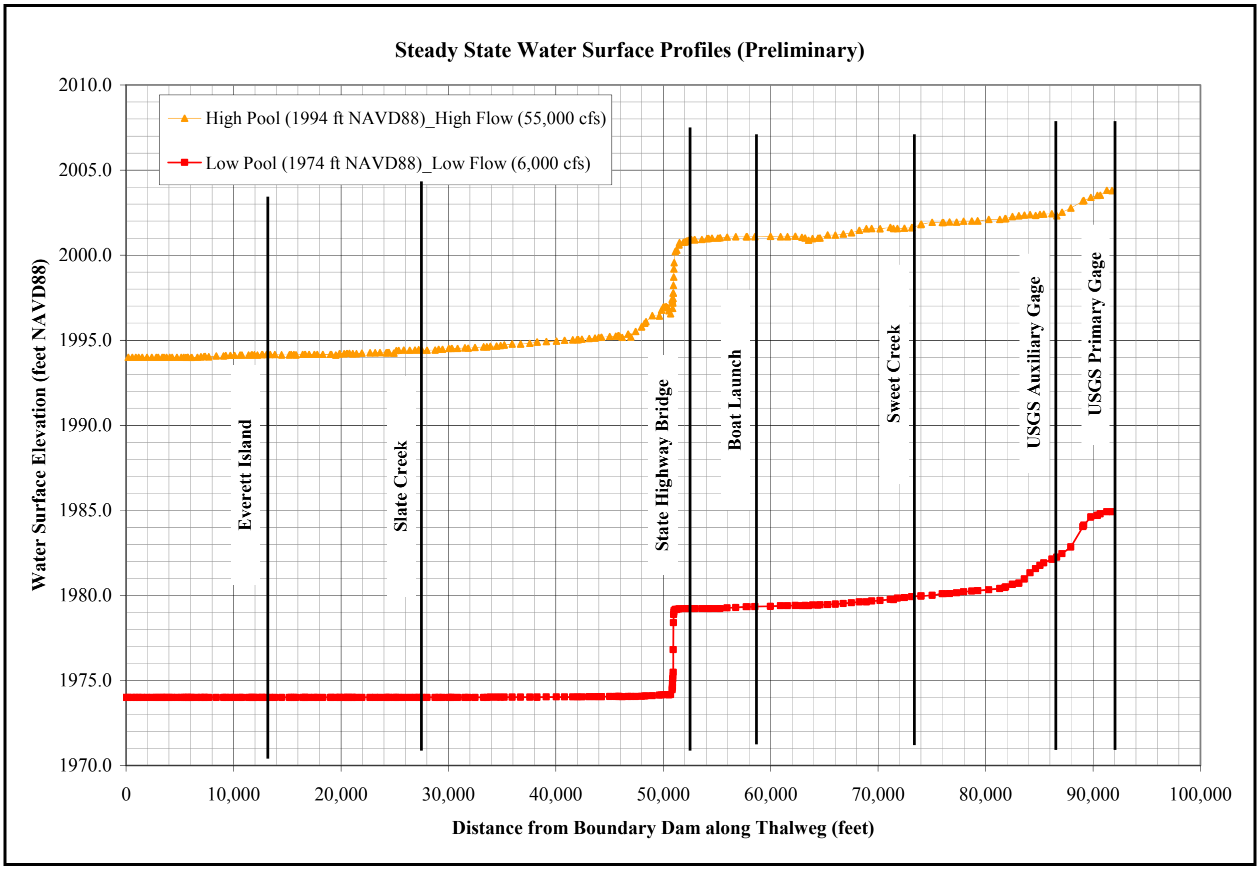


Figure 4.3-6. Constant flow profiles at 6,000 cfs low pool and 55,000 cfs high pool used to determine elevation range for GIS identification of stranding and trapping areas.

Using the elevation ranges noted within each of these potential stranding and trapping areas, the slopes less than 4 percent were shown and pools that formed were also determined. The pools were labeled with the elevation rounded to the nearest 1 foot, when they became disconnected. The maximum depth of the pool was also shown for each. This data can then be displayed on maps for both field crews to use while doing field surveys and modeling purposes. The areas associated with each pool and the contributing drainage areas are also being developed.

An example of one of the stranding and trapping maps is provided in Figure 4.3-7. All 22 stranding and trapping region maps are provided in Appendix 6 in Figures A.6-1 to A.6-22. Figure 4.3-8 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. Figure 4.3-9 provides an enlargement to illustrate the detail provided by the mapping for specific stranding and trapping areas.

Table 4.3-11 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 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 mapping. A parameter derived from GIS-based parameters is the contributing basin area factor. The contributing basin area is derived directly from GIS, but the contributing basin factor utilizes the contributing basin area and the contributing basin area factor curve to determine the actual contributing basin area factor for the specific basin.

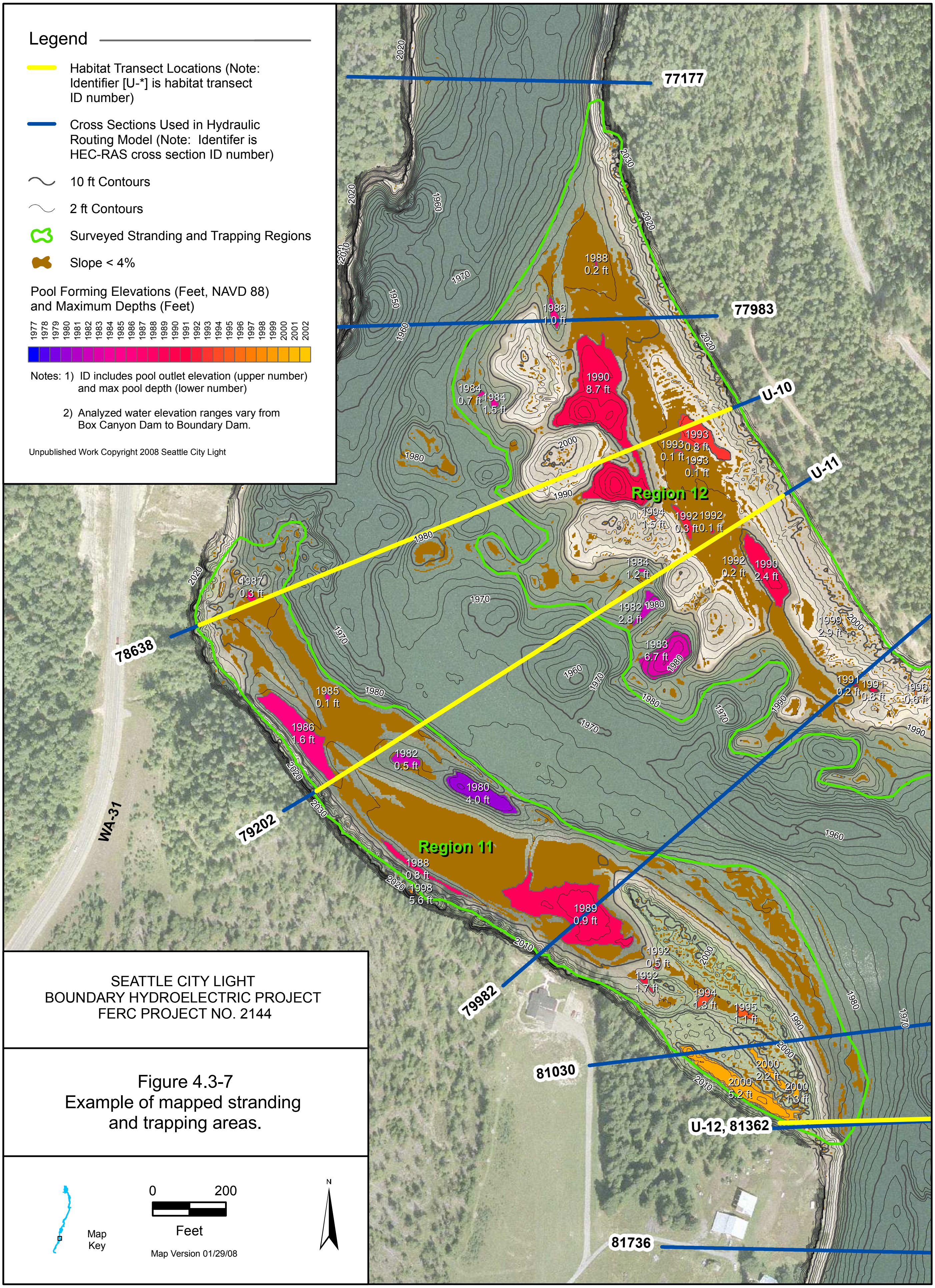


Figure 4.3-7
Example of mapped stranding and trapping areas.

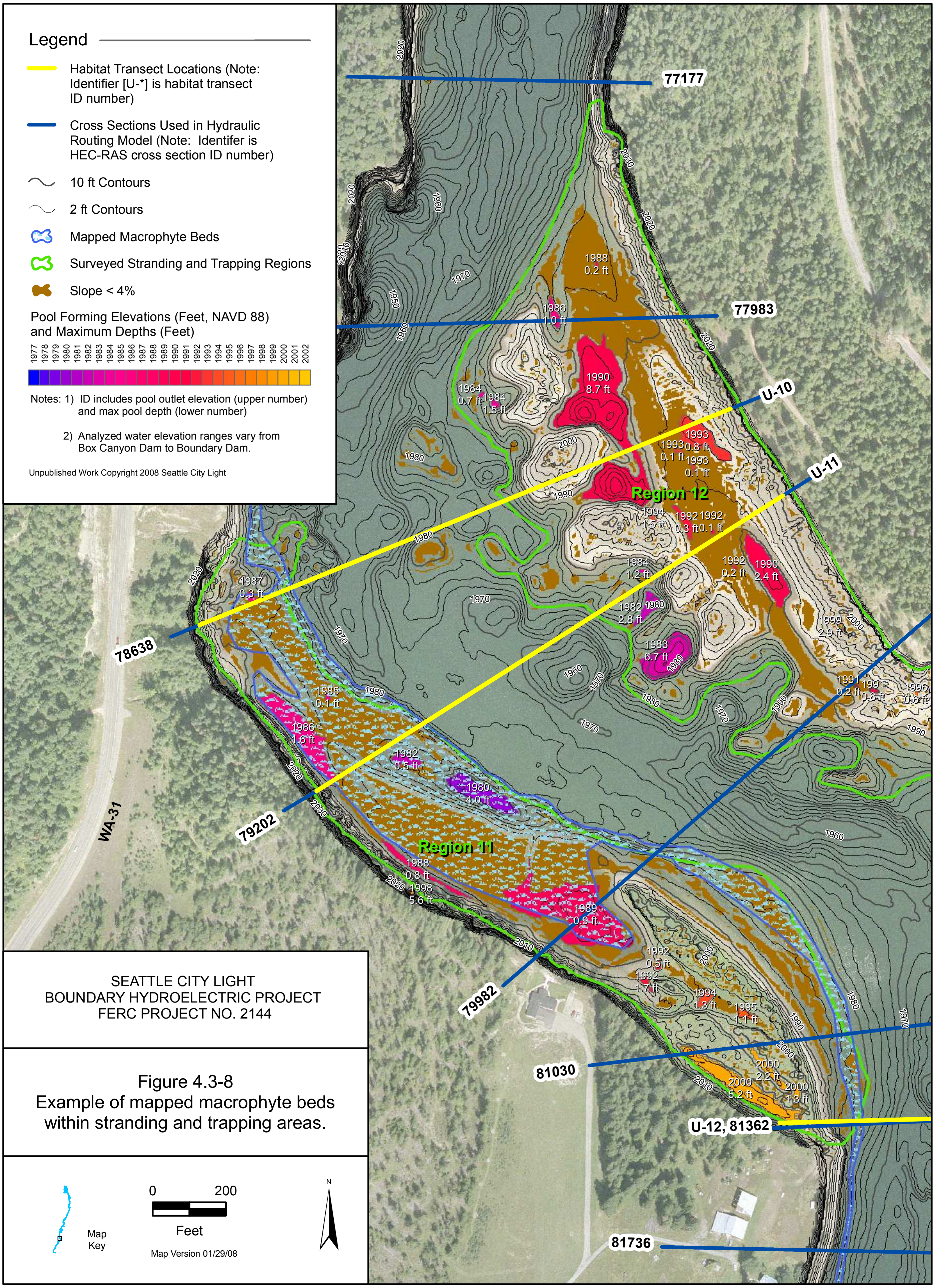
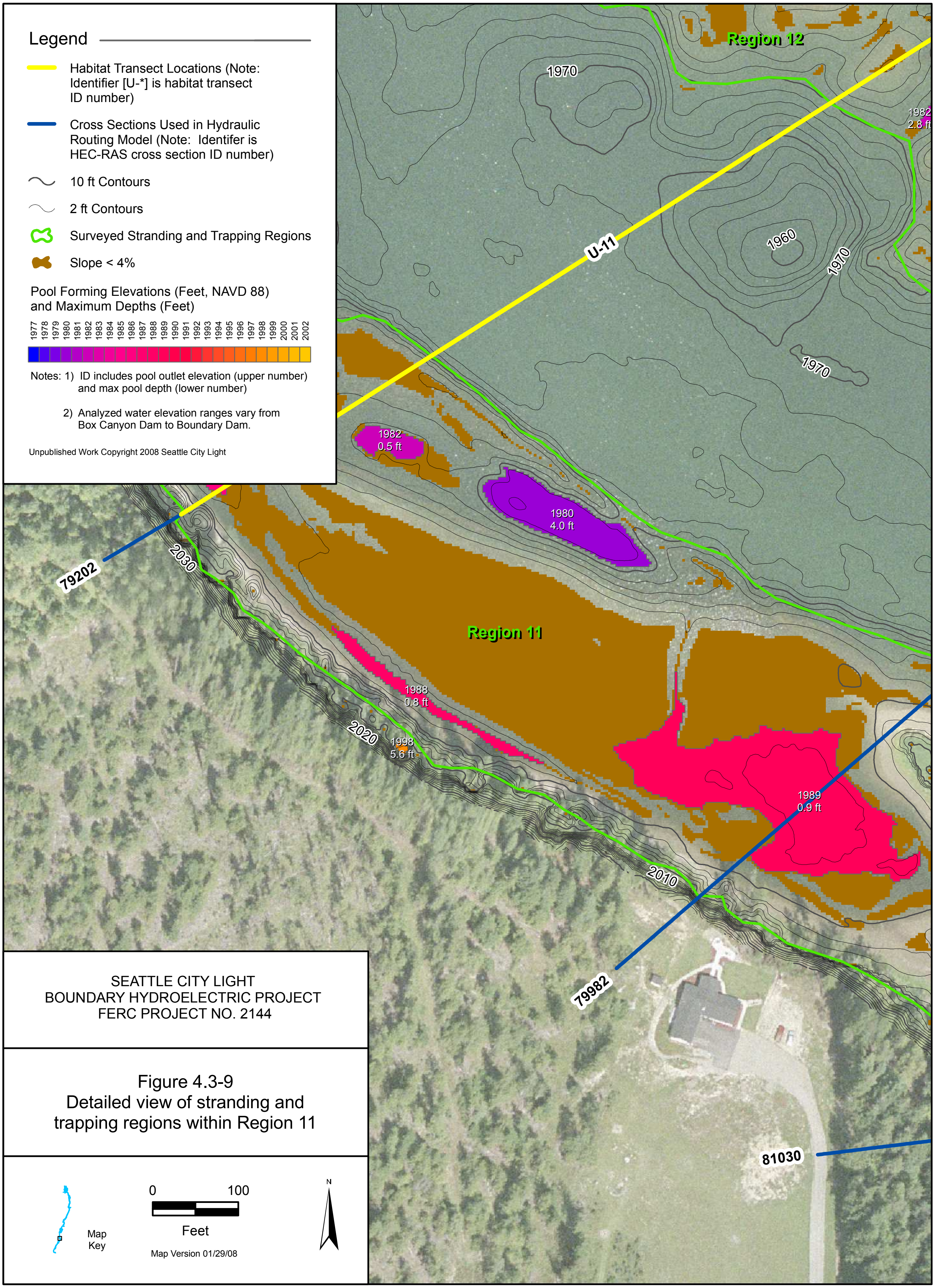


Figure 4.3-8
Example of mapped macrophyte beds within stranding and trapping areas.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 4.3-9
Detailed view of stranding and trapping regions within Region 11

Table 4.3-11. 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	Contributing basin area trapping (square feet)	Y	---	---
3	Contributing basin factor trapping	N	2	
4	Outlet elevation trapping (feet NAVD 88)	Y	---	---
5	Effective outlet elevation trapping (feet NAVD 88)	N	4	---
6	Duration of trapping (hours)	N	5	Y
7	Percent aquatic macrophyte trapping (percent)	Y	---	---
8	Macrophyte cover factor trapping	N	7	---
9	Presence of aquatic macrophyte stranding (Y/N)	Y	---	---
10	Stranding slope (percent)	Y	---	---
11	Stranding area (square feet)	Y	9,10	---
12	Aquatic macrophyte cover factor stranding	N	9,10	---
13	Elevation of stranding area (feet NAVD 88)	Y	---	---
14	Hourly water surface elevation (feet NAVD 88)	N	---	Y
15	Inundation and dewatering, stranding	N	13	Y

Notes:
HRM – hydraulic routing model
GIS – geographic information system

4.3.9.4. Hydraulic Routing Model Integration

The hydraulic routing model 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 hydraulic routing model will be run for each operations scenario, which will result in development of a set of the hourly water surface elevations associated with each scenario.

The hydraulic routing model includes nearly 200 cross sections in the Box Canyon Dam to Boundary Dam portion of the study area. The typical spacing between cross sections is 300 to 800 feet. The hydraulic routing model for the portion of the study area from Boundary Dam to Red Bird Creek has not been completed as of January 2008, but it will have similar spatial resolution as the portion between Box Canyon Dam and the Boundary Dam. The hydraulic routing model will calculate the water surface elevation at each of these cross sections for each hourly time interval. The water surface elevations at a cross section will provide the estimate of the water surface elevation at adjacent stranding and trapping areas. Because of the relatively flat gradient of the study reach and the close spacing of transects, the water surface elevation will typically vary by less than 0.2 foot between adjacent transects. In the most extreme cases (e.g., very low flows and the upper 2 miles of the study area just downstream of Box Canyon Dam), the typical water surface elevation difference between cross sections, at a given hourly time interval, will be less than 0.4 foot. Therefore, the elevations at the cross sections are applied directly to the adjacent stranding and trapping areas without need for interpolation.

The hourly water surface elevations from the hydraulic routing model will be 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.

4.3.9.4.1. Stranding

As presented in Section 4.3.9.2, the stranding areas identified from the bathymetry using GIS will be divided into zones of 1-foot elevation increments. The 1-foot increments will be set at even feet. The elevation chosen to represent a stranding zone will be 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) 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) will be compared against the water surface elevation from the nearest cross section 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 1983 feet NGVD 29) will be 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 will be considered to be dewatered.

The longitudinal extent of the stranding zones will be divided at the midpoint between cross sections (Figure 4.3-10 – plan view). As shown in this figure, a cross section (e.g., cross section 2) will be used to represent the water surface elevation for the portion of stranding zones located from halfway to the next cross section downstream (e.g., cross section 1) to halfway to the next cross section upstream (e.g., cross section 3). Thus the difference in elevation between the portion of the stranding zone at the cross section and the furthest points within the zone upstream and downstream of the cross section will be half the water surface elevation difference between cross sections (Figure 4.3-10 – profile view). Therefore the error introduced by using the cross section water surface elevation to represent even the furthest portions of the stranding zone from the cross section will typically be on the order of 0.1 foot or less and in the most extremes cases on the order of 0.2 foot or less.

In performing the calculation of the stranding index, the area within each stranding elevation zone associated with a cross section, the area weighted cover factor for stranding and the representative elevation for each zone will be tabulated. For each hourly time increment, the hourly elevation from the hydraulic routing model for the representative cross section will be compared against the midpoint elevations for each stranding zone to determine which stranding zones become dewatered during the current time increment. When the hydraulic routing model 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 only calculated 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 since 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 4.3-12 summarizes the four possible combinations of current and previous dewatering and inundation conditions and action the stranding modeling procedure takes.

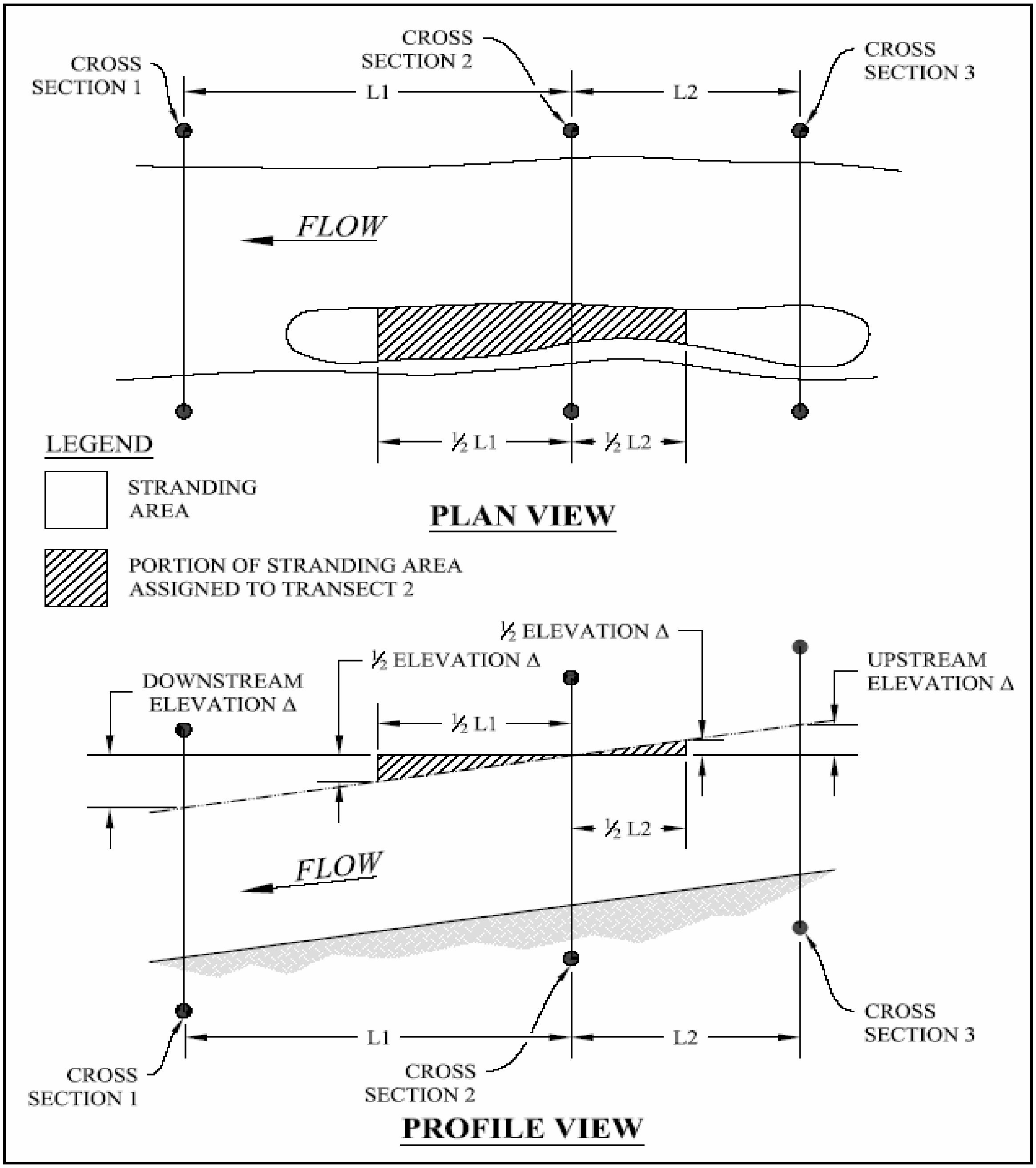


Figure 4.3-10. Conceptual sketch of relationship between trapping areas and water surface elevations represented by specific cross sections in the hydraulic routing model.

Table 4.3-12. 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

4.3.9.4.2. Trapping

As presented in Section 4.3.9.1, the trapping areas will be identified from the bathymetry using GIS tools. The effective outlet elevation will be set at either 0.5 foot or 0.1 foot above the outlet invert of the trapping area based on the presence or absence of macrophytes, respectively. Each trapping area will be assigned a cross section from the hydraulic routing model to determine the hourly water surface elevations adjacent to the trapping area. Trapping areas will be assigned to the cross section closest to their outlets. Therefore each hydraulic routing model cross section will be used to represent the water surface elevation for the all trapping areas with outlets located from halfway to the next cross section downstream to halfway to the next cross section upstream. As is the case for stranding, the typical maximum error introduced by using the cross section water surface elevation to represent even the furthest trapping areas from the cross section will be on the order of 0.1 foot or less and in the most extremes cases on the order of 0.2 foot or less.

For each trapping area associated with a cross section, the area, effective outlet elevation, maximum depth, contributing basin factor and cover factor will be tabulated. For each hourly time increment, the hourly elevation from the hydraulic routing model for the representative cross section will be compared against the effective outlet elevation for each trapping area zone to determine whether a trapping area 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 area 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 area, 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 is 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 then added to the previously summed trapping index value for the given trapping area. Table 4.3-13 summarizes the four possible combinations of current and previous disconnected and connected conditions and what action the trapping modeling procedure takes.

Table 4.3-13. 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.

4.3.10. Varial Zone Model

The varial zone analysis will involve development and 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 will allow comparison, between operations scenarios for the Project, on habitat suitability within the varial zone. The analysis will cover the range of conditions encountered for operations scenario and be performed for key biota of interest which consist of macrophytes, periphyton, and BMI.

This section presents the analytical procedures to be utilized in developing the indices to evaluate habitat suitability within the varial zone associated with operations scenarios. The methods to perform the field investigations and develop basic HSC are presented in Sections 4.2, 4.3, and 4.4 and their associated appendices. The general approach was presented to the relicensing participants and agreed upon at the July 24, 2007 Fish and Aquatics Workgroup meeting in Spokane.

4.3.10.1. General

The varial zone is defined as the areas of the channel alternately inundated and dewatered by water surface elevation fluctuations. Figure 4.3-11 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 since 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 4.3-12 illustrates the elevation limits of the varial zone analysis within a transect.

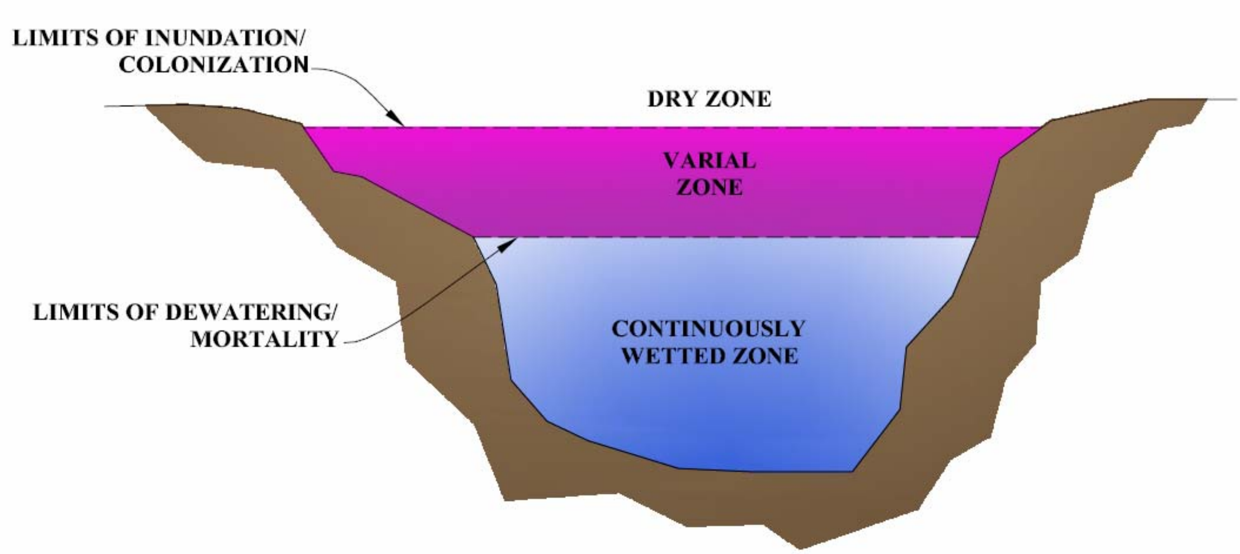


Figure 4.3-11. Conceptual sketch of varial zone definition.

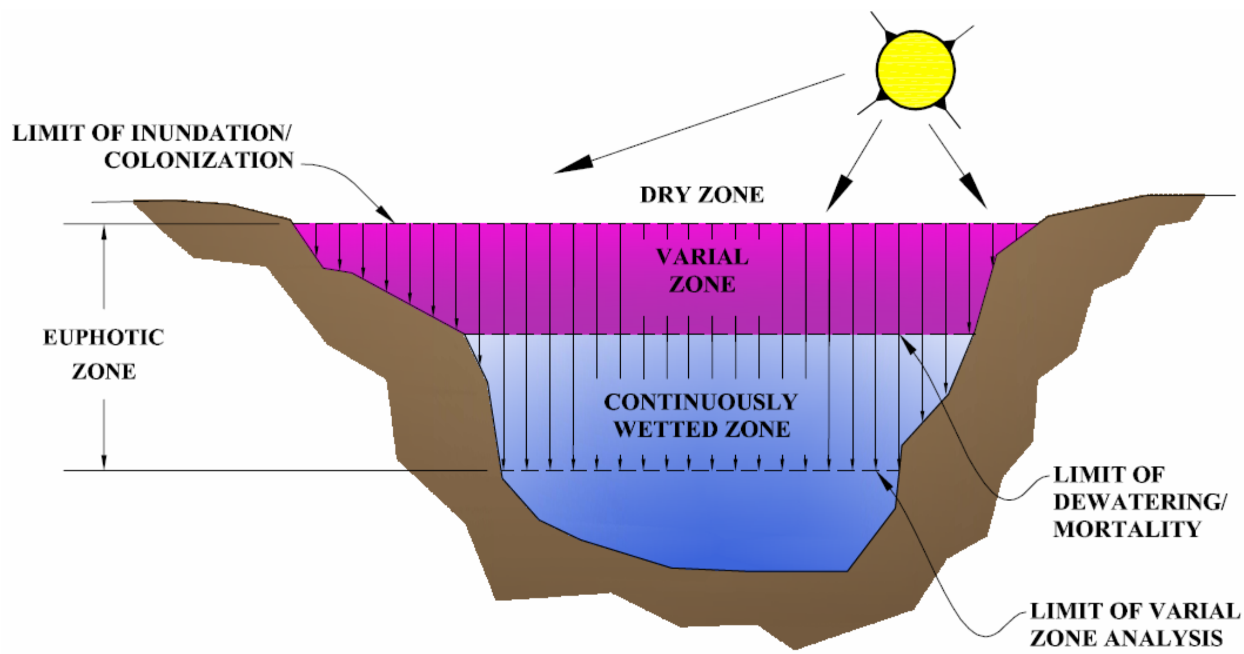


Figure 4.3-12. Conceptual sketch of varial zone analysis limits based on depth of euphotic zone.

4.3.10.1.1. Integration with Hydraulic Routing Model

The water surface elevation fluctuations within the varial zone are dependent on three factors: Project operations, location within the Project, and upstream inflows (outflow from Box Canyon Dam). Figures 4.3-13 and 4.3-14 present historic reservoir elevations for selected periods in the Boundary forebay that provide examples of these influences. In Figure 4.3-13, 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 4.3-13) was for a relatively low flow period, whereas the information for the May and June period in 2003 (Figure 4.3-14) 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 into the mid-1980s and lower; however, at high flows (May 2003) the fluctuations created in the forebay from existing Project operations are greatly reduced upstream at the USGS gage below Box Canyon Dam. The flows rose above approximately 50,000 cfs and existing Project operations 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.

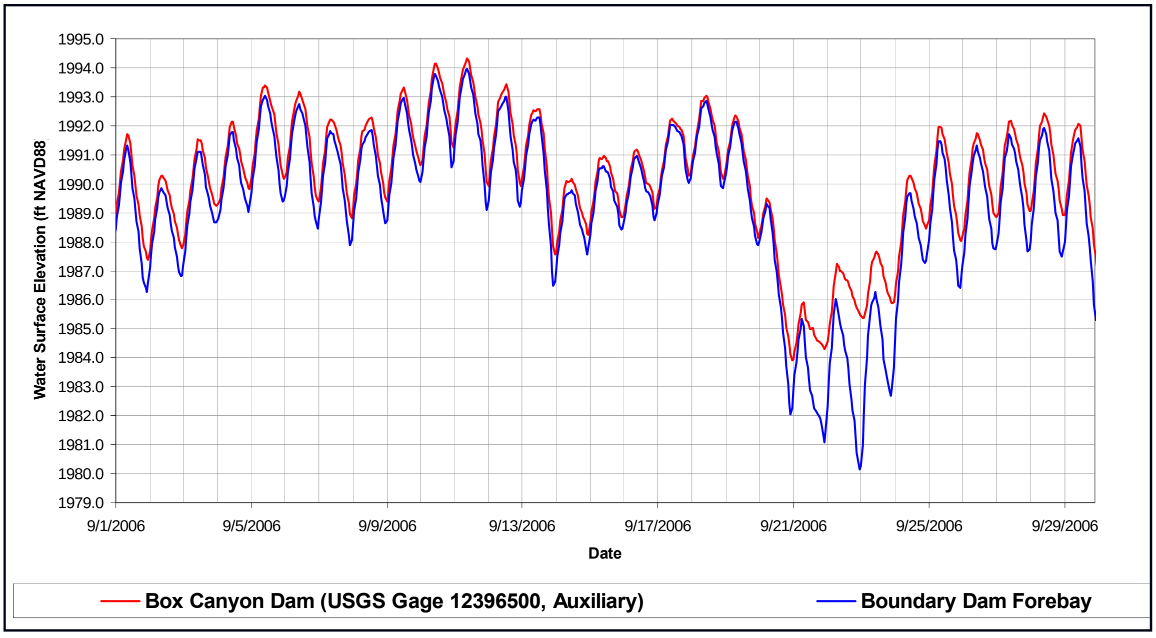


Figure 4.3-13. Example water surface elevation fluctuations below Box Canyon Dam and Boundary forebay, September 2006.

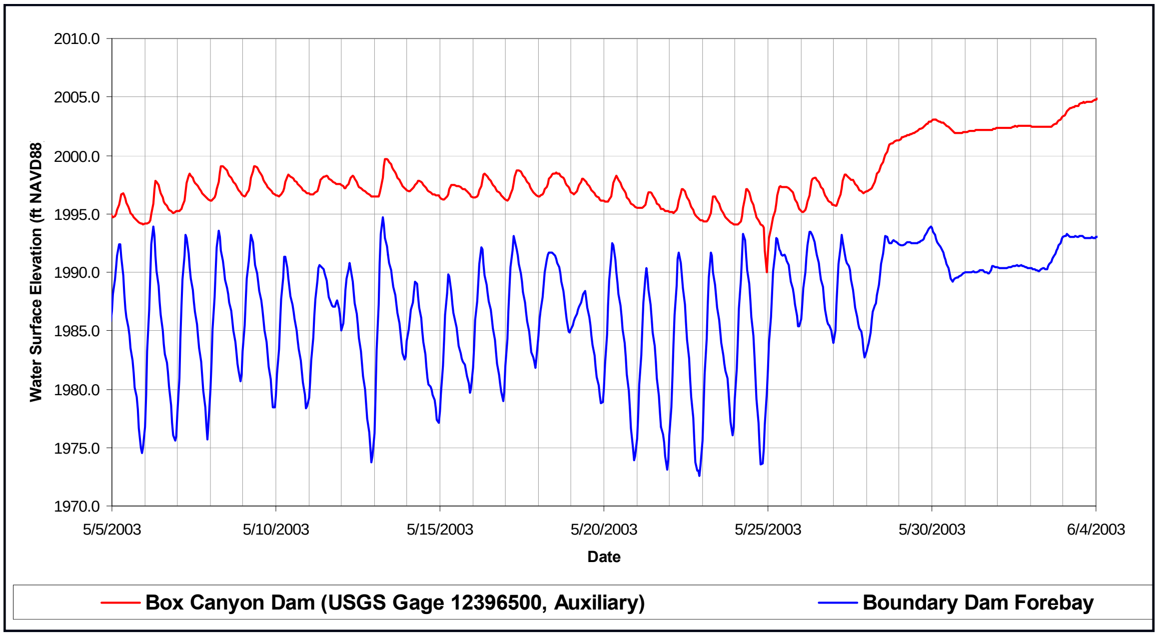


Figure 4.3-14. Example water surface elevation fluctuations below Box Canyon Dam and Boundary forebay, early May though early June 2003.

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 hydraulic routing model and will be 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.

4.3.10.1.2. 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 is 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 the biota of interest (macrophytes, periphyton, and BMI) are presented in Section 4.4 and the associated appendices.

The composite suitability index 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 4.3-15 and 4.3-16 provide conceptual examples of the DI and DD HSI curves.

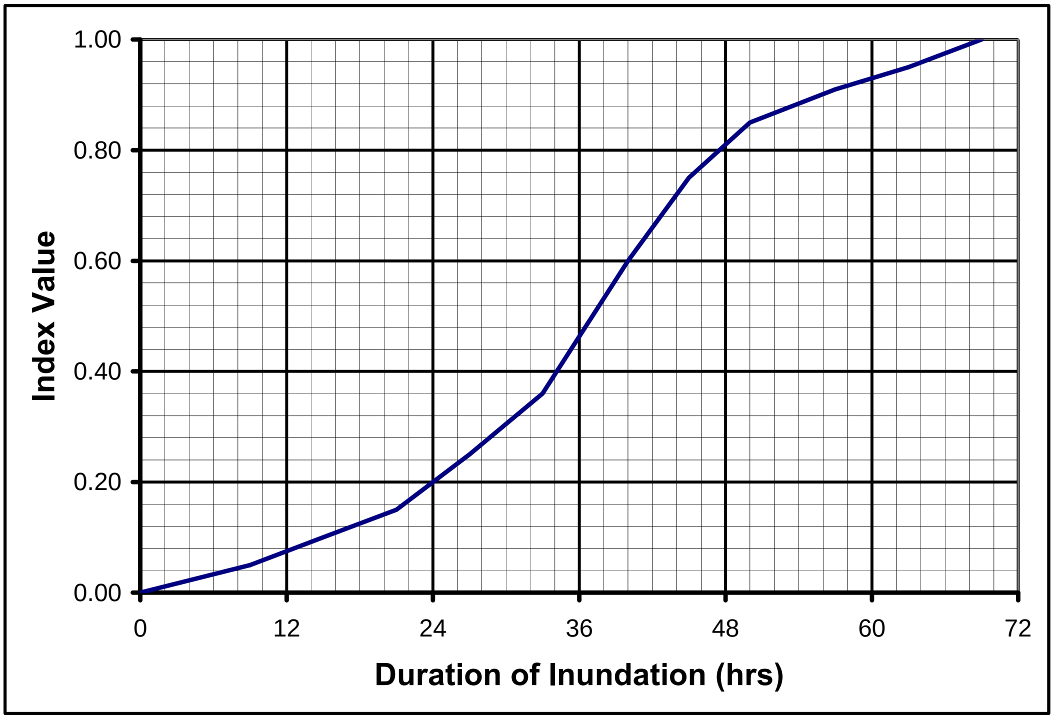


Figure 4.3-15. Conceptual example of DI HSI curve for calculation CSI in the varial zone analysis.

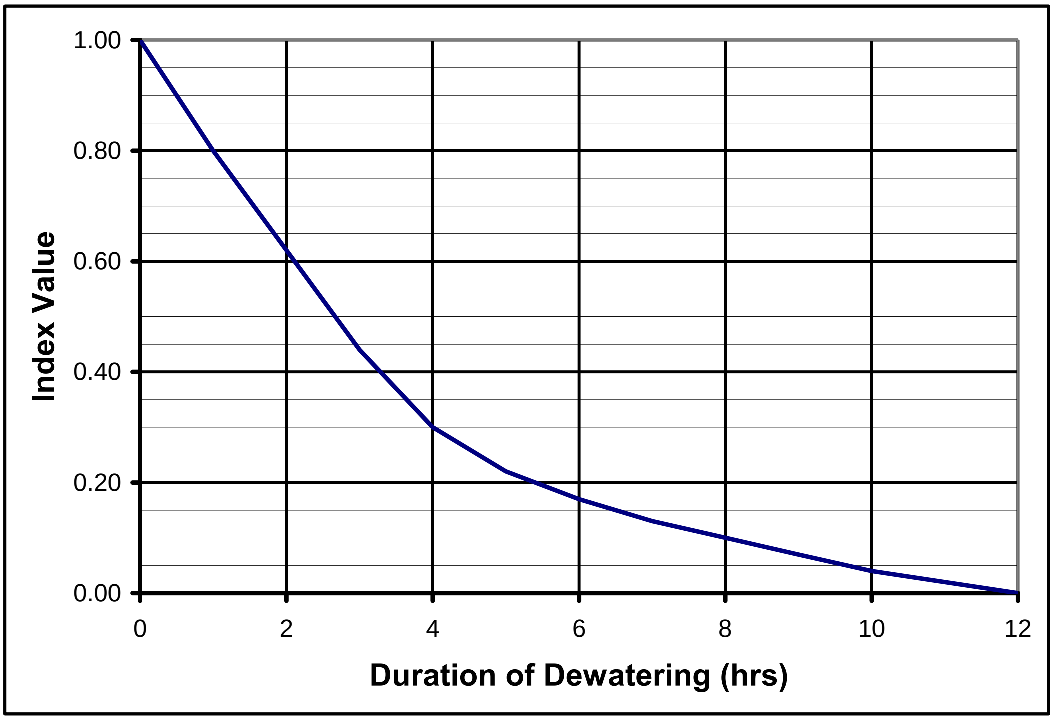


Figure 4.3-16. Conceptual example of DD HSI curve for calculation CSI in the varial zone analysis.

4.3.10.2. Composite Suitability Index 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 4.3-15 and 4.3-16. Table 4.3-14 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 4.3-15 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 4.3-14. 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 1/2 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 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 4.3-15. 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*

Step 1 – Depth, velocity, and substrate

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.

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 4.3-15.

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 4.3-15, 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.

<u>Step 5a – Look up HSI value for inundated state of cell</u>
The example problem is entered on the 25th time step at a depth of 5 feet and an 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 4.3-17. 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 4.3-17 and the resulting HSI_i values are tracked in Table 4.3-15. 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.

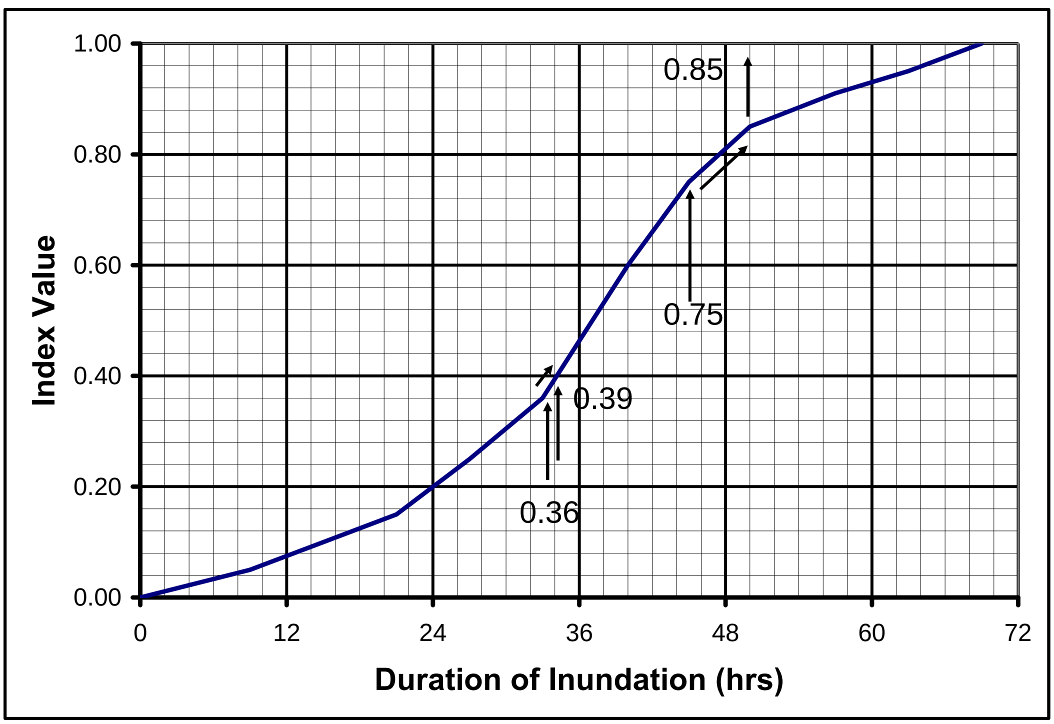


Figure 4.3-17. Illustration of use of DI HSI curve for determination of HSI during the periods of inundation in the CSI example calculation.

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 hours. 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 4.3-18.

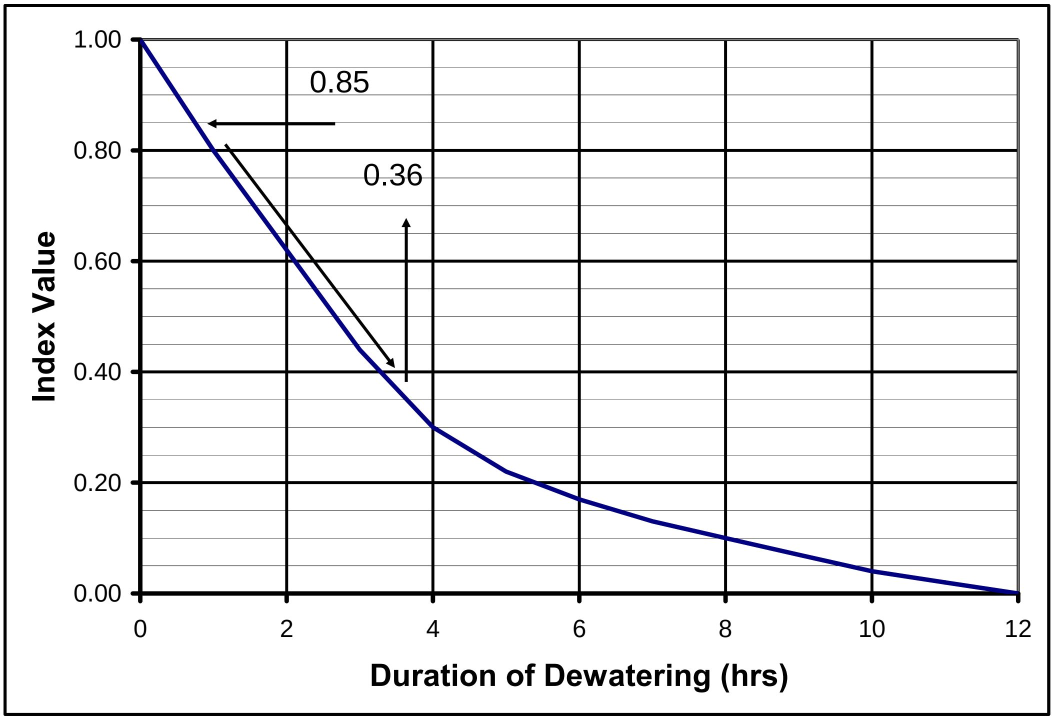


Figure 4.3-18. Illustration of use of DD HSI curve for determination of HSI during the period of dewatering in the CSI example calculation.

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.

<u>Steps 8 through 14 – Iteration steps to obtain weighted CSI transect, reach and study area</u>
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 transect CSI is multiplied by half the distance to the next upstream transect and half the 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; or it could be a series of years in the hydrologic record; or it could be 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 are a (WUA).

The steps presented above can be performed for each of the three biota of interest for the varial zone: macrophytes, periphyton, and BMI. Since each set of calculations use the same set of information, except for the specific HSI and HSC curves, the calculations can be performed together. It would also be possible to incorporate the WUA calculations for the fish species and lifestages of interest during the same computational sequence; however, the WUA calculation for fish is simpler because the history of inundation and dewatering for each cell does not need to be tracked. The lack of the need to track the history of inundation and dewatering by cell allows for the fish-related WUA to be calculated using the look up table procedure described in the Section 4.3.11. Conversely, the need to track the history of inundation and dewatering prevents the application of the look up table approach for calculation of the WUA for the varial zone biota of interest.

4.3.11. Weighted Usable Area

WUA is a habitat index in relation to discharge that provides an estimate of both the quantity and quality of available species-specific habitat, which is then used to compare the effects of 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 HSC developed specifically for a particular life stage of a particular fish species. The WUA is the product of the respective suitabilities 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 Φ), since it is a dimensionless value that does not represent true area (Payne 2007). However, the original conceptualization of weighted usable area is retained in this section for consistency with the literature.

This section describes two potential procedures that will be used in the determination of WUA for fish species of interest. The procedures used to determine WUA for periphyton, macrophytes, and benthic invertebrates were described previously in Section 4.3.10.

4.3.11.1. Look Up Table Procedure

The first procedure uses a set of transect specific look up tables of WUA_T values computed for a specific water surface elevation and a defined range of flow rates as the basis to determine the habitat index values for each hourly increment for each habitat transect. Table 4.3-16 is an example of such a look up table for adult rainbow trout. The calibrated PHABSIM model would be used along with the calibrated HEC-RAS hydraulic routing model to generate the WUA_T values in the look up tables. The WUA_T index values represent width and length-weighted habitat index values specific to the transect and hydraulic conditions in the table as computed in the two equations below:

$$WUA_i = D_i * Vo_i * S_i$$

Where:

WUA_i = composite habitat suitability of cell i
D_i = HSC suitability associated with depth in cell i
Vo_i = HSC suitability associated with velocity in cell i
S_i = HSC 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
L_i = length of cell i
WUA_T = width weighted aggregate habitat suitability for the transect

The cell-specific suitability values (D_i, Vo_i, and S_i) are obtained from the HSC curves for the particular life stage and fish species. The individual HSC curves are presented in Appendix 1 of this interim study report.

For the analysis of habitat conditions for a particular operations scenario, the HEC-RAS hydraulic routing model would be executed and hourly time series of water surface elevations and flow rates would be generated. For each hour, the look up tables would be used to determine the width and length-weighted habitat index value (WUA_T) for each transect and for each life stage of each fish species. Accessing the look up tables would require linear interpolation in those instances when the water surface elevation and flow rate for a particular hour are not identical to the bounding hydraulic conditions used to develop the look up table.

Table 4.3-16. Example WUA_T look up table for range of discharges and water surface elevations using depth and velocity data from Habitat Transect U-2 and adult rainbow trout HSC.

Simulated Discharge (cfs)	Simulated Water Surface Elevation (feet NAVD 88)									
	1980.0	1982.0	1984.0	1986.0	1988.0	1990.0	1992.0	1994.0	1996.0	1998.0
4,000	443,555	443,699	446,478	450,607	455,890	463,494	469,086	472,117	475,056	478,598
6,000	460,104	466,354	473,874	480,970	487,928	495,690	500,263	501,934	503,544	505,907
8,000	464,667	471,705	480,841	490,488	500,431	511,720	519,635	524,102	527,722	531,258
10,000	467,298	474,590	484,058	494,009	504,430	516,614	526,189	532,757	538,620	544,323
12,000	468,484	475,948	485,683	496,018	506,910	519,539	529,463	536,454	542,936	549,731
14,000	468,991	476,592	486,565	497,221	508,303	521,216	531,385	538,608	545,319	552,342
16,000	469,270	476,836	486,968	497,715	509,042	522,164	532,499	539,937	546,803	554,083
18,000	469,171	476,996	487,284	498,088	509,519	522,730	533,155	540,783	547,761	555,204
20,000	464,775	476,763	487,561	498,462	509,890	523,197	533,675	541,366	548,339	555,952
22,000	433,452	471,995	487,255	498,745	510,256	523,665	534,195	541,856	548,866	556,549
24,000	391,135	442,982	481,769	498,410	510,623	524,132	534,715	542,345	549,392	557,058
26,000	354,364	404,493	455,783	492,247	510,289	524,561	535,206	542,835	549,918	557,564
28,000	317,575	368,486	419,758	469,552	503,659	523,976	535,561	543,270	550,441	558,071
30,000	285,040	335,320	384,898	435,890	483,833	517,296	534,649	543,545	550,867	558,536
35,000	226,432	265,046	311,871	361,531	407,227	456,660	500,179	530,273	547,377	558,388
40,000	178,951	215,340	254,232	296,430	344,002	392,816	433,198	473,256	510,071	540,273
45,000	135,962	171,166	208,797	246,236	285,156	330,707	375,232	414,547	450,544	488,286
50,000	105,369	131,147	167,393	205,515	242,067	280,156	318,178	357,346	396,833	432,156
55,000	81,959	102,415	130,918	166,627	205,525	243,616	277,725	309,457	345,199	382,291
60,000	67,388	81,468	104,788	133,575	169,475	208,965	243,337	273,201	302,899	335,602
65,000	56,765	67,041	85,614	110,520	139,068	174,601	208,738	238,922	267,273	295,014
70,000	48,979	57,128	71,579	92,715	117,110	145,527	176,134	205,281	233,974	260,989
75,000	43,179	49,301	61,152	77,962	98,979	125,321	149,076	174,677	202,551	230,483
80,000	37,960	42,761	53,638	66,469	84,408	107,108	129,208	150,271	174,799	201,773
85,000	32,763	37,211	47,807	58,291	73,769	92,452	112,164	131,355	151,513	175,613

Notes:
Individual values of WUA_T are example values only used only for illustrating the methodology.
Individual values of WUA_T represent width and length weighted habitat index values for habitat transect U-2 and are expressed in units of square feet (sf).

This results in a weighted usable area for the transect (WUA_T) for the hourly time interval. This process is repeated for all hours in the simulation, resulting in WUA_T values for each hourly time interval for all transects. The resulting WUA_T values would then be summed for each time period of interest. The time period of interest could be a year representing a specific hydrologic condition such as wet, dry, or average; or it could be a series of years in the hydrologic record; or it could be a particular season for all years. The final step would be to sum the individual WUA_T values first by reach (Upper, Canyon, Forebay and Tailrace) to develop the weighted usable area of the reach (WUA_R), and to sum the reach values to produce the overall weighted usable area for the entire reservoir or tailrace study area (WUA_O).

4.3.11.2. Alternative Procedure

An alternative approach to using look up tables is to use a methodology similar to that which was described in Section 4.3.10 (Varial Zone Analysis). Instead of first developing look up tables, the alternate approach would preserve the hourly velocity, depth, and substrate values and use them in the determination of the cell based HSI values.

For this alternative procedure, the analysis of habitat conditions for a particular operations scenario would begin with the execution of the HEC-RAS model to generate hourly time series of water surface elevations and flow rates. This model output would then be used as input to the calibrated PHABSIM model. The PHABSIM model would then be executed in batch mode for each transect to generate WUA_T values at each hour. The computed WUA_T values would be based on the exact hydraulic conditions predicted by the HEC-RAS model. Once the hourly WUA_T values were determined, then the remainder of the procedure to determine the WUA_R and WUA_O values would be identical to that described in the previous subsection.

4.3.12. Post-Processing

The mainstem habitat modeling effort involves collection of data, analysis of data, development of a variety of models, and application of these models to quantify effects of operations scenarios. The foundation on which these models are based includes two components:

1. Application of the Scenario Tool to provide hourly Boundary Project forebay water surface elevations and Project outflows for each operations scenario, and
2. Execution of the hydraulic routing model to determine the hourly water surface elevations and flow rates throughout the study area.

For two of the analyses, downramping analysis (Section 4.3.8), and stranding and trapping (Section 4.3.9), the hourly water surface elevations and flow rates throughout the study area are sufficient to provide the input to the models used to assess the effects of the operations scenarios for these areas of interest. However, for the varial zone analysis (Section 4.3.10) and the weighted useable area (Section 4.3.11), these models require determination of hydraulic conditions (i.e., velocity and depth) at discrete cells across the channel. To accomplish this, the distribution of velocities across the habitat transects are determined using hydraulic model results that are calibrated to reproduce the depth and velocity measurements conducted during the habitat transect measurements effort (Section 4.3.4).

It is the hydraulic information, represented by either water surface elevations and flow rates or velocity and depth distributions across a transect, along with other characteristics describing the physical habitat conditions, that will be post-processed in the suite of mainstem habitat modeling efforts to produce the indices used to evaluate the effects of operations scenarios. Descriptions of the specific analysis and modeling efforts to be conducted to post-process the information are provided in Sections 4.3.8 through 4.3.11. The modeling efforts that will be conducted, referenced to the appropriate report section, are listed below:

- Determination of downramping rates (4.3.8)
- Identification of critical downramping rate (4.3.8)

- Macrophyte composite suitability index and WUA (4.3.9)
- Periphyton composite suitability index and WUA (4.3.9)
- BMI composite suitability index and WUA (4.3.9)
- Fish stranding and trapping (4.3.10)
- WUA for fish species and lifestages of interest (4.3.11)

The sections identified above should be consulted for the specifics on the modeling efforts that will be used to post-process the results of the hydraulic routing model, transect cell velocity distributions and physical habitat characteristics. The post-processing will produce the indices and other information used to identify the effects of operations scenarios on mainstem aquatic habitats.

Though these various modeling efforts may differ in their formulation, there are some common elements within the post-processing efforts. First, each operations scenario will require application of the Scenario Tool and the hydraulic routing model to determine the hourly water surface elevation, flow rates and hydraulic conditions associated with the scenario. The first scenario evaluated will represent existing conditions. After the Scenario Tool and hydraulic routing model are applied, the results will be post-processed using the suite of models developed to describe various mainstem aquatic habitats. The operations scenarios will be run through the post-processing models to establish base conditions that will allow for comparing the effects of existing Project operations to the effects of operations scenarios. Each indicator of environmental effect will be tallied separately, and the relative effects of operations scenarios on various aquatic resources may be determined.

4.4. Habitat Suitability Indices Development

HSIs are in the process of being developed for four biological components: fish (Section 4.4.1), macrophytes (Section 4.4.2), periphyton (Section 4.4.3), and BMI (Section 4.4.4). Each effort is following a similar general approach in developing the HSIs, which includes a literature search for available information, conducting field studies to supplement literature-based information and to provide site-specific data, and use of a panel of relicensing participants to finalize HSI curves. The initial development of literature-based HSI curves has been performed while the field studies and relicensing panel review are underway.

4.4.1. Fish HSI

Fish HSI variables are 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 are developed for each species and each life stage that are selected to represent the fish community in the Project area. The HSI variables are 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. This information will be used to evaluate the effects of operations scenarios on fish habitat. Effects on fish habitat are then implied to exert effects on the fish populations themselves.

The principal HSI variables will describe the relative suitability of water depth, mean column water velocity, and bottom substrate type, for each target species and life stage. Additional physical habitat parameters that are being collected include instream cover, presence of velocity shear zones, and distance to bank. Additional analysis will determine if, and how, any of these additional variables can be used to model fish habitat in the project area. An additional component of fish HSI is periodicity, which describes the time periods when each target species and life stage is present in the project area.

Interim fish HSI and periodicity dates were developed using a combination of literature-based information and site-specific data collection, and will be reviewed and finalized by consensus from a panel of HSI experts. Periodicity information based on literature and site-specific information is supplied as part of Appendix 1. This section will simply summarize the detailed information provided in Appendix 1 relating to both Fish HSI and periodicity.

4.4.1.1. Develop Draft HSI Curves

Draft interim HSI were developed for spawning, fry, juvenile, and adult life stages of target species including bull trout, cutthroat trout, rainbow/redband trout, mountain whitefish, and smallmouth bass. It should be noted, however, that some of these species/life stages are not known to occur in Boundary Reservoir, such as the spawning life stage for bull trout and cutthroat trout, and all life stages of redband trout; consequently these life stages are proposed for fish habitat modeling in the Boundary tailrace, but not within the reservoir habitat. In addition to the target species listed above, interim HSI were also developed to represent forage fish species that are utilized by larger gamefish. The original forage species in the RSP was redside shiner. Following meetings with relicensing participants the forage target species 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 Variances and Modifications (Section 7.2.4.1). Interim suitability curves have been developed to represent the suitability of depth and mean column velocity, but HSI have not yet been completed for substrate or any other habitat attributes. HSI curves for substrate and/or other habitat attributes will be evaluated and potentially incorporated into the HSI analysis at a future date.

Draft interim 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 (Appendix 1a). For juvenile and adult 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.

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 Boundary study area, and those data were also plotted with the literature-based HSI curves in order to better assess probable suitability for target species in the Project area. Draft interim HSI curves have been plotted on the common figure to serve as a placeholder Boundary curve until the suite of interim HSI curves are discussed and finalized by an HSI workgroup.

4.4.1.2. Develop a Periodicity Table

Interim periodicity tables were developed for target species to describe the temporal periods when each target species and life stage is expected to occur in the Project area. Additional periodicity dates were also developed for non-target 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 (SCL 2008f) electrofishing surveys or fish stranding surveys. Periodicity dates from literature sources were plotted together along a common timeline, then site-specific fish captures were added to the timeline. Interim periodicities for each species and life stage were then visually estimated by giving greater weight to site-specific 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 Boundary Reservoir (as of October 2007 sampling) and the dates were adjusted accordingly. Additional details and assumptions regarding the methods used to develop the interim periodicity tables can be found in Appendix 1b.

The site-specific data include information collected from the regular distribution and abundance sampling (Study 9, SCL 2008f) and the stranding and trapping study included in this report. Results from the Stranding and Trapping Field Surveys were used to help refine species periodicity dates for fish in the Project area. Observations of target species and life stages were plotted on a timeline with literature-based periodicities, and with other site-specific observations (from electrofishing in Study 9 [SCL 2008f]), to develop interim periodicity dates for those species.

The interim periodicity dates reported in this document are expected to be revised as additional site-specific data are acquired and with the addition of new literature information. These interim dates will then be reviewed by a panel of relicensing participants for the purpose of finalizing the periodicity tables.

During 2008 additional information on early life stages of target species will be obtained from shoreline backpack electrofishing (see Study 9 recommendations [SCL 2008f]). In this way some of the earliest young-of-the-year occurrence data may be improved. Additional data will be obtained from the ongoing stranding and trapping studies that would occur from February into late summer on early life stages. Also efforts at examining smallmouth bass spawning habitat will occur in 2008 that will augment available information on spawning periods for this target species. Standard fish distribution and abundance sampling that occurs monthly will also provide additional periodicity data.

4.4.1.3. Site-Specific Habitat Utilization Data

Site-specific HSI data have been collected in the Boundary project area using biotelemetry for adult target species, and boat electrofishing for fry, juvenile, and adult target species. It was expected that biotelemetry would provide the least biased HSI information for adult fish, since efficient electrofishing is restricted to shallow, nearshore locations. The data specifically collected to develop HSI were acquired in concert with the ongoing biotelemetry and electrofishing studies. Refer to the Study 9 interim report (SCL 2008f) for the specific methods used to collect measurements of depth, mean column water velocity, substrate type, cover type, and other potential variables.

The site-specific HSI data collected by boat electrofishing or biotelemetry studies were expected to be combined with the literature-based HSI curves for developing the draft interim HSI curves. This interim report contains site-specific HSI data collected from March through September 2007; however, additional site-specific data are anticipated to result from continued sampling through 2008. All new site-specific HSI data will be added to the draft interim HSI curves prior to review by the expert panel. If sufficient site-specific data were collected in the Boundary Project area, new site-specific HSI curves may be possible. A generally accepted "rule of thumb" is that 150 to 200 site-specific observations of habitat use by a target species and life stage are usually needed to construct new and robust HSI curves (Bovee 1986). Consequently, new HSI curves are only proposed to be created for those target species and life stages that have a minimum of 150 observations and show a biologically realistic distribution of utilization for depths, velocities, and substrate. Even for those species with abundant site-specific data, subjective decisions regarding habitat suitability will be 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 do not meet the sample size or distribution criteria, the existing site-specific data will be used to select or modify an existing HSI curve from among the literature-based curves described in Appendix 1, or to modify the interim Boundary curve through consensus among the relicensing participants (see Section 4.4.1.4).

In addition to the habitat utilization data collected at fish capture or relocation sites, habitat availability data have also been collected to represent the physical habitat where electrofishing studies were conducted. This habitat availability data may be used to "adjust" the site-specific habitat utilization data to better account for differences in sampling effort among habitat types. For the biotelemetry study, habitat availability information was not collected due to the potential use of the entire project area by the tagged fish. If adjustment of biotelemetry-based utilization data is desired, habitat availability data may be derived from the Physical Habitat Model Development.

At this time, specific habitat utilization histograms have not been developed. The need for these will be examined when additional site-specific data are collected.

As noted in the 2008 recommendation in Study 9 (SCL 2008f) and in the current document recommendations (Section 7.2.4.1), some changes would occur in the data collection methods and periods in 2008. The recommendations include eliminating collection of HSC data during electrofishing in early 2008 and elimination of collection of velocity measurements from biotelemetry tracking of adult size target species. Study 9 (SCL 2008f) supplies the background information for the boat electrofishing HSC and the results of this study discuss the problems with biotelemetry velocity measurement.

4.4.1.4. Relicensing Participant and Expert Panel

A panel of biologists knowledgeable on the target species, local fish populations, and habitat modeling methodologies will be convened in the spring of 2008 to review the interim HSI and periodicity information and to finalize the input data for the physical habitat model. Interim HSI and periodicity tables for each species and life stage will be presented to the panel with the underlying literature-based and the site-specific data to be reviewed and discussed for the purpose of reaching consensus on HSI curves and periodicity dates.

4.4.2. Macrophyte HSI

Macrophytes are included in the mainstem aquatic habitat model in the form of HSC and HSI to estimate aquatic macrophyte productivity for various reservoir management scenarios. Provisional literature-based HSC and HSI have been developed that will describe the response of macrophytes to cyclic inundation and dewatering that may change physical parameters that the macrophytes are exposed to, such as water depth, water velocity, and light. These literature-based HSC and HSI will be supplemented by site-specific information developed through field studies described in the Interim Report for Study 7 Methods Section 4. This report describes data collected through field studies conducted from June through August 2007.

In order to assess the impact of operations scenarios on the growth and distribution of macrophytes within Boundary Reservoir, literature-based HSI models (curves) were developed and will be field validated. These curves will then be used in the Mainstem Aquatic Habitat and Tributary Delta Aquatic Habitat modeling to evaluate the potential distribution of macrophytes for operations scenarios.

First, a literature review was conducted to develop HSI curves for macrophyte growth within the Pend Oreille River. HSI curves were developed for macrophyte growth as a function of depth, velocity, substrate, and the duration of inundation and dewatering (rates of macrophyte colonization and dewatering mortality).

Second, field surveys were conducted of aquatic plant distribution and abundance data at various depths, velocities, and substrate type extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions. Field surveys consisted of measurements of macrophyte abundance, depth, velocity, substrate, and the reservoir routing model will provide duration of inundation and dewatering data.

Finally, literature-based information from the first task and field data from the second task will be used to validate HSI curves for depth, velocity, substrate, and duration of inundation and dewatering as a function of macrophyte abundance.

4.4.2.1. Literature-Based Macrophyte HSI Curves

An extensive literature review was conducted to compile existing information on macrophyte ecology and habitat requirements to develop seasonal periodicity and habitat requirements for macrophytes within the Pend Oreille River. HSI curves were developed for macrophyte growth as a function of depth, velocity, substrate, and duration of inundation and dewatering (rates of macrophyte colonization and dewatering mortality). Literature-based HSI curves were then developed to address habitat conditions expected to exist in Boundary Reservoir. Further details of the HSI development methodology is outlined in the literature-based HSI portion of the Macrophyte HSI Interim Report (Appendix 2).

4.4.2.2. Aquatic Plant Field Surveys

Field surveys were conducted to assess aquatic plant distribution and abundance data within Boundary Reservoir. Measurement of macrophyte abundance and macrophyte mapping surveys were conducted in August during peak macrophyte growth. The entire shoreline of Boundary Reservoir 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 100 meters along the outside of the beds. Enough points were taken to clearly define the limits of each macrophyte bed present. At each GPS point within the beds, plant species present and the respective percent cover were recorded. If dewatered and dry macrophytes were encountered, the species were identified and the respective percent cover was estimated.

4.4.2.3. Validate HSI Curves for Depth, Velocity, Substrate, and Frequency of Inundation

Field surveys were also conducted to assess existing habitat conditions in macrophyte beds within Boundary Reservoir. Measurements of depth, velocity, and substrate types extending to the depth of the euphotic zone in established macrophyte beds exposed to a range of inundation and dewatering conditions were collected. Macrophyte HSI study sites were selected based on the habitat mapping, presence of macrophytes, and representativeness of the study reach.

Literature-based information from the HSI development and the field data will be used to validate HSI curves for depth, velocity, substrate, and duration of inundation and dewatering as a function of macrophyte abundance. This will be conducted through the development of a histogram (i.e., bar chart) for each of the habitat parameters (e.g., depth, velocity, substrate, frequency of inundation and dewatering) using the site-specific field observations. A histogram developed using field observations will then be compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve 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, for existing Project operation and Pend Oreille River hydrology, had been colonized by aquatic macrophytes within the Boundary Reservoir. Measurements of macrophyte density in these areas will then be correlated to the duration of inundation and dewatering associated with antecedent Project operations. This portion of Study 7.4.2 will be conducted in 2008.

4.4.2.4. Develop HSI Information for pH and Dissolved Oxygen

High pH levels have been documented throughout the Pend Oreille River and in Boundary Reservoir (Ecology 2005, SCL 2006). The specific cause of these high pH levels has not been investigated prior to this study, but both background geologic conditions and the growth of macrophytes have been suggested as contributing factors. The geochemical makeup of the Pend Oreille River basin, and specifically within the reservoir wetted area of Boundary Reservoir, includes exposed deposits of limestone and other calcium carbonate-bearing rock, which tends to buffer the acidity of the water toward an alkaline condition. Study 6 (SCL 2008d) established the following goals to: 1) assess whether macrophytes are contributing to high pH and low dissolved oxygen (DO) readings in Boundary Reservoir, and 2) investigate potential indirect effects of existing Project operations on pH and DO via macrophytes.

Macrophyte study sites were established in select beds: upstream, in bed (i.e., low, medium, and high density), and downstream. The sampling locations were initially selected as part of a site review using aerial photography (DeGross 2005) and confirmed based on site visits during July and August 2007. The RSP indicated that there would be six potential macrophyte monitoring locations (M1-M6). After the site visit in July 2007, it was determined that macrophyte growth in the Lower Reservoir was limited and site M3 was not to be included in the sampling efforts. Following the site visit in August 2007, sites M1 and M2 were relocated to areas of sufficient macrophyte growth.

Continuous water quality monitoring occurred at site M6, approximately 0.75 mile upstream from Lost Creek on the east bank. A Hydrolab MS5 was attached 1 meter beneath a buoy containing a radio telemetry system at three locations within M6: upstream, downstream, and within the macrophyte bed. Calibration and sampling were performed per manufacturer specifications and distributor configuration. In situ water quality data (temperature, pH, DO, and conductivity) were measured every 15 minutes through the data collection period of June through November 2007.

4.4.2.5. Confirm Macrophyte HSI Curves

The HSI curves developed for macrophytes will be reviewed by a panel of relicensing participants and regional experts. Panel members will review the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. The panel may consist of relicensing participants and regional experts (agency, tribal, industry, and university researchers). This task will occur in 2008.

4.4.2.6. Provide Finalized Information to Aquatic Habitat Models

Once the macrophyte HSI model is finalized, the HSI curve will be provided for use in conjunction with this Mainstem Aquatic Habitat Model. Estimates of macrophyte distribution and abundance for operations scenarios will be used to evaluate the effects of potential operational changes relative to changes in aquatic habitats, and will also be used to evaluate the efficacy of operational measures to control invasive macrophytes. This task will occur in 2008.

4.4.2.7. Provide Necessary Information to the Productivity Assessment Study

Information on macrophyte abundance, distribution and productivity data developed in Study 7.4.2 will be provided for use in the Productivity Assessment (Study 11, SCL 2008i), where the information will be used to evaluate the potential need and opportunities for macrophyte management.

4.4.3. Periphyton HSI

The primary objective of Study 7.4.3 is to develop a periphyton HSI to help assess the effects of operations scenarios on aquatic production. Three sample areas were selected to represent a high fluctuation area (Lower Boundary Reservoir), a lower fluctuation area (Upper Boundary Reservoir), and a control area (Box Canyon Reservoir). Study 7.4.3 includes five primary tasks necessary to develop accurate and comprehensive HSI, including a literature-based component, field data collection, and final validation of HSI information for Boundary Reservoir. The methods used for each of those tasks are briefly described below; however, more detailed descriptions may be found in the Methods section (Section 4) of the Study 7.4.3 Periphyton HSI Interim Report (Appendix 3).

4.4.3.1. Literature-based Periphyton HSI Curves

An extensive literature review was conducted to gather any existing information and data on periphyton habitat preferences in terms of depth, substrate, velocity, and frequency of inundation and dewatering. During the literature review, no appropriate suitability curves were found for periphyton, so other literature was used to develop suitability values based on professional judgement. A more detailed explanation of the methodology used to create the literature-based periphyton HSI curves can be found within the literature-based HSI report in Appendix 3. With the information collected, HSC and a habitat suitability were developed for periphyton. The HSI value and HSC values were then multiplied to create a Boundary Project periphyton model, or composite suitability index. Additional details regarding the methods used in the literature-based HSC and HSI portion of Study 7.4.3, as well as the methods used to determine provisional values for each of the five variables, are described in the Study 7.4.3 Interim Report (Appendix 3).

4.4.3.2. Periphyton Communities on Hard Substrates

The methods and equipment used to sample hard substrates in Study 7.4.3 were intended to mimic natural substrate habitat utilized by periphyton in the reservoir during various seasons and to evaluate the response of periphyton to a range of water surface elevation fluctuations and the effects of operations scenarios. Hard substrate sampling was conducted at fixed locations in the lower and upper Boundary Reservoir, as well as in Box Canyon Reservoir. Sampling units were deployed at six pre-determined elevation intervals for a period of 8 weeks. Hard substrate sampling units were deployed in a vertical orientation, suspended from rock walls, in the lower Boundary and Box Canyon reservoirs; however, conditions did not allow for vertical sampling in the upper Boundary Reservoir (Table 4.4-1). Sampling was also conducted at the same six elevation intervals, and for the same period of 8 weeks, along the shorelines in the lower Boundary, upper Boundary, and Box Canyon reservoirs with the samplers placed on the substrate (Table 4.4-2). Following the 8-week deployment, all hard substrate samples were

Table 4.4-1. Hard substrate sample deployment and retrieval schedule for vertical face sites.

Deployment Date	Macroinvertebrates/Periphyton Vertical Face 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	February[1]
Total				**144**	
Treatments/Sites					
A) High Fluctuation-Canyon Reach					
B) Low Fluctuation-Box Canyon Reservoir					

Note:
1 Weather permitting.

Table 4.4-2. 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	February[1]
Total				**216**	
Treatments/Sites					
A) High Fluctuation-Downstream of Metaline Falls					
B) Moderate Fluctuation-Upstream of Metaline Falls					
C) Low Fluctuation-Box Canyon Reservoir					

Note:
1 Weather permitting.

collected and processed for periphyton. All samples collected were placed into sample bottles and brought back to the field house, where each sample was filtered using a 0.45 µm filter. Filters were preserved and frozen before being shipped to the laboratory for analysis of chlorophyll *a* concentration. Once results were received from the laboratory, the data were uploaded into a database to determine total periphyton biomass (mg/m^2) for each sample as a measure of periphyton production in the different sample areas.

4.4.3.3. Periphyton Colonization Rates

The benthic colonization study was designed to assess colonization rates of periphyton communities throughout various seasons at three different elevation intervals on hard substrate within a reservoir. Periphyton colonization sampling was conducted along the shoreline at a fixed location in Box Canyon Reservoir. Colonization sampling units, which were of the same design as those used in the vertical and shoreline hard substrate deployments, were placed at three pre-determined elevation intervals for various periods of time ranging from 8 weeks to 3 days. Following the full 8-week period, all units were collected and processed. Samples were then placed into sample bottles, filtered, preserved, and frozen before being shipped to the laboratory for analysis. Once the data were received from the laboratory, the data were uploaded into a database to determine total periphyton biomass for each sample and the periphyton colonization rate per elevation interval.

Colonization samples used the same frame and rock basket setup 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 4.4-3. For summer and winter periods, sets of three frame and rock baskets were deployed incrementally

Table 4.4-3. Colonization sample deployment and retrieval schedule.

Season	Colonization Period	Deployment Date	Retrieval Date
Summer	8 weeks	July 6th	September 1st
	6 weeks	July 20th	September 1st
	4 weeks	August 3rd	September 1st
	2 weeks	August 16th	September 1st
	1 week	August 23rd	September 1st
	3 days	August 28th	September 1st
Winter[1]	8 weeks	December 8th	February 2nd
	6 weeks	December 21st	February 2nd
	4 weeks	January 4th	February 2nd
	2 weeks	January 18th	February 2nd
	1 week	January 25th	February 2nd
	3 days	January 30th	February 2nd

Note:
1 Winter colonization baskets deployment and retrieval is depending on weather and reservoir conditions.

for set periods of colonization time (e.g., 8, 6, 4, 2, and 1 week) and then pulled simultaneously at the conclusion of the colonization period. Colonization samples were placed at elevation intervals of 5, 15, and 25 feet. The same deployment and retrieval procedures were used for the colonization samples as for the hard substrate shoreline samples.

4.4.3.4. Validation of Periphyton HSI Curves

Following the literature review, development of literature-based HSCs, and collection of field data, histograms for each of the habitat parameters researched in the literature review were developed. The histograms will incorporate the site-specific field data collected in Boundary and Box Canyon reservoirs. The histograms will then be compared with the literature-based HSI curves to validate the applicability of the literature-based HSI curve for aquatic habitat modeling. This portion of Study 7.4.3 will be conducted following the conclusion of field work in 2008.

4.4.3.5. Finalize Periphyton HSI Information

The HSI curves for each periphyton metric will be reviewed by a panel of relicensing participants and regional experts. Panel members will review the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. The panel may consist of relicensing participants and regional experts (agency, tribal, industry, and university researchers). Once the final periphyton HSI curves are developed, they will be used in the aquatic habitat modeling study to estimate the production of periphyton, in response to selected environmental variables, in relation to various dam operational scenarios. This task will be conducted in 2008.

4.4.4. Benthic Macroinvertebrate HSI

The primary objective of Study 7.4.3 is to develop a BMI HSI to help assess the effects of operations scenarios on aquatic productivity. Three sample areas were selected to represent a high fluctuation area (Lower Boundary Reservoir), a lower fluctuation area (Upper Boundary Reservoir), and a control area (Box Canyon Reservoir). Study 7.4.3 includes six primary tasks necessary to develop accurate and comprehensive HSI, including a literature-based component, field data collection, and final validation of HSI information for Boundary Reservoir. The methods used for each of those tasks are briefly described below; however, more detailed descriptions may be found in the Methods section of the Study 7.4.3 Benthic Macroinvertebrate HSI Interim Report (Appendix 4).

4.4.4.1. Literature-based BMI HSI Curves

An extensive literature review was conducted regarding the response of BMI to water depth, velocity, substrate, and inundation and dewatering. Of the literature obtained and reviewed, no appropriate suitability curves were found that would directly apply to the conditions in Boundary Reservoir, so information regarding lotic environments, as well as published and unpublished literature on BMI, recommendations from BMI specialists, and professional judgement on habitat preferences of BMI in lentic environments were used to create provisional suitability values. Specific details on this process are included in Appendix 4. With this information, HSC and a habitat suitability were developed. The HSI and HSC values were then multiplied to create a Boundary Project benthic macroinvertebrate model, or composite suitability index. Additional details regarding the methods used in the literature-based HSC and HSI portion of Study 7.4.3, as well as the methods used to determine provisional values for each of the five variables, are described in the Appendix 2 of the Benthic Macroinvertebrate Literature-Based HSI Interim Report (Appendix 4).

4.4.4.2. BMI Communities on Hard Substrates

The methods and equipment used to sample hard substrates in Study 7.4.3 were intended to mimic natural substrate habitat utilized by BMI in the reservoir during various seasons and to evaluate the response of BMI to a range of pool level fluctuations and the effects of operations scenarios. Hard substrate sampling was conducted at fixed locations in the lower and upper Boundary Reservoir, as well as in Box Canyon Reservoir. Sampling units were deployed at six pre-determined elevation intervals for a period of 8 weeks. Hard substrate sampling units were deployed in a vertical orientation, suspended from rock walls, in Lower Boundary and Box Canyon reservoirs; however, conditions did not allow for vertical sampling in the upper Boundary Reservoir. Sampling was also conducted at the same 6 elevation intervals, and for the same period of 8 weeks, along the shorelines in the lower Boundary, upper Boundary, and Box Canyon reservoirs with the samplers placed on the substrate. Following the 8-week deployment, all hard substrate samples were collected and processed for benthic macroinvertebrates. All samples collected were then placed into sample bottles, preserved, and shipped to a processing laboratory for identification of taxa, life stage, length, and enumeration. Once the data were received back from the laboratory, the data were uploaded into a database to determine total biomass for each sample as a measure of invertebrate production in the different sample areas.

4.4.4.3. BMI Communities in Soft Substrates

The soft substrate collection methods used in Study 7.4.3 were designed to capture BMI within a given volume of sediment to assess the effects of pool level fluctuations and various dam operational scenarios on BMI utilizing soft substrates within the reservoir. Soft substrate sampling was conducted in the lower Boundary, upper Boundary, and Box Canyon reservoirs. Soft sediment was collected using a 2.4-liter petite ponar dredge at the same six pre-determined elevation intervals as were sampled for hard substrate. Three sediment grabs were taken at each elevation interval to obtain triplicate samples. Each sample collected was placed into a bottle, preserved, and shipped to the processing laboratory for identification of taxa, life stage, length, and enumeration. Once the data were received back from the laboratory, the data were uploaded into a database to determine total biomass for each sample as a measure of invertebrate production in the different sample areas.

4.4.4.4. BMI Colonization Rates

The benthic colonization study was designed to assess colonization rates of BMI throughout various seasons at three different elevation intervals on hard substrate within a reservoir. Benthic colonization sampling was conducted along the shoreline at a fixed location in Box Canyon Reservoir. Colonization sampling units, which were of the same design as those used in the vertical and shoreline hard substrate deployments, were placed at three pre-determined elevation intervals for various periods of time ranging from 8 weeks to 3 days. Following the full 8-week period, all units were collected and processed. Samples were then placed into sample bottles, preserved, and shipped to the laboratory for identification of taxa, life stage, length, and enumeration. Once the data were received back from the laboratory, the data were uploaded into a database to determine total biomass for each sample as a measure of invertebrate production in the different sample areas.

4.4.4.5. Validation of BMI HSI Curves

Following the literature review, development of literature-based HSC, and collection of field data, histograms for each of the habitat parameters researched in the literature review were developed. The histograms will incorporate the site-specific field data collected in Boundary and Box Canyon reservoirs. A histogram for velocity may not be developed as this data will not be collected as part of Study 7.4.3. The histograms will then be compared with the literature-based HSI curves to validate the applicability of the literature-based HSI curve for aquatic habitat modeling. This portion of Study 7.4.3 will be conducted following the conclusion of field work in 2008.

4.4.4.6. Finalize BMI HSI Information

The HSI curves for each benthic metric will be reviewed by a panel of relicensing participants and regional experts. Panel members will review the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. Once the final benthic HSI curves are developed, they will be used in the Aquatic Habitat Modeling Study to estimate the production of benthic macroinvertebrates, as they respond to selected environmental variables, in relation to operations scenarios. This task will be conducted in 2008.

4.5. Stranding and Trapping Field Surveys

To address the issue of fish stranding and trapping as identified in Study 7, Fish HSI, Task 4, this study was designed as a survey to identify, characterize and sample stranding and trapping habitats throughout the Boundary Dam Reservoir and tailrace area within the U.S. Information obtained through the field portion of this study will aid in development of parameters to be used in the modeling of stranding and trapping as part of mainstem habitat model. To address seasonal differences in stranding and trapping occurrences at targeted areas, surveys were conducted in the summer season (July to September) of 2007 and additional sampling is planned for 2008 (February to August).

The goal of this study is to obtain data regarding the risk of stranding and trapping of fish in Boundary Reservoir; provide insights into effects of operations scenarios on stranding and trapping; and to identify the habitat characteristics that pose the highest risk of stranding and trapping on fish. The information gained from this study will be used in development of the stranding and trapping model as presented in Section 4.3 of this document.

The objectives of this study are as follows:

1. Conduct a reconnaissance survey to identify regions with stranding or trapping potential.
2. Identify the location, area, and potential stranding and trapping mechanisms at identified regions.
3. Record habitat characteristics at each site.
4. Record life history information on stranded or trapped fish sampled at each site.
5. Collect data on the physical and biological site characteristics that can be used to develop and validate the fish stranding and trapping model.

4.5.1. Methods 2007

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. Information important to document that effect stranding and trapping includes: local slope; location and depth of pool forming sites; substrate, macrophyte abundance and location; pool and slope elevation; and fish timing, species, and size. 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 cause fish to become stranded or trapped (Sections 4.5.1.1 to 4.5.1.3).

4.5.1.1. 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 (Study 9, SCL 2008f). Additionally, the study considered a local resident report of where fish stranding or habitat with fish stranding potential, had occurred in the past. The survey crew included Golder staff who had extensive knowledge and experience of stranding habitat characteristics from multiple studies conducted in similar regions of the Pacific Northwest and Terrapin 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.

4.5.1.2. Region Identification

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 air photos and bathymetric maps. Regions selected for sampling either 1) encompassed pools that were expected to isolate as reservoir levels drop during Project operations, 2) low gradient shoreline profiles (e.g., primarily less than 4 percent), or 3) have coarse substrate or other cover 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 (Figure 4.5-1). During sampling, four other regions were identified and sampled that had not been initially noted during the reconnaissance survey in June (see Section 4.5.3). Approximate areas from the GIS mapping of each identified region are provided in Table 4.5-1. The areas presented in Table 4.5-1 include the area of whole study region of the specific location; they do not represent actual stranding and trapping area within each of these regions, which may not be directly proportional to the areas shown. However, the areas do provide a general level of magnitude of the distribution of these areas within Boundary Reservoir. Overall, based on the preliminary region identification, more than 94 percent of the area with some potential for trapping and stranding is in the upper reservoir. The tailrace area at the time of this report was not determined but is a small portion (estimated less than 5 acres) of the entire Tailrace Reach.

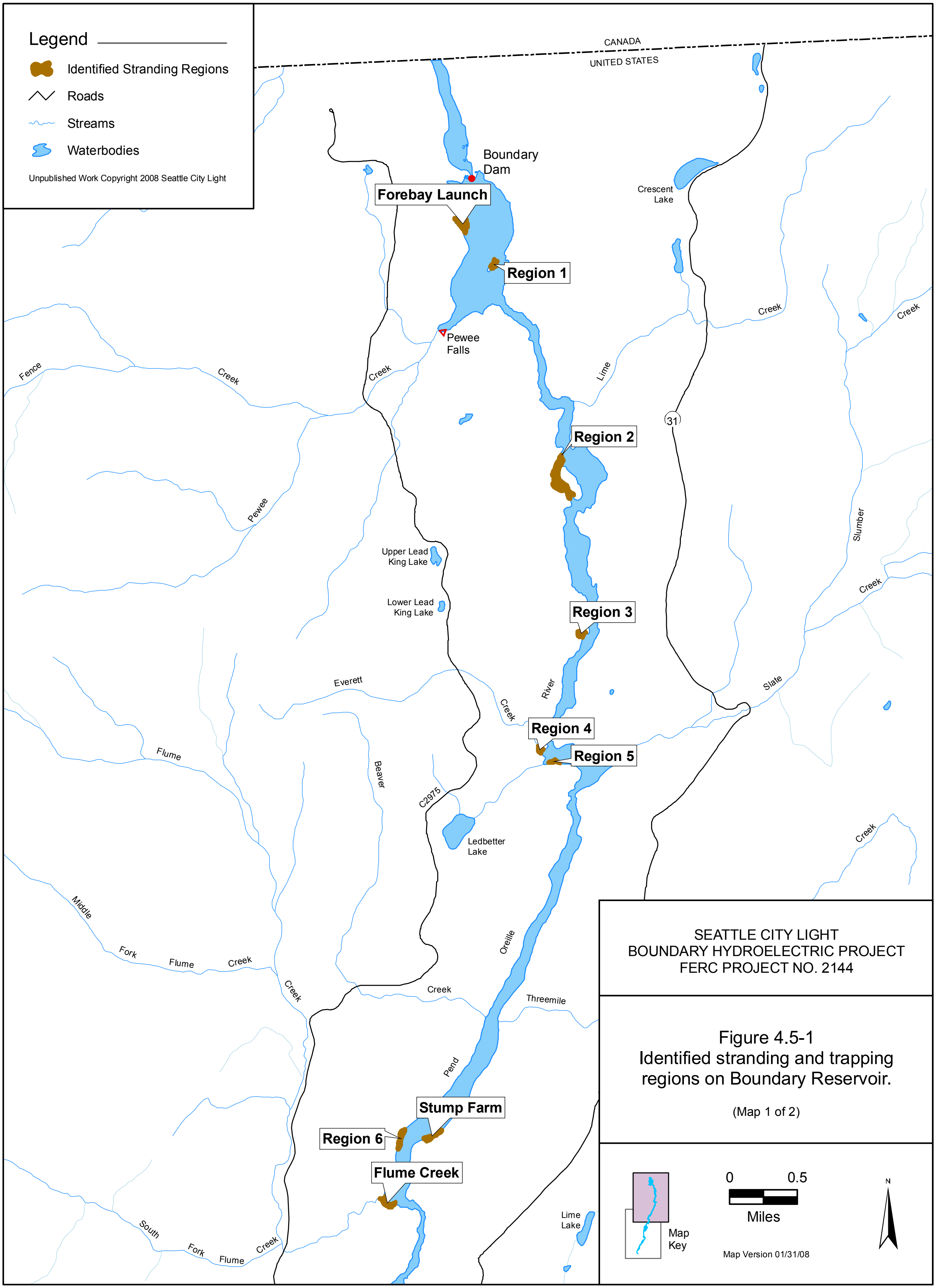
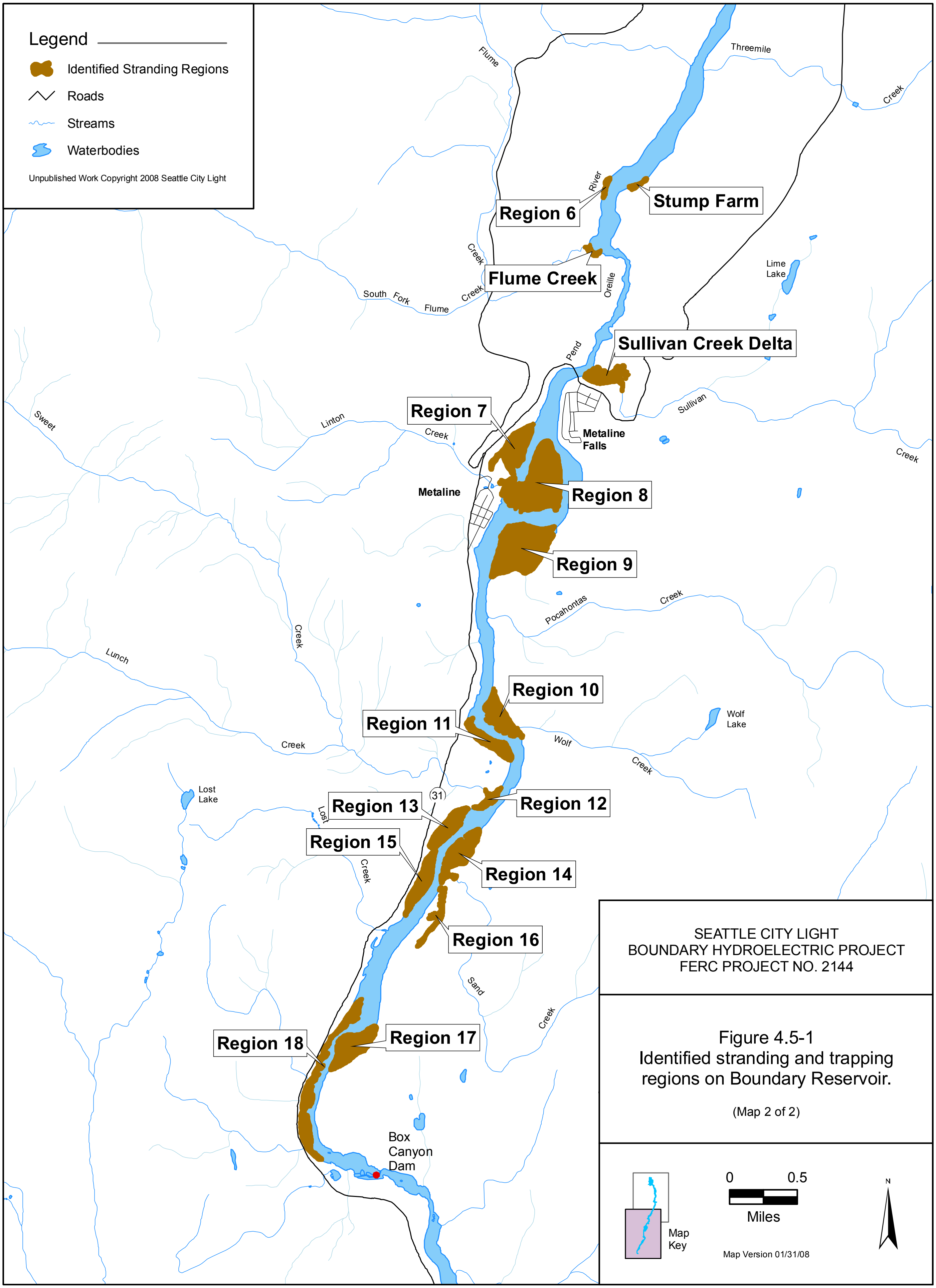


Figure 4.5-1
Identified stranding and trapping regions on Boundary Reservoir.
(Map 1 of 2)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 4.5-1
Identified stranding and trapping regions on Boundary Reservoir.

(Map 2 of 2)

Table 4.5-1. Approximate areas (in acres) of identified stranding and trapping regions on Boundary Reservoir.

Region	Reach	Area (acres)
Forebay Launch	Forebay	40.9
1	Forebay	13.6
2	Canyon	113.9
3	Canyon	18.0
4	Canyon	9.9
5	Canyon	8.6
Stump Farm	Canyon	20.9
6	Canyon	24.0
Flume Creek	Canyon	24.1
Sullivan Creek	Upper Reservoir	201.6
7	Upper Reservoir	331.0
8	Upper Reservoir	947.6
9	Upper Reservoir	834.9
10	Upper Reservoir	262.1
11	Upper Reservoir	199.6
12	Upper Reservoir	73.9
13	Upper Reservoir	225.2
14	Upper Reservoir	309.5
15	Upper Reservoir	243.5
16	Upper Reservoir	95.0
17	Upper Reservoir	346.9
18	Upper Reservoir	413.3

4.5.1.3. 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. Detailed habitat information was collected during the surveys conducted between August 3 and September 8. During the survey of the lower reservoir on September 7, three additional potential stranding and trapping regions were identified. Stump Island (across from Region 6) and Flume Creek Mouth were surveyed on September 7, and the Forebay Launch was surveyed on 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/loading. The dates of these surveys, along with the standing and trapping regions surveyed are presented in Table 4.5-2.

Table 4.5-2. Stranding and trapping survey dates and regions sampled, July to September 2007.

Survey Date	Stranding and Trapping Regions Sampled
11 July	7, 8, 10
12 July	Sullivan Creek Delta, 11, 13, 14, 15, 16, 17, Boundary Tailrace
3 August	10, 12, 13, 14, 16, 17, 18
22 August	7, 8, 9, 11, 15
7 September	1, 2, 3, 4, 5, 6, Stump Island, Flume Creek Mouth
8 September	Forebay Launch, 10, 14, 15, 16, 17

Stranding and trapping surveys were conducted 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 photos. By September, preliminary versions of the bathymetric maps were completed, and a combination of these maps and aerial photos was used to record the locations of trapping pools and stranding areas observed during surveys conducted in September. By December 2007, these bathymetric maps were finalized and are described in Section 4.3.9. 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 4.5.3.1. Stranded and trapped fish were either captured by dip net or collected by hand and life history information was recorded (described in Section 4.5.3.2).

4.5.1.3.1. 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 some specific sites within each region surveyed:

- Approximate area of the site drawn on aerial photos 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 handheld calibrated thermometers accurate to +/- 1 ^{o}C); and,
- Maximum pool depth at time of sampling, area and available cover of each trapping pool or stranding area after isolation 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 aquatic macrophytes. Factors that affect the likelihood and severity of trapping include the elevation drop, the 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.

Additional data collected during the last survey included relative trapping pool elevation information. This included either collection of depth of water over the pool sill when connected to the mainstem river or hand-level measurements of relative elevations from the pool sill to the mainstem river. These data were collected to help verify the elevation of the pools shown in detailed bathymetry analysis, which will be needed to develop the stranding and trapping model. This information is not included in this report, as it will require the water surface elevation estimated by the hydraulic routing model at the time of the survey.

4.5.1.3.2. 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

4.5.2. Recommended Methods 2008

The methods proposed for 2008 are primarily to supply information needed to help verify modeling factors for the stranding and trapping model. These field methods will be similar to 2007 but will be more directed at supplying information to be used in the model being developed. The connection between the 2008 field investigation and the modeling effort are summarized here to provide background on how the field study effort relates to the model parameters proposed for development.

The methods to be used to model stranding and trapping relative to operations scenarios are described in detail in Section 4.3.9. That section includes a description of the two indices used for trapping and stranding. The indices are an estimate of relative potential of a channel area to either trap or strand fish. The indices include factors that represent biological and physical aspects that influence the potential for stranding or trapping within the area. The values used for each of these factors considered the results of initial 2007 stranding and trapping sampling. The rationale for these values is discussed in Section 4.3.9. Generally, such factors as pool depth, cover type, duration of pool isolation, and season are all important factors to scale the effects on trapping and stranding. The two indexes to be used are shown below:

$$TI = A_T * B_T * T_{T(D)} * C_T$$

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

$$SI = A_S * C_S$$

Where:

SI = stranding index

AS = stranding area in square feet

CS = cover factor for stranding

The stranding and trapping field effort is intended to aid in validating or modifying the values used for the factors in the two indexes shown above. It is anticipated these field studies through a combination of measuring habitat conditions, fish species presents, their relative abundance and survival, and type of habitat conditions where these fish are found will refine the values used for these factors. The relationship of office and field portions of the stranding and trapping study is shown in Table 4.5-3.

The sections below describe how the specific field methods of the study will be done to achieve the needs of the two indexes shown above. The recommended schedule for sampling during 2008 is shown in Table 4.5-4.

4.5.2.1. Field Coordination Survey

A field coordination survey will be conducted during winter 2008. This survey will have multiple purposes. One of the main purposes will be ensure that hydraulic modelers and field crew conducting the study are in agreement on the details of the site selection and specific locations for future field measurement relating to pool elevations and stage monitoring. Prior to the survey, potential sites will be selected for placement of stage gage and sill level measurements (see below). During this survey, most of these sites will be visited and specific locations for gages and sill depth measurements will be located. Additionally, potential sites (pools and slopes) to be surveyed will be viewed so that modelers and site field staff agree upon how the information will be collected and used in the model. This will aid in providing the most usable final product that will be applied in the stranding and trapping model. Additionally, sites with apparent high potential for stranding or trapping of young-of-the-year mountain whitefish will be viewed, as this life stage will likely be the first to appear during stranding and trapping field efforts in 2008.

4.5.2.2. Region and Site Selection

Regions and sites among the 23 regions examined in 2007 will be sampled during 2008. Within the regions, sites will be sampled that encompass a range of conditions that were documented to influence stranding and trapping during the 2007 surveys. The emphasis will be on sampling areas that have pools, backwater and side channel habitats, and slopes with macrophytes (when present), as these are the areas that were noted to have the highest occurrences of stranding and trapping. Effort will be made to sample these types of habitat at differing reservoir elevations and at varied times of exposure. Since most of the habitat area that has been found to affect stranding and trapping is present in the upper reservoir, this area will be given greater effort, although sampling will also occur in the tailrace and lower reservoir (Canyon and Forebay reaches) to ensure local differences are considered. Some of the areas targeted for sampling will include Region 2 in Canyon Reach because it has some of the only low gradient habitat in the lower reservoir (see Section 5.5). In the Upper Reservoir Reach, Regions 7, 8, and 14 will be

Table 4.5-3. Stranding and trapping index factors and information sources relative to stranding and trapping field studies.

Factor Definition	Trapping Index Factors and Their Sources of Information		
	Factor Code	**Office and Hydraulic Model**	**Stranding and Trapping Field Studies**
Trapping Area	A_T	GIS stranding and trapping bathymetry	Some estimate of pool size will occur in the field but the pool size information will primarily be from the GIS estimates as they will be more accurate and will give pool size when first isolated.
Contributing Basin Area	B_t	GIS stranding and trapping bathymetry	The relative abundance of fish will be measured in pools. Pools of varied contributing drainage basin sizes will be sampled to encompass the ranges of those used in the index (e.g., 1 to >3). This value can be a metric to compare against the relative drainage basin sizes for evaluating the assignment of index factor value.
Duration of Trapping	$T_{T(d)}$	GIS and Hydraulic model. Using location elevation data and the hydraulic routing model, an estimate of pool isolation duration can be determined.	Stage reduction monitors will be used to help develop estimates on how long different type pools hold water, since this may be the most important factor controlling fish survival. Pools will be sampled to encompass a range of characteristics (substrate, depths, elevations) that may affect rate of draining. Maximum depth of pools during sampling will be recorded. Additionally, the level of effect isolation has on fish will be determined by monitoring fish relative survival (live and dead) by sampling isolated pool portions and surrounding dewatered slopes. Sampling would occur over a range of isolation periods. Sampling will occur during different periods (winter and summer) to account for potential seasonal differences.
Cover Factor	C_T	Locations of macrophytes and density from the macrophyte surveys, recorded in the GIS database, will be used for modeling purposes.	The amount and type of cover (primarily concentration of macrophytes), will be reported for specific pools. The relative abundance of fish in the pools will be the metric used to evaluate this cover factor. Substrate composition and characteristics will be recorded to confirm whether it may be a factor affecting trapping (substrate has not been included in the initial formation of the cover factor, but will be incorporated if 2008 data indicate a strong influence on trapping).
Stranding Index Factors and Their Sources of Information			
Stranding Area	A_S	GIS database calculating areas of less than 4 percent slope. Also the macrophyte layer will be used for all areas within the elevational limits of Project operations.	As noted for cover factor, macrophyte presence and distribution on slopes will be reported during surveys, especially in areas with >4 percent slope.
Cover Factor	C_S	The GIS macrophyte layer will be used to indicate where macrophytes are present.	Relative fish density stranded will be the metric for evaluating effects of cover on stranding. An index of relative stranded fish abundance in potential stranding areas will be developed. Areas with varied substrate will be examined during field studies and relative abundance of fish observed will be reported, including absence of fish. Areas examined would consist of with and without macrophytes as 2007 data suggest macrophytes were the major factor affecting stranding. Macrophytes on slopes greater than 4 percent will be reported separately. Substrate composition and characteristics will be recorded to confirm whether it may be a factor affecting stranding (substrate has not been included in the initial formation of the cover factor, but will be incorporated if 2008 data indicate a strong influence on stranding).

Table 4.5-4. Sampling schedule during 2008 for Stranding and Trapping Field Surveys.

Activity	February[1]	March early	March late	April	May[2]	June[2]	July	August	November
Task 1. Field Coordination	x								
Task 2. Field Surveys Conducted During Flow Reduction	x	x	x	x	x	x	x	x	
Task 3. Sill Elevation Data Collection			x				x[3]	x[3]	
Task 4. Stage Rate Reduction Monitoring	x	x	x	X[4]	X[4]	X[4]	X[4]	X[4]	
Task 5. Report Writing									x

Notes:
All dates tentative and dependent on flow conditions and biological activity.
1 Two surveys will be attempted, weather permitting, but if not, an additional survey will be moved to early April.
2 Monitoring during this period will occur if flow levels are low enough to allow project induced water surface elevation fluctuations to occur (flows are less than approximately 40,000 cfs).
3 If insufficient elevations are completed in March, additional measurements will be made in lower flow months.
4 If sufficient data to predicatively model trapping area dewatering rates are obtained during the early season monitoring, spring and summer stage rate reduction monitoring will be discontinued.

targeted as these regions have diverse species and large potential areas of stranding and trapping habitat. Region 18 will also be examined in the early spring as mountain whitefish are suspected to spawn near this region. Since one of the main goals of the 2008 survey is to collect information that can be used to develop scaling factors for the stranding and trapping model analysis, emphasis will be on sampling sites and conditions that will aid in this development. The parameters measured during the field surveys will be directed at tying to the model component factors discussed in Section 4.3.9 of Study 7 (as noted in Section 4.5.2.1).

4.5.2.3. Stranding and Trapping Surveys

Sampling would occur during late winter, spring, and summer to encompass a range of life stage occurrences and physical conditions. Sampling during 2008 will be scheduled to commence at the time when a significant drop in pool level associated with existing Project operations is predicted, following a period of stable or high pool levels. However, if these conditions cannot be predicted or do not occur, data will be collected during the monthly periods for typical daily Project operations. Field crews will use detailed maps developed in 2007 that indicate where past stranding and trapping areas occurred (see above for regions and site selection). Since changes in tailrace elevation are difficult to predict, examination of these areas will occur during other sampling as opportunities allow. Tailrace areas examined would include pools and sloping shorelines in the 1-mile reach below the dam that have stranding or trapping potential. Since multiple fish sampling activities occur each month in the tailrace, opportunities to obtain stranding and trapping information will be common.

The purpose the stranding and trapping sampling in 2008 will be to obtain additional physical and habitat condition information (e.g., pool depth, substrate, macrophyte density) to correlate with fish information (e.g., species presence, abundance, and sizes) through the winter, spring, and summer. This will aid in developing indices for the stranding and trapping model. The recommended sampling period will commence in late winter (February) to determine what habitat and Project operations may result in stranding or trapping of overwintering reservoir fish stocks, prior to emergence of young-of-the-year. Sampling in March, April, and May will be primarily directed at identifying whether newly emerged mountain whitefish are observed and if recruitment is from the mainstem Boundary Reservoir or tributary or upstream habitats. If mountain whitefish fry are observed, field efforts will be directed at determining what conditions may influence potential stranding and trapping of emerging mountain whitefish.. Continued monthly sampling from June into August will be conducted to obtain associated habitat conditions that may influence stranding and trapping and survival of many of the remaining target species and other resident fish during varied water flow, temperature, and water surface elevation fluctuation conditions.

Monitoring during May and June is contingent on flow conditions. Typically, high flows occur during this period that limit project effects on daily water surface elevation fluctuations, particularly in the upper reservoir. Monitoring during this period would occur only if flows drop below 40,000 cfs, as existing Project operations generally have minimal effects on daily water surface elevation changes above this flow in the Upper Reservoir Reach. But a survey on the descending limb of the seasonal hydrograph will be made to help identify conditions causing isolation of side channel habitat areas independent of load-following operations. Also, some young-of-the-year fish may be present during this period (e.g., yellow perch, mountain whitefish, largescale sucker, and centrarchids toward the end of this period) that may be susceptible to stranding or trapping. Sampling during this period would allow obtaining metrics on pools and slopes that may be less available as some of these species grow in size.

4.5.2.3.1. Habitat Data Collection

The field crew will have copies of the detailed stranding and trapping map areas to be surveyed for the specific trip. At each of the areas sampled, the field crew will record the following habitat characteristics at each site, relying on the GIS map as the basis for the surveys:

- Individual stranding and trapping sites will be recorded by marking the detailed GIS stranding and trapping bathymetry map. The approximate outline of the area of each stranding and trapping site surveyed will also be marked on the map. If a site appears to deviate markedly from the map, it will be measured for area using tape or rangefinder.
- Stranding or trapping mechanism will be recorded (e.g., stranding, trapping then stranding, trapping only).
- Size of exposed substrate characterized will be recorded using the modified Wentworth method.

- Exposed substrate parameters will be recorded (including embeddedness, angularity and compaction).
- Slope will not be measured as this information is available from the detailed GIS maps for the 4 percent slope areas. Slopes in macrophyte areas that exceed 4 percent will be estimated because of potential for these areas to strand fish.
- Mainstem and isolated pool water temperatures will be recorded (using handheld calibrated thermometers accurate to +/- 1°C).
- Depth at time of sampling, area and available cover of each trapping pool, or stranding area after isolation from the reservoir will be recorded. At trapping pools, the residual depth (i.e., maximum pool depth minus water depth at outlet sill) or maximum pool depth if outlet sill is dry will be recorded. If the pool is draining, it will be noted if the mainstem water surface elevation has dropped below the sill or if the pool is still connected to the mainstem at the time of sill water depth measurement. Also, an approximation of the decrease in pool depth below the sill pool depth will be made by use of a hand level if the pool is not still draining at the time of the survey. Sill elevations relative to mainstem river level will not be measured using a hand level but will be determined at selected pools separately from these surveys (see Section 4.5.2.3.3 below for measurement methods). The detailed accurate bathymetry information will be the primary source of sill elevations for areas not specifically surveyed for elevation using the methods noted below.

Based on results of 2007 surveys, macrophytes appeared to influence both stranding and trapping. Therefore, additional emphasis will be given to identifying relative abundance of macrophytes in both pools and sloped areas in 2008. For trapping pools, relative macrophyte coverage will be noted in categories of 0, <25, 25 to <50, 50 to <75 , or 75 to 100 percent of the pool area. The approximate dewatered shoreline areas containing macrophytes will also be noted on maps. This will include all shoreline areas with macrophytes independent of slope. Again emphasis will be given to large regions of occurrence of macrophytes.

4.5.2.3.2. Fish Collection

During 2008 surveys, sampling isolated pools at selected regions and sites will be conducted using a backpack electrofisher. Field crews will note any concentrations of fish in the area immediately prior to dewatering but only collect and record data from fish that are stranded or trapped at each site. Sampling of pools will include recording sampling time so relative catch per unit effort can be determined for each of these sites.

Stranding areas will be sampled by examining for fish under cobble or woody debris, or trapped in macrophyte beds. A total count or subsampled count by species will be made for stranding areas, as well noting what habitat the fish were associated with (e.g., macrophytes, large cobble, and fine substrate) so that a relative scaling factor can be developed for stranding areas. Stranding areas will be designated as to whether they are part of drained pool or slope area independent of a pool.

The results of the stranding and trapping surveys will supplement data on the size, number and species of fish captured along reservoir margins as part of Study 9 (SCL 2008f). Data collected from nearshore backpack electrofishing conducted by Study 9 in 2008 will be a supplemental source of information for when young-of-the-year may be present in the shallow shoreline waters.

All fish captured during the pool level reduction surveys will be processed for the following life history information:

- Species will be recorded. Should larval fish be encountered a subsample will be preserved and returned to office where species identification will be made.
- Length (mm) will be recorded.
- Overall health will be recorded.
- Number of fish captured will be recorded, and where possible number observed but not captured by species will be reported. The numbers and characteristics of species (size, condition such live or dead) will be reported by specific region where possible to aid in future modeling of stranding and trapping.
- If possible, the proportion and number of fish in specific trapping pools that are live and dead will be measured. If measurements are not possible (e.g., too deep or area too large to fully sample) reasonable attempts will be made to approximate portion and number of live and dead in the pool. Stranded numbers of fish found in associated pool slope areas will be recorded to aid in determining mortality associated with specific pools. Again the goal is to supply a relative number of fish and survival to aid developing the values used in the factors of the indices for the stranding and trapping model (Section 4.3.9).

4.5.2.3.3. Pool Sill Elevation Data Collection

During the 2008 surveys, a specific subtask will be conducted to confirm the accuracy of the bathymetric data indicating reservoir elevation at which pools become isolated. The pools and specific locations where elevations will be measured will be initially determined during the winter coordination survey. The location selected will be determined in coordination with the modeling group and stranding and trapping field team. In the reservoir, the measurements will be done with a two-person crew separate from the stranding and trapping surveys. One crew member will be a member of the crew conducting the stranding and trapping surveys who is knowledgeable about where pools are located and the other member will be from the hydraulics group. This activity will include measuring the depth at the sills or surveying with standard surveying equipment (e.g., level tripod and rod) and the sill depth relative to the river elevation at a specific date and time. This will be done at a subset of pools (about 25 to 50 pools) present in the reservoir. Pools will be measured over a range of areas in the reservoir and tailrace including the upper and lower portions of the Upper Reservoir Reach. Since elevation will vary little along the length of the Forebay and Canyon reaches for the same elevation at Boundary dam and because fewer potential stranding and trapping areas are present in this region, effort will be higher in the Upper Reservoir Reach. During the regular aquatic sampling in the tailrace (e.g., electrofishing, gillnetting) depth of sill areas will be measured when pools appear with measurements made when the pool is draining but still connected to the mainstem channel. The final elevation at these locations will be determined with the use of a hydraulic routing model for both the reservoir and tailrace. The results will be compared to the data from the bathymetry map to determine accuracy of the data.

4.5.2.3.4. Monitoring Pool Depth Reduction in Isolated Pools and Side Channel Habitats

A separate task recommended for 2008 is to study the rate at which isolated pools and side channels dewater. This involves the deployment of up to 10 stage recorder stations in a subset of pool and sidechannel habitats. The stations will then be downloaded as needed. The locations will be determined during the reconnaissance site visit. Sill elevations will be measured relative to the mainstem river level for each of the pools where the gages are located. Pools will be selected to cover the range of pool types. This would include variable depths, substrate type, and relative elevations. The physical characteristics of each pool will be reported at the time of sampling. The hydraulic routing model will be used to determine the range of mainstem water elevations relative to pool sill elevations that occurred during the monitoring period that stage recorders were in place. After the pool depth reduction rates of the selected sites are determined, this information can be applied to the stranding and trapping modeling parameter development (Section 4.3.9).

The basis for this recommendation is the order or orders of magnitude difference observed in stranded and trapped fish mortalities during 2007 stranding surveys between flow reductions durations of 12 hours or less compared to flow reductions that persist for several days. To accurately model the potential risks of extended duration drawdowns, empirical data from a subset of trapping habitats is needed to establish rates of dewatering and habitat factors that contribute to these rates.

5 PRELIMINARY RESULTS

This section provides information on the preliminary results of the Mainstem Aquatic Habitat Modeling Study effort conducted throughout 2007. Data collection efforts are covered through early November 2007. Analysis of the information continued into mid December 2007. As with the methods presented in Section 4, the results are subdivided into five subsections based on the study components:

- Section 5.1—Habitat Mapping (Study 7.1)
- Section 5.2—Hydraulic Routing Model (Study 7.2)
- Section 5.3—Physical Habitat Model Development (Study 7.3)
- Section 5.4—Habitat Suitability Indices Development (Study 7.4)
- Section 5.5—Stranding and Trapping Field Surveys (Study 7.5)

The 2007 results primarily consist of data collection efforts, with the most significant efforts involving the measurements for the mainstem habitat transects, the field data collection, and in some cases, laboratory analysis efforts associated with the development of the various HSI, and the data collection supporting stranding and trapping analysis. Much of the analysis effort relies on results of the data collection to progress beyond the development and refinement of methods and will be performed in 2008. However, one major analysis effort was well underway in 2007; the development of the hydraulic routing model. The hydraulic routing model has been developed and calibrated for the portion of the study area between Box Canyon Dam and Boundary Dam. Additionally, literature-based HSI curves and periodicity tables have been developed as part of Study 7.4. Some analysis of data collected for the HSI development effort has also been conducted and is discussed in this section.

Not all data collected in 2007 are presented in this section, though a description of the extent of information collected has been provided. An example of this is Section 5.3.4, mainstem habitat transect measurements. There is a tremendous amount of information associated with the raw data from the ADCP readings. This information is currently undergoing reduction and quality assurance/quality control (QA/QC) efforts. The data reduction efforts include determining cell velocities for specific cell widths and estimating mean column velocities for cells where the depth exceeded the range of the equipment (deep water reservoir areas greater than approximately 50 feet). QA/QC efforts include not only reviewing data for reasonableness and consistency, but also incorporating the transects into the hydraulic routing model to check elevations and compare the transect profiles with those generated by the bathymetry survey. A complete report on the results of the 2007 transect data collection effort will be prepared and distributed in the spring of 2008.

5.1. Habitat Mapping

The results of the habitat mapping by habitat category are presented in Sections 5.1.1 through 5.1.7. As discussed in Section 4.1, the primary purpose of the habitat mapping task has changed from one of providing information to support transect selection in Boundary and Seven Mile reservoirs, to describing habitat conditions in the reservoirs that relate to fish and other aquatic issues. Therefore, some of the habitat mapping identified in the RSP are not included in this section such as delineating the reservoir into reaches based on habitat characteristics (e.g., runs, pools and riffles).

Section 5.1.1 documents the reconnaissance-level mesoscale habitat mapping work effort conducted in the Canadian portion of the Tailrace Reach (Section 5.1.1). The determination of wetted width and wetted surface area was not conducted as originally conceived in the RSP, and Sections 5.1.2 and 5.1.3 document this deviation. Section 5.1.4 describes the distribution and characteristics of large woody debris (LWD) in the reservoir and Section 5.1.5 summarizes the type, distribution, and density of aquatic vegetation determined during the site assessment conducted in the late summer of 2007. Information gathered from the angler interviews is provided in Section 5.1.6 and is presented by species. Finally, the data compilation task of the habitat mapping effort, as originally conceived in the RSP, was not conducted and this is documented in Section 5.1.7.

5.1.1. Channel Typing

Due to the availability of high resolution aerial photography and detailed bathymetry, channel typing was not used to select habitat transect locations within any of the reaches in the study area, with the exception of the Canadian portion of the Tailrace Reach. Detailed bathymetry was not available for the Canadian portion of the Tailrace Reach prior to the transect selection process. In the absence of the detailed bathymetry, verification of the transect locations in the Canadian portion of the Tailrace Reach was conducted using reconnaissance-level mesoscale habitat mapping. The locations of the selected transects were compared to the mesoscale habitat mapping results, resulting in the elimination of three of the original habitat transects (T-4, T-6, and T-8) and final recommendation for retaining the remaining eight habitat transects in the Canadian portion of the Tailrace Reach. The number and locations of the Canadian Tailrace transects were presented at and approved at the July 24, 2007 Fish and Aquatics Workgroup meeting.

The reconnaissance level mesoscale habitat mapping of the Canadian portion of the Tailrace Reach was completed by Golder Associates on May 30, 2007. The results were presented in a technical memorandum dated June 13, 2007 (Golder 2007). The survey was conducted by a two-person crew. The crew drifted downstream by river boat along the thalweg of the Pend Oreille River from the border downstream to the Salmo River. Water depth was sampled at regular intervals (approximately every 30 seconds) using a Garmin GPSMAP 169 sounder. A waypoint and major changes in meso-habitat (e.g., run, flat, eddy, etc.) were also recorded at each sample location. The survey was conducted within a 1-hour time period. During this period, the Seven Mile forebay elevation was relatively constant.

Refer to Golder (2007) for detailed results of the meso-habitat survey as well as the tabular presentation of the sampling locations and the associated meso-habitat description at each sampling location.

The results of the meso-habitat survey divided the Canadian portion of the Tailrace Reach into five sections, each section representing unique habitat characteristics. The proposed habitat transects were then overlaid onto the meso-habitat survey results to verify that the transect locations adequately represented the variability of habitat present in the Canadian portion of the Tailrace Reach. Based on the potential variability of meso-habitat located throughout the Canadian portion of the Tailrace Reach (in terms of width, depth, eddies, surface type and presence of islands), the following conclusions were made:

- Transect T11, T10, and T9 are well placed to be representative of low-gradient riffle conditions, which increase in depth in the downstream direction.
- Transects T8, T7, T6, T5, and T4 are all located within a single extended run meso-habitat unit.
- Transects T3 and T2 are located within a short section of pool. One transect is located in a narrower portion with a gravel/cobble bar and the other is located in a wider portion without a bar. Therefore, the two transects are representative of the range of pool hydraulic conditions.
- Transect T1 is located near the lower end of the Tailrace Reach near the confluence with Red Bird Creek in a separate run meso-habitat unit that extends all the way down to the confluence with the Salmo River.

As described above, five of the original eleven habitat transects in the Canadian portion of the Tailrace Reach are located within a single meso-habitat unit (run habitat). Therefore it was recommended that three of these habitat transects (T4, T6, and T8) be eliminated. This recommendation was made at the July 24, 2007 Fish and Aquatics Workgroup meeting and was subsequently approved by the workgroup.

5.1.2. Wetted Width Calculations

Due to changes in the methodology used to determine the habitat transect locations, the calculation of wetted width within the study area was not necessary and was therefore not conducted.

5.1.3. Wetted Surface Area Calculations

Due to changes in the methodology used to determine the habitat transect locations, the calculation of wetted surface area within the study area was not necessary and was therefore not conducted.

5.1.4. LWD Mapping

Figure 5.1-1 shows the locations of LWD in the Boundary Reservoir as surveyed in August 2007. Details on the survey can be found in Study 10, Large Woody Debris Management Study (SCL 2008g). Each LWD symbol on the map indicates the presence of between 1 and 70 actual pieces of LWD. LWD includes all wood from the high water surface elevation in the respective region of the reservoir (as designated by vegetation presence, change in slope, or water line marks) to the water surface elevation at the time of the survey. The water surface elevation at the Boundary forebay at the time of the survey ranged from 1,977 to 1,993 feet NAVD 88 (1,973 to 1,989 feet NGVD 29). The amount of wood varied significantly by location, with relatively few locations containing most of the LWD present. The LWD site numbers 1 to 10 and 186 to 194 are in the Forebay Reach, 11 to 185 in the Canyon Reach, and 195 to 254 in the Upper Reservoir Reach.

5.1.5. Aquatic Vegetation Mapping

The existing distribution and abundance of macrophytes in Boundary Reservoir was assessed during field surveys conducted in August 2007. The results of the macrophyte mapping effort are presented in a series of maps as Figure 5.2-1 in Appendix 2. The series of maps present information regarding macrophyte distribution, abundance, and species present throughout Boundary Reservoir. Figure 5.1-2 is an example of one of these maps. Table 5.1-1 provides a summary of the macrophyte species found throughout the reservoir.

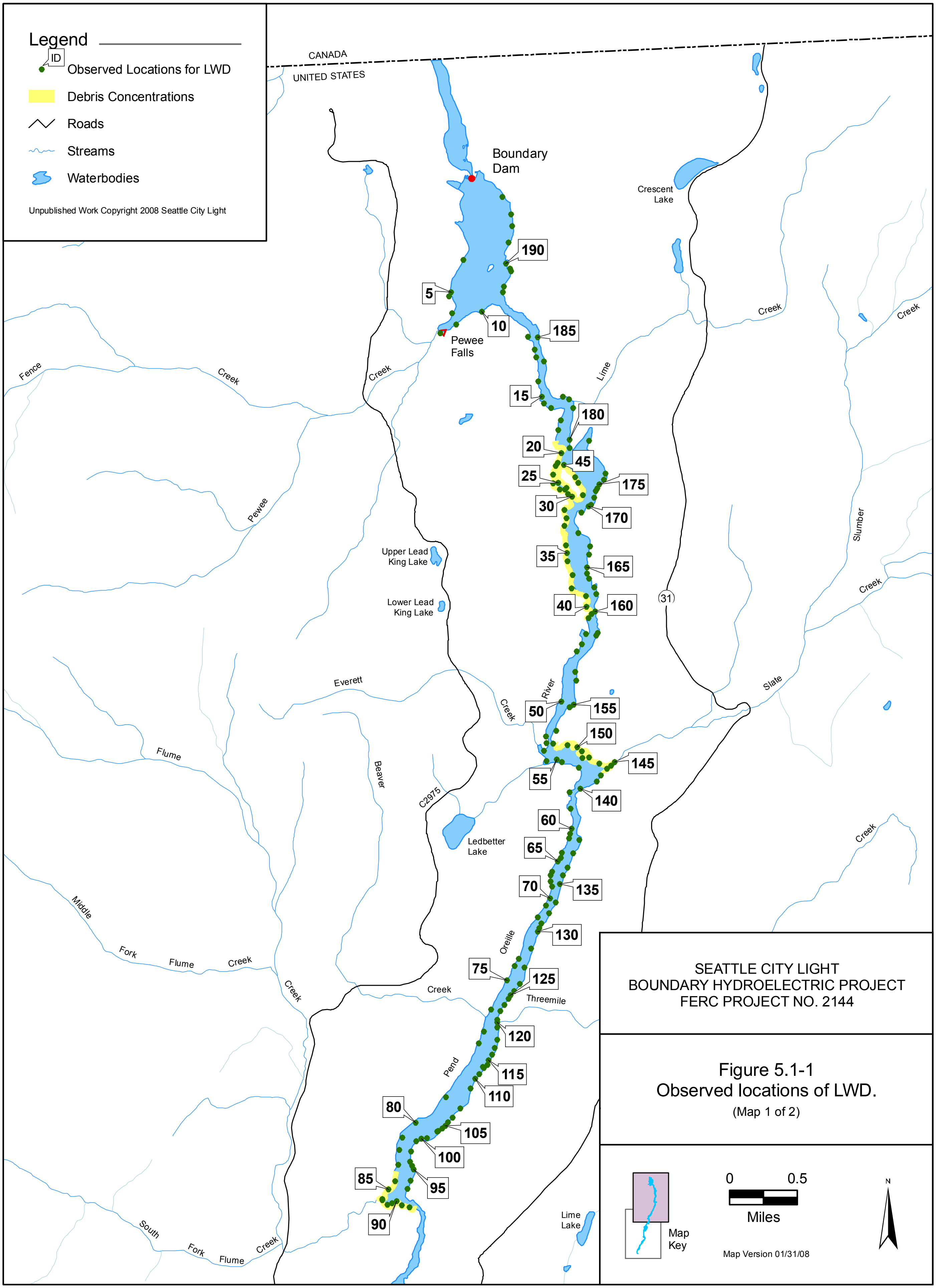


Figure 5.1-1
Observed locations of LWD.
(Map 1 of 2)

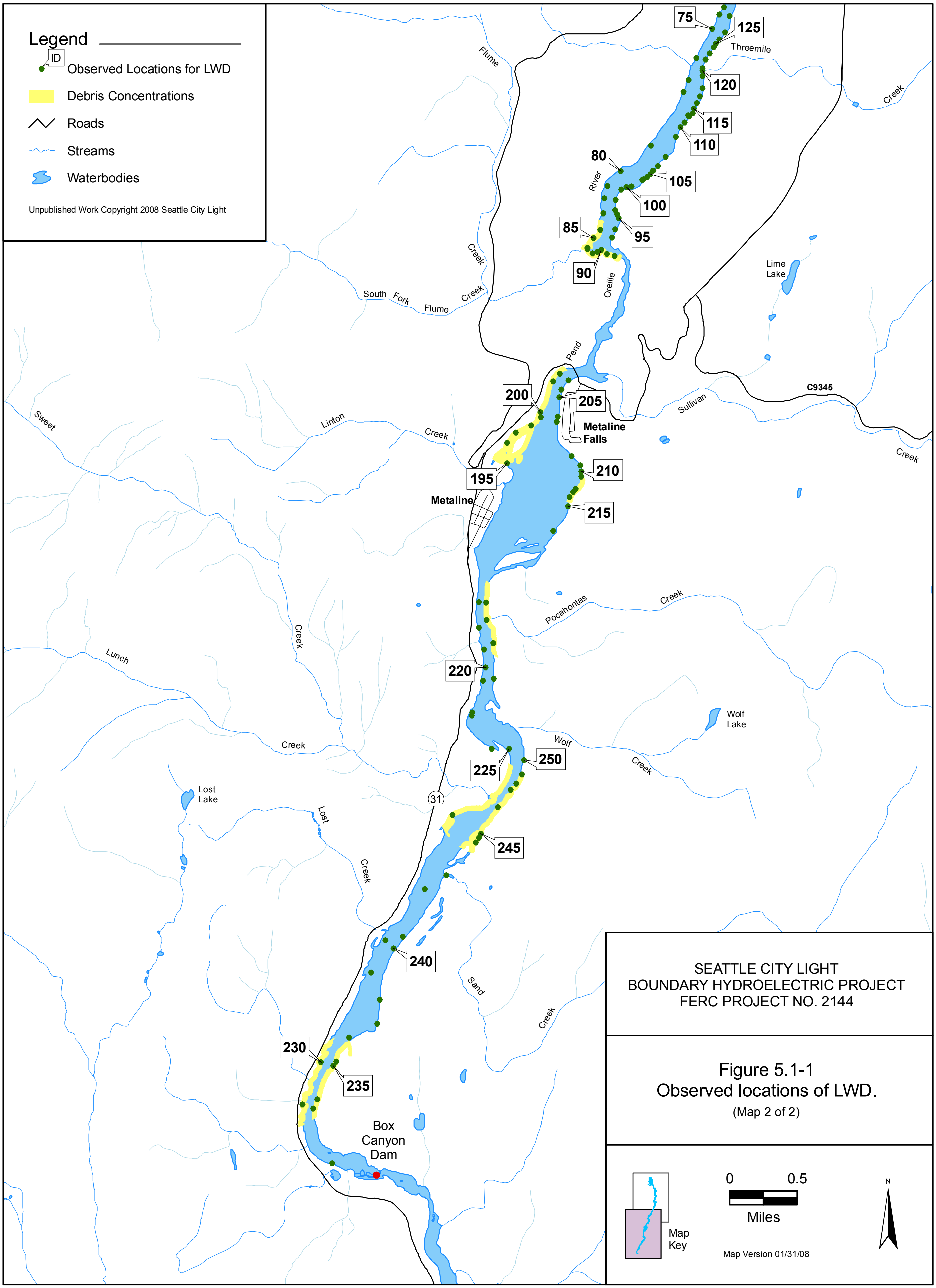


Figure 5.1-1
Observed locations of LWD.
(Map 2 of 2)

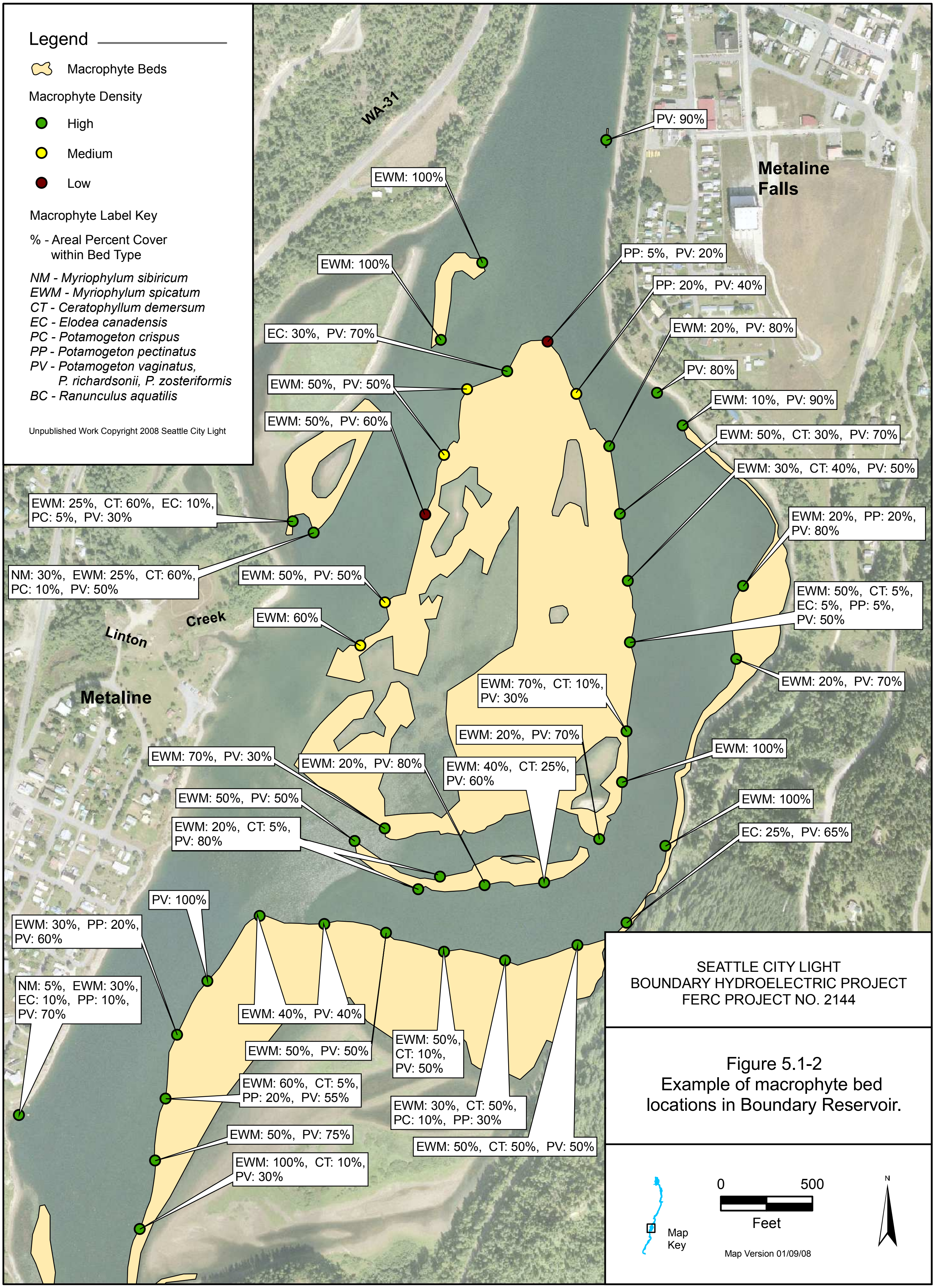


Figure 5.1-2
Example of macrophyte bed locations in Boundary Reservoir.

Table 5.1-1. 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 covered 18.6 acres in Lower Boundary Reservoir and 137.6 acres in Upper Boundary Reservoir. Eurasian watermilfoil, potamogeton species, and coontail were the dominant plant species found in Boundary Reservoir (refer to Figure 5.2-1; Appendix 2). Table 5.1-2 summarizes the relative number of macrophyte beds found in 2007 August survey by above and below Metaline Falls.

The distribution and abundance measures will be correlated with habitat features in the reservoir including depth, velocity, substrate, and duration of inundation and dewatering as these data become available (see Study 7.5.2, Section 5.3 in Appendix 2) Depths at which macrophytes were found in the August 2007 survey calculated using GPS and bathymetry will be cross-checked with actual depth data collected at habitat transects in August 2007 (see Study 7.4.2, Section 5.3 in Appendix 2). This cross-check will ensure a more accurate determination of macrophyte habitat is achieved.

Table 5.1-2. Date and locations of macrophyte bed sampling during 2007.

Collection Date	Reservoir Zone	No. of Macrophyte Beds	Macrophyte Bed Size Range (acres)
August 25-27, 2007	Box Canyon Tailrace	0	0
August 25-27, 2007	Above Metaline Falls	25	0.017-55.66
August 25-27, 2007	Canyon Reach	28	0.0006-5.34
August 25-27, 2007	Boundary Forebay	4	0.008-2.83
August 25-27, 2007	Boundary Tailrace	0	0

5.1.6. Angler Interviews

Twenty-six anglers (referred to as respondents) were interviewed between May and early December, 2007. The majority of respondents (23) stated that they have been pursuing fish in Boundary Project area for at least 7 years and fished the reservoir several days (6 or more) a year. The remaining three respondents stated they fished the reservoir only during the bass tournament. In addition to the 26 respondents described above, 16 other anglers were contacted during the early May bass tournament. These 16 acknowledged they were not very familiar with the Project waters or other fisheries in the area. Their contribution was limited to fishing techniques and areas of capture during the tournament. The information gathered from the interviews is provided by species in the subsections that follow. Figure 5.1-2 illustrates the locations of smallmouth and/or largemouth bass spawning, native salmonid capture areas, and trapping and stranding areas referenced in the following discussions.

5.1.6.1. Smallmouth Bass

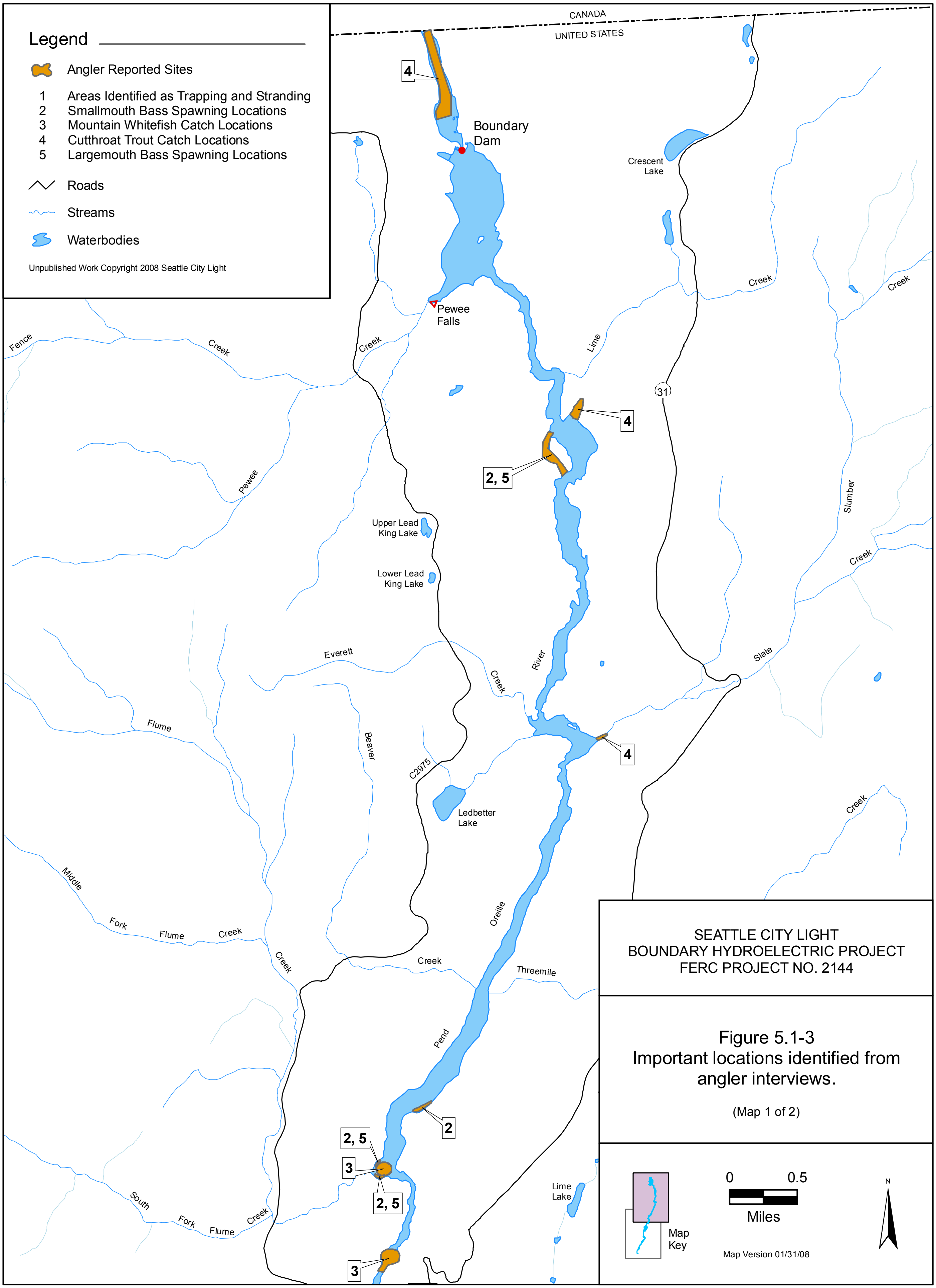
Most anglers interviewed during or immediately following the bass tournament (early May) stated that angling success was mostly associated with waters less than 10 feet in depth. Many of the anglers stated that the smallmouth bass were predominantly caught at about the 6- to 8-foot depth, most in areas with some aquatic vegetation as well as emergent grasses along the shorelines, but a few taken along steep rocky banks with current shear zones in the canyon area. Many anglers believed that the fish captured during the tournament were pre-spawning smallmouth bass.

Fourteen of the respondents believed that the tournament occurs prior to spawning. They typically observed fish associated with what they considered spawning areas during June. At least six of the respondents believed fish move away from the grassy areas into cobble/gravel areas for spawning during June. Ten respondents spoke of observing or capturing smallmouth bass during the spawning period at specific locations (Figure 5.1-3). Several respondents specifically referred to the shallows across from the Metaline Launch as well as a variety of off-channel and shallow margins upstream from the launch in the upper reservoir. Four of respondents spoke specifically of seeing what they believed to be bass nests dewatered during June in off channel and near shoreline shallow areas in the upper reservoir. These same respondents also reported stranded fish (bass and other unidentified species) in various locations, including the shallows across from the Metaline Launch, the islands near Wolf Creek, and off-channel areas near the high school (Figure 5.1-3). Two respondents identified specific spawning areas within the Canyon Reach, including the side channel area on the west side of Everett Island and shallow near shore drop-off areas near and downstream of Flume Creek.

Four respondents spoke of catching smallmouth bass in deeper water (greater than 10 feet) as the summer progressed, noting that the bedrock walls and boulder humps in the canyon provide for successful target areas. Another deeper area discussed by two respondents includes the rocky run water across from the mouth of Sweet Creek. One angler claimed capture of several 3- to 4-pound smallmouth bass from the area in August and September. Habitat in this area is characterized by boulder banks and bottom associated with relatively swift currents, thus providing what appears to be favorable ambush feeding stations within the velocity shadows and cover created by the boulder substrates. Other areas particularly noted for later summer concentrations of smallmouth bass include the area along the eastern side of Everett Island and the shorelines near the Lime Creek embayment, where steeply rocky banks afforded concealment habitat.

5.1.6.2. Mountain Whitefish

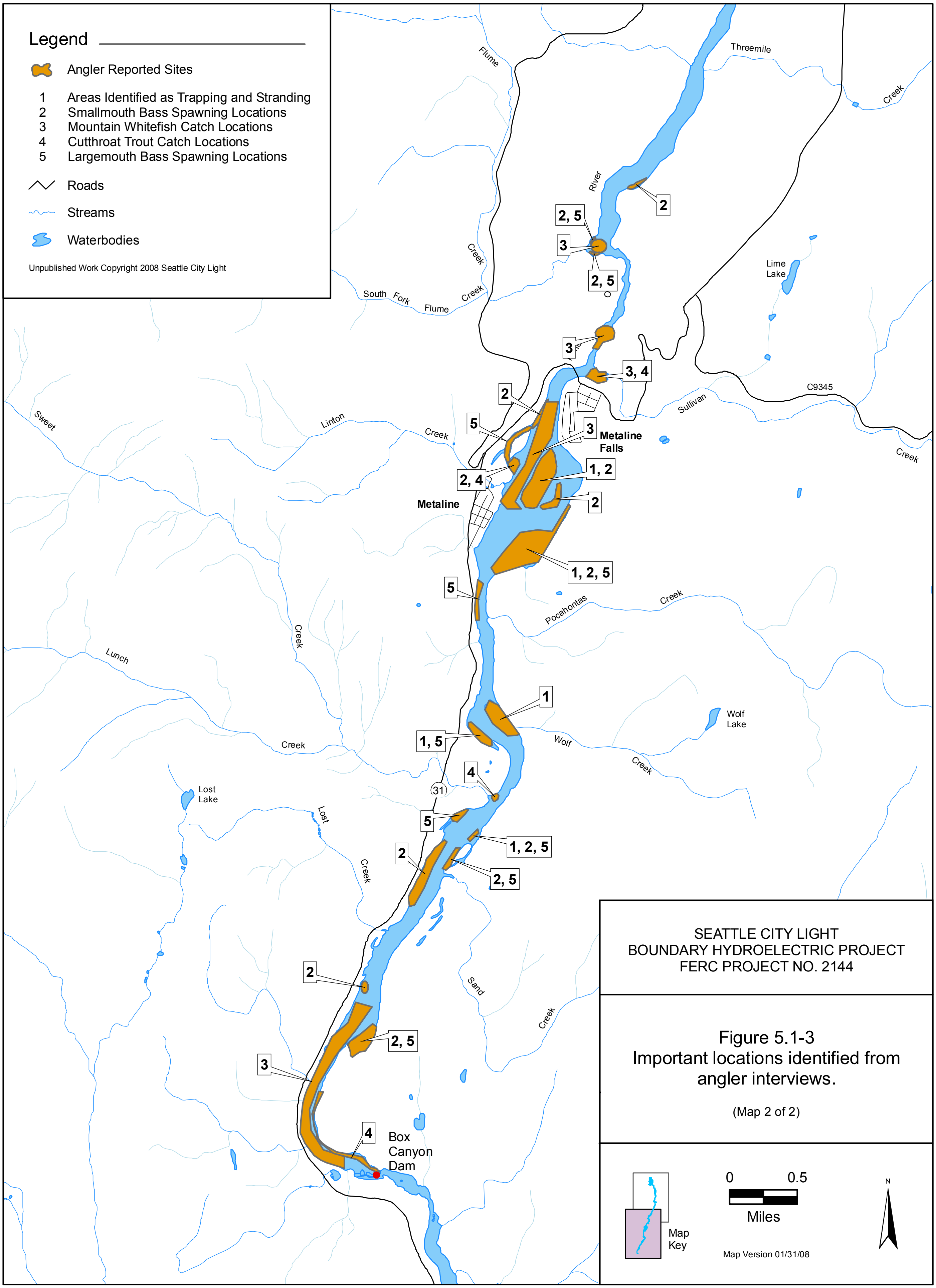
Few of the anglers interviewed pursued mountain whitefish. Fifteen of the respondents spoke of capturing whitefish in the reservoir, seven of which reported targeting whitefish during the late fall through late winter. The primary locations where mountain whitefish were reported captured



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.1-3
Important locations identified from angler interviews.

(Map 1 of 2)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.1-3
Important locations identified from angler interviews.

(Map 2 of 2)

during the late fall and winter included the areas within 1 mile of the Box Canyon Dam, at the mouth of Sullivan Creek, in Deadman's eddy near Flume Creek mouth, and near the Metaline Launch. Reported capture locations during other seasons included those mentioned above, as well as the area just downstream of Metaline Falls, the tailrace of Box Canyon dam, and the narrow channel just upstream of the town of Metaline. None of the respondents claimed that they caught numerous whitefish during any one outing, suggesting there were limited congregations of whitefish.

5.1.6.3. Cutthroat Trout

Most anglers questioned specifically about cutthroat trout said that they were rarely captured. Only 12 of the 26 respondents had recollections of capturing cutthroat trout, although all of them claimed to have captured several triploids and a few wild rainbow trout, suggesting cutthroat trout are rarer in the reservoir than these other species. These 12 respondents all said that the species was rarely captured, even as long as 15 years ago. Three respondents spoke specifically of capturing what they considered “cutbows,” that is rainbow/cutthroat trout hybrids. Areas specifically noted for capturing cutthroat trout included the embayment near Lime Creek, the mouths of Slate Creek, Sullivan Creek, and Sweet Creek, the area near Metaline Launch, and the tailrace of both Boundary Dam and Box Canyon Dam. One respondent reported catching cutthroat on occasion near Linton Creek. Only one respondent claimed that he regularly catches cutthroat trout in the Project waters, with the majority of captures occurring in the Boundary Dam tailrace between December and March.

5.1.6.4. Bull Trout

Few anglers had information on bull trout in the reservoir, tailrace, or tributaries. Four respondents claimed to have caught “a few” bull trout in the reservoir, three of which reported captures at the mouth of Sullivan Creek and in the Box Canyon tailrace. One respondent reported capturing two bull trout at the mouth of Sullivan Creek several years ago, both less than “2 pounds.” One respondent claimed that he captured a bull trout he estimated at approximately 10 pounds about 10 years ago at the mouth of Sullivan Creek. Another respondent described capturing “a few” bull trout at the base of Box Canyon dam over the past 15 years. None of the anglers reported bull trout at any other tributary delta, although most stated they had fished at the creek mouths of all the major reservoir tributaries.

5.1.6.5. Other Sport Fish

Other sport fish species discussed by the respondents included walleye, northern pike, largemouth bass, wild rainbow trout, and triploid trout. Six of the respondents believed that their catch of wild rainbow trout and “cutbows” have declined over the past several years. Four of the respondents also commented on the congregations of triploid trout around the mouths of Sweet Creek, Flume Creek, and Slate Creek during the hot summer months.

Three respondents spoke specifically of their increased catch rates of walleye and northern pike in the upper reservoir over the last 5 years; one respondent specifically noted that he and his partner caught 10 northern pike in 1 day of fishing. All northern pike catches were reported in the upper reservoir. Walleye catches were associated with the faster water downstream of Box

Canyon Dam, as well as the moderate depths along the eastern shore of the reservoir just upstream of the Metaline Falls Bridge.

Eleven respondents discussed largemouth bass catch and observations in the upper reservoir, noting both spawning fish and rearing juvenile fish throughout the side channels and off-channel areas (i.e., areas that are wetted by backwatering) in the upper reservoir. The flats across from the Metaline Launch and the sloughs near the high school were areas that several respondents reported observing spawning largemouth bass (Figure 5.1-3).

5.1.6.6. Trapping and Stranding

Only four respondents specifically expressed concern regarding the potential dewatering of "bass nests" and the occasional trapping of fish in backwater sloughs. Each of these respondents stated they had observed either dewatered nests or trapped fish in the upper reservoir during late June and July. Specific locations identified included the mid channel shallows and backwater sloughs near the Metaline Launch, the cobble islands near Wolf Creek, and the off channel areas on both sides of the river near the Selkirk High School. Three of these respondents reported seeing trapped or dead fish associated with these areas; two of the three reported observing trapped fish, including adult bass. All observed fish were observed in isolated puddles. None of the respondents commented observing fished trapped among dense aquatic vegetation, although they acknowledged that they did not specifically look in the macrophyte beds.

5.1.7. Data Compilation

As described in Section 4.1.7, the data compilation task of the habitat mapping effort, as originally conceived in the RSP, was not conducted.

5.2. Hydraulic Routing Model

This section includes a brief summary of the model development and the results of the primary calibration of the upstream hydraulic model (Boundary Dam to Box Canyon Dam). Appendix 5 includes a more thorough and detailed documentation of these results. The development of the upstream hydraulic model is nearly complete, with the only remaining task to replace the DTM derived cross section geometry with the ADCP-derived transect geometry at each of the habitat transect locations. The primary calibration effort for the upstream hydraulic model is complete, meaning that all data available through December 2007 have been incorporated into the calibration of the model.

The downstream hydraulic model (Boundary Dam to Seven Mile Dam) has not been developed nor calibrated at this time, and as such is not discussed in detail in this section.

5.2.1. Description of System and Need for Hydraulic Routing Model

Based on hydraulic conditions, the Pend Oreille River between Box Canyon Dam and Boundary Dam can be divided into three distinct reaches: 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. Flow velocities through the reach are quite low due to the backwater created by Boundary Dam. In contrast to the Canyon Reach, the Upper Reservoir Reach is characterized as more of a riverine reach, since backwater effects from Boundary Dam are reduced during low Boundary forebay conditions due to 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.

Water surface elevation fluctuations originating in the Boundary forebay are translated for the 17.5 mile distance to Box Canyon Dam. However, the wave characteristics dampen, or attenuate, as the wave travels upstream. Variability in the channel morphology of the Pend Oreille River upstream of Boundary Dam affects the wave travel time and the magnitude of the wave attenuation. Metaline Falls is an example of this variability.

5.2.2. Data Used to Construct and Calibrate the Hydraulic Routing Model

This section presents various aspects of the upstream hydraulic model development, including:

- Bathymetry and topography used to develop the upstream hydraulic model
- Cross section location and development
- Boundary conditions for the upstream hydraulic model
- Data and information specifically used to calibrate the upstream hydraulic model

5.2.2.1. Bathymetry and Topography

A multibeam sonar bathymetric survey was conducted within the Boundary Dam Reservoir by Global Remote Sensing, LLC (GRS) in 2006. The data from this survey were supplemented and checked, in selected areas, with a high resolution multibeam bathymetry and scanning laser shoreline survey, collected 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. More detail regarding the methods and results of this data collection effort are summarized in the Study 25 (Bathymetric Survey) report (SCL 2008j).

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 and LIDAR data were merged together to form a continuous digital terrain model (DTM) in the form of a triangulated irregular network (TIN).

5.2.2.2. Cross Sections

Cross sections are used in the hydraulic model to characterize the hydraulic conditions and the conveyance capacity at specific locations along the river. Cross section locations were identified at changes in channel bed slope and channel shape and where changes in channel roughness conditions were observed during the site visits. Cross sections were also located at the habitat transect locations and at specific points where hydraulic information will be required for input to other studies during the relicensing process. For the upstream hydraulic routing model, 231 cross sections were ultimately included in the model. Figure 5.2-1 is an example figure showing

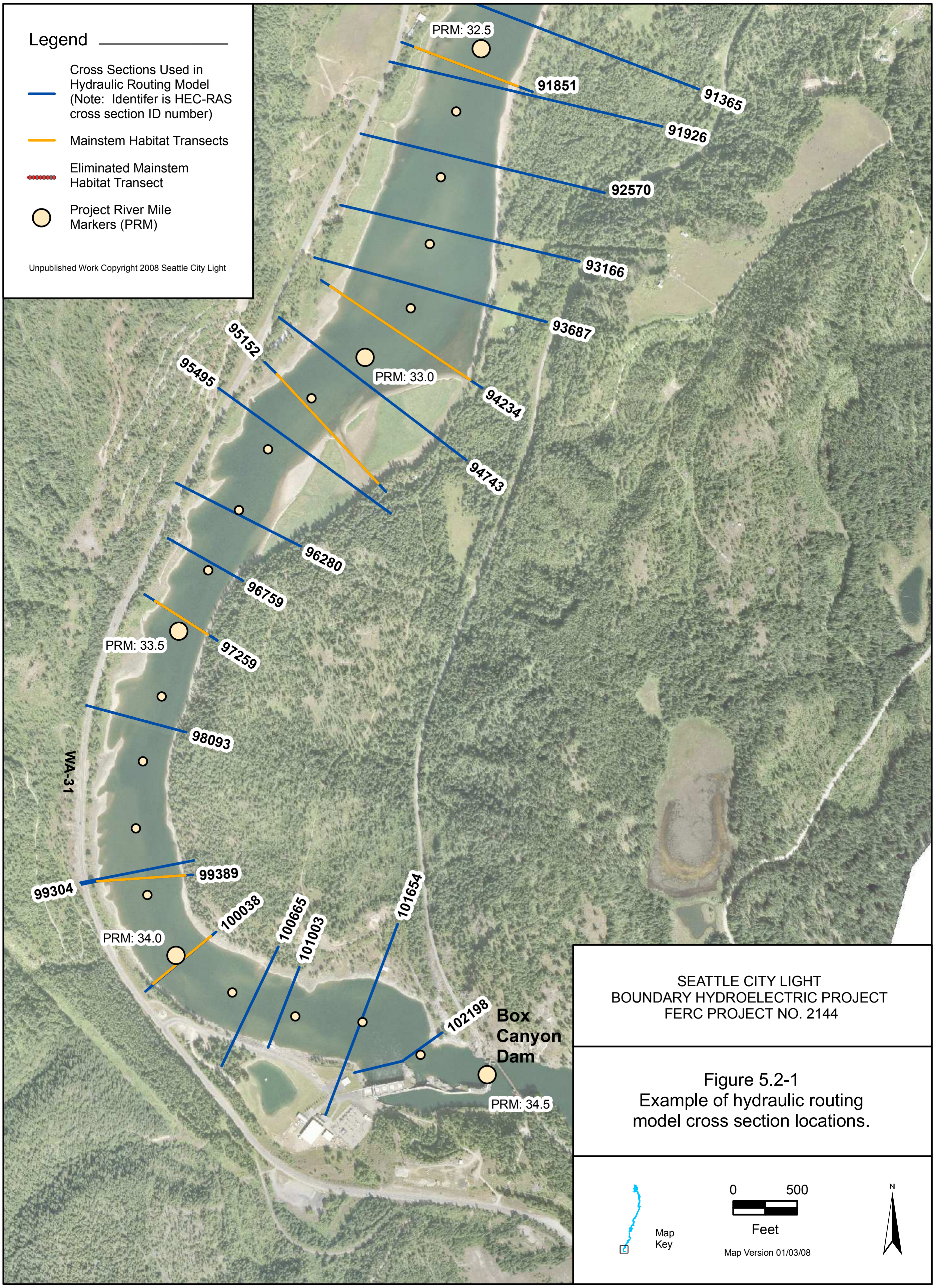


Figure 5.2-1
Example of hydraulic routing model cross section locations.

the cross section locations at the upstream end of the Upper Reservoir Reach. A complete set of figures showing all cross section locations is included in Appendix 5.

Cross section geometry was generated by "cutting" through the DTM using the HEC-GeoRAS software. The cross section geometry was then imported into the HEC-RAS model. All cross sections currently included in the upstream hydraulic model were derived from the DTM. Once the habitat transect cross section geometry is available, each cross section located at a habitat transect will be replaced with the field surveyed habitat transect geometry.

5.2.2.3. Boundary Conditions

The boundary conditions for the calibration of the upstream hydraulic model included a time series of Boundary Project forebay elevations (downstream boundary condition) and a time series of flow rates as measured at the USGS Gaging Station 12396500 (upstream boundary condition). The boundary conditions that will be used to calibrate the downstream hydraulic routing model will include a time series of Seven Mile Project forebay elevations (downstream boundary condition) and a time series of Boundary Project outflow data as provided by SCL.

For the evaluation of operations scenarios, the calibrated hydraulic routing models will use model output from the Scenario Tool optimization, along with measured data, as the boundary conditions.

5.2.2.4. Information for Calibration

The period of record that the upstream (and downstream) hydraulic routing models will ultimately be calibrated to includes the months of September 2006 through December 2008, inclusive. It has been proposed, although it has not been approved, to maintain the pressure transducer installations only through July 2008. The model has currently been calibrated to the data collected through September 2007, therefore representing a 13-month period of continuously collected data at a 15-minute time increment.

Available data used for the calibration of the upstream hydraulic model (including verification) include the following:

- USGS water surface elevation data at USGS Gage Station 12396500
- Water depth data collected at five pressure transducer installations between Boundary Dam and Box Canyon Dam

Data that are not yet available but that will be used for model calibration include the water surface elevation data collected at each habitat transect during specific flow conditions in 2007.

5.2.3. Model 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.

5.2.3.1. Initial n-Value and Loss Coefficient Estimates

Initial estimates of the main channel and overbank Manning's roughness coefficients and the expansion and contraction loss coefficients were based on observations made during the September 2007 site visit and guidance presented in USACE-HEC (2006), Barnes (1967), and Arcement and Schneider (1989). Table 5.2-1 summarizes the estimated initial values.

Table 5.2-1. Initial estimates of model calibration parameters for upstream hydraulic routing model.

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	100038	34.39	34.01	0.045	0.040	0.045	0.1	0.3
100038	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	27.59	26.90	0.035	0.030	0.035	0.1	0.3
60555	60143	26.90	26.83	0.028	0.028	0.028	0.1	0.3
60143	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 Appendix 5 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.

5.2.3.2. Primary Calibration and Verification of Hydraulic Model

Calibration of the upstream hydraulic model used an iterative process proceeding from the downstream end of the model (Boundary forebay) to the upstream end of the model (Box Canyon tailrace). The magnitudes of the Manning's roughness coefficients and the expansion and contraction loss coefficients were iteratively adjusted within physically acceptable ranges until the model-predicted water surface elevations were within the error ranges as established in Section 4.2. The calibration process also included defining ineffective flow areas within each cross section, as appropriate, so as to simulate flow expansion and contraction in a physically consistent manner. Table 5.2-2 presents the final estimated values for the model calibration parameters.

Table 5.2-2. Final estimates of model calibration parameters for upstream hydraulic routing model.

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	98093	34.39	33.64	0.060	0.037	0.050	0.1	0.3
98093	94743	33.64	33.03	0.060	0.036	0.050	0.1	0.3
94743	90344	33.03	32.24	0.050	0.032	0.050	0.1	0.3
90344	83995	32.24	31.08	0.040	0.028	0.040	0.1	0.3
83995	81030	31.08	30.54	0.050	0.032	0.050	0.1	0.3
81030	76404	30.54	29.75	0.050	0.032	0.075	0.1	0.3
76404	72815	29.75	29.08	0.050	0.032	0.050	0.1	0.3
72815	60555	29.08	26.90	0.050	0.032	0.050	0.3	0.5
60555	60143	26.90	26.83	0.089	0.089	0.089	0.5	0.7
60143	59729	26.83	26.75	0.123	0.123	0.123	0.5	0.7
59729	59451	26.75	26.69	0.123	0.123	0.123	0.9	0.9
59451	57424	26.69	26.31	0.089	0.089	0.089	0.9	0.9
57424	12044	26.31	17.99	0.089	0.089	0.089	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 Appendix 5 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.

Table 5.2-3 presents a tabular summary of the Phase One results of the model calibration at each of the six calibration locations for the group of calibration periods. This table was developed by comparing the model-predicted water surface elevation to the actual observed water surface elevation at each of the 15-minute time ordinates at each calibration location for each calibration period. The calibration periods encompass a total of 92 days of observed conditions, and therefore, nearly 8,800 time ordinate comparisons were made at each calibration location.

Table 5.2-3 shows that for 96 percent of the time, the model-predicted water surface elevations were within 0.6 feet of the actual observed water surface elevations at all of the calibration locations. With the exception of the Auxiliary USGS location, the model-predicted water surface elevations were within 0.4 feet of the observed water surface elevations more than 93 percent of the time. As described previously in Section 4.2, an initial goal of a maximum absolute error of 0.75 foot was defined at the onset of the model calibration process. Table 5.2-3 shows that this goal was attained at three of the calibration locations, including the two transducer locations upstream and downstream of Metaline Falls.

The fourteen instances where the absolute error was greater than 0.75 feet are not necessarily attributed to an unsuccessful model calibration. Nearly half of them are instead attributed to unique occurrences when outflow from Box Canyon Dam was rapidly reduced or rapidly increased for a brief period of time. 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. The calibrated model did not replicate the precise timing of the resulting downstream water surface elevation fluctuation. Figure 5.2-2 illustrates this phenomenon for the occurrence during the Hi_Lo calibration period. As seen in this figure, the calibrated model replicated the magnitude of the water surface fluctuation, but not the exact timing. Appendix 5 includes a more detailed discussion of the calibration results, and includes additional post-processing analysis that illustrates the success of the model calibration.

Table 5.2-3. Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the calibration periods.

Cumulative Range	Calibration Location[1,2]					
	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
< 0.2 feet	59.40 %	62.21 %	48.04 %	75.71 %	80.92 %	99.76 %
< 0.4 feet	92.30 %	95.04 %	80.39 %	95.25 %	93.65 %	99.99 %
< 0.6 feet	99.95 %	98.59 %	95.65 %	98.50 %	99.57 %	100.00 %
< 0.75 feet	99.97 %	99.99 %	99.89 %	100.00 %	100.00 %	100.00 %

Notes:
1 There were 92 calendar days represented in the calibration periods.
2 Model output and observed data were compared at 15-minute time intervals.

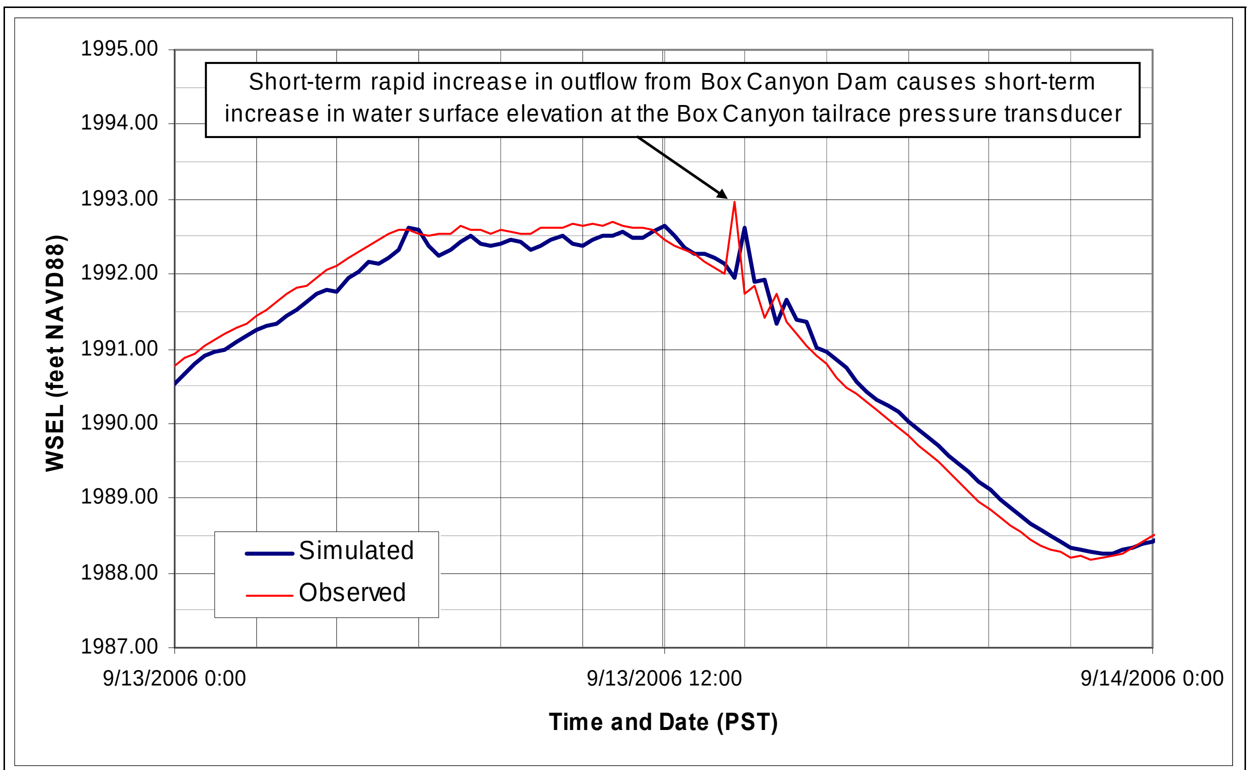


Figure 5.2-2. Example of timing associated with rapid short-term change in Box Canyon Dam outflow.

Verification of the calibrated hydraulic model (Phase Two) was conducted by executing the calibrated model for five time periods (verification periods) that were not originally included in the model calibration effort. No changes to the model input parameters were made. Based on the same evaluators that were used to quantify the success of the model calibration, it was found that the model-predicted results for the verification periods equaled or exceeded the success achieved using the calibration periods. The results of the verification model runs provided an independent substantiation to the model calibration, and it was therefore determined that adjustments to the model input parameters were not warranted or necessary.

Table 5.2-4 presents a tabular summary of the results of the model verification for each verification period at each of the six calibration locations. This table is the same format as the table previously presented for the calibration result. The verification periods encompass a total of 54 days of observed conditions, and therefore, approximately 5,100 time ordinate comparisons were made at each of the calibration locations.

This table shows that for 96 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. With the exception of the Auxiliary USGS location, the model-predicted water surface elevations were within 0.4 foot of the observed water surface elevations more than 91 percent of the time. Finally, the table shows that the results for the verification periods were within the 0.75 foot goal established in Section 4.2 at the two pressure transducers located downstream of Metaline Falls. As mentioned previously in the calibration discussion, and as discussed in detail in Appendix 5, those few instances where the maximum absolute error was greater than 0.75 foot are not necessarily attributed to an unsuccessful model calibration.

Table 5.2-4. Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the verification periods.

Cumulative Range	Calibration Locations[1,2]					
	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
< 0.2 foot	61.38 %	68.62 %	44.11 %	83.10 %	88.54 %	99.98 %
< 0.4 foot	91.41 %	96.55 %	80.91 %	99.12 %	99.69 %	100.00 %
< 0.6 foot	99.88 %	99.96 %	96.31 %	99.96 %	100.00 %	100.00 %
< 0.75 foot	99.92 %	99.98 %	99.90 %	99.96 %	100.00 %	100.00 %

Notes:
1 There were 54 calendar days represented in the verification periods.
2 Model output and observed data were compared at 15-minute time intervals.

The final step of the calibration process (Phase Three) was to execute the calibrated model for the entire 13-month period of available pressure transducer data, which was inclusive of the previously run calibration and verification periods. This step is considered a broad verification of the calibrated model in that it provides verification of the model calibration using all pressure transducer data collected to date. Table 5.2-5 presents a tabular summary of the results of the model verification for the broad verification period at each of the six calibration locations. The broad verification period includes nearly 13 months of continuously collected data, and therefore, there were a total of nearly 38,000 time ordinate comparisons made at each of the calibration locations.

Table 5.2-5. Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the broad verification period.

Cumulative Range	Calibration Locations[1,2,3]					
	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
< 0.2 foot	62.24 %	73.88 %	56.23 %	82.47 %	87.39 %	99.75 %
< 0.4 foot	94.20 %	98.11 %	88.59 %	98.64 %	97.93 %	99.99 %
< 0.6 foot	99.96 %	99.65 %	98.13 %	99.65 %	99.90 %	100.00 %
< 0.75 foot	99.98 %	99.99 %	99.96 %	99.99 %	100.00 %	100.00 %

Notes:

1 There were 13 months represented in the broad verification period.

2 Broad verification period includes the entire 13-month period of data collection used for the primary model calibration.

3 Model output and observed data were compared at 15-minute time intervals.

5.2.4. Primary Calibration Results

This section presents the primary calibration results in graphical form to provide illustration of the success of the model calibration and presents the conclusions regarding the need for a separate seasonal model. Appendix 5 includes a more thorough presentation of these results. Using the calibrated model as an interpretive tool, Appendix 5 also includes discussion and graphs that illustrate the Pend Oreille River system's hydraulic characteristics, such as the point-in-time variability of the flow rate through the length of Boundary Reservoir and the magnitude of the attenuation and translation of the floodwaves that originate in the Boundary forebay.

Figure 5.2-3 is a time series plot that compares the model-predicted water surface elevation to the observed water surface elevation for the pressure transducer location located immediately upstream of Metaline Falls (US_MET) for the Lo_Mod calibration period (Low Pool and Moderate Flow). Appendix 5 contains similar plots for each of the six calibration locations during each of the six calibration periods. Appendix 5 also includes similar plots for the five verification periods.

Figure 5.2-3 illustrates the calibrated model's success in replicating the rising and falling limbs of the floodwaves and in replicating the timing of the peaks. Quantitative analysis of the accuracy of the model to predict peak timing was not conducted, but time series plots such as shown in Figure 5.2-3 and in Appendix 5 provide the basis to state qualitatively that the calibrated model is accurately replicating the timing of fluctuating water surface elevations, and therefore the translation of the floodwaves throughout the reach upstream of the Project.

Based on the tabular results presented in Section 5.2.3 and in Appendix 5, and the graphical results presented in Section 5.2.4 and Appendix 5, it is concluded that the primary calibration of the upstream hydraulic routing model was successfully completed. The model calibration was conducted for inflow rates ranging between 2,400 cfs and 55,400 cfs and for Boundary forebay elevations ranging between 1,964.62 and 1,995.08 feet NAVD 88 (1,960.59 and 1,991.05 feet NGVD 29).

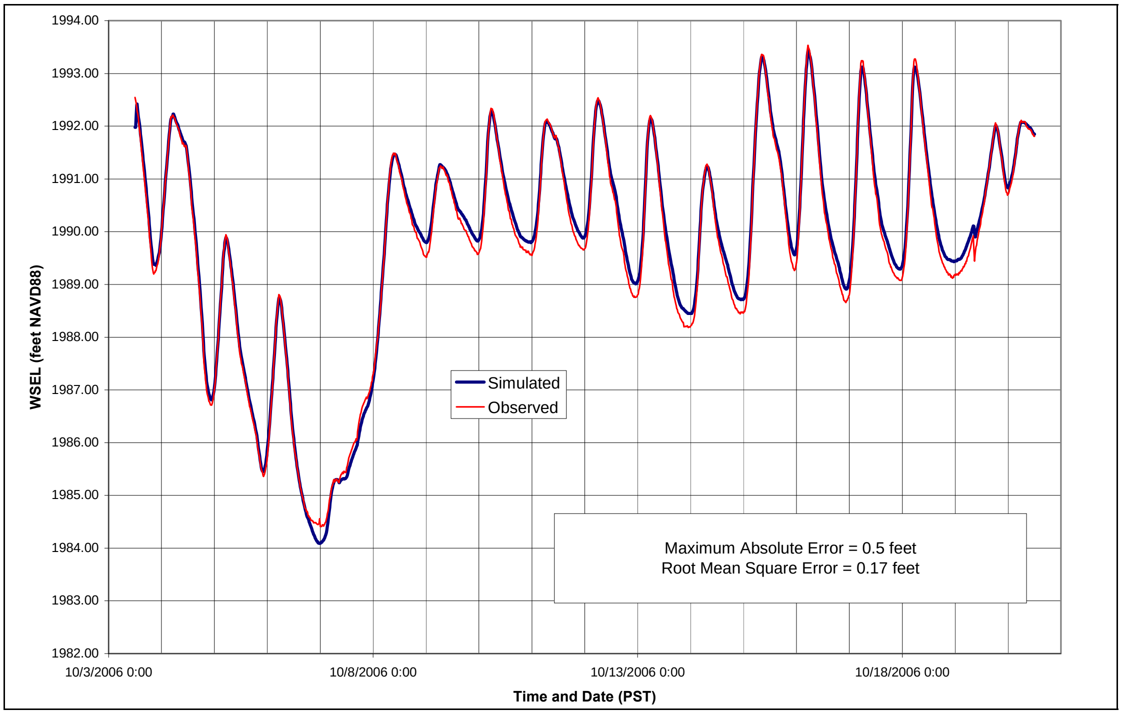


Figure 5.2-3. Model calibration results for Lo_Mod Calibration Period at US_MET Pressure Transducer Location.

5.2.4.1. Assessment of the Need for Separate Seasonal Models

Successful model calibration and verification was attained for the 13-month data collection period without the need for using seasonal correction factors to account for the potential 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 or backwater areas where flow is not effectively conveyed or where average velocities are very low. 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.

This initial conclusion was substantiated with a detailed evaluation of the 13-months of output from the calibrated model. The results were reviewed to determine if the calibrated 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 macrophytes in the summer months. 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 is 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.

5.3. Physical Habitat Model Development

A summary of the results of the Physical Habitat Model Development effort (Study 7.3) for 2007 primarily involves the tasks associated with the data collection effort for the mainstem transect measurements. The efforts include the selection of transect locations, coordination and approval of the transect locations by the relicensing participants, performing the substrate and cover characterization for the transects, performing the velocity and depth measurements for the transects, and development of the cross-sectional velocity profiles. The transect selection process has been completed for the entire study area and the data collection effort has been conducted for the three reaches upstream of Boundary reservoir. The collection of the transect measurements for the Pend Oreille River below Boundary Dam, referred to as the Tailrace Reach, is scheduled for March 2008.

The mainstem habitat transect data collection results from 2007 are not presented in detail, but are summarized by providing a description of the extent of information collected. There is a tremendous amount of information associated with the raw data from the ADCP readings. This information is currently undergoing reduction and quality assurance / quality control (QA/QC) review. The data reduction efforts include determining cell velocities for specific cell widths and estimating mean column velocities for cells in which the depth exceeded the range of the equipment (deep water reservoir areas greater than approximately 50 feet). The QA/QC efforts include reviewing data for reasonableness and consistency, incorporation of the transects into the hydraulic routing model to check elevations, and comparison of the transect profiles with those generated by the bathymetry. A complete report on the results of the 2007 transect data collection effort will be prepared and distributed in the spring of 2008.

The final five tasks in the Physical Habitat Model Development effort involve development of specific modeling routines and application of the models. The work effort associated with this aspect of Study 7.3 includes refinement of the methods used to conduct the various analyses. These efforts are represented by the presented in Section 4.3. The actual application of the physical habitat models will occur in 2008 and early 2009. The suite of physical habitat models will be applied to the flow conditions determined from the hydraulic routing for each operations scenario to evaluate the changes in aquatic habitat in the Mainstem Pend Oreille River between Box Canyon Dam and Red Bird Creek.

5.3.1. 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. Sixty-three transects were required to describe aquatic habitat conditions within the Pend Oreille River from Box Canyon Dam to near Red Bird Creek. The transect distribution, by reach, is presented in Table 5.3-1 and the transect locations are shown in Figure 5.3-1.

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 this same meeting the number and locations of the transects upstream of the Boundary Dam were approved (Table 5.3-1 and Figure 5.3-1), 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 transects in the U.S. portion of the Tailrace Reach were approved.

Detailed bathymetry was not available for the Canadian portion of the 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 bathymetric 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.–Canadian border. The number and locations of the transects in the Canadian portion of the Tailrace Reach were approved at the July 24, 2007 Fish and Aquatics Workgroup meeting.

Table 5.3-1. Number and location of transects selected for Physical Habitat Model Development.

Reach	Range of Project River Miles	Length of Reach (miles)	No. of Transects
Upper Box Canyon Dam to Metaline Falls	PRM 34.5 to 26.8	7.7	24
Canyon Metaline Falls to Canyon mouth	PRM 26.8 to 18.0	8.8	20
Forebay Canyon mouth to Boundary Dam	PRM 18.0 to 17.0	1.0	5
Tailrace			
Boundary Dam to US/Canadian Border	PRM 17.0 to 16.0	1.0	6
US/Canadian Border to Redbird Creek	PRM 16.0 to 13.9	2.1	8
Totals		20.6	63

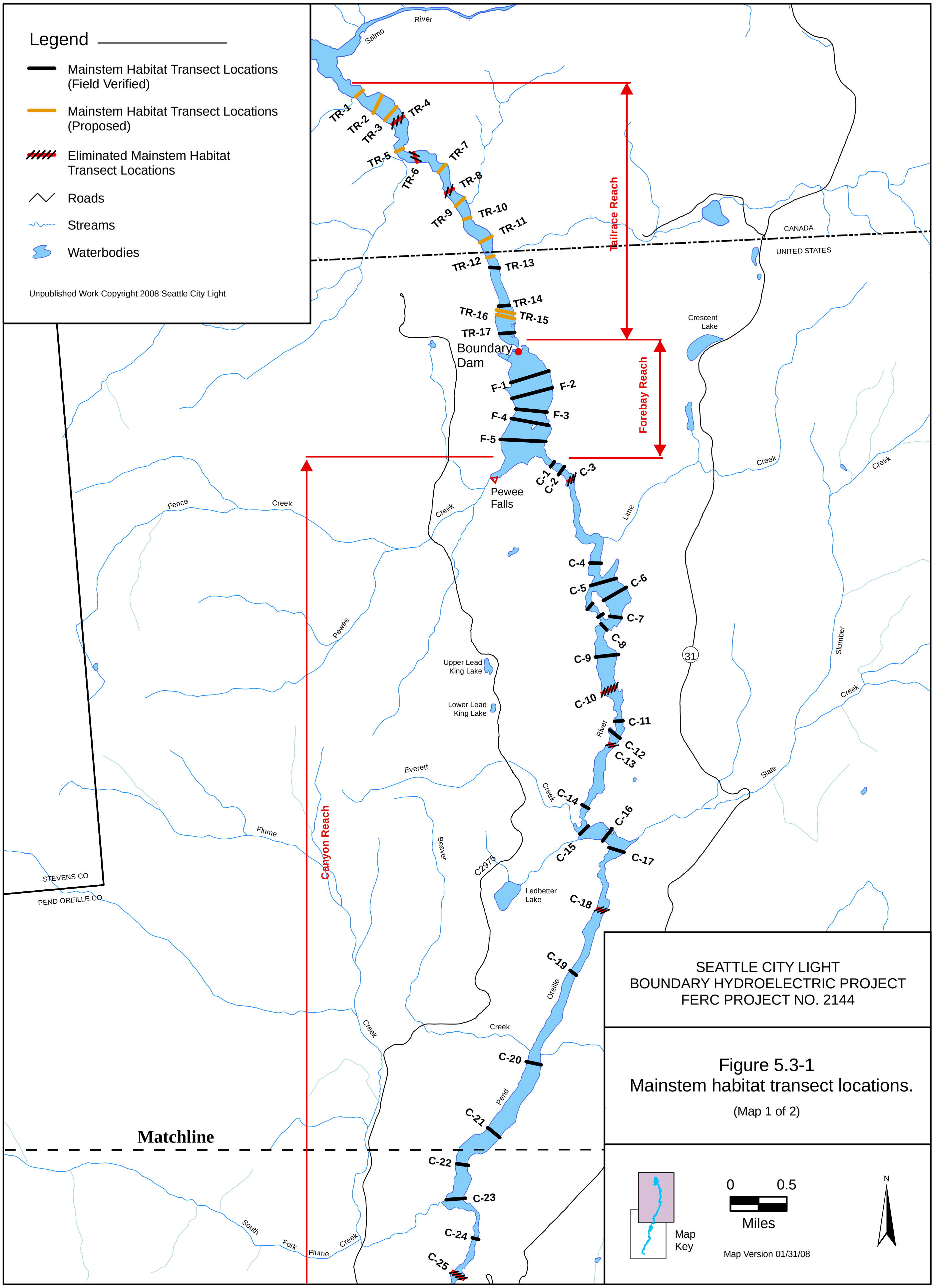
.

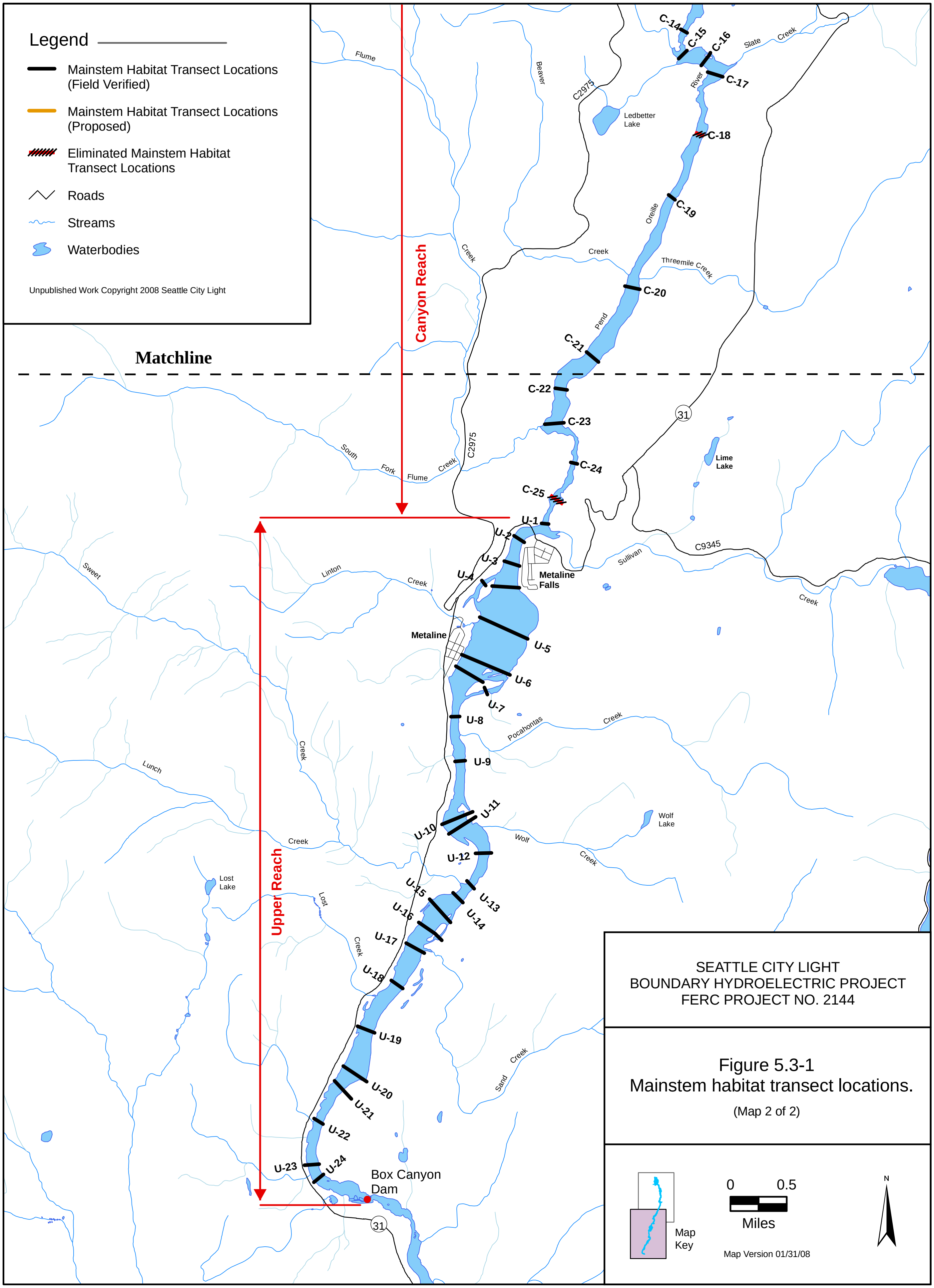
5.3.2. Relicensing Participant Site Visit

As described in transect selection (Section 5.3.1), proposed transect locations were reviewed and discussed with relicensing participants during the meetings of the Fish and Aquatics Workgroup held on April 24, June 7, and July 24, 2007. As a result of these meetings, modifications were made to the number of transects and their locations prior to reaching consensus. 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.

5.3.3. Substrate and Aquatic Vegetation Characterization

Substrate and aquatic vegetation were mapped and characterized at selected transect locations to a depth of 50 feet below the full pool water surface. An underwater video camera was used to map and characterize substrate and aquatic vegetation in water too deep to observe from the surface. Cover types were characterized using the codes presented in Table 4.3-3, substrate was characterized using the codes in Table 4.3-4, and aquatic vegetation was characterized using the codes and subcodes in Tables 4.3-5 and Table 4.3-6, respectively. Substrate and cover coding occurred from September 6 through 9, 2007. Partial measurements on transects with expected macrophyte growth occurred on April 3, 2007 to document conditions prior to macrophyte growth.


Legend
Mainstem Habitat Transect Locations (Field Verified)
Mainstem Habitat Transect Locations (Proposed)
Eliminated Mainstem Habitat Transect Locations
Roads
Streams
Waterbodies
Unpublished Work Copyright 2008 Seattle City Light
Salmo
River
TR-1
TR-2
TR-3
TR-4
TR-5
TR-6
TR-7
TR-8
TR-9
TR-10
TR-11
TR-12
TR-13
TR-14
TR-15
TR-16
TR-17
Tailrace Reach
CANADA
UNITED STATES
Crescent Lake
Boundary Dam
F-1
F-2
F-3
F-4
F-5
Forebay Reach
C-1
C-2
C-3
Pewee Falls
Creek
Lime
Fence
Creek
Pewee
C-4
C-5
C-6
C-7
C-8
C-9
C-10
C-11
C-12
C-13
C-14
C-15
C-16
C-17
C-18
C-19
C-20
C-21
C-22
C-23
C-24
C-25
31
Slumber
Creek
Slate
Upper Lead King Lake
Lower Lead King Lake
River
Everett
Creek
Flume
Canyon Reach
Beaver
C2975
Ledbetter Lake
STEVENS CO
PEND OREILLE CO
Oreille
Pend
Creek
Matchline
South
Fork
Flume
Creek
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure 5.3-1
Mainstem habitat transect locations.
(Map 1 of 2)
Map Key
0
0.5
Miles
N
Map Version 01/31/08



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.3-1
Mainstem habitat transect locations.
(Map 2 of 2)

5.3.4. Velocity and Depth Measurements

Table 5.3-2 presents the schedule for the collection of flow velocity, water surface elevation, and bottom profile measured at the selected habitat transect alignments during a variety of flow and reservoir pool combinations.

In the Upper Reservoir Reach, the velocity measurements and flow data were collected at the 24 transects during high, middle, and low flow with low pool elevation as well as at high flow with high pool elevation (Tables 5.3-3 and 5.3-4). Flow, profile, and water surface elevation data were also collected on April 3 and 4, 2007 with high pool and high flow conditions at transects likely to have macrophyte growth (Transects U-4, U-5, U-6, U-10, U-11, U-15, U-20, and U-21). Macrophyte growth did not, however, impact ADCP measurements until the July middle flow data collection.

Table 5.3-2. 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	Actual Flow for Velocity and Water Surface Measurements (*or anticipated schedule*) [1,2]
Upper Box Canyon Dam to Metaline Falls	High pool: 43,000 - 53,000 cfs (May 24 - 26 2007) Low pool: 34,000 - 39,000 cfs (May 30-31, 2007) 17,000 - 22,000 cfs (July 11-12, 2007) 7,500 – 9,700 cfs (August 22-23, 2007)
Canyon Metaline Falls to Canyon mouth	High pool: 34,000 - 42,000 cfs (May 26-28, 2007)
Forebay Canyon mouth to Boundary Dam	High pool: 40,000 cfs (May 27, 2007)
Tailrace Boundary Dam to U.S.-Canada Border U.S.-Canada Border to Redbird Creek	High pool: *early spring 2008* Low pool: *early spring 2008* *early spring 2008* *early spring 2008* High pool: *early spring 2008*
Total	

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.

Table 5.3-3. Preliminary water surface elevations and discharges measured in the Upper Reservoir Reach transects for all target calibration flows at the high pool condition.

Transect	Water Surface Elevation (ft)[1]	Flow Rate (cfs)[2]	Date of Measurement
U-1	1,998.28	47,326	25-May-07
U-2	1,998.33	47,195	24-May-07
U-3	1,998.25	48,116	24-May-07
U-4	1,998.28	48,157	24-May-07
U-4 SC[3]	1,998.22	904	24-May-07
U-5	1,998.23	46,398	24-May-07
U-6	1,997.92	45,723	24-May-07
U-7	1,997.67	45,952	24-May-07
U-7 SC[3]	1,997.70	-546	24-May-07
U-8	1,998.09	50,210	24-May-07
U-9	1,997.73	48,110	24-May-07
U-10	1,998.27	53,028	24-May-07
U-11	1,998.19	48,114	24-May-07
U-12	1,999.55	46,828	25-May-07
U-13	1,999.36	46,242	25-May-07
U-14	1,999.60	45,669	25-May-07
U-15	1,999.59	46,346	25-May-07
U-16	1,999.43	47,334	25-May-07
U-17	1,999.27	45,778	25-May-07
U-18	1,999.17	45,986	25-May-07
U-19	1,999.05	47,452	25-May-07
U-20	1,999.03	44,271	25-May-07
U-21	1,999.06	47,050	25-May-07
U-22	1,999.09	46,516	25-May-07
U-23	1,998.78	43,199	26-May-07
U-24	1,999.10	44,356	26-May-07

Notes:
1 All water surface elevations are preliminary and are referenced to the NAVD 88 datum.
2 Flow rates determined from ADCP measurements.
3 SC = Side Channel.

Table 5.3-4. Preliminary water surface elevations and discharges measured in the Upper Reservoir Reach transects at all target calibration flows for low pool condition.

	High Flow Target			Moderate Flow Target			Low Flow Target		
Transect	Water Surface Elevation (ft)[1]	Flow Rate (cfs)[2]	Date of Measurement	Water Surface Elevation (ft)[1]	Flow Rate (cfs)[2]	Date of Measurement	Water Surface Elevation (ft)[1]	Flow Rate (cfs)[2]	Date of Measurement
U-1	1,991.75	35,834	31-May-07	1,988.22	22,344	11-Jul-07	1,984.78	9,696	22-Aug-07
U-2	1,992.22	34,035	31-May-07	1,988.51	20,918	11-Jul-07	1,985.01	9,094	22-Aug-07
U-3	1,992.12	34,041	31-May-07	1,988.33	21,499	11-Jul-07	1,984.64	9,393	22-Aug-07
U-4	1,992.20	33,963	31-May-07	1,988.22	19,262	11-Jul-07	1,983.69	8,435	22-Aug-07
U-4 SC[3]	1,992.16	285	31-May-07	1,988.11	0	11-Jul-07	Dry	0	22-Aug-07
U-5	1,992.69	34,861	30-May-07	1,987.98	19,533	11-Jul-07	1,984.46	9,213	22-Aug-07
U-6	1,992.64	36,711	30-May-07	1,988.82	17,271	12-Jul-07	1,984.35	8,459	22-Aug-07
U-7	1,992.46	39,198	30-May-07	1,987.75	18,122	11-Jul-07	1,984.086	8,714	22-Aug-07
U-7 SC[3]	1,992.36	-93	30-May-07	Dry	0	11-Jul-07	Dry	0	22-Aug-07
U-8	1,992.34	35,804	30-May-07	1,987.92	21,480	11-Jul-07	1,983.94	8,973	22-Aug-07
U-9	1,992.38	34,533	30-May-07	1,987.69	21,144	11-Jul-07	1,983.78	8,850	22-Aug-07
U-10	1,992.86	36,489	30-May-07	1,988.01	20,904	11-Jul-07	1,983.99	8,807	22-Aug-07
U-11	1,992.83	34,575	30-May-07	1,987.97	20,264	11-Jul-07	1,983.96	8,352	22-Aug-07
U-12	1,992.96	36,146	30-May-07	1,988.13	20,528	11-Jul-07	1,983.91	8,612	22-Aug-07
U-13	1,992.88	34,232	30-May-07	1,987.99	19,791	11-Jul-07	1,983.67	8,568	22-Aug-07
U-14	1,993.12	34,407	30-May-07	1,988.08	19,750	11-Jul-07	1,983.64	8,569	22-Aug-07
U-15	1,993.15	34,124	30-May-07	1,988.07	18,761	11-Jul-07	1,983.50	8,386	22-Aug-07
U-16	1,993.05	34,173	30-May-07	1,989.17	18,389	12-Jul-07	1,984.06	8,191	23-Aug-07
U-17	1,992.99	35,465	30-May-07	1,989.03	18,025	12-Jul-07	1,984.24	8,222	23-Aug-07
U-18	1,993.05	34,115	30-May-07	1,988.75	19,050	12-Jul-07	1,984.30	8,094	23-Aug-07
U-19	1,993.39	35,021	31-May-07	1,988.58	18,467	12-Jul-07	1,984.22	8,274	23-Aug-07
U-20	1,993.51	35,409	31-May-07	1,988.61	18,736	12-Jul-07	1,984.33	7,796	23-Aug-07
U-21	1,993.68	3,570	31-May-07	1,988.55	18,893	12-Jul-07	1,984.45	8,365	23-Aug-07
U-22	1,993.91	35,039	31-May-07	1,988.80	19,459	12-Jul-07	1,984.63	8,786	23-Aug-07
U-23	1,994.48	35,681	31-May-07	1,989.29	18,931	12-Jul-07	1,985.22	8,117	23-Aug-07
U-24	1,995.03	35,449	31-May-07	1,989.94	18,478	12-Jul-07	1,985.75	7,444	23-Aug-07

Notes:
1 All water surface elevations are preliminary and are referenced to the NAVD 88 datum.
2 Flow rates determined from ADCP measurements.
3 SC = Side Channel.

High pool data collection for the Upper Reservoir Reach transects occurred from May 24 to May 26 with transect pool elevations between 1,997.67 and 1,999.60 feet NAVD 88 (1,993.64 and 1,995.57 feet NGVD 29) and discharges between 43,000 and 53,000 cfs as measured at the transects. Note that point discharges in the project area upstream of Boundary Dam vary depending on the outflow from Box Canyon Dam and the Boundary Dam power generation schedule, thus creating deviations from the mean daily discharges (41,700 cfs to 48,200 cfs) for the same period (Table 5.3-3). Hourly water surface fluctuations in the Boundary forebay created fluctuations in point discharges within the study area.

Subsequent to the high pool data collection, the pool elevation was dropped and low pool, high flow data were collected for the Upper Reservoir Reach transects on May 30 and 31. The pool elevation and flow at the transects varied from 1,991.75 to 1,995.73 feet NAVD 88 (1,987.72 and 1,991.70 feet NGVD 29) and 34,000 to 39,105 cfs, respectively, during those measurements. The average daily discharges below the Box Canyon dam at the USGS gage 12396500 were 33,400 cfs and 33,700 cfs, respectively.

Low pool, middle flow data were collected for the Upper Reservoir Reach transects on July 11 and 12, with transect water surface elevations between 1,987.69 and 1,989.94 feet NAVD 88 (1,983.66 and 1,985.91 feet NGVD 29) and flows measured at the transects between 17,271 and 22,344 cfs. The average daily discharges below the Box Canyon dam at the USGS gage 12396500 were 20,100 and 19,000 cfs.

Low pool, low flow data were collected for the Upper Reservoir Reach transects on August 22 and 23, 2007, with substrate and cover coding prior and subsequent to those days. The water surface elevation and flow measured at the transects ranged from 1,983.50 to 1,985.75 feet NAVD 88 (1,979.47 to 1,981.72 feet NGVD 29) and 7,444 to 9,696 cfs, respectively. The average daily discharges below the Box Canyon dam at the USGS gage 12396500 were 9,030 and 9,250 cfs.

In the Canyon Reach, the water velocities and profiles were measured at high pool and high flow on May 26 through May 29, 2007 with pool water surface elevations at the transects ranging from 1,991.59 to 1,994.33 feet (NAVD 88) and discharges ranging from 33,900 to 42,400 cfs, as determined from the calibrated hydraulic routing model (Table 5.3-5). Mean daily flow rates as reported at the USGS Gage 12396500 ranged from 34,400 to 41,700 cfs during the data collection period.

Forebay Reach transects were measured at high pool and high flow, with pool elevations at the transects between 1,992.17 and 1,992.60 feet NAVD 88 (1,988.14 and 1,988.57 feet NGVD 29) and discharges ranging from 38,000 to 41,600 cfs, as determined from the calibrated hydraulic routing model (Table 5.3-5).

Since the velocity pattern in the deep Canyon and Forebay Reach transects was measured with the ADCP to a depth of only 50 feet, and the remaining velocities were interpolated, the discharges at the transects were determined from the output of the hydraulic routing model.

Table 5.3-5. Preliminary water surface elevations and discharges measured in the Canyon Reach and Forebay Reach transects at the high flow target calibration flow for the high pool condition.

Transect	Water Surface Elevation (ft)[1]	Flow Rate (cfs)[2]	Date of Measurement	Time of Measurement (PDT)[4]
C-1	1,992.25	40,500	27-May-07	9:17:32
C-2	1,992.24	39,200	27-May-07	11:18:57
C-4	1,991.60	40,900	28-May-07	11:32:35
C-5	1,993.12	34,100	29-May-07	7:01:58
C-6	1,993.23	33,900	29-May-07	7:27:56
C-6 SC[3]	1,992.96	N/A	29-May-07	7:49:26
C-7	1,993.11	35,400	29-May-07	8:20:13
C-7 SC[3]	1,993.00	N/A	29-May-07	8:52:15
C-8	1,991.59	37,400	28-May-07	9:14:55
C-9	1,991.65	38,200	28-May-07	9:34:11
C-11	1,992.00	35,600	28-May-07	11:15:21
C-12	1,991.99	35,600	28-May-07	11:53:08
C-14	1,992.22	35,700	28-May-07	13:00:58
C-15	1,992.34	35,600	28-May-07	13:28:29
C-16	1,992.46	35,300	28-May-07	6:47:16
C-16 SC[3]	1,992.50	N/A	28-May-07	7:16:40
C-17	1,992.57	35,900	28-May-07	7:48:01
C-19	1,992.20	40,700	29-May-07	8:49:43
C-20	1,993.09	35,700	29-May-07	9:07:49
C-21	1,993.41	34,900	29-May-07	9:48:00
C-22	1,993.04	42,100	26-May-07	10:57:34
C-23	1,993.49	34,900	29-May-07	11:32:33
C-24	1,994.19	34,500	29-May-07	12:08:51
F-1	1,992.60	38,000	27-May-07	6:43:39
F-2	1,992.51	39,500	27-May-07	7:20:06
F-3	1,992.42	41,600	27-May-07	7:58:45
F-4	1,992.25	41,400	27-May-07	8:33:39
F-5	1,992.17	40,200	27-May-07	9:11:39

Notes:
N/A = side channel flow rate not available from hydraulic routing model output.
1 All water surface elevations are preliminary and are referenced to the NAVD 88 datum.
2 Flow rates were obtained from output from the calibrated hydraulic routing and were rounded to the nearest 100 cfs.
3 SC = Side Channel.
4 Time of measurement relative to Pacific Daylight Savings Time (PDT); however, hydraulic modeling analysis is exclusively relative to PST.

5.3.5. Develop Cross-Sectional Profiles

The distribution of flow velocity was measured across the selected habitat transects for the combinations of flow and reservoir pool elevations presented in Section 5.3.4. The ADCP 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. While the data have been collected and processed, the QA/QC has not yet been conducted.

5.3.6. Hydraulic Model Integration

Cross section geometry collected during the ADCP transect data collection effort described in Section 5.3.4 will be incorporated into the hydraulic routing models. The ADCP collected transect geometry will replace the DTM-derived cross section geometry only at the selected habitat transect locations. For each habitat transect, the recorded positions of the left and right end points of the ADCP data collection will be overlaid onto the DTM. The portion of the DTM-derived cross section between these two endpoints will be replaced with the ADCP derived geometry and the hydraulic routing model will be revised. Once the ADCP data goes through QA/QC procedures, the data will be integrated into the hydraulic model.

5.3.7. Calibrate Hydraulic Model

The hydraulic routing model must be calibrated to not only the observed water surface elevations as described in Section 5.3.4, but must also be calibrated to the horizontal velocity distributions that were measured during the ADCP data collection periods. The calibration of this aspect of the hydraulic model cannot be performed until these data undergo QA/QC processes.

5.3.8. Downramping Analysis

The primary effort performed in 2007 on the downramping analysis was development of the methods. The methods for performing the downramping analysis were presented in Section 4.3.8. The downramping analyses will be performed in 2008.

5.3.9. Stranding and Trapping Analysis

The primary effort performed in 2007 on the standing and trapping analysis was development of the methods. The methods for performing the stranding and trapping analysis were presented in Section 4.3.9. Field data collection efforts to support the stranding and trapping analysis were conducted in 2007 with a summary of results presented in Section 5.5. The stranding and trapping analyses will be performed in 2008.

5.3.10. Varial Zone Model

The primary effort performed in 2007 on the varial zone analysis was development of the methods. The methods for performing the varial zone analysis were presented in Section 4.3.10. The varial zone analyses will be performed in 2008.

5.3.11. Habitat Weighted Usable Area

The primary effort performed in 2007 on the habitat WUA analysis was development of the methods. The methods for performing the habitat WUA were presented in Section 4.3.11. The habitat WUA analyses will be performed in 2008.

5.3.12. Post-Processing

The post processing of the physical habitat modeling data will occur as the modeling components described in Sections 5.3.5 through 5.3.11 are performed for each operations scenario.

5.4. Habitat Suitability Indices Development

Development of HSI is being performed to support the Physical Habitat Model Development and application effort. The work includes development of HSI for fish (Study 7.4.1), macrophytes (Study 7.4.2), periphyton (Study 7.4.3) and benthic macroinvertebrates. Each of these efforts had significant portions of the work effort performed in 2007 and in general, the work efforts performed to date are at a similar level. All four efforts have completed a major portion of their data collection efforts and in the case of macrophytes the data collection effort associated with the HSI development has been completed. Each effort also included development of literature-based HSI curves, which have also been completed. The Fish HSI included the development of a literature-based periodicity table, which has also been completed.

The data collected to date have not been used to modify the literature-based HSI curves. For the fish HSI, data have been plotted on the literature-based curves. The fish periodicity table has been updated to reflect data collected in 2007 and the addition of more species based on information from the literature. In the case of the data collected for macrophytes, periphyton and BMI, it has been reviewed but has not been plotted on curves due to the need to have results from the hydraulic routing model to interpret the data. (The hydraulic routing model was not completed until late December 2007 due to delays in receiving final bathymetry.)

The following subsections present a summary of the results for each of the four HSI studies. The detailed information for each of these studies is provided in Appendices 1 through 4.

5.4.1. Fish HSI

The results of the literature-based HSI, with inclusion of site-specific field measurement of habitat use, are presented below. Additionally, the periodicity of target species by life stage and other species that were found to be potentially stranded or trapped is also provided. Depending on fish species and life stage distribution within the Project area, some HSI curves presented will only be used in the reservoir and others only in the tailrace (see Section 5.4.1.1). Limited field data are available for native salmonids in the reservoir or tailrace areas to develop HSI curves, so the primary source of curve development will be literature. Initial judgement curves for the life stages to be used for future discussions with resource groups are also provided. Literature and some site-specific data were available do determine when important life stages may be present in the system. All information will be used in future expert panel discussions to determine the final HSI curves and periodicity to use in the mainstem habitat model.

5.4.1.1. Development of Literature-Based HSI

Available literature was searched for information describing HSI relationships and life-stage periodicity for each target species, including mountain whitefish, bull trout, cutthroat trout, redband trout, smallmouth bass, and cyprinid forage species. The principal HSI variables of depth and mean column velocity were plotted with all candidate HSI curves to identify general trends in habitat suitability, particularly the ranges of habitat showing zero suitability and ranges showing maximum suitability. Draft interim HSI curves were then developed by professional judgement according to the trends in the available data, along with patterns of habitat use shown by site-specific observations of target fish in the Project area. Appendix 1a contains the draft interim HSI curves for each target species and life stage, with the associated literature-based HSI data and the site-specific HSI data collected as of September 2007. Figure 5.4-1 provides an example of the suite of available HSI curves from literature sources, along with site-specific HSI data from the Boundary Project area, and the interim Boundary HSI curve based on that data. Note that all target species and life stages are not known to occur in all Project reaches. For example, the spawning life stage for bull trout and cutthroat trout and all life stages of redband trout are assumed to occur in the Boundary tailrace reach, but not within the Boundary Reservoir reach.

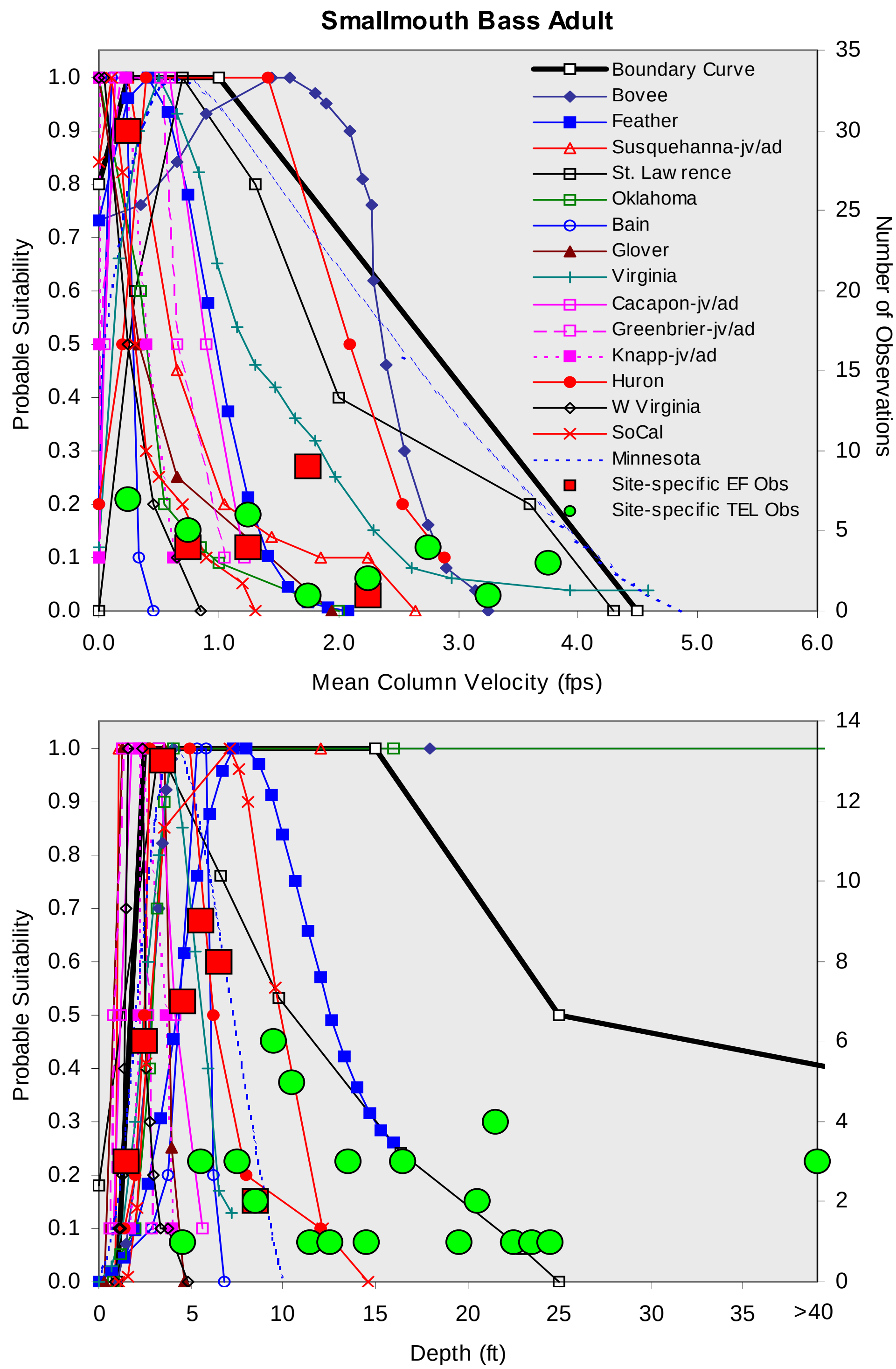


Figure 5.4-1. Example of HSI curve-sets for adult smallmouth bass, showing available literature-based curves, site-specific electrofishing (EF) and biotelemetry (TEL) observations from the Boundary Project area, and the interim Boundary curves.

(Note: *See Appendix 1a for HSI curves and associated data tables for all target species and life-stages.*)

5.4.1.2. Data Collection Efforts for Fish HSI

Site-specific HSI data were collected for target species using biotelemetry and boat electrofishing methodologies. It was expected that biotelemetry would provide the least biased HSI information for adult fish, since 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, and some changes in data collection are recommended for 2008 based on those limitations (as well as the overall rarity of several target species) (see Section 7). The details regarding fish capture and fish observation methodologies from the biotelemetry and the electrofishing efforts, as well as the associated data statistics, can be found in the Study 9 interim report (SCL 2008f). A summary of the number of electrofishing cells sampled by electrofishing and the number of fish tagged with radio or CART tags, along with the number of individual HSI observations associated with those samples, is given in Table 5.4-1. This table illustrates the rarity of several target species and the expected need to rely on literature-based HSI for these species and life-stages.

Table 5.4-1. Summary of site-specific HSI data from electrofishing and biotelemetry on the Project, April through September 2007.

Sampling Method	Month	# Electro-fishing Cells[1]	Fish Species[2]							
			Bull Trout	Cut-throat Trout	Rainbow Trout (wild)	Mountain Whitefish	Smallmouth Bass <6 cm	Smallmouth Bass 6-15 cm	Smallmouth Bass >15cm	Forage <10cm[3]
Boat Electro-fishing	March	11	0	0	1	0	0	0	0	1
	April	103	0	0	1	0	0	2	3	4
	May	87	0	0	1	1	0	5	10	4
	June	0	0	0	0	0	0	0	0	0
	July	60	0	0	0	0	1	4	4	0
	Aug	97	0	0	0	0	9	28	13	14
	Sept	96	0	0	0	0	2	19	4	7
	Total # Cells	454	0	0	3	1	12	58	34	30
	Total # Fish	NA	0	0	3	1	12	93	44	92
Bio-telemetry[4]	# Tagged Fish	NA	0	2	3	1	0	0	15	0
	# HSC Observation	NA	0	6	0	2	0	0	44	0

Note:
1 Number of HSI cells sampled by electrofishing.
2 Number of cells with target species and total number of fish in cells.
3 Forage species are cyprinids less than about 10 cm length.
4 Number of tagged fish; number of observations includes multiple observations for several tagged fish.

The sample sizes for all target species and life stages are well below the minimum suggested goal of 150-200 observations (Bovee 1986), especially if the number of electrofishing cells, rather than the number of individual fish, is considered. Although additional HSI data are anticipated to be collected through the remainder of 2007 and into 2008, it is unlikely that any species or life stages will achieve 150 observations. Consequently, it is anticipated that the primary use of the site-specific HSI data will be to help evaluate the representativeness of the existing HSI curves. In this case, an existing curve should be selected or a new curve developed based on the interim Boundary curve, which is considered a placeholder curve for subsequent discussion (see Appendix 1 for HSI curve data).

5.4.1.3. Periodicity Tables

Periodicity information was acquired from literature sources. When available, site-specific observations of target species and non-target species from Project electrofishing or stranding and trapping studies were also plotted against the literature periodicity data. Table 5.4-2 summarizes the interim periodicity dates for each species and life stage. The associated literature-based periodicities and site-specific capture data are detailed in Appendix 1b. Note that it is assumed that juvenile and adult salmonids and smallmouth bass are present year-round in the project area, although they may not all be present in Boundary Reservoir (e.g., redband trout). The assumption of year-round periodicity also appears to apply to cyprinid fish greater than fry size up to the forage size maximum of 10 cm, which were captured from early spring, based on 1999 sampling in Boundary Reservoir by WDFW (McLellan and O'Conner 2001) to late-fall, based on SCL electrofishing in October. Periodicity dates for spawning and fry rearing for the target species and the non-target species will also serve to assess the stranding and trapping potential for those vulnerable life stages during operations scenarios.

Table 5.4-2. Interim periodicity dates for target and non-target species and life-stages in the Boundary Project area.

Species	Spawning	Incubation	Fry (<u><</u>55 mm) Rearing
Mountain Whitefish	15 Oct – 25 Feb	15 Oct – 1 May	1 Apr – 15 Aug
Bull Trout[1]	1 Sep – 15 Dec	1 Sep – 25 Mar	15 Mar –15 July
Cutthroat Trout[1]	15 Mar – 15 June	15 Mar – 1 Aug	15 June – 30 Oct
Redband Trout[2]	1 Mar – 30 June	1 Mar – 15 Aug	1 May – 30 Oct
Smallmouth Bass	15 May – 15 July	15 May – 1 Aug	1 June – 15 Oct
Cyprinid Forage	25 Apr – 20 July	25 Apr – 1 Aug	22 Apr – 30 Sept
Largescale Suckers	25 Mar – 30 June	25 Mar – 15 July	7 Apr – 31 Oct
Yellow Perch	15 Mar – 15 May	15 Mar – 25 May	25 Mar – 30 Sept
Largemouth Bass	15 June – 31 July	15 June – 7 Aug	20 June – 31 Oct
Sunfish spp.	1 June – 31 Aug	1 June – 3 Sept	3 June – 31 Oct

Notes:
See Appendix 1b for additional details.
1 Life history stages are only proposed to be considered for the Tailrace Reach not Boundary Reservoir as these life stages are not present.
2 Life stages only apply to the tailrace as these life stages are not present in the Boundary Reservoir.

5.4.2. Macrophyte HSI

Interim habitat suitability curves were developed for macrophytes utilizing information from the literature. Data collection was performed in 2007 to support continued development of the macrophyte HSI. This information has not been incorporated into the HSI development since it required application of the hydraulic routing model to interpret. The hydraulic routing model has just been completed and the support analysis will be conducted in February. The information presented in the following subsection is a summary of the macrophyte HSI development effort. A complete stand-alone report is provided in Appendix 2.

5.4.2.1. Development of Interim HSI

An extensive literature search was conducted in 2007 to identify available information regarding the habitat suitability of macrophytes in a reservoir system with respect to depth of light, velocity, and substrate, and inundation and dewatering. With the information gathered, HSC were developed for each variable, as well as a HSI. Field studies have been conducted to gather site-specific data related to macrophyte communities in the Boundary Reservoir. The field data collected will be used to calibrate and revise the literature-based provisional suitability curves. This will be conducted through the development of a histogram (i.e., bar chart) for each of the habitat parameters (e.g., depth, velocity, substrate, frequency of inundation and dewatering) using the site-specific field observations. A histogram developed using field observations will then be compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve for aquatic habitat modeling. Once the suitability curves have been finalized, they will be incorporated into the larger HSI model, along with the periphyton, BMI, and fish data to gain a broader understanding of the biotic response to operations scenarios at the Project. The HSC are briefly described below and details regarding the results of the literature-based HSI may be found in Appendix 2.

Available literature regarding macrophyte habitat suitability suggests that macrophytes generally grow best in high-light levels. Depth of light suitability generally increased up to 3.2 feet. Habitat suitability then gradually decreases to where the suitability value reaches zero at >16.5 feet. A detailed review of the literature regarding the depth of light suitability for macrophytes is found in Appendix 2. Figure 5.4-2 displays the provisional depth of light suitability curve for macrophytes which is based on literature and professional judgement and will be refined based on field data.

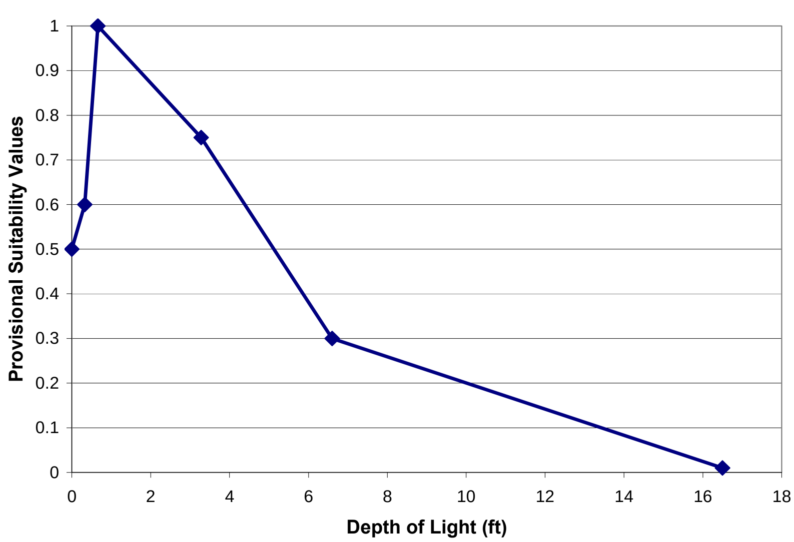


Figure 5.4-2. Provisional depth of light suitability curve for macrophytes.

Provisional suitability values for velocity were selected based on a synthesis of information found in the literature. The provisional suitability curve for water velocity was similar to that of depth in that it showed an initial increase in suitability as velocity increases up to a point at which it then gradually decreased. Available literature suggests that peak suitability for macrophytes is found at velocities between 0.66 to 3.26 feet (0.2 m to 0.99 m). A detailed review of the literature regarding velocity suitability for macrophytes is found in Appendix 2.

Figure 5.4-3 displays the provisional velocity suitability curve for macrophytes. The velocity suitability curve is based on literature and professional judgement and will be refined further based on data collected in the field to determine ranges of suitable velocities for macrophyte growth in Boundary Reservoir.

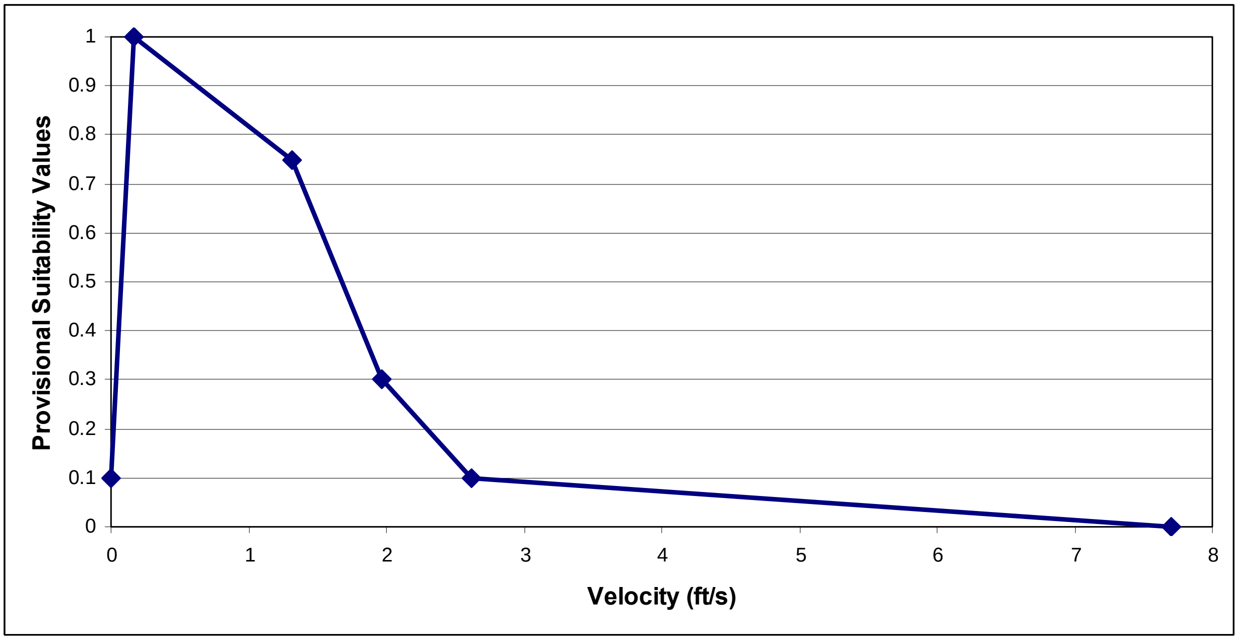


Figure 5.4-3. Provisional velocity suitability curve for macrophytes.

Available literature suggests that organic and fine texture substrates are the most suitable substrate for macrophytes as attachment and nutrient uptake is most available, whereas coarser substrates also provide suitable habitat for macrophytes but are less preferred. Bedrock provides no habitat for macrophytes as they are unable to attach and unable to acquire nutrients. 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. A detailed review of the literature regarding substrate suitability for macrophytes is found in Appendix 2. Figure 5.4-4 displays the provisional substrate suitability values for macrophytes.

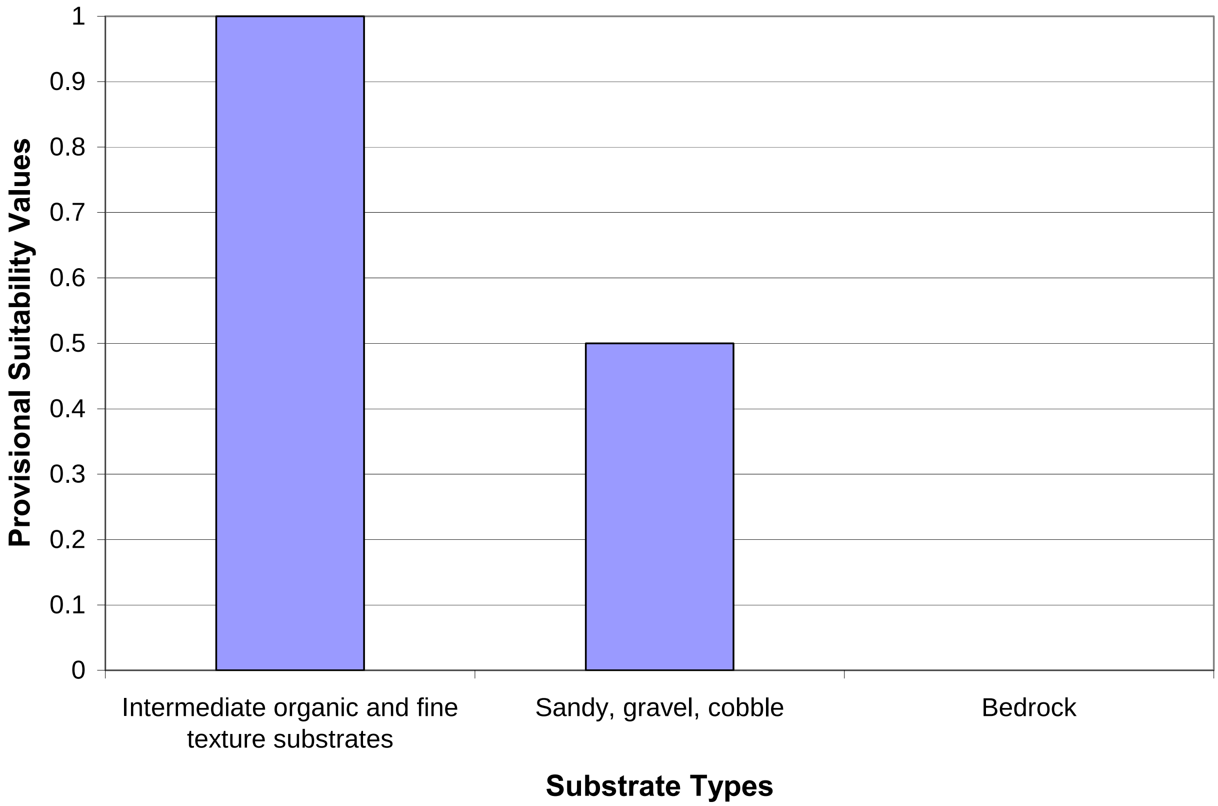


Figure 5.4-4. Provisional substrate suitability values for macrophytes.

Available literature regarding submergent macrophytes suggests that as the duration of dewatering increases, habitat suitability generally decreases. Several studies found that a duration of dewatering as little as 3 to 4 days is sufficient to kill submersed macrophytes (WSNWCB [undated]), whereas others suggest that only prolonged (one month or more) exposure is sufficient to achieve macrophyte control (Cooke 1980). Eurasian water milfoil 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 [undated]). Figure 5.4-5 displays the provisional duration of the dewatering suitability curves for submergent macrophytes. The provisional duration of dewatering suitability curve in Figure 5.4-5 was based on literature and professional judgement and will be refined further based on data collected in the field to determine ranges of suitability for macrophyte growth in Boundary Reservoir. A detailed review of the literature regarding the effects of dewatering on the habitat suitability of macrophytes is found in Appendix 2.

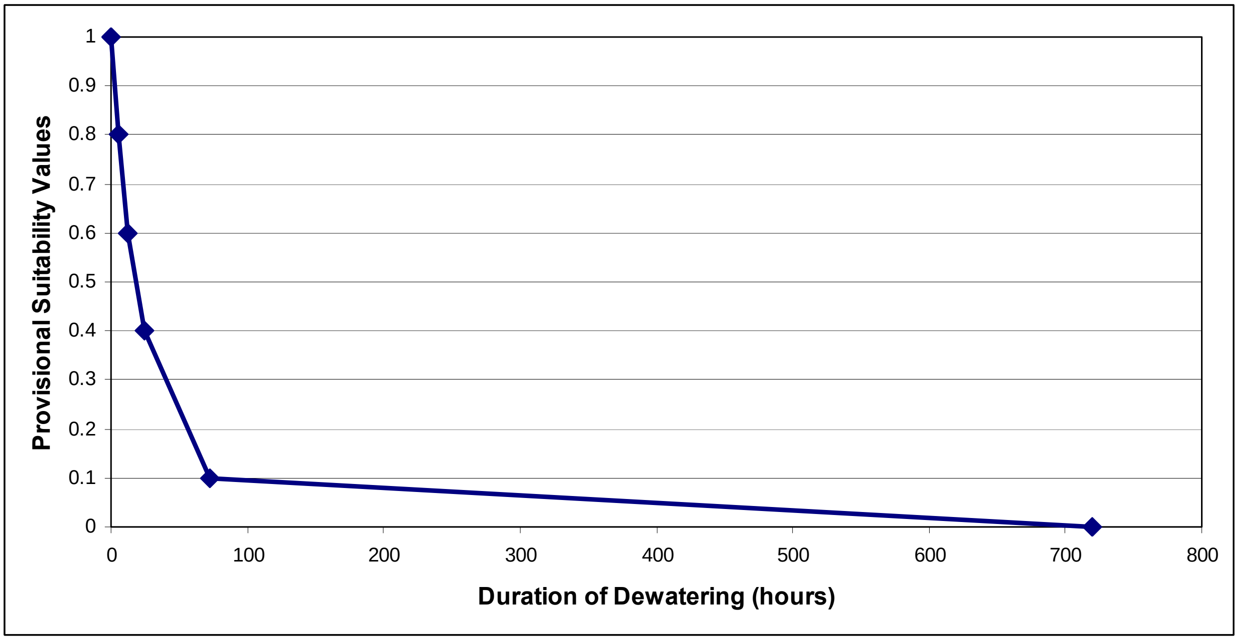


Figure 5.4-5. Provisional duration of dewatering suitability curve for submergent macrophytes.

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 5.4-3). The duration of inundation HSI factor will only be included during spring time steps in the Boundary Reservoir Physical Habitat Model.

Table 5.4-3. Duration of inundation provisional suitability values for macrophytes.

Constant Inundation	Provisional Suitability Values
yes	1.0
no	0

5.4.2.2. Data Collection Efforts

Field data were collected to validate the HSI curves for the following parameters: depth, velocity, substrate, and duration of inundation and during of dewatering as a function of macrophyte abundance. Selection of macrophyte HSI study sites was determined based on the habitat mapping. Sites were selected based on presence of macrophytes and representativeness of the study reach. Depth, velocity, and substrate data were collected along a total of 63 transects throughout the study area. Along each transect when aquatic plants were observed, additional descriptive and density data were recorded. In order to acquire data along depth, velocity, and substrate gradients, measurements were taken for both high and low water surface 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]) 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. Macrophyte habitat data (depth, velocity, and substrate), collected in August 2007), along with the duration of inundation and dewatering calculated from the hydraulic routing model will be sufficient to validate and refine macrophyte HSI curves for Boundary Reservoir.

5.4.3. Periphyton HSI

Interim habitat suitability curves were developed for periphyton utilizing information from the literuate. Data collection was performed in 2007 to support continued development of the periphyton HSI. This information has not been incorporated into the HSI development since it required application of the hydraulic routing model to interpret. The hydraulic routing model has just been completed and supporting analysis will be conducted in January and February to determine water surface elevations during the periphyton data collection efforts. Additional data collection will be performed through early 2008. The information presented in the following subsection is a summary of the periphyton HSI development effort. A complete stand-alone report is provided in Appendix 3.

5.4.3.1. Development of Interim HSI

An extensive literature search was also conducted to identify available information regarding the habitat preferences of periphyton with respect to water depth, velocity, and substrate, and inundation and dewatering in a reservoir system. With the information gathered, HSC were developed for each variable, as well as a HSI, for the periphyton model. Field studies are currently underway to gather site-specific data related to periphyton communities in the Boundary Reservoir. The site-specific field data collected will be used to calibrate and revise the literature-based provisional suitability curves. Once the suitability curves have been finalized, they will be incorporated in the larger HSI model, along with the macrophyte, BMI, and fish data, to gain a broader understanding of the biotic response to operations scenarios at the Project. The HSC are briefly described below and details regarding the results of the literature-based HSI may be found in Appendix 3.

Provisional depth suitability values for periphyton were selected based on estimates of the depth of the euphotic zone in Boundary Reservoir and available literature values. 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 5.4-6 displays the provisional depth suitability curve for periphyton. A detailed review of the literature regarding the depth suitability for periphyton is found in Appendix 3.

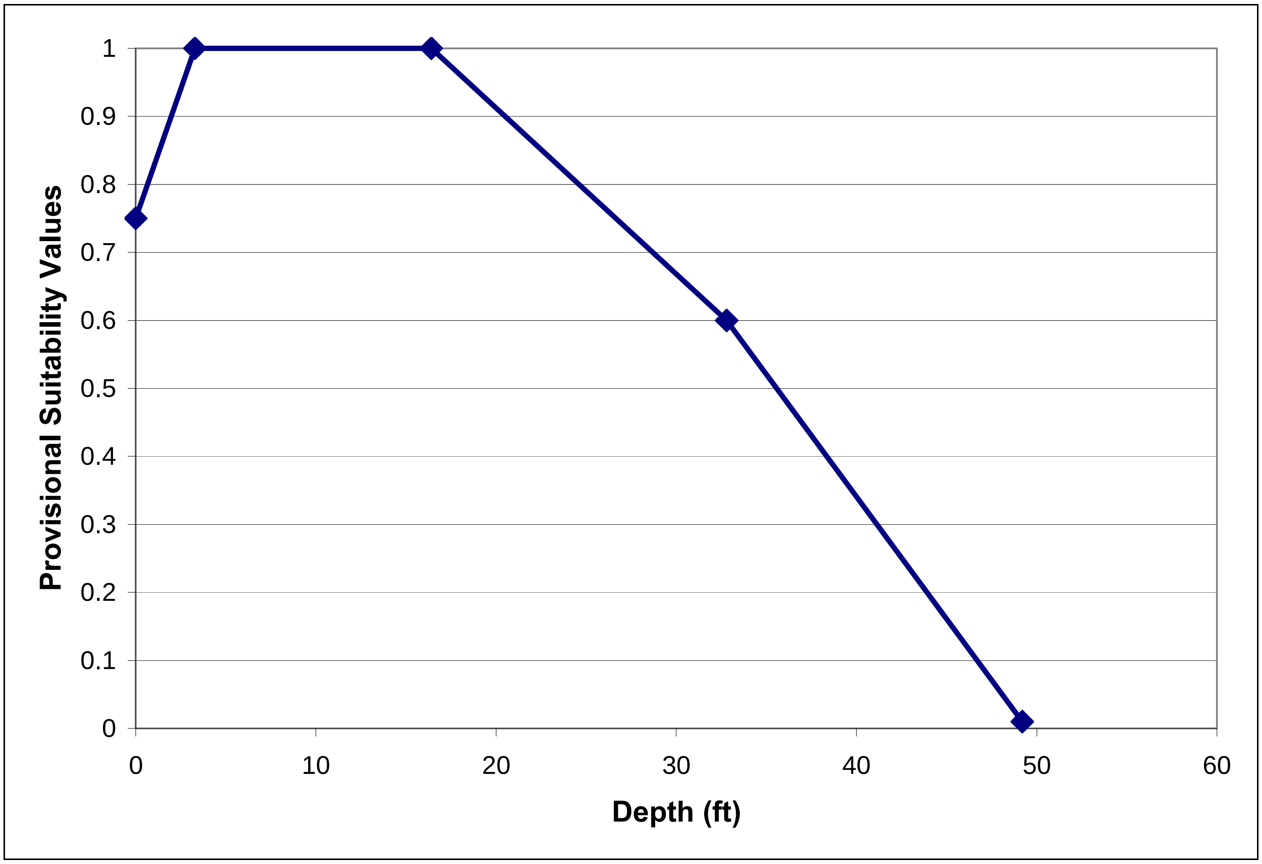


Figure 5.4-6. Provisional depth suitability curve for periphyton.

(Note: *Value is zero at 98 feet where light is insufficient for photosynthesis.*)

Provisional velocity suitability values were selected based on a synthesis of the available literature. Habitat suitability is highest at very low velocities up to 1.64 feet/second (0.5 meter/second). Velocity suitability values then sharply decrease until habitat is unsuitable for periphyton growth, over 3.28 feet/second (1 meter/second). Figure 5.4-7 displays the provisional velocity suitability curve for periphyton. A detailed review of the literature regarding velocity suitability for periphyton is found in Appendix 3.

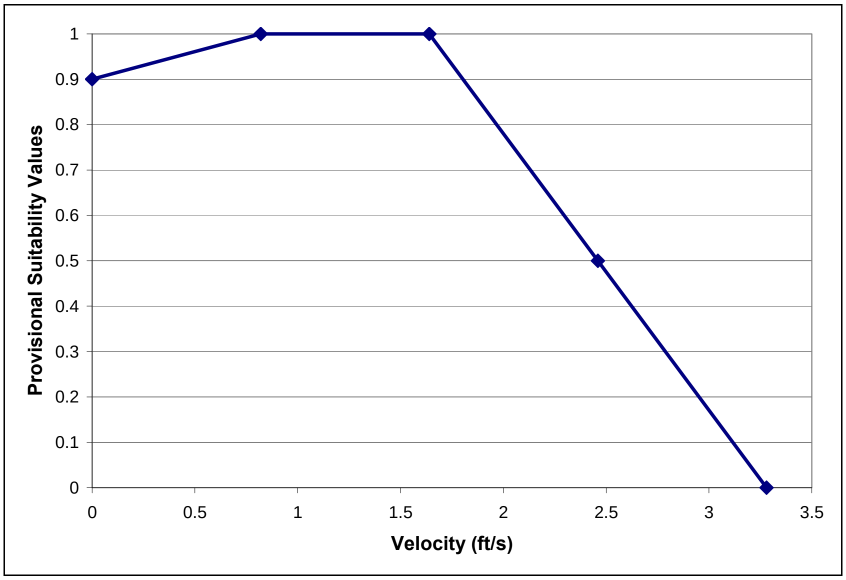


Figure 5.4-7. Provisional velocity suitability curve for periphyton.

By definition, periphyton includes algae growing on solid or hard substrates (rock, wood, sediment, macrophytes). 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, a value of 1.0 is assumed. Figure 5.4-8 displays the provisional substrate suitability values for periphyton.

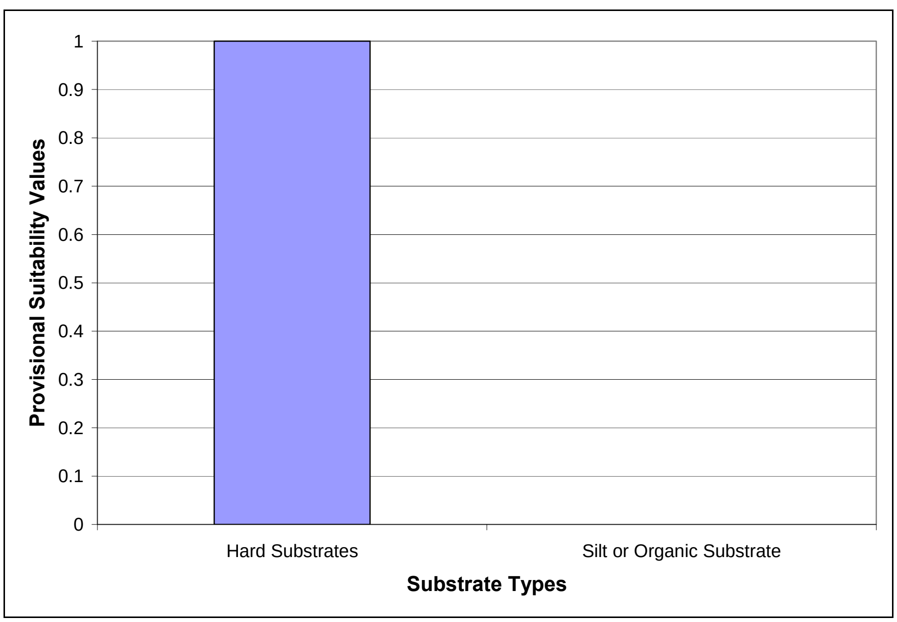


Figure 5.4-8. Provisional substrate suitability values for periphyton.

Provisional suitability values for duration of dewatering were selected based on the effects of varying exposure times found in the literature. These studies suggest that as the duration of dewatering increases, habitat suitability gradually decreases after 6 hours of exposure. Once the duration of dewatering extends beyond 12 hours, little to no suitable habitat remains. Figure 5.4-9 displays the provisional duration of dewatering suitability curve for periphyton. A detailed review of the literature regarding the effects of dewatering on periphyton is found in Appendix 3.

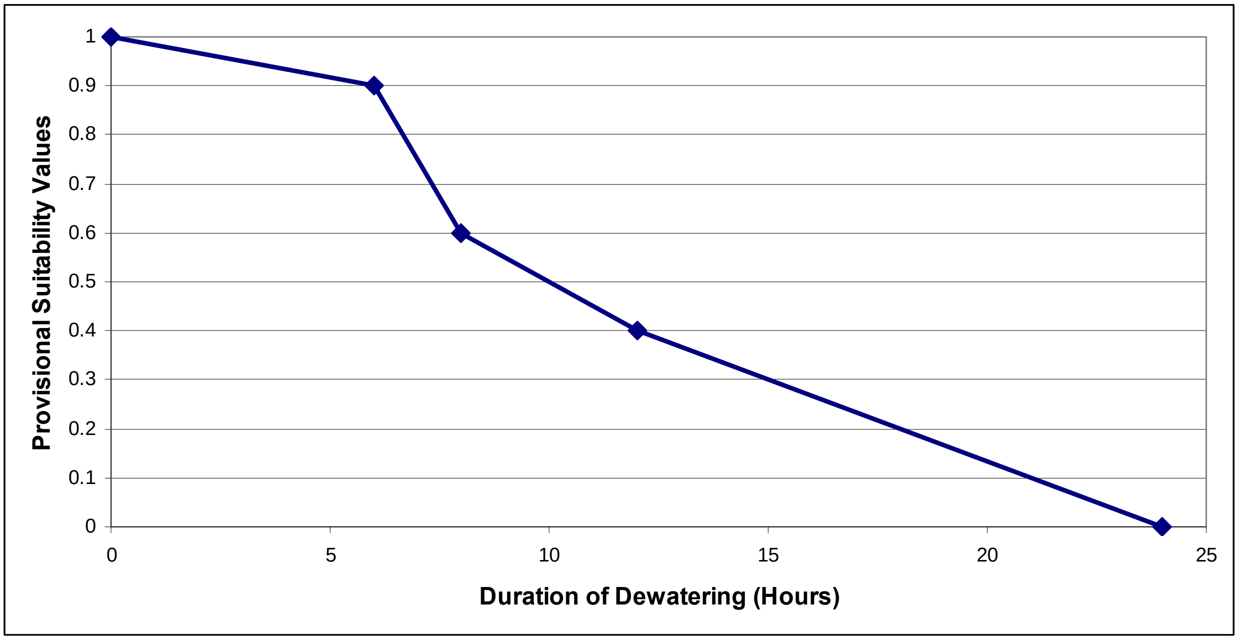


Figure 5.4-9. Provisional duration of dewatering suitability values for periphyton.

(Note: *At 24 hours of exposure, it is assumed that viable periphyton is zero*.)

Provisional suitability values for duration of inundation were selected based on the effects of varying colonization rates of periphyton found in the literature. Figure 5.4-10 displays the provisional duration of inundation suitability curve for periphyton. The literature suggests that as the duration of inundation increases, habitat suitability increases. A provisional suitability value of 1 was found to be approximately 21 days. Inundation of less than 3 days appears to result in the least preferred conditions for periphyton. A detailed review of the literature regarding colonization and the effects of the duration of inundation on periphyton is found in Appendix 3.

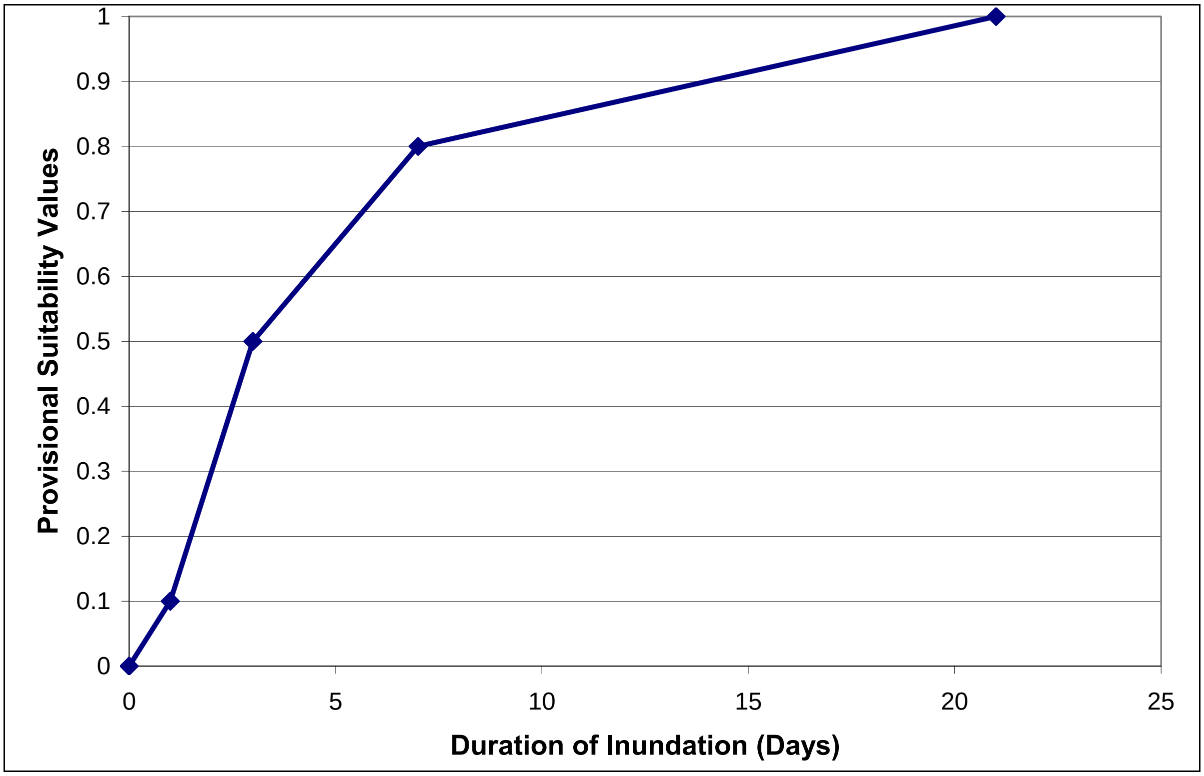


Figure 5.4-10. Provisional duration of inundation suitability curve for periphyton.

5.4.3.2. Data Collection Efforts

Periphyton site-specific monitoring consisted of two sampling components: 1) artificial substrate sampling on hard substrate surfaces, and 2) determination of seasonal colonization rates. The artificial substrates for periphyton sampling consisted of small rock baskets containing rocks with diameters ranging from 1 to 3 inches. Artificial substrate samples on hard substrate surfaces were collected at both vertical rock face and shoreline sites. Samples were set at elevation intervals intended to encompass the fluctuation zones in the upper and lower Boundary reservoir reaches. The schedule for deployment and retrieval of hard substrate samples is shown in Tables 5.4-4 and 5.4-5. To date all samples have been deployed and all samples have been retrieved, except for the final sample which is to be retrieved in February, weather and reservoir conditions permitting, and may not be retrieved until March. All hard substrate samples (shoreline and vertical face sites) were retrieved 8 weeks following deployment.

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 5.4-6. To date the summer samples have been collected and the winter samples are in progress. For both the summer and winter periods, sets of three frame and rock baskets were to be 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. Colonization samples were placed at elevation intervals intended to encompass the fluctuation of the reservoir at this location.

Table 5.4-4. 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	February[1]
Total				**216**	
Treatments/Sites					
A) High Fluctuation-Downstream of Metaline Falls					
B) Moderate Fluctuation-Upstream of Metaline Falls					
C) Low Fluctuation-Box Canyon Reservoir					

Note:
1 Weather permitting.

Table 5.4-5. Hard substrate sample deployment and retrieval schedule for vertical face sites.

Deployment Date	Macroinvertebrates/Periphyton Vertical Face 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	February*
Total				**144**	
Treatments/Sites					
A) High Fluctuation-Canyon Reach					
B) Low Fluctuation-Box Canyon Reservoir					

Note:
1 Weather permitting.

Table 5.4-6. Colonization sample deployment and retrieval schedule.

Season	Colonization Period	Deployment Date	Retrieval Date
Summer	8 weeks	July 6th	September 1st
	6 weeks	July 20th	September 1st
	4 weeks	August 3rd	September 1st
	2 weeks	August 16th	September 1st
	1 week	August 23rd	September 1st
	3 days	August 28th	September 1st
Winter[1]	8 weeks	December 8th	February 2nd
	6 weeks	December 21st	February 2nd
	4 weeks	January 4th	February 2nd
	2 weeks	January 18th	February 2nd
	1 week	January 25th	February 2nd
	3 days	January 30th	February 2nd

Note:
1 Winter colonization baskets deployment and retrieval is depending on weather and reservoir conditions.

The data for two of the hard substrate sampling events (spring and summer), as well as the summer colonization data, are presented in detail in the Periphyton HSI Interim Report (Appendix 3). Additional field data collected in 2007 and 2008 will be reported in 2008.

5.4.4. Benthic Macroinvertebrate HSI

Interim habitat suitability curves were developed for BMI utilizing information from the literature. Data collection was performed in 2007 to support continued development of the BMI HSI and additional data collection will be performed in 2008. This information has not been incorporated into the HSI development since it requires application of the hydraulic routing model to interpret for Boundary Dam and additional data from the Box Canyon Production Manager that needs to be matched to the data standards for the Boundary Dam elevation data. The hydraulic routing model has just been completed and supporting analysis will be conducted in January and February to determine water surface elevations during BMI data collection efforts. Compatibility checking is currently being done for the elevation data for Box Canyon Reservoir. The information presented in the following subsection is a summary of the BMI HSI development effort. A complete stand-alone report is provided in Appendix 4.

5.4.4.1. Development of Interim HSI

An extensive literature search was conducted in 2007 to identify available information regarding the habitat preferences of BMI with respect to water depth, velocity, substrate, and inundation and dewatering in a reservoir system. With the information gathered, HSC were developed for each variable, as well as a HSI, for the BMI model. Field studies are currently underway to gather site-specific data related to benthic macroinvertebrate communities in the Boundary Reservoir. The information collected will be used to calibrate and revise the literature-based provisional suitability curves. Once the suitability curves have been finalized, they will be incorporated into the larger HSI model, along with the periphyton, macrophyte, and fish data, to gain a broader understanding of the biotic response to operations scenarios at the Project. The HSC are briefly described below and details regarding the results of the literature-based HSI may be found in Appendix 4.

Available literature regarding BMI and habitat suitability suggests that as water depth increases, preference generally increases up to approximately 10 feet to 15 feet of depth. At depths greater than 15 feet, however, habitat suitability decreases (Figure 5.4-11). A detailed review of the literature regarding water depth suitability for BMI is found in Appendix 4. A provisional suitability value of 1 was found between approximately 10 and 15 feet of water depth, suggesting this range as the depth most preferred by benthic macroinvertebrates.

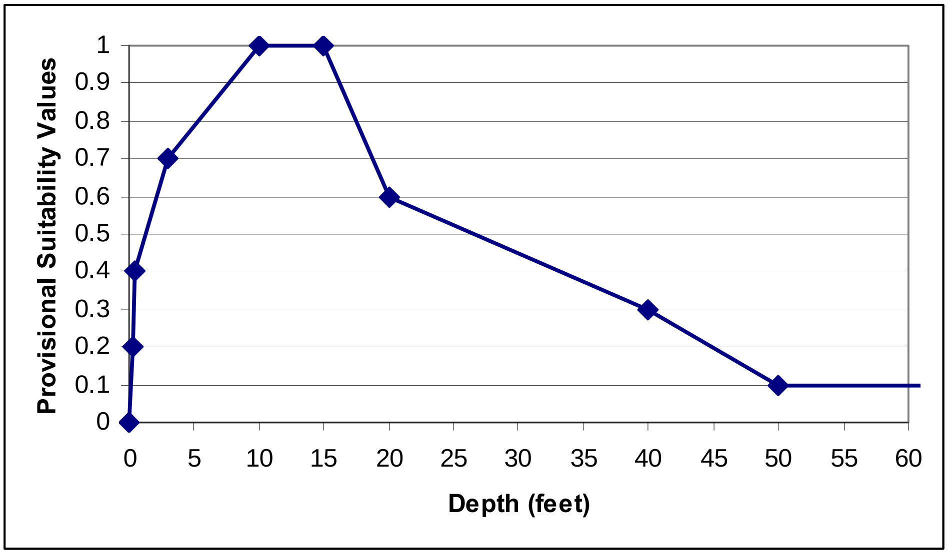


Figure 5.4-11. Provisional depth suitability curve for BMI.
(Note: *Maximum depth in this study exceeds 60 feet.*)

The provisional suitability curve for water velocity was similar to that of depth in that it showed an initial increase in preference as velocity increases up to a point at which it then sharply decreased. Available literature suggests that peak suitability for BMI is found at velocities of approximately 1.5 to 3 feet per second (Figure 5.4-12). At velocities greater than 3 feet per second, preference sharply decreases. A detailed review of the literature regarding velocity suitability for BMI is found in Appendix 4.

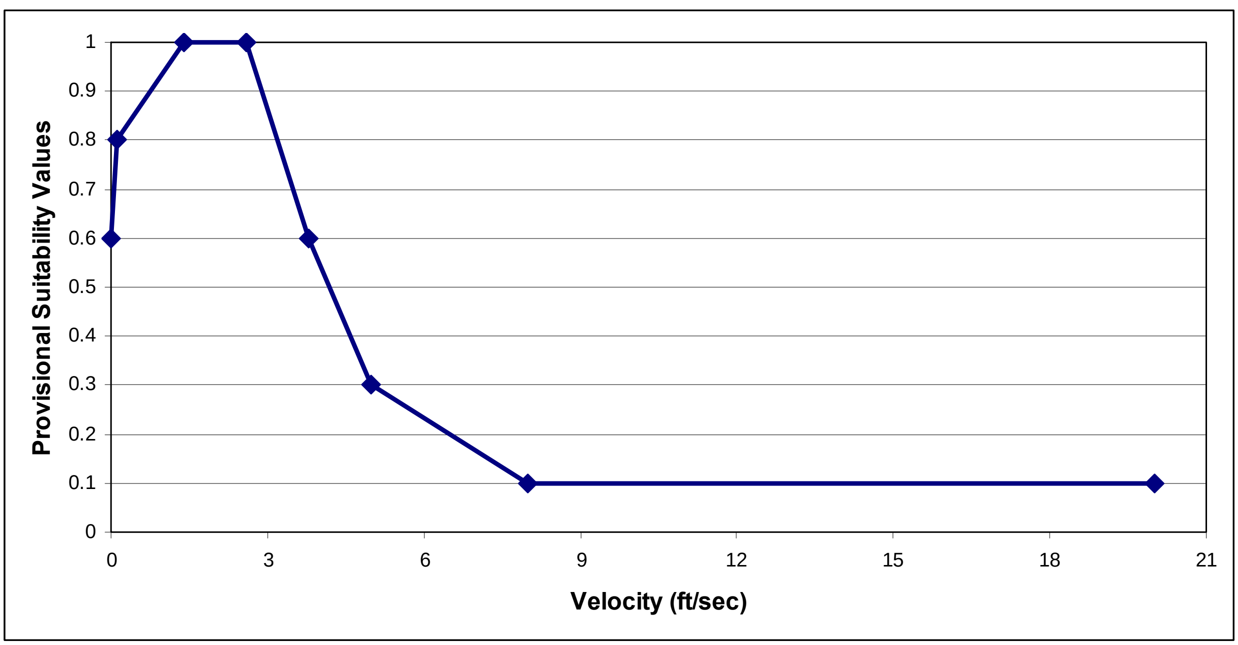


Figure 5.4-12. Provisional velocity suitability curve for BMI.

(Note: *Maximum velocity values in this study exceed 10 ft/sec.*)

Available literature suggests that gravel, cobble, and boulder substrates are the most suitable substrate type for benthic macroinvertebrates, with a provisional suitability value of approximately 1 (Figure 5.4-13). Smaller substrate such as sand, silt, and organic matter and macrophytes also provide suitable habitat to BMI, but are less preferred. Of the substrates evaluated, bedrock was least suitable. A detailed review of the literature regarding substrate suitability for BMI is found in Appendix 4.

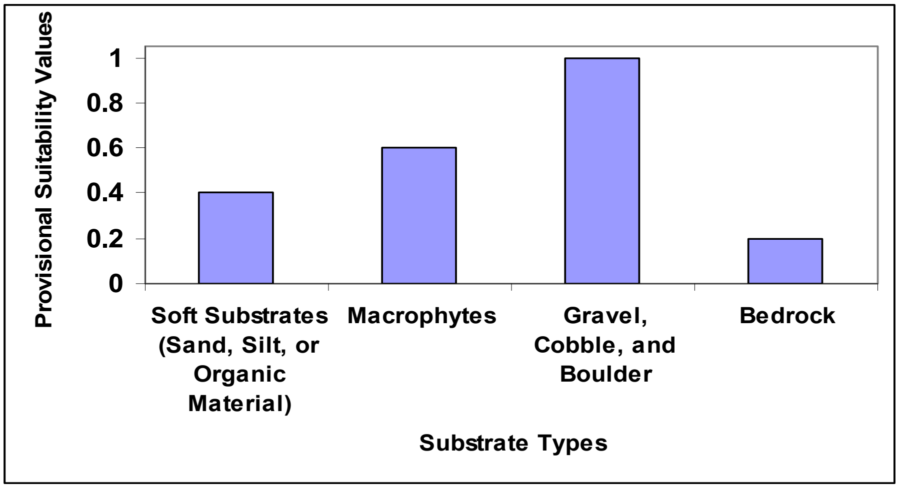


Figure 5.4-13. Provisional substrate suitability curve for BMI.

The literature review revealed that as duration of dewatering increases, habitat suitability for BMI generally decreases. As seen in Figure 5.4-14, the greatest decline in suitability occurs during the first 24 hour period of dewatering, when the provisional suitability value drops from 1 to approximately 0.2. As duration of dewatering increases beyond 24 hours, this value continues to drop, but at a slower rate. A detailed review of the literature regarding the effects of dewatering on BMI is found in Appendix 4.

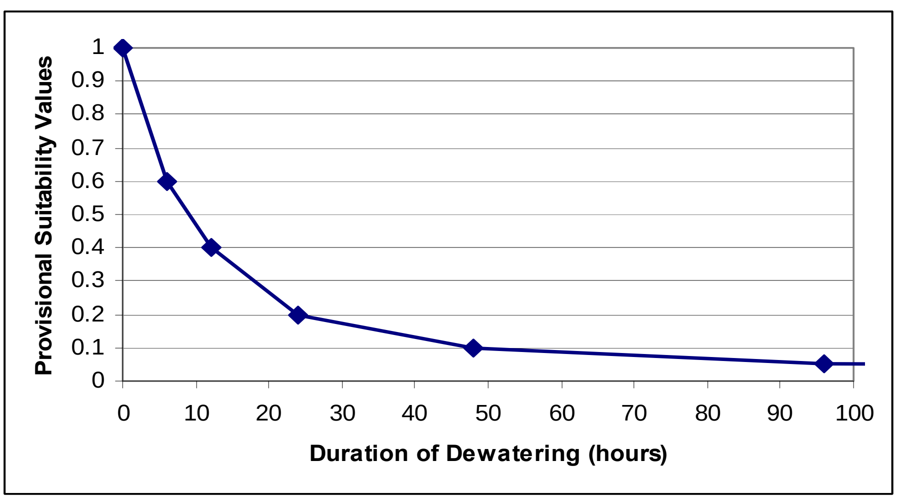


Figure 5.4-14. Provisional duration of dewatering suitability curve for BMI; curve goes to zero after 30 days.

Available literature regarding BMI suggests that as the duration of inundation increases, habitat suitability increases. A provisional suitability value of 1 was found to be at approximately 45 days of inundation (Figure 5.4-15). Inundation of less than 15 days appears to result in the least preferred conditions for BMI. A detailed review of the literature regarding colonization and the affects of the duration of inundation on BMI is found in Appendix 4.

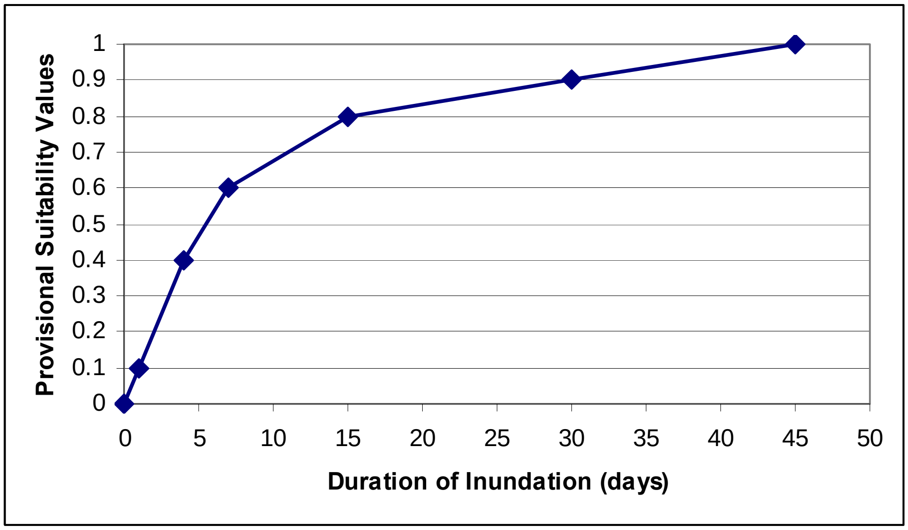


Figure 5.4-15. Provisional duration of inundation suitability curve for benthic macroinvertebrates.

5.4.4.2. Data Collection Efforts

Field studies were conducted to collect benthic macroinvertebrate data specific to Boundary Reservoir to be used in the calibration and revision of the literature-based HSC that were developed as part of Study 7.4.3. Sampling locations were chosen in Lower Boundary, Upper Boundary, and Box Canyon reservoirs to represent habitats with high, moderate, and low water surface elevation fluctuations. Various types of substrate and habitat conditions were sampled, including hard substrate in vertical and shoreline orientations, and soft substrate. Additionally, a study was conducted to evaluate the rate of colonization of BMI at different depths and during various seasons of the year.

The 2007 field activities included multiple collection events of hard and soft substrate data and one collection event for the colonization study. The data for two of the hard and soft substrate events, as well as the colonization data, are presented in detail in the Benthic Macroinvertebrate HSI Interim Report (Appendix 4) and Table 5.4-7 summarizes the number of samples collected in 2007, which are described in that report. Initial results indicate a high number of *Hydra* sp. present in the spring shorline and vertical samples from all three reservoir locations. Details on these results can be found in Appendix 4. Additional field activities conducted in 2007 and the remaining activities scheduled for 2008 will be reported in 2008.

Table 5.4-7. Summary of data collection efforts for BMI HSI.

Sampling Type	Number of Samples Collected		
	May 2007	September 2007	Total
Hard Substrate - Vertical	36	36	72
Hard Substrate - Shoreline	54	54	108
Soft Substrate	51[1]	51[1]	102
Colonization	18	18	36

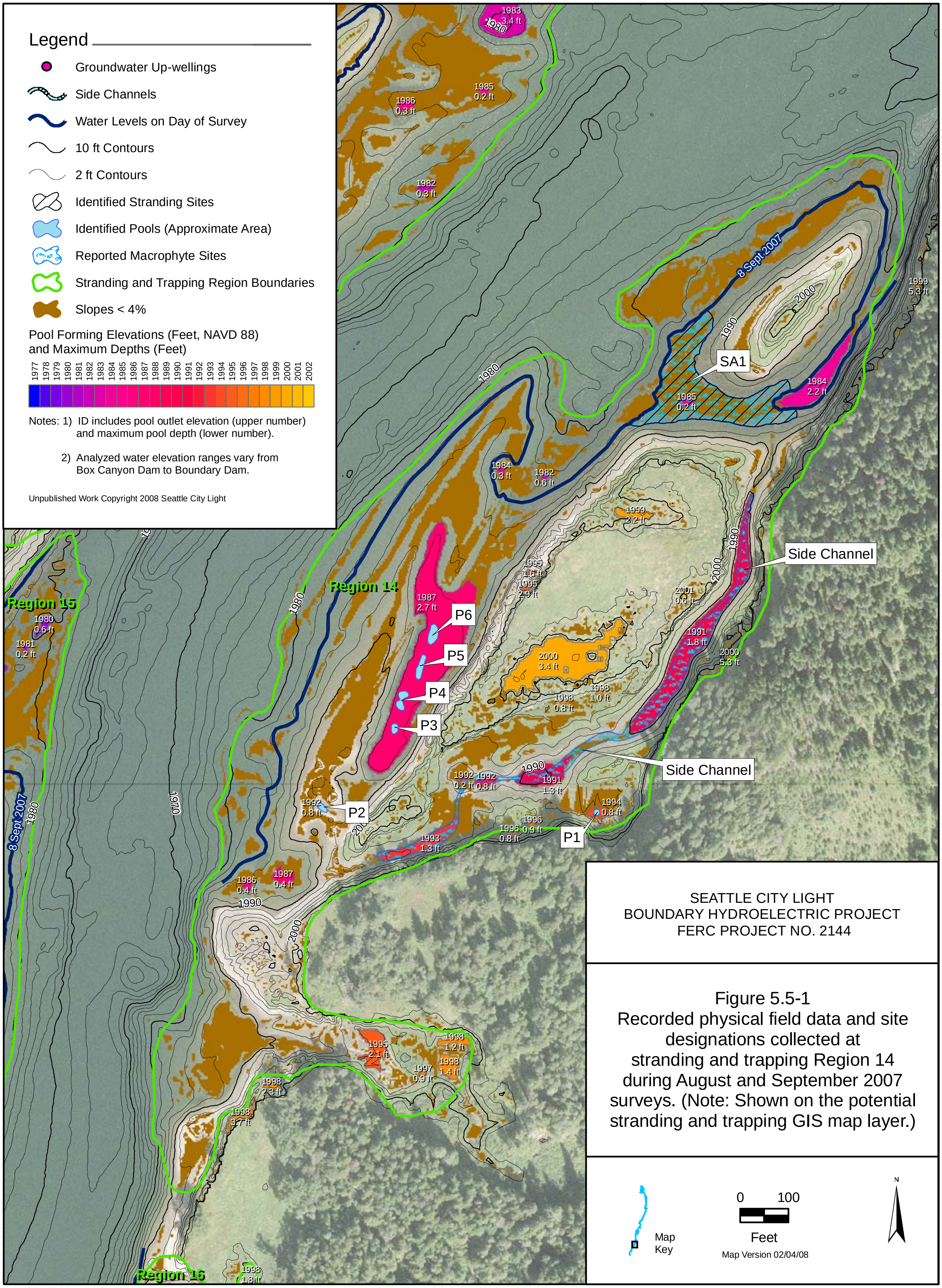
Notes:

1 Soft sediment could not be located at 40 feet of depth in Upper Boundary; therefore, it was not collected.

5.5. Stranding and Trapping Field Surveys

This section presents information on the reservoir habitat exposed as water surface elevations recede and the factors contributing to fish stranding and trapping. Water elevation information collected during surveys is presented in Section 5.5.1. Results of the August and September surveys in the lower reservoir (Forebay and Canyon reaches) downstream of Metaline Falls (Section 5.5.2), the Upper Reservoir Reach upstream of Metaline Falls (Section 5.5.3) and the Tailrace Reach of Boundary Dam (Section 5.5.4) are presented separately. A summary of fish observations and life history collected during all surveys is presented in Section 5.5.5. All regions discussed in this section have the potential to either strand fish, because of low slope or other habitat features that are exposed during some drawdown conditions, or the potential to trap fish, by forming pools. The result of drawdown at each site: stranding, and or trapping, are noted for each region. The regions described are categorized by either numbers or proper names because original region number assignments were supplemented with additional sites during subsequent field surveys.

Locations of the regions are presented in the Methods section (Section 4.5) and shown in Figure 4.5-1. Maps of initial potential stranding and trapping areas by region are shown in Appendix 6, Figures A.6-1 to A.6-22. Photo examples of various stranding and trapping areas surveyed during the summer of 2007 are also presented in Appendix 6, Figures A.6-23 to A.6-28. The locations of these regions and pools are shown on the respective map figures in Appendix 6. The maps show, by regions, the low slope areas (less than 4 percent) which would have the highest potential of having stranding habitat, at elevations that may become dewatered sometime during the year for operations scenarios (see Section 4.3.9 for details on elevations used by reservoir location). Additionally, information is presented on pools (at least 100 square feet in size), the elevation where they would form (rounded up to the nearest foot elevation in NAVD 88), and maximum pool depth (nearest 0.1 foot) when the pool first becomes isolated for existing Project operations. The initial information was based on GIS-based bathymetric data analysis. Field data reported in the following subsections (5.5.2 and 5.5.3) were added to the original stranding and trapping bathymetric maps based on field notes, observations, and measurements taken at the times of the surveys. The level of detail reported by region varies depending on water surface elevation at the time of the survey, availability of detailed bathymetric maps at the time of the survey, and amount of total regional area that was surveyed during the specific site visit. An example of a regional map showing the initial GIS information and field data reported is shown in Figure 5.5-1 for Region 14 in the upper reservoir. Figure 5.5-1 as well as the figures in the appendix include "reported macrophyte sites." These are specific macrophytes noted during the strands and trapping field surveys and not the results of the macrophyte mapping effort.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.5-1
Recorded physical field data and site designations collected at stranding and trapping Region 14 during August and September 2007 surveys. (Note: Shown on the potential stranding and trapping GIS map layer.)

5.5.1. Relative Boundary Reservoir Elevations

Surveys of stranding and trapping habitat and fish observations occurred over a variety of reservoir elevations during the summer of 2007 (Figure 5.5-2). Figure 5.5-2 is an index of elevations that occurred at each site, as actual specific regional elevations vary by location along the reservoir and time of day. The figure shows hourly elevations which, during 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 by the Terrapin crew 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.

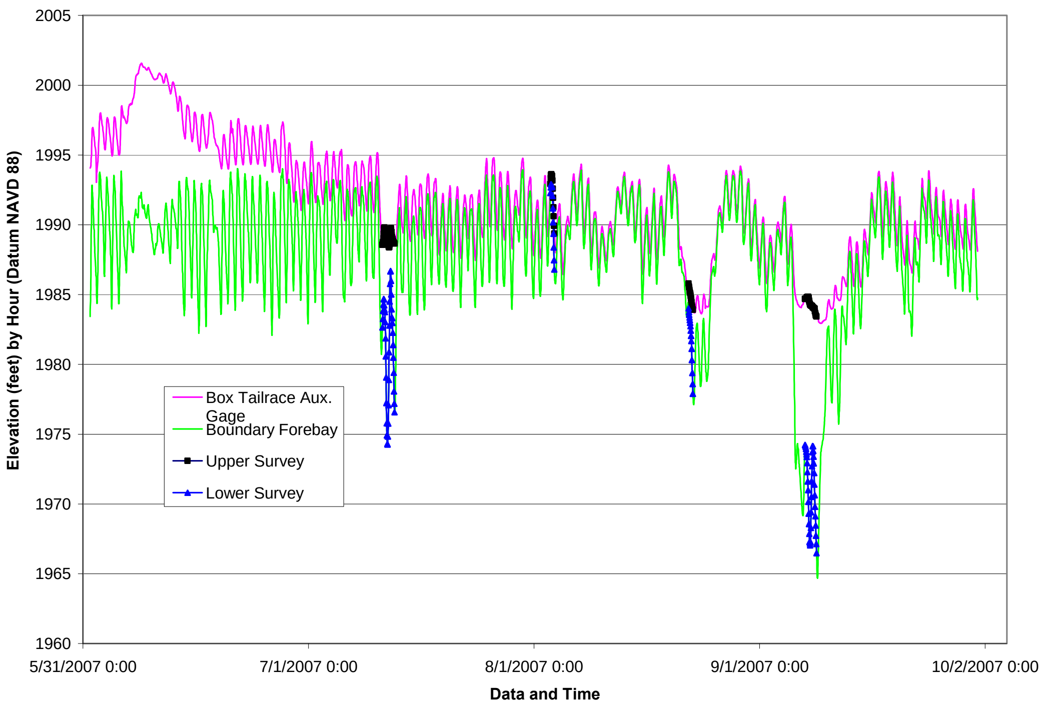


Figure 5.5-2. Boundary Reservoir hourly elevation at Box Canyon Tailrace USGS Auxiliary gage and Boundary forebay (NAVD 88) (June 1 to September 30) showing elevations on dates of reconnaissance and regular stranding and trapping surveys in 2007.

5.5.2. Lower Reservoir (Forebay and Canyon Reaches)

The following subsections present the results of physical information collected at each of the nine regions sampled in the lower reservoir. This reach contains sites with relatively small areas and few potential stranding and trapping areas because of the steep characteristics of most of the regions. See Appendix 6 (Figures A.6-1 to A.6-9) for detailed bathymetric maps of each region discussed below.

5.5.2.1. 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. Habitat information on this region is provided in Table 5.5-1 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-1).

Table 5.5-1. Habitat characteristics recorded at the Forebay Launch Region on September 8, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (^oC)	Fish Cover Types (%)[2]			Vegetation Type
Emb.	Ang.	Comp.						SP	AV	INT	
L	L	L	1 (silt)	P1	N/R[3]	N/R[3]	N/R[3]	79	20	1	macrophyte
				P2	N/R[3]	N/R[3]	N/R[3]	50	50		macrophyte
				P3	N/R[3]	N/R[3]	N/R[3]	25	75		macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Moderate
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 N/R = not recorded

5.5.2.2. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-2).

5.5.2.3. 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 reach. 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 (estimated area 1,076 square feet). At the outlet of the channel downstream of the ridge, a large stranding area (estimated area 5,382 square feet) 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. Both stranding and trapping were observed at this region. Habitat information on this region is provided in Table 5.5-2 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-3).

Table 5.5-2. Habitat characteristics recorded at stranding and trapping Region 2 on September 7, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (^oC)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						SP	AV	
L	L	L	1 (silt)	P1	N/R[3]	N/R[3]	N/R[3]	50	50	macrophyte
				P2	N/R[3]	N/R[3]	N/R[3]		100	macrophyte
				P3	162	0.4	N/R[3]		100	macrophyte
				P4	1,076	dry	N/A[4]		100	macrophyte
				SA1	5,382	dry	N/A[4]		100	macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Moderate
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation
3 N/R = not recorded
4 N/A = not applicable

5.5.2.4. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-4).

5.5.2.5. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-5).

5.5.2.6. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-6).

5.5.2.7. 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. Habitat information collected at this region is provided in Table 5.5-3 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-8).

Table 5.5-3. Habitat characteristics recorded at stranding and trapping Region 6 on 7 September 2007.

Substrate Parameters[1]			**Modified Wentworth Mean**	**Pool (P)/ Stranding Area (SA) Sites**	**Size (ft^2)**	**Max. Depth (ft)**	**Temp (°C)**	**Fish Cover Types (%)**[2]			**Vegetation Type**
Emb.	**Ang.**	**Comp.**						**SP**	**AV**	**INT**	
L	L	L	4 (med. gravel)	P1	dry	N/A[3]	N/A[3]	100			
				P2	dry	N/A[3]	N/A[3]	80	20		macrophytes
				P3	183	0.9	13	100			

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 NA = not applicable

5.5.2.8. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-7).

5.5.2.9. 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. 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. Habitat information collected at this region is provided in Table 5.5-4 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-9).

Table 5.5-4. Habitat characteristics recorded at the Flume Creek Mouth on 7 September 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (^{o}C)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						DP	INT	
L	L	L	1 (silt)	P1	43	> 3	16	95	5	N/A[3]

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: DP = Deep Pool, INT = Interstices
3 NA = not applicable

5.5.3. Upper Reservoir Upstream of Metaline Falls

The following sections present the results of physical information collected by each of the twelve regions sampled in the upper reservoir. This region includes the largest total and proportional area of potential stranding and trapping sites in the reservoir. See Appendix 6 (Figures A.6-10 to A.6-22) for detailed bathymetric maps of each region discussed below.

5.5.3.1. 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. Habitat data were not recorded, but a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-10).

5.5.3.2. 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. Detailed information on fish observations at this region is discussed in Section 5.5.5.

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. Habitat information recorded at this region is provided in Table 5.5-5 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-11).

Table 5.5-5. Habitat characteristics recorded at stranding and trapping Region 7 on June 21 and August 22, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (^oC)	Fish Cover Types (%)[2]			Vegetation Type
Emb.	**Ang.**	**Comp.**						**SP**	**AV**	**TV**	
L	L	L	1 (silt)	u/s outlet	N/A[4]	0.3	23		100		macrophyte
				d/s outlet	N/A[4]	0.3	23	10	90		macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, TV = Terrestrial Vegetation
3 N/R = not recorded
4 N/A = not applicable

5.5.3.3. 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. Detailed information on fish observations at this region is discussed in Section 5.5.5.

Several pools surveyed were too large to obtain area and depth measurements. Due to the size of the region, Modified Wentworth measurements would not be representative of the substrate size at the site and therefore were not taken. Both stranding and trapping were observed at this region. Habitat information recorded at this region is provided in Table 5.5-6 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-12).

Table 5.5-6. Habitat characteristics recorded at stranding and trapping Region 8 on August 22, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						SP	AV	
L	L	L	N/R[3]	P1	N/R[3]	N/R[3]	26	90	10	macrophyte
				P2	N/R[3]	N/R[3]	26	90	10	macrophyte
				P3	N/R[3]	N/R[3]	26	90	10	macrophyte
				P4	301	0.3	26	90	10	macrophyte
				P5	53	0.2	26	75	25	macrophyte
				P6	323	0.2	24	80	20	macrophyte
				P7	N/R[3]	0.3	24	70	30	macrophyte
				P8	194	0.7	27	95	5	macrophyte
				P9	N/R[3]	0.3	27	75	25	macrophyte
				P10	N/R[3]	N/R[3]	25	5	95	macrophyte
				P11	N/R[3]	N/R[3]	25	20	80	macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation
3 N/R = not recorded

5.5.3.4. 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 (P4) 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. 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. Both stranding and trapping were observed at this region. Habitat information collected at this region is provided in Table 5.5-7 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-13).

Table 5.5-7. Habitat characteristics recorded at stranding and trapping Region 9 on August 22, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft²)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]	Vegetation Type
Emb.	Ang.	Comp.						AV	
L	L	L	1 (silt)	P1	N/R[3]	N/R[3]	N/R[3]	100	macrophyte
				P2	N/R[3]	N/R[3]	N/R[3]	100	macrophyte
				P3	N/R[3]	N/R[3]	N/R[3]	100	macrophyte
				P4	N/R[3]	N/R[3]	N/R[3]	100	macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: AV = Aquatic Vegetation
3 N/R = not recorded

5.5.3.5. 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 (P1, P2, and P3), 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 (P4 to P8) 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. Both stranding and trapping were observed at this region. Habitat information recorded at this region is provided in Table 5.5-8 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-14).

Table 5.5-8. Habitat characteristics recorded at stranding and trapping Region 10 on August 3 and September 8, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]				Vegetation Type
Emb.	Ang.	Comp.						DP	SP	AV	INT	
L	L	L	5 (Lg. Gravel)	P1	> 1076	0.7	26				100	
				P2	570	0.5	25				100	
				P3	> 1076	N/R[3]	25				100	
				P4	> 1076	> 3	18	20			80	
				P5	> 1076	> 3	18	40		1	59	macrophytes
				P6	291	0.3	26				100	
				P7	65	0.8	20				100	
				P8	431	1.6	18		50		50	

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: DP = Deep Pool, SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 N/R = not recorded

5.5.3.6. 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 (P4), and was connected to the mainstem. Pool P4 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. Both stranding and trapping were observed at this region. Habitat information recorded at this region is provided in Table 5.5-9 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-15).

Table 5.5-9. Habitat characteristics recorded at stranding and trapping Region 11 on August 22, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft²)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						SP	AV	
L	L	L	1 (silt)	P1	118	0.3	23	100		macrophyte
				P2	242	0.4	23	90	10	macrophyte
				P3	67	0.2	26	10	90	macrophyte
				P4	N/R[3]	N/R[3]	23		100	macrophyte
				SA1	N/R[3]	0.1	N/R[3]		100	macrophyte

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation
3 N/R = not recorded

5.5.3.7. 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 (P1) 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. Habitat information recorded at this region is provided in Table 5.5-10 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-16).

Table 5.5-10. Habitat characteristics recorded at stranding and trapping Region 12 on August 3, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft²)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]	
Emb.	Ang.	Comp.						SP	INT
M	M	L	3.4 (fine to med. gravel)	P1	754	0.6	17	95	5

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, INT = Interstices

5.5.3.8. 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. Habitat information recorded at this region is provided in Table 5.5-11 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-17).

Table 5.5-11. Habitat characteristics recorded at stranding and trapping Region 13 on August 3, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						SP	AV	
L	L	M	1 (silt)	P1	16	0.2	27	100		
				P2	1792	0.2	27	90	10	grasses

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation

5.5.3.9. 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 (see Figure 5.5-1). On August 3, the side channel was deep and still connected to the mainstem, and stranded or trapped fish were not observed. Pools P1 and P2 were present during the August 3 survey only.

On September 8, the side channel was completely dry as were pools P1 and P2. 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 (P3 to P6) 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. Both stranding and trapping were observed at this region. Habitat information collected at this region is provided in Table 5.5-12 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-18).

Table 5.5-12. Habitat characteristics recorded at stranding and trapping Region 14 on August 3 and September 8 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]			Vegetation Type
Emb.	Ang.	Comp.						SP	AV	INT	
L	L	L	1 (silt)	P1	11	0.2	26	100			
				P2	1319	1.1	26	80		20	
				P3	161	0.5	14		100		macrophytes
				P4	129	0.2	24	50	50		macrophytes
				P5	2153	1.0	16	25	75		macrophytes
				P6	dry	N/A[3]	N/A[3]		100		macrophytes
				SA1	dry	N/A[3]	N/A[3]		100		macrophytes

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 N/A = not applicable

5.5.3.10. 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. 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. Habitat information recorded at this region is provided in Table 5.5-13 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-19).

Table 5.5-13. Habitat characteristics recorded at stranding and trapping Region 15 on August 22 and September 8, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool/ Stranding Area Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]			Vegetation Type
Emb.	Ang.	Comp.						SP	AV	INT	
L	L	L	2.9 (sand to fine gravel)	P1	807	N/R[3]	N/R[3]		100		macrophytes
				P2	dry	N/A[4]	N/A[4]	90		10	

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 N/R = not recorded
4 N/A = not applicable

5.5.3.11. 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. 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. Habitat information recorded at this region is provided in Table 5.5-14 and a detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-20).

Table 5.5-14. Habitat characteristics recorded at stranding and trapping Region 16 on August 3 and September 8, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]			Vegetation Type
Emb.	Ang.	Comp.						SP	AV	TV	
L	L	L	1 (silt)	P1	910	0.4	27	95		5	grasses
				P2	N/R[3]	N/R[3]	19		100		macrophytes
				P3	N/R[3]	N/R[3]	13		100		macrophytes
				P4	N/R[3]	N/R[3]	8	20	80		macrophytes

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation, INT = Interstices
3 N/R = not recorded

5.5.3.12. 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 (P1 and P2) 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 (P3) 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. Detailed information on fish observations at this region is discussed in Section 5.5.5. The potential for both stranding and trapping were observed at this region. Habitat information recorded at this region is presented in Table 5.5-15.

Table 5.5-15. Habitat characteristics recorded at stranding and trapping Region 17 on August 3 and September 8, 2007.

Substrate Parameters[1]			Modified Wentworth Mean	Pool (P)/ Stranding Area (SA) Sites	Size (ft^2)	Max. Depth (ft)	Temp (°C)	Fish Cover Types (%)[2]		Vegetation Type
Emb.	Ang.	Comp.						SP	AV	
L	L	L	2 (sand)	P1	198	0.1	24	100		
				P2	255	0.1	22	100		
				P3	22	0.2	14		100	macrophytes

Notes:
1 Substrate Parameters: Emb. = Embeddedness, Ang. = Angularity, Comp. = Compaction, L = Low, M = Medium
2 Cover Types: SP = Shallow Pool, AV = Aquatic Vegetation

5.5.3.13. 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. A detailed bathymetric map of this region is provided in Appendix 6 (Figure A.6-22).

5.5.4. 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 (approximately 650 square feet each) that recently formed were also 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.

5.5.5. Fish Observations and Life History Information

Of the 23 regions surveyed (most only surveyed once), stranded or trapped fish were not observed at 10 of the sites (1 in the Tailrace Reach, 7 in the Canyon/Forebay reaches, and 2 in the Upper Reservoir Reach). The remaining 12 regions had from 2 to approximately 6,400 fish observed as either stranded or trapped between the July and 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 indicted 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.

Fish observations and life history information collected during reconnaissance-level surveys on July 11-12, 2007 are presented in Appendix 6, Table A.6-1, and are summarized by period in Figure 5.5-3 and number by region in Figure 5.5-4. These July data were collected during an unusual extended drawdown event specifically scheduled for relicensing studies that normally would not typically occur for existing Project operations at this time of year. The numbers shown in the figure are not exact by site, as 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 (Appendix 6, Table A.6-1). Highest numbers were observed at Regions 14 and 16 in the Upper Reservoir Reach (Figure 5.5-4). Of these numbers, about 70 percent were mortalities. The vast majority of fish observed in July were young-of-the-year suckers (most less than 50 mm), approximately 70 percent of all fish (Figure 5.5-3). Yellow perch accounted for a little over 20 percent and bass species less than 10 percent of all stranded or trapped fish observed. Few other species were observed during July surveys. Regions in the lower reservoir were not surveyed at this time.

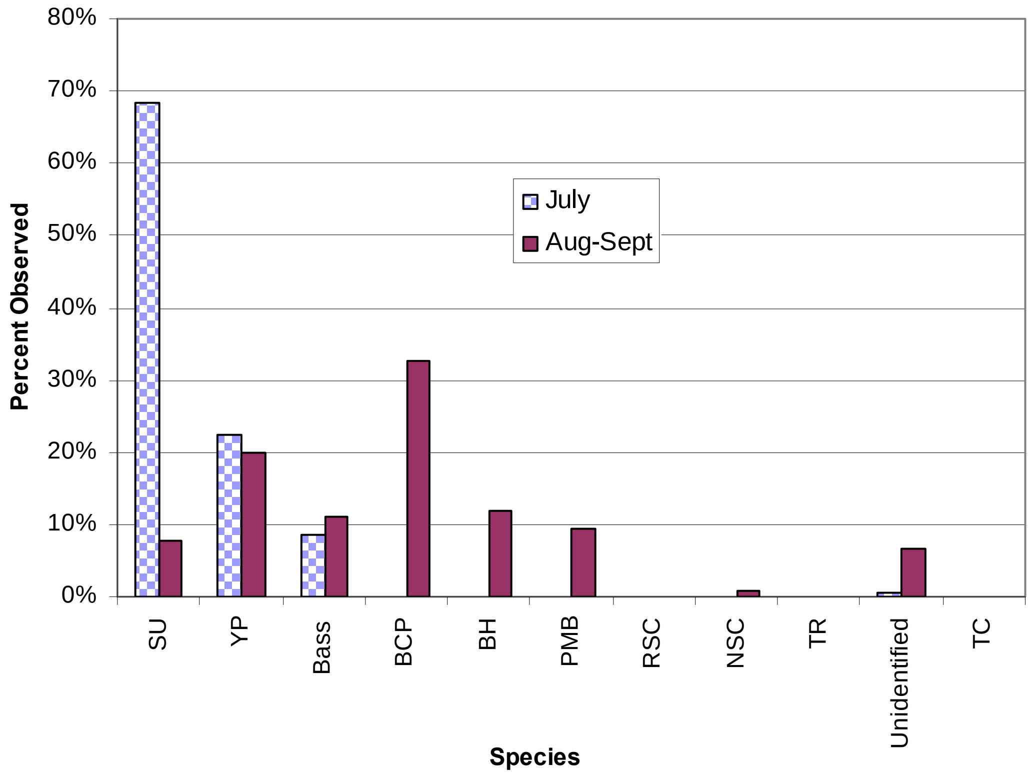


Figure 5.5-3. Approximate portion of fish species observed during stranding and trapping surveys in July, August, and September 2007 in Boundary Reservoir.

(Note: *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*.)

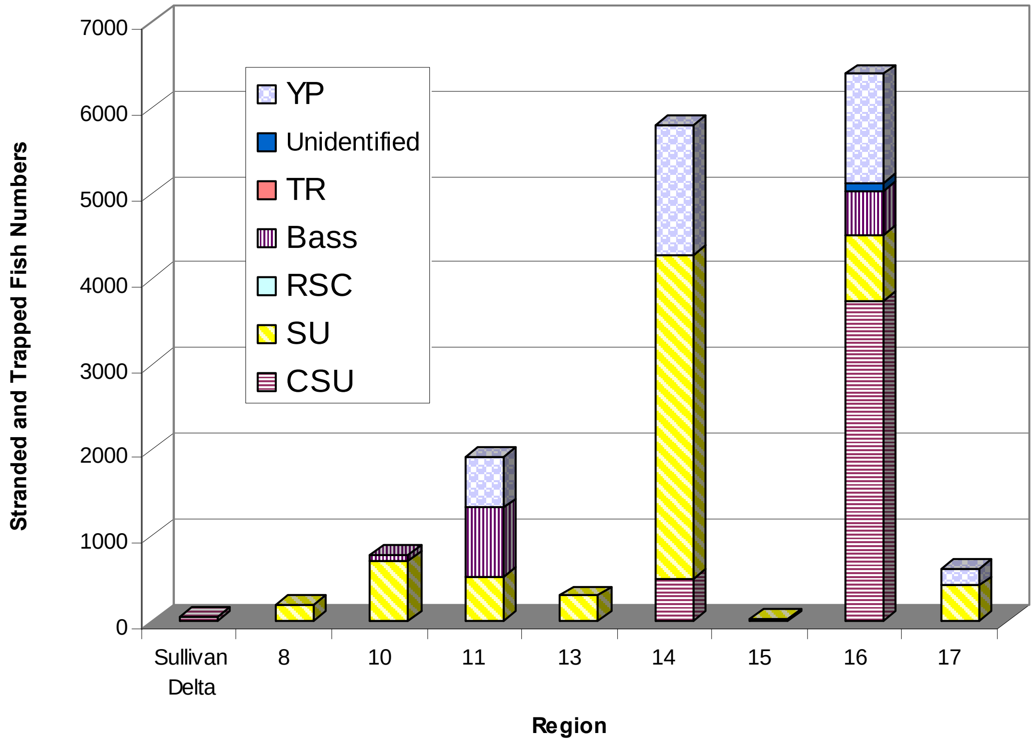


Figure 5.5-4. Summary of stranded and trapped fish observed on July 11 and 12, 2007, during reconnaissance surveys.

(Note: *Abbreviations: YP = yellow perch, TR = undetermined trout spp., SMB = smallmouth bass, RSC = redside shiner, SU = sucker spp., CSU = largescale sucker.*)

Fish observations collected during stranding and trapping surveys between August and September are summarized by region in Figure 5.5-5. 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 get 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 (Figure 5.5-5). Of all fish observed, the most abundant was black crappie at approximately 33 percent (Figure 5.5-3). 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.

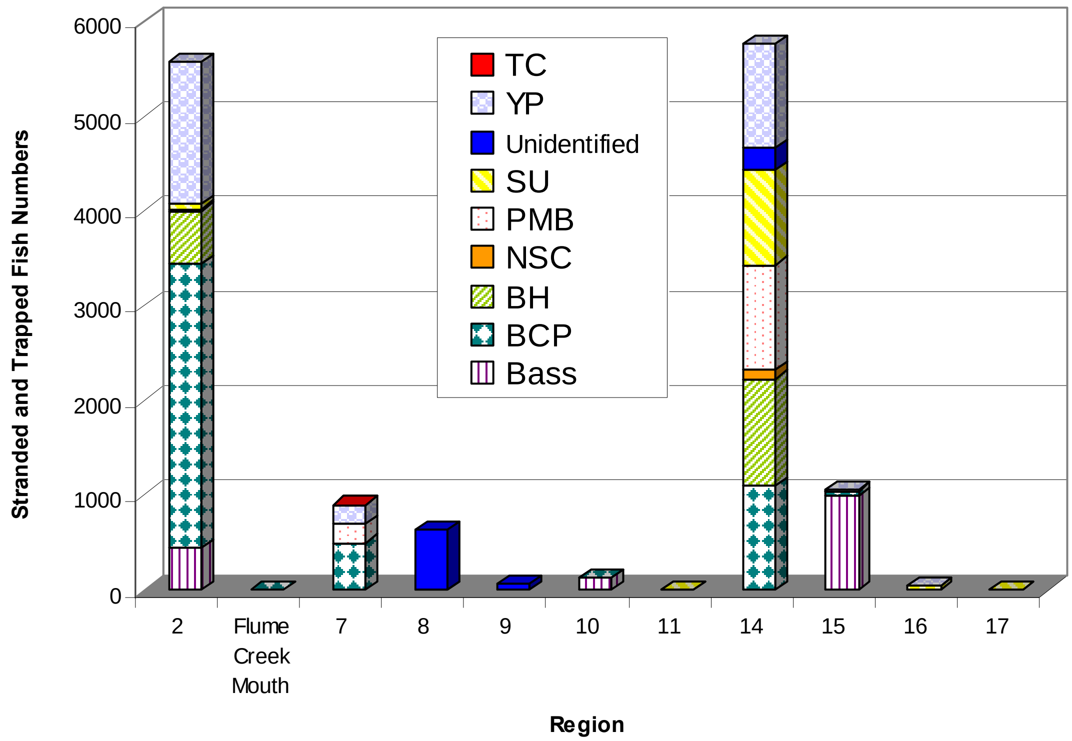


Figure 5.5-5. Summary of stranded and trapped fish observed between August 3 and September 8, 2007 during stranding and trapping surveys.

(Note: *Abbreviations: TC= tench, YP = yellow perch, SU = sucker spp., PMB = pumpkinseed, NSC = northern pikeminnow, BH = bullhead spp., BCP = black crappie, Bass = bass spp.*)

During the reconnaissance survey in June 21 and stranding and trapping surveys in August and September, general observations on fish in the mainstem reservoir or in wetted areas still connected to the mainstem reservoir were noted.

5.5.6. 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 5.5-16. As discussed in Section 5.5.1, the values shown are an index, as dewatering will vary with location along the reservoir and could be longer for sites below Metaline Falls.

Table 5.5-16. 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

5.5.7. Results Summary

The following summary discussion provides an overview of the key findings of the 2007 stranding and trapping surveys. 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 5.5-4 and 5.5-5). 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. Aquatic macrophytes are discussed in Section 6.5.2 and gradients are discussed in Section 6.5.3.

Results from Study 9, Fish Distribution, Timing and Abundance (SCL 2008f) 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, 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. Habitat conditions with the highest catch rates of all mountain whitefish consisted of moderately sloped areas dominated by gravel and cobbles (SCL 2008f). 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.

5.5.7.1. 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 (Appendix 6, Table A.6-1). Alternately, stranded and trapped fish numbers observed increased substantially for all reductions that lasted 24 hours or longer (Appendix 6, Table A.6-1). 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.

5.5.7.2. Aquatic Macrophytes

The highest rates of stranding and trapping occurred in areas with high concentrations of aquatic macrophyte growth (Appendix 6, Tables A.6-1 and A.6-2). 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 (see Section 5.1 for a map of macrophyte distribution).

5.5.7.3. 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. Bathymetric information is required to discern what gradients pose the greatest risk of stranding and trapping.

5.5.7.4. 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. Upon completion of the bathymetric maps, the elevation at which each pool isolates and the area of each isolating pool can be determined, which will allow a relationship between pool size and trapping risk to be identified. See Section 4.3.9 for information on how modeling of stranding and trapping will occur.

6 SUMMARY

The majority of the field effort associated with Study 7 was performed in 2007; however, as planned in the RSP, significant portions of the data analysis and model development remain to be performed in 2008. Field data collection in 2007 included measurement of mainstem habitat transects in Boundary Reservoir, collection of data supporting the HSI curve development for various biological groups, and field surveys for stranding and trapping. Data analyses conducted in 2007 included development of the hydraulic routing model for the mainstem Pend Oreille reaches upstream of Boundary Dam, development of literature-based HSI curves for all biological groups, development of initial periodicity tables for species of interest, and refinement and coordination of study methods with relicensing participants. The majority of the work remaining to be performed involves analysis, model development, and model execution. Some of the remaining work had originally been scheduled to be performed in 2007, but has been moved into early 2008 due to delays in development of final bathymetry. Revised schedules are provided in Section 7. This section summarizes work that has been completed in 2007 and lists the work that remains to be completed in 2008. The cross-over elements for each study component are also identified.

6.1. Habitat Mapping

Table 6.1-1 summarizes the work completed and the remaining efforts to be performed for the Habitat Mapping component (Study 7.1) of Study 7. The primary purpose of the habitat mapping task has changed from one of providing information to support transect selection in Boundary and Seven Mile reservoirs to one of describing habitat conditions in the reservoirs that relate to fish and other aquatic issues. Therefore, the scope of several of the tasks for the Habitat Mapping component changed from what was originally envisioned and two of the tasks (Wetted Width Calculations and Wetted Surface Area Calculations) were not conducted. The result from the Habitat Mapping work effort will provide information that will be useful in helping define some of the specific distribution and locations of habitat conditions relating to the aquatic habitat characteristics of Boundary Reservoir.

The majority of the work conducted in 2007 for this study component involved meso-scale habitat mapping in support of verifying proposed locations of the habitat transects in the Canadian Portion of the Tailrace Reach; field identification and mapping of large woody debris locations and aquatic vegetation; and one-on-one interviews with angler regarding their knowledge of major fish spawning locations, fish concentrations and potential stranding and trapping locations. The meso-scale habitat mapping work effort was conducted only within the Canadian portion of the Pend Oreille River upstream of Red Bird Creek and was conducted in June 2007. Large woody debris mapping was accomplished as part of Study 10 (Large Woody Debris Management [SCL 2008g]); and the Study 10 data collection was incorporated into the Habitat Mapping component of Study 7. 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. The angler interviews were conducted between May and early December 2007 and included a total of 26 anglers.

Table 6.1-1. Summary of work status for Habitat Mapping (Study 7.1) component of Study 7.

RSP Task / Interim Study Report Section	Task Name	Status of work effort
1/ 4.1.1	Channel Typing	Meso-scale habitat mapping was completed in the Canadian portion of the Tailrace Reach and was used to verify habitat transect location./*No work remaining.*
2/ 4.1.2	Wetted Width Calculations	Due to a change in methodology to determine habitat transect locations, this task was not completed./*No work remaining.*
3/ 4.1.3	Wetted Surface Area Calculations	Due to a change in methodology to determine habitat transect locations, this task was not completed./*No work remaining.*
4/ 4.1.4	LWD Mapping	A complete census of all observable LWD within the Boundary Reservoir was completed. Each piece of LWD was classified according to size and status of decay./*No work remaining.*
5/ 4.1.5	Aquatic Vegetation Mapping	Measurement of macrophyte abundance and macrophyte mapping surveys was conducted in August during peak macrophyte growth. The entire shoreline from Box Canyon Tailrace to Boundary Dam was surveyed for the presence of macrophytes./*Additional mapping of macrophyte beds is recommended during 2008 to provide higher resolution coverage for potential fish stranding and trapping areas including side channels, depressions and low gradient bars.*
6/ 4.1.6	Angler Interviews	Twenty-six anglers (respondents) were interviewed for this task. Information provided by the interviews was organized by fish species. GIS mapping was developed to present spawning areas and trapping and stranding areas identified by the respondents./ *No work remaining.*
7/ 4.1.7	Data Compilation	The habitat mapping data were compiled into the interim study report. GIS mapping was developed for LWD and macrophytes./ *Incorporation of the 2008 macrophyte mapping update.*

Notes:
RSP – Revised Study Plan
LWD – large woody debris

The following is a list of cross-over study elements for the Habitat Mapping (Study 7.1) effort:

- The macrophyte field surveys and mapping work products from Study 7.1 will be used in Study 6 (Relationship of pH and DO to Macrophytes [SCL 2008d]) to assist in addressing the potential effect of existing macrophyte beds on pH and dissolved oxygen. Close coordination of this work is being ensured by the studies sharing the same study lead and many of the same staff members.
- The LWD field survey and mapping is a coordinated work effort between Study 7.1 and Study 10 (Large Wood Debris Management [SCL 2008g]). While the details of the mapping effort are provided in Study 10, the contribution of LWD distribution on aquatic habitat will be addressed in Study 7.1.
- Study 9 (Fish Distribution, Timing and Abundance Study [SCL 2008f]) will provide baseline biological information and supporting information for the aquatic habitat modeling study (Study 7) as a whole. Information from the angler interviews will aid in future sampling for spawning fish and concentrated sampling for 2008 radio tagging.

6.2. Hydraulic Routing Model

Table 6.2-1 summarizes the work completed and the remaining efforts to be performed in the Hydraulic Routing Model development component (Study 7.2) of Study 7. The majority of the work conducted in 2007 for this study component has involved data collection and post-processing of all pressure transducer data collected between September 2006 and September 2007, development of the upstream hydraulic routing model (Box Canyon Dam to Boundary Dam), and calibration (including verification) of the upstream hydraulic routing model to all data collected between September 2006 and September 2007.

A wide range of technical efforts have been conducted to support the integration of the hydraulic routing model with the Scenario Tool and to support the stranding and trapping methodology (Study 7.5). Coordination has been conducted with the relicensing participants to provide status updates regarding the model calibration efforts.

Table 6.2-1. Summary of work status for Hydraulic Routing Model (Study 7.2) component of Study 7.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort
1/ 4.2.1	Routing Model Construction	The upstream hydraulic model has been constructed using cross section geometry cut from the DTM./*The habitat transect channel geometry needs to be incorporated into the upstream HRM. The downstream HRM needs to be constructed.*
2/ 4.2.2	Model Calibration	The upstream hydraulic model has been calibrated using continuous pressure transducer and USGS stage data for specific portions of the September 2006 through September 2007 data collection period. The calibration was verified using the entire 13-month data collection period./*The calibration of the upstream hydraulic model will incorporate the water surface elevations surveyed at each habitat transect and will include additional continuous stage data collected subsequent to September 2007. The downstream hydraulic model will be calibrated and verified. A report on the calibrated hydraulic model with be presented to the relicensing participants in May 2008 for review. Concurrence by the relicensing participants will be sought in July 2008.*
3/ 4.2.3	Evaluate Need for Separate Seasonal Models	Evaluation of the upstream hydraulic model calibration results led to the preliminary conclusion that there is no need to develop separate seasonal models or separate seasonal specific calibration parameters./*This evaluation will be finalized once the habitat transects are incorporated into the upstream hydraulic model and once the habitat transect water surface elevations are incorporated into the calibration.*
4/ 4.2.4	Model Documentation and Executable	The framework for the integration of the hydraulic routing model with the other models in the relicensing effort has been outlined in the interim study report./*Coordination with the Technical Scenario Team will continue related to the integration with the ST. Integration with the habitat models will continue.*

Notes:
DTM – digital terrain model
HRM – hydraulic routing model
RSP – Revised Study Plan
ST – Scenario Tool
USGS – US Geological Survey

The following is a list of cross-over study elements for the Hydraulic Routing Model (Study 7.2) effort:

- Downramping rate information is being developed in Study 7.3 and will be useful to Study 1 (Erosion Study [SCL 2008a]) in evaluating potential influences on shoreline erosion processes. Information generated from Study 7.3 will be exceedance for specific ramping rates as specific ramping rates ranging from 1 inch per hour to 12 inches per hour. If additional information is needed on specific ramping rates, or upramping rates are required, they will be provided from this study. These two efforts share the same study lead, so close coordination between the two efforts is ensured.
- The development of the hydraulic model for Study 2 (Peak Flood Flow Condition Analysis [SCL 2008b]) will use the calibrated hydraulic routing model developed for Study 7 as the starting point. For Study 2, additional model calibration will be conducted for the peak flow events of 1972, 1974, and 1997. The study will also determine if the Boundary Project influences inundation during the peak flow events. Studies 7 and 2 are closely coordinated, since the same Study lead and staff are performing both efforts.
- Study 4 (Toxics Assessment [SCL 2008c]) will use model results from the hydraulic model to identify likely regions of deposition for various sized sediments transported in the Pend Oreille River. This work was completed in spring 2007; however, it will be updated once final calibration of the hydraulic routing model is completed.
- Study 8 (Sediment Transport and Tributary Delta Habitats [SCL 2008e]) will use cross section geometry from the hydraulic routing model for development of the mainstem sediment transport model, hydraulic model output for evaluating hydraulic conditions at the toe of tributary deltas, and the hourly water surface elevations for tributary delta habitat modeling. Close coordination of this work is being ensured by the studies sharing the same study lead and many of the same staff members.
- The hydraulic routing model will provide information on the elevation and discharge present at specific locations during various sampling events conducted for Study 9 (Fish Distribution, Timing and Abundance Study [SCL 2008f]). Coordination of these requirements has been initiated. The study leads for both efforts are also working closely on several other aspects of Study 7, including the HSI curve development and the stranding and trapping analysis and field study efforts.
- Many of the Terrestrial Resource studies will require input on water surface elevations throughout the study area for both interpreting conditions during field studies and in understanding potential influences of operations scenarios on certain aspects of their resources. For example, Study 15, Waterfowl/Waterbird (SCL 2008i) examines water surface elevations on and adjacent to islands and bars in order to understand the potential for inundation of nesting sites and for inundation of land bridges that might otherwise provide access to nesting sites by predators. Coordination of these efforts is being conducted through the monthly multi-discipline meetings.
- Coordination of the Hydraulic Routing Model Development with the Scenario Tool effort is essential. The overall modeling approach for the Boundary Relicensing effort requires that these two models be linked. The hydraulic routing model needs to take the Scenario Tool output (Boundary Dam outflows and forebay elevations) and use these to determine flow rates and water surface elevations at hourly intervals

throughout the study reaches above and below Boundary Dam. This requires acquisition of forebay elevation data for Seven Mile Dam. Coordination is also required to address the issue of properly accounting for the complex storage conditions upstream of Metaline Falls. Members of the Scenario Tool development team and the Hydraulic Routing Model Development team have been exchanging information through 2007 and will continue through 2008. Key personnel from both efforts participate in the TST Workgroup which conducts periodic meetings and conference calls. Key members of the Hydraulic Routing Model Development team will be participating in the execution of the Scenario Tool for operations scenarios.

6.3. Physical Habitat Model Development

Table 6.3-1 summarizes the work completed and the remaining efforts to be performed in the Physical Habitat Model Development component (Study 7.3) of Study 7. The majority of the work conducted in 2007 for this study component has involved data collection and compilation of information. The primary data collection effort has been performing the mainstem habitat transect measurements in Boundary Reservoir including velocity, depth, and coding for substrate, cover and vegetation. A wide range of other field efforts has been conducted to support development of the HSI curves (Study 7.4 and Study 9 [SCL 2008f]), periodicity tables (Study 7.4 and Study 9 [SCL 2008f]), and the stranding and trapping analysis (Study 7.5); however, these efforts were conducted for other Study 7 components or Study 9 (SCL 2008f). Considerable coordination has been conducted with the relicensing participants to provide details on study methods and to seek agreement on these methods through provision of written materials, site visits, and Fish and Aquatic Workgroup meetings. For the execution of technical work, the major efforts have involved preparation of methods for various elements of the mainstem habitat model and performing GIS analysis to support stranding and trapping effort. While the integration of the habitat transects into the hydraulic routing model has not yet been completed, DTM-based cross sections in the hydraulic routing model have been located at every habitat transect location.

Table 6.3-1. Summary of work status for the Physical Habitat Model Development component of Study 7 (Study 7.3).

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed/*Remaining*)
1/ 4.3.1	Transect Selection	The transect selection effort has been completed with a total of 63 transects located, including 24 in the Upper Reservoir Reach, 20 in the Canyon Reach, 5 in the Forebay Reach, and 14 in the Tailrace Reach./*No work remaining*
2/ 4.3.2	Relicensing Participant Site Visit	The relicensing participant site visit task has been completed. (Transect locations were proposed, discussed and agreed upon at a series of Workgroup meetings on April 24, June 7, and July 24, 2007. A follow-up site visit to confirm/modify habitat transect selections was offered by SCL, but no RPs indicated desire or need, so the trip was not implemented./*No work remaining.*
3/ 4.3.3	Substrate and Aquatic Vegetation Characterization	Codes for substrate, cover and aquatic vegetation were presented to the relicensing participants and agreed upon at the July 24, 2007 Workgroup meeting. The field work for this task was completed for the Upper, Canyon, and Forebay reaches during the early September 2007 drawdown./*The field work for the 14 transects in the tailrace reach needs to be conducted and is scheduled for March 2008. Information for all reaches needs to go through a QA/QC process, then reported.*
4/ 4.3.4	Velocity and Depth Measurements	The field work for this task was completed for the Upper, Canyon, and Forebay reaches during the period from April to August 2007./*The field work for the 14 transects in the tailrace reach needs to be conducted and is scheduled for March 2008. Information for all reaches needs to go through a QA/QC process, then reported.*
5/ 4.3.5	Develop Cross-Sectional Profiles	Initial reduction of the collected raw ADCP data to cell data has been completed for the Upper, Canyon, and Forebay reaches./*The reduction of the raw data for 14 transects in the tailrace reach needs to be conducted after the data are collected. Information for all reaches needs to go through a QA/QC process and then reported.*
6/ 4.3.6	Hydraulic Model Integration	DTM based cross sections in the HRM have been located at every habitat transect location./*The habitat transect geometry will replace the DTM-based geometry at each habitat location for the upstream hydraulic model. The Tailrace Reach data have not been collected and the HRM has not been developed.*
7/ 4.3.7	Calibrate Hydraulic Model	Proposed methods for calibrating to the mean column velocities were presented in the interim study report./*Calibrate the mean column velocities for all reaches. Calibrate the upstream and downstream hydraulic model to the water surface elevations for each of the habitat transects. Results of the transect calibration will be presented in a report to the relicensing participants in May 2008 and concurrence sought in July 2008.*
8/ 4.3.8	Downramping Analysis	The methods for this effort have been developed and are presented in the interim study report./*The model runs and GIS analysis to define critical pool levels need to be performed. As operations scenarios are developed, ramping exceedance of 1, 2, 4, 6, and 12 inches per hour will be determined.*
NA/ 4.3.9	Stranding and Trapping Analysis	The methods to perform the stranding and trapping analysis have been developed and are included in the interim study report. GIS analysis of the areas have been initiated./*GIS analysis needs to be completed. Post-processing routines need to be developed. Final determination of the stranding and trapping factors will be coordinated with RPs.*

Table 6.3-1, continued…

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed/Remaining)
9/ 4.3.10	Varial Zone Model	The methods to perform the varial zone analysis have been developed and are included in the interim study report./*Macrophyte, periphyton, and BMI HSI/HSC efforts in Study 7.4 need to be completed and incorporated into varial zone models. Post-processing routines to perform analysis from results of the HRM need to be developed.*
10/ 4.3.11	Habitat Weighted Useable Area	The methods to perform the WUA calculations have been developed and are presented in the interim study report./*Fish HSI/HSC efforts in Study 7.4 need to be completed and incorporated into varial zone models. Post-processing routines need to be developed to perform analysis from results of the HRM.*
11/ 4.3.12	Post-Processing	The methods to perform the post-processing efforts have been developed and are presented in the interim study report./*Post –processing routines are being developed in the downramping, stranding and trapping, varial zone, and WUA analyses; post-processing will need to be performed operations scenarios after running the ST and HRM.*

Notes:
ADCP – acoustic doppler current profile
GIS – geographic information system
HRM – hydraulic routing model
HSC – Habitat Suitability Curve
HSI – Habitat Suitability Index
QA/QC – quality assurance/quality control
RP – relicensing participants
RSP – Revised Study Plan
ST – Scenario Tool
WUA – weighted useable area

The following is a list of cross-over study elements for the Physical Habitat Model Development effort (Study 7.3):

- Study 9 (Fish Distribution, Timing and Abundance [SCL 2008f]) will provide refinement to periodicity table that will help guide application of the aquatic habitat model and assist in interpretation of results.
- The varial zone analysis from Study 7 will provide information to Study 11 (Productivity [SCL 2008h]) concerning the influence of operations scenarios on macrophytes, periphyton, and BMI abundance.

6.4. Habitat Suitability Indices Development

Each HSI is presented in its own subsection with an associated table indicating the work effort performed in 2007 and the remaining work effort to be conducted in 2008. In each of the four efforts, the development of literature-based HSI curves was completed and field investigations were initiated. For the execution of technical work, the major efforts have involved preparation of methods for various elements of the mainstem habitat model and performing GIS analysis to support the stranding and trapping effort. While the integration of the habitat transects into the hydraulic routing model has not yet been completed, DTM-based cross sections in the hydraulic routing model have been located at every habitat transect location.

6.4.1. Fish HSI

As of October 2007, literature-based fish HSI and related literature-based fish life history stage periodicity information have been gathered and summarized. Field information has been gathered through Study 9 (SCL 2008f) and the Stranding and Trapping Field Survey (Study 7.5) in 2007 and used to modify HSI curves and define local periodicity. Table 6.4-1 presents a summary of the status of work completed and the remaining efforts to be performed for HSI and periodicity components of Study 7.

Table 6.4-1. Summary of work status for the fish HSI component of Study 7.

RSP Task/Interim Study Report Section	Task Name	Status of Work Effort (Completed/*Remaining*)
1/4.4.1.1	Develop draft HSI curves	This task has been completed./*No work remaining.*
2/4.4.1.2	Develop periodicity tables	This task has been completed as scoped in RSP./*Additional information from Study 9 and stranding and trapping work in 2008 may modify current periodicity.*
3/4.4.1.3	Collect site-specific habitat suitability information	Some data collected from electrofishing, but limited from biotelemetry in 2007./ *Limited data are recommended to be collected from electrofishing in early 2008 and possibly from spawning surveys. Additional depth use data from biotelemetry for adult target species remains through mid-summer 2008.*
4/4.5	Stranding and trapping field surveys	This task is addressed separately (Section 6.5) and is not discussed here.
5/4.4.1.3	Habitat utilization frequency histogram	Data from 2007 plotted on literature-based curves and incorporated in initial curve development for depth and velocity./Histogram w*ill be developed further in 2008 when additional data are gathered.*
6/4.4.1.4	Relicensing participant and expert panel	This task not yet initiated./*A panel will be convened in 2008 after additional field data added to existing curves to discuss HSI and periodicity.*

Notes:
RSP – Revised Study Plan

Site-specific fish HSI data were collected in the Boundary project area using two independent methodologies. Biotelemetry was intended to be the primary source of HSI information for adult individuals of the target species (if sufficient numbers were tagged), whereas electrofishing was expected to provide auxiliary HSI information for adult fish and for all smaller life-stages of target fish. Boat electrofishing through September 2007 resulted in the sampling of 454 discrete HSI cells, which contained a total of 245 fish among the target species (Table 5.4-2, and Appendix 1). Additional biotelemetry sampling in 2007 and into 2008 is expected to yield additional HSI observations. Eighteen radio or CART tags were implanted into adult individuals of the target fish species (mostly smallmouth bass). These tagged fish were relocated and resulted in the collection of 52 HSI measurements. Additional tags (cutthroat trout: 6 radio, 1 CART tags; mountain whitefish: 17 radio, 9 CART tags) have been implanted since September 2007 and will add to the existing biotelemetry-based HSI data through the remainder of 2007 and into 2008 (John Knutzen, Tetra Tech, personal communication, December 14, 2007). However, the rarity of several target species and the low sample sizes collected to date despite significant field efforts illustrates the difficulty of developing site-specific HSI in the Project area. Consequently, proposed changes to the HSI data collection efforts for 2008 are presented in the recommendations portion of this Study 7 report.

Periodicity data from available scientific and gray-literature sources as well as site-specific fish observations from 2007 SCL electrofishing and stranding studies were combined to develop interim fish periodicity tables for use in the physical habitat modeling and the assessment of stranding and trapping potential (Table 5.4-1 and Appendix 1b).

As noted in Section 4.4.1.2, additional information will be obtained during 2008 on periodicity from continuing active and passive sampling, additional shoreline backpack electrofishing, smallmouth bass spawning surveys, and continuing stranding and trapping surveys.

Site-specific fish HSI data from the Boundary project area were plotted with available literature-based HSI curves. Interim Boundary HSI curves were then plotted by professional judgement with reference to the literature curves and the site-specific data. The site-specific collection efforts through September 2007 illustrate the rarity of several target species (bull trout, cutthroat trout), and the improbability of achieved desired sample size goals to develop site-specific HSI curves for the Boundary relicensing studies. Instead, the available site-specific data will be used to evaluate existing HSI curves from other locations to select a curve (or modification thereof) for use in the Physical Habitat Model Development. If continued sampling throughout 2007 and into 2008 generate significant additional HSI data, new HSI curves may be possible for the more common species (e.g., smallmouth bass, forage cyprinids). However, it is expected that the interim HSC curves and the suite of literature-based HSI curves will be evaluated by a panel of instream flow experts and relicensing participants, and the selection of final HSI curves for physical habitat modeling will be based on a combination of existing information and site-specific data.

Interim fish periodicity dates are presented in Section 5 (Table 5.4-1). These dates are anticipated to be reviewed and potentially modified by a panel of relicensing participants and expert panelists at a future meeting.

All site-specific HSI data collected in the Boundary project area are based on concomitant studies of fish distribution, timing, and abundance, using boat electrofishing and biotelemetry methodologies (Study 9, SCL 2008f). The Study 9 site-specific data will be used to evaluate existing literature-based HSI curves and the interim Boundary HSI curve and select the most appropriate curve for use in the Boundary habitat simulation models. Site-specific species periodicity data was also derived from the electrofishing efforts, as well as the stranding and trapping studies.

The following is a list of cross-over study elements for the Fish HSI development (Study 7.4.1):

- All site-specific HSI data collected in the Boundary project area is based on concomitant studies of fish distribution, timing, and abundance, using boat electrofishing and biotelemetry methodologies (Study 9, SCL 2008f). The Study 9 site-specific data HSI data will be used to evaluate existing literature-based HSI curves and develop, if enough quality data is collected, site specific interim Boundary HSI curves to aid in panel based selection of the most appropriate curve for use in the Boundary habitat simulation models.

- Periodicity from site-specific species data was also derived from the electrofishing efforts (Study 9), as well as the Stranding and Trapping Field Surveys (Study 7.5). Additional information from shoreline backpack shocking in 2008 will also provide early life history information for target and additional species.

6.4.2. Macrophyte HSI

At this time, literature-based HSI curves have been developed for macrophytes within Boundary Reservoir. The HSI curve developed addresses macrophyte response to changes in depth, velocity, substrate, and duration of inundation and dewatering. During the literature review, no appropriate suitability curves were found for macrophytes, so other literature information was used to develop professional judgement-based suitability values. In addition, macrophyte characteristics and density data have been collected along depth, velocity, and substrate gradients both through physical habitat transect data collection efforts and a separate river-wide aquatic vegetation mapping effort. Although the depth, velocity, and substrate data from cross-sectional habitat transects have been collected, these data are currently undergoing analysis that includes association with biological observations. These analyses are not yet complete relative to use in refinement of the literature-based HSI curves. This analysis will continue in order to complete this process. However, preliminary assessment of cross-sectional data indicates that there are adequate data to complete the HSC/HSI validation. This is based in part by the fact that the habitat cross sections were located upstream, downstream, and within some of the macrophyte beds. Using this information, along with the mapping of macrophyte beds in the reservoir, will allow us to evaluate the complete range of reservoir conditions. The more intensive mapping effort (see Substudy 7.4.2, Section 4) to characterize location and composition of beds resulted in the description of all settings in Boundary Reservoir where macrophytes were established. More detail is provided in Appendix 2 regarding the Macrophyte HSI model development.

Table 6.4-2 presents a summary of the status of work completed and the remaining efforts to be performed for the macrophyte HSI component of Study 7.

The following is a list of cross-over study elements for the Macrophyte HSI development (Study 7.4.2):

- This component of Study 7 will provide input to Study 11 (Productivity [SCL 2008h]). Data collected for macrophyte HSI development will be used in the determination of the level of secondary productivity in the reservoir.
- This component of Study 7 will use input from the Physical Habitat Model Development component to determine the site-specific conditions for the physical habitat parameters during each sample period in Boundary Reservoir. This component of Study 7 will be combined with the macrophyte, periphyton, and fish HSI models to define the relationship between habitat quality and quantity for different operations scenarios.

Table 6.4-2. Summary of work status for the Macrophyte HSI component of Study 7.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed/*Remaining*)
1/ 4.4.2.1	Literature Review	Effort has been completed./*No work remaining.*
2/ 4.4.2.2	Aquatic Plant Field Surveys	Surveys were completed during August 2007./ *Additional mapping of macrophyte beds is recommended during 2008 to provide higher resolution coverage for potential fish stranding and trapping areas including side channels, depressions, and low gradient bars.*
3/ 4.4.2.3	Validate HSI curves for depth, velocity, substrate, and frequency of inundation	This task has been initiated./*A histogram for each habitat parameter will be developed using the site-specific data; need to compare histograms to the literature-based HSI curves to validate applicability.*
4/ 4.4.2.4	Develop HSI Information for pH and DO	Based on analysis of macrophyte community structure, no impact on macrophyte habitat was found due to pH or DO levels and habitat limitation induced by macrophyte control by pH or DO was not found in Study 6 (SCL 2008d)./*No work remaining.*
5/ 4.4.2.5	Confirm Macrophyte HSI curves	This task has not been initiated./*Need to convene panel of RPs and regional experts to review HSI curves and site-specific data to finalize HSI curves after Tetra Tech evaluation of field data and formulation of revised draft models.*
6/ 4.4.2.6	Provide finalized information to Aquatic Habitat Models	This task has not been initiated./*Will be done after completion of Task 5.*
7/ 4.4.2.7	Provide necessary information to the Productivity Assessment Study	On-going assessments in conjunction with Tasks 3, 4, and 5./*Continue to coordinate with Tasks 3, 4, and 5.*

Notes:
RSP – Revised Study Plan
DO – dissolved oxygen
HSI – Habitat Suitability Index
RPs – relicensing participants

6.4.3. Periphyton HSI

At this time, a literature-based HSI curve has been developed for periphyton within Boundary Reservoir. The HSI curve developed addresses periphyton responses to changes in depth, velocity, substrate, DD, and DI. During the literature review, no appropriate suitability curves were found for periphyton, so other literature information was used to develop suitability values. These suitability values will be refined based on site-specific field data collected in 2007 and 2008.

Site-specific periphyton data have been collected in Boundary and Box Canyon Reservoirs for spring, summer, and fall seasons. Fall periphyton samples are currently being analyzed by the laboratory and will be presented along with winter data in the final report. Winter periphyton data samples and periphyton colonization samples are to be collected in February 2008, weather and reservoir conditions permitting. Retrieval of winter periphyton samples and colonization baskets may not occur until March due to adverse weather and reservoir conditions (i.e. ice).

The site-specific data collected from field efforts, along with results from the hydraulic model, will be used to calibrate and validate the literature-based HSI curve.

Table 6.4-3 presents a summary of the status of work completed and the remaining efforts to be performed for the periphyton HSI component of Study 7.

Initial analysis of data indicates that periphyton responses in Boundary and Box Canyon reservoirs are responding to select environmental variables as per experimental design, which will lead to refinement of the HSI periphyton literature-based model. At all treatment sites and seasons with the exception of the shoreline treatment sites in the summer, periphyton chlorophyll *a* is decreasing with decreasing elevation intervals after reaching maximum. The variability in the summer chlorophyll *a* concentrations at the shoreline treatment sites indicates that periphyton growth is being affected by other factors such as study drawdown and potential seasonal conditions. A comparative analysis of the periphyton data with outputs from the hydraulic model and habitat transect data will take place in 2008 and will allow for deciphering these conditions for further validation of the HSI curves. Specifically, chlorophyll *a* data in combination with cross-sectional data of depth, velocity, and substrate combined with the output for reservoir water surface elevation and velocities from the hydraulic routing model will result in a Boundary Reservoir definition that supports any refinement of the periphyton HSI.

The artificial baskets and suspended platforms used to collect periphyton create an environmental condition that diverges from velocity gradients present in hard rock substrate within the Boundary Reservoir. This reduction in velocity may result 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 colonization within artificial baskets and in situ communities is needed to verify the influence of velocity on periphyton accumulation within the substrate. An additional study will be conducted in 2008 to compare the periphyton found in the artificial substrate samplers with periphyton on natural hard substrate at shoreline sites in all three reservoir sites. The study will evaluate 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 will be used to verify the validation of HSI curves and to test the hypothesis that the influence of velocity on periphyton growth is being underestimated by the geometry of the baskets.

Table 6.4-3. Summary of work status for the Periphyton HSI component of Study 7.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed/*Remaining*)
1/ 4.4.3.1	Literature-based Periphyton HSI Model	Effort has been completed./*No work remaining.*
2/ 4.4.3.2	Periphyton Communities on Hard Substrates	Sample collection included deployment and retrieval of artificial substrates beginning April 2007 through December 2007. Samples have been retrieved for deployment dates in April, July, and September./ *Samples deployed in December will be collected in February 2008, weather permitting. Samplers may not be retrieved until March Comparison study of artificial samplers and natural rock substrate will be initiated in 2008.*
3/ NA	Periphyton Communities on Soft Substrates	The soft substrate task is only applicable to the BMI./*No work to be performed.*
4/ 4.4.3.3	Periphyton Colonization Rates	Summer season colonization studies were completed./*Winter colonization sample collection is expected to be finalized in February 2008, weather and reservoir conditions permitting. Colonization sample collection may not occur until March 2008.*
5/ 4.4.3.4	Validation of Periphyton HSI Model	This task has not been initiated./*A histogram for each habitat parameter needs to be developed using the site-specific data; need to compare histograms to the literature-base HSI model to validate applicability.*
6/ 4.4.3.5	Finalize Periphyton HSI Information	This task has not been initiated./*Need to convene panel of RPs and regional experts to review HSI model and site-specific data to finalize HSI model.*

Notes:
RSP – Revised Study Plan
NA – Not applicable

The following is a list of cross-over study elements for the Periphyton HSI development (part of Study 7.4.3):

- This component of Study 7 will provide input to Study 11 (Productivity [SCL 2008h]). Data collected for periphyton HSI development will be used in the determination of the level of secondary productivity in the reservoir.
- This component of Study 7 will use input from the Physical Habitat Model Development component to determine the site specific conditions for the physical habitat parameters during each sample period in Boundary Reservoir. This component of Study 7 will be combined with the macrophyte, periphyton, and fish HSI models to define the relationship between habitat quality and quantity for different operations scenarios.
- Results of field work provide information to be used in Studies 3, 4, and 5.

6.4.4. Benthic Macroinvertebrate HSI

Much of the work for the macroinvertebrate HSI development and a substantial portion of the field data collection and analysis were completed in 2007. In general, the literature-based HSC curves have been developed for macroinvertebrate response to changes in depth, velocity, substrate, and DI and DD. For the field data collection, tasks for 2008 include lab analysis of the samples collected, collection of additional samples, analysis of the biotic data with respect to the output from the physical habitat model, and comparison of the results of data analysis with the literature-based HSC curves. Field collection of samples in 2008 will be conducted (weather permitting) during the winter months. Collection may also be affected by staff availability and the availability of necessary equipment, should weather require scheduling changes. In 2008, the HSC curves and site-specific data will be reviewed by relicensing participants to finalize the benthic macroinvertebrate HSI, which will be incorporated into the larger HSI model. This section summarizes the work completed in 2007 and work remaining to be completed in 2008 and 2009. Cross-over elements with other studies are also identified.

The tasks for field data collection are at different states of completion and the work status is summarized in Table 6.4-4. Efforts for the development of literature-based HSC for use in the calculated macroinvertebrate HSI model were completed in 2007. In terms of field data, in 2007, three of the four sets of hard and soft substrate samples were collected, and two sets of those samples were identified, measured, and enumerated by the lab. The data from the lab were used to calculate biomass for each sample using a length/mass relationship for each taxon. One of the two sets of colonization samples was collected in 2007 and these data were also analyzed and biomass was calculated in the same way. In 2008, the fourth set of hard and soft substrate samples, and the second set of colonization samples will be collected. Data from these samples will be analyzed and compared to output from the physical habitat model. In 2008, a group of relicensing participants will review the HSC curves, the HSI model, and the site-specific data and provide input, as needed, to finalize the HSI model for benthic macroinvertebrates.

Recommendations are to conduct an additional field effort in 2008 to compare the effects of using artificial substrate samplers to conditions of natural rock substrate in Boundary Reservoir, above and below Metaline Falls, and Box Canyon Reservoir. The study would evaluate differences observed in BMI community structure and biomass that may result from the use of sampling baskets in comparison to colonization of natural reservoir substrate outside of the baskets.

Table 6.4-4. Summary of work status for the benthic macroinvertebrate HSI component of Study 7.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed/*Remaining*)
1/ 4.4.4.1	Literature-based Benthic HSI Curves	Effort has been completed./*No work remaining.*
2/ 4.4.4.2	Benthic Communities on Hard Substrates	Sample collection and data processing has been initiated with two of four sets complete./*Collection of the final set of samples and data processing will be performed. A comparison study of artificial samplers and natural rocks substrate is recommended to be performed in 2008.*
3/ 4.4.4.3	Benthic Communities on Soft Substrates	Sample collection and data processing has been initiated with two of four sets complete./*Collection of the final set of samples and data processing will be performed.*
4/ 4.4.4.4	Benthic Colonization Rates	Sample collection and data processing has been initiated with one of two sets complete./*Collection of the final set of samples and data processing will be performed.*
5/ 4.4.4.5	Validation of Benthic HSI Curves	This task has not been initiated./*A histogram for each habitat parameter will be developed using the site-specific data; need to compare histograms to the literature-based HSI curves to validate applicability.*
6/ 4.4.4.6	Finalize Benthic HSI Information	This task has not been initiated./*Need to convene panel of RPs and regional experts to review HSI curves and site-specific data to finalize HSI curves.*

Notes:
RSP – Revised Study Plan
RPs – relicensing participants
HSI – Habitat Suitability Indices

The following is a list of cross-over study elements for the Benthic Macroinvertebrates HSI development (part of Study 7.4.3):

- This component of Study 7 will provide input to Study 11 (Productivity [SCL 2008h]). Data collected for benthic macroinvertebrate HSI development will be used in the determination of the level of secondary productivity in the reservoir.
- This component of Study 7 will use input from the Physical Habitat Model Development component to determine the site-specific conditions for the physical habitat parameters during each sample period in Boundary Reservoir. This component of Study 7 will be combined with the macrophyte, periphyton, and fish HSI models to define the relationship between habitat quality and quantity for operations scenarios.

6.5. Stranding and Trapping Field Surveys

The status of study elements for the field portion of the stranding and trapping analysis is shown in Table 6.5-1. One year of initial study has been completed for the field portion of stranding and trapping. The study included the initial scoping of potential areas to examine for stranding and trapping conditions and sampling of the potential stranding and trapping areas. Development of a potential stranding and trapping map using GIS also occurred as part of this study. Following an initial reconnaissance survey to select regions (23 total), field studies occurred in July, August, and September 2007. In most cases, the physical characteristics of sites within each region were examined and recorded including slope, substrate, macrophyte abundance, and pool depth of trapping areas. In many areas, water surface elevation and remaining pool size were recorded on field maps for transfer to GIS. Also, the number and species of fish were noted and often fish lengths were measured. All 23 regions were examined during drawdown events at least once during 2007. Finalized detailed bathymetric maps (developed December 2007) showed pool areas that were over 100 square feet in size, with slope areas less than 4 percent. Information from the field studies is presented on these GIS-based maps (Appendix 6). This information collected in the field will aid in the final model being developed to address stranding and trapping (Section 4.3.9). Additional field studies to be conducted in 2008 will be directed at validating model index factors currently proposed in Section 4.3.9.

Table 6.5-1. Summary of work status for the Stranding and Trapping Field Surveys.

RSP Task / Interim Study Report Section[1]	Task Name	Status of Work Effort (Completed/*Remaining*)
4/4.5.1.1, 4.5.2.1	Reconnaissance survey	Reconnaissance survey to select regions completed in 2007. / Crew coordination *surveys are recommended to occur in early spring 2008 to confirm field data collection methods and to select sites for stage recorders and elevation measurement sites.*
4/4.5.1.2, 4.5.2.2	Region Identification and Site Selection	Twenty-three regions were selected for study in 2007./*It is recommended that in 2008, subgroups of sites within these regions be selected for survey.*
4/4.5.1.3, 4.5.2.3	Stranding and Trapping Surveys	Initial habitat and fish stranding and trapping data and bathymetric stranding and trapping maps were completed in 2007./*Directed surveys to validate stranding and trapping model parameters are proposed for 2008.*

Notes:
RSP – Revised Study Plan
1 All interim study report sections are part of RSP Task 4 for Fish HSI.

Initial results have indicated several factors influence the amount of stranding and trapping that occurs. Presence of macrophytes both in trapping pools and slopes has been a major factor affecting amount of stranding and trapping. Substrate does not appear to be a major factor, although additional information will aid in that determination. The length of time pools are isolated and the magnitude of drawdown also are critical in influencing severity of effects on fish. Season is also important, as the vast majority of fish stranded were early life stages (larvae, young-of-the-year). About 10 species were observed stranded or trapped. Species most commonly stranded or trapped in July were sucker and yellow perch. By August and September more commonly stranded species were young-of-the-year centrarchids (small and largemouth bass, black crappie, pumpkinseed). Yellow perch and sucker were also observed during this timeframe, but in few numbers. Only one unidentified trout was observed to be stranded among over 30,000 fish seen.

The following is a list of cross-over study elements for the Stranding and Trapping Field Surveys (Study 7.5):

- Information from stranding and trapping will be used by Study 9 (Fish Distribution, Timing and Abundance [SCL 2008f]), when characterizing life stage use of habitat by species for reach area discussions and seasonality of young-of-the-year.
- Information from Study 9 on occurrence and location of young-of-the-year species will be used in the stranding and trapping analysis when discussing where and when fish may be found relative to potential stranding and trapping regions. This will include information on tributary downstream movement of small fish into the reservoir, particularly native salmonids, as well as regular electrofishing and shoreline backpack electrofishing data.

7 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

This section presents and discusses variances from the FERC-approved RSP (SCL 2007a) and proposed modifications. Variances address changes in FERC-approved study plans and changes in the approved study schedules presented in the RSP. Proposed modifications are additions or refinements to the study effort to address study needs that have been 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 have been made and how the relicensing participants were involved in the process.

7.1. Variances

Variances from FERC-approved RSP are presented for the study components within Study 7.

7.1.1. Habitat Mapping

The primary purpose of the Habitat Mapping component (Study 7.1) as envisioned in the RSP (SCL 2007a) was to support selection of 1) mainstem habitat transect locations, 2) the number of transects, and 3) the weighting factors to be applied in computing habitat WUA. Because of changes in the manner in which habitat transects were determined, the purpose of the Habitat Mapping component has changed from that described in the RSP. Transects were to be selected based on channel type and major habitat features, and then each was to be given an appropriate weighting within the model. The information to support this process was to be developed in the Habitat Mapping component.

As a result of the changed approach, the following tasks as identified in the RSP were not performed:

- Task 1) Channel Typing
- Task 2) Weighted Width Calculation
- Task 3) Wetted Surface Area Calculations
- Task 7) Data Compilation

The remaining Study 7.1 tasks were performed and provide information to be used in study efforts other than the selection of transects. The Habitat Mapping tasks that were performed as identified in the RSP include:

- Task 4) LWD Mapping
- Task 5) Aquatic Vegetation Mapping
- Task 6) Angler Interviews

The revised approach was presented to relicensing participants and resulted in using a similar number of transects in Task 1 of the proposed methodology for Physical Habitat Model Development (page 29 of the RSP), and was approved following discussions and minor revisions in transect placement at the April 24, 2007 Fish and Aquatic Workgroup meeting.

Task 5, aquatic vegetation mapping, is being modified to include an effort in 2008 that will provide additional information on the presence of aquatic macrophytes within the mainstem of the Pend Oreille River. This expanded effort is being conducted to provide support for performing the stranding and trapping analysis. Section 7.2.1 discusses the macrophyte mapping effort proposed for 2008. The macrophyte mapping effort is expected to be conducted in August 2008. Other than conducting this macrophyte mapping effort, there are no schedule changes proposed for Study 7.1, Habitat Mapping.

7.1.2. Hydraulic Routing Model

One variance in the study plan for Study 7.2 (Hydraulic Routing Model) has been identified. It is proposed that collection of the water surface elevations using the pressure transducers be terminated at the end of June 2008 rather than continuing through December 2008 as identified in the RSP. Continuing the measurements through June 2008 will include an additional spring freshet season with potentially higher flows than experienced in 2007. Further data collection in 2008 is not expected to yield additional information on medium and low flow conditions beyond that captured in the 2007 data set.

7.1.3. Physical Habitat Model Development

The variances from methods outlined in the RSP (SCL 2007a) for Study 7.3, Physical Habitat Model Development, involve tasks associated with the habitat transects and the schedule for conducting the study effort.

7.1.3.1. Transect Selection

Transects for the Mainstem Aquatic Habitat Model were to be selected based on channel typing and major habitat features, and then each 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), and was approved following discussions and minor revisions in transect placement at the April 4, 2007 Fish and Aquatic 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.

7.1.3.2. 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.

7.1.3.3. 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 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.

7.1.3.4. 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.

7.1.4. HSI Development

There are several variances for the HSI Development efforts. All four HSI efforts had variances from FERC-approved study plans; however, these variances were minor and were a result of adapting efforts to site-specific conditions.

7.1.4.1. Fish HSI

Only one variance occurred 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, 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 Aquatic Workgroup meetings, 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 would be targeted as those suitable as forage fish.

Using small cyprinids as the target taxa, initial HSI curves can be developed using literature information from other cyprinid taxa. Information collected in the field for habitat use would include redside shiner, as well as the fry and juvenile stages of primarily peamouth and northern pikeminnow. In this way the analysis would address habitat used by fish of the same general size that would make suitable prey, and include similar taxa. Also, commonly abundant species within the system would be used to help develop site-specific curves. It is anticipated that similar habitat would be occupied by these taxa during their early life stages.

While spawning surveys were not conducted during 2007, which is part of the RSP guidelines for developing HSI curves, surveys of likely spawning habitat of smallmouth bass will be done in spring and summer 2008.

7.1.4.2. Macrophyte HSI

There have been no variances from the FERC-approved RSP (SCL 2007a).

7.1.4.3. Periphyton HSI

Study 7.4.3 was conducted in accordance with the FERC-approved RSP (SCL 2007a).

7.1.4.4. Benthic Macroinvertebrate HSI

Study 7.4.3 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 have been 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 in Study 7.4.3, 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 will be used to extrapolate the biomass for the September sample.

7.1.5. Stranding and Trapping Field Surveys

The original FERC-approved RSP had limited detail. The only variance was not conducting electrofishing surveys prior to reduction in water surface elevations. A methods outline describing the procedures to be followed for 2007 did not include this activity as one of the tasks, as other methods were considered more suitable for meeting the objectives of this study. This detailed methods outline provided improved methodologies for sampling, literature reviews, and refined plans. It was prepared and submitted for relicensing participant review prior to the June 7, 2007 meeting where agreement was reached on the approach (SCL 2007b).

7.2. Recommended Modifications

Study recommendations are modifications to the effort that do not involve changes to the FERC-approved RSP. In general, recommended modifications are additions or refinements that address needs that have been identified during the study by either the study team or the relicensing participants. The recommended modifications in Study 7 involve all efforts except Hydraulic Routing Model (Study 7.2) and BMI HSI Development (Study 7.4.4).

7.2.1. Habitat Mapping

Additional mapping of existing macrophyte beds in depressions, on low gradient bars, side channel and other habitats with potential for stranding and trapping is recommended for 2008. This additional macrophyte data will be used to support the study of potential for stranding and trapping of fish (Studies 7.3 and 7.5). The GIS base bathymetry that has been processed to identify potential stranding and trapping areas will be used to direct field crews to the areas to be mapped. The mapping will be performed utilizing mapping grade GPS set to track the locations as the perimeter of the macrophyte beds are being traced. This effort is proposed for August 2008.

7.2.2. Hydraulic Routing Model

There are no recommended study modifications to the Hydraulic Routing Model component of Study 7.

7.2.3. Physical Habitat Model Development

The recommended modification to the Physical Habitat Model Development is to create a separate task specifically for stranding and trapping. The stranding and trapping analysis described in Section 4.3.9 reflects this approach.

7.2.4. HSI Development

Several recommendations for modifications have been made for the following HSI Development efforts: fish HSI, macrophyte HSI, and periphyton HSI. These recommendations are discussed in more detail in the following sections.

7.2.4.1. Fish HSI

The following recommended changes address the collection of HSI field data and curve use.

1. The recommended change to the biotelemetry HSI data collection is to eliminate measurements of velocity during mobile tracking due to its expected poor representation of velocities actually utilized by the fish. This recommendation was also included in Study 9 (SCL 2008g). Water velocity data recorded at these locations are not suitable for HSC curve development for the following reasons: limited accuracy (+/- 33 feet) associated with fish locations identified by radio telemetry, the likelihood that fish may be 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. Depth measurements, however, do supply useful information for HSC curve development.

2. We recommend cessation of all HSI data collection by electrofishing after February 2008. The current RSP schedule shows HSI data collection continuing through the second quarter of 2008, so this recommendation is a slight variance from the RSP. Also 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 (Table 5.4-2). Less than four HSI data points were collected for any native salmonid (e.g., bull trout, cutthroat trout, wild rainbow trout, or mountain whitefish). While some additional data will have been collected through December 2007, it appears unlikely that enough information will be obtained to do any significant modification to curve development through electrofishing field data collection. Moderate to large literature databases are available from which to build curves for these species and life stages, as shown in Appendix 1.

   Some useful data have been collected for rearing stages of smallmouth bass and forage species, and data collection through fall 2007 and early winter 2008 will further increase the number of data points, but for the effort expended, these numbers remain insufficient for developing new HSI curves. Also, boat electrofishing has some limitations, as the habitat area sampled is restricted to the nearshore waters to depths less than 7 feet deep, which in this deep reservoir system is a small portion of the total habitat. Also, use of shallower water (less than 1 foot) by small fry may be under-represented due to boat limitations. Therefore, there are limitations regarding the usefulness of electrofishing HSI data, even if more data points were to be collected. Spawning stages of any fish species were also absent from any HSI data collection.

3. We recommend not conducting analyses 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 do 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, we have not obtained any samples 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 (see Study 9, SCL 2008f). Considering the potential impact of existing Project effects on the life stages of these species in the mainstem reservoir habitat would not be justified because of their absence of use.

7.2.4.2. Macrophyte HSI

There are no recommendations for additional or altered efforts in 2008 concerning the Macrophyte HSI study. Additional mapping of macrophyte beds is recommended as part of Study 7.1.

7.2.4.3. Periphyton HSI

Additional sampling is recommended in 2008 to compare the periphyton found in the artificial substrate samplers with periphyton on natural hard substrate at shoreline sites in all three reservoir locations. The study would evaluate 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 would be used to verify the validation of HSI curves and to test the hypothesis that the influence of velocity on periphyton growth is adequately described based on initial results from collection with artificial substrate. Artificial baskets and existing periphyton community conditions would be characterized simultaneously at all three reservoir sites to define the difference in maximum accumulation of periphyton biomass as well as relative colonization time.

The possibility that velocity within the artificial substrate does not represent the natural environment is being tested. If there is a difference between artificial and natural substrate response from biota, then the nature of the differences along each environmental gradient (e.g., depth, velocity, and substrate) will be examined for parallel response, convergent response, or divergent response. Existing results for periphyton will be modified (e.g., developing a correction factor) if non-uniform biological response along environmental gradients occurs originating from use of artificial substrate. This will ensure that the artificial substrate data reflect the continuum of responses along each environmental gradient that would be expected from biota collected on natural substrate. The estimates of biomass and densities may be higher on artificial substrate, but the important point is that the community response to each portion of the environmental gradient reflects the natural condition.

7.2.4.4. Benthic Macroinvertebrate HSI

Additional sampling recommended for 2008 would include a study to compare the effects of using artificial substrate baskets on BMI community structure and biomass. The artificial samplers may create a protected environment over that of natural rock substrate that potentially alters the BMI community structure in favor of those species that prefer slower water velocities. Altered velocity conditions may also artificially increase the biomass due to increased production of periphyton. The additional field study would include sampling using both artificial samplers and native substrate at the shoreline sites in all three reservoir locations.

The possibility that velocity within the artificial substrate does not represent the natural environment is being tested. If there is a difference between artificial and natural substrate response from biota, then the nature of the differences along each environmental gradient (e.g., depth, velocity, and substrate) will be examined for parallel response, convergent response, or divergent response. Existing results for BMI will be modified (e.g., developing a correction factor) if non-uniform biological response along environmental gradients occurs originating from use of artificial substrate. This will ensure that the artificial substrate data reflect the continuum of responses along each environmental gradient that would be expected from biota collected on natural substrate. The estimates of biomass and densities may be higher on artificial substrate, but the important point is that the community response to each portion of the environmental gradient reflects the natural condition.

The comparison between results from artificial versus natural substrate will be evaluated by direct comparison of BMI response (with and without *Hydra* sp.) under each depth, velocity, and substrate scenario. These comparisons will tell us if biological response is parallel between artificial and natural substrates along each environmental gradient or if it varies. If the responses are not parallel, then other factors must be identified and examined to learn if they have a greater influence than does inundation and dewatering. These comparisons will be useful for determining how to adjust and use results from the 2007 sampling effort by identifying if responses to environmental gradients are in the same direction and magnitude or if they vary along each environmental gradient.

7.2.5. Stranding and Trapping Field Surveys

There were a few modifications to the field work originally planned in the 2007 season and recommended modifications 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 proposed for 2008 are intended to obtain winter stranding and trapping information and directing studies more specifically at validating the model index parameters that will be used to model stranding and trapping.

7.2.5.1. Modifications During 2007

Minor changes from the methods outline were implemented during 2007 (SCL 2007b). 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.

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.

7.2.5.2. Recommended Modifications for 2008

Based on the results from the 2007 stranding and trapping surveys in Boundary Reservoir, the following study design modifications are recommended for the 2008 stranding and trapping surveys to increase the amount of data recorded on fish use at identified sites. Recommendations are also provided to support analysis of the seasonal differences in stranding and trapping rates at each identified site and to aid in scalar development needed for the stranding and trapping model development (see Section 4.9). Additionally, recommendations are included to augment documentation of aquatic macrophyte growth at each site. All of the recommended changes for 2008 sampling are presented in detail in Section 4.5. Additionally, a mid-season interim report is recommended to aid in model development of stranding and trapping. Finally, recommendations are provided to determine the rate at which pools and side channels drain during flow reduction.

Items identified for modification in the current work plan include:

1. Macrophyte coverage in pools and slopes will be characterized as 0, <25, 25–49, 50–74, and 75–100 percent of the areas. During the stranding and trapping surveys in 2007, it was documented that aquatic macrophyte growth plays a significant role in stranding and trapping rates. An estimate of percentage was given for aquatic macrophyte growth in all pools and low gradient stranding areas. Currently the proposed model (Section 4.3.9) has only three macrophyte coverage categories. The inclusion of more categories during the field sampling will help validate if the original categorization is adequate for modeling purposes. These categories will also be in closer agreement with the methods used to determine macrophyte coverage during the designated macrophyte surveys. Macrophyte mapping from Study 7.1, Habitat Mapping, will be used in the stranding and trapping model for defining macrophyte coverage for depressions and slopes that are not surveyed as part of the Stranding and Trapping Field Surveys.
2. The survey schedule will be 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 is recommended in late winter and early spring of 2008. To address stranding and trapping during winter and early spring, surveys are recommended in the months of February and March. During the spring and summer months, monthly surveys are recommended following reductions in Boundary forebay water surface elevations. To increase the data collected in the Boundary tailrace, it is recommended

that regular surveys in the tailrace area be conducted by Terrapin Environmental, coinciding with their work activities in the area (Study 9).

3. During drawdown events, it is recommended that backpack electrofishing or beach seines be used for pool sampling where live fish are present.
4. It is recommended that the rate at which water surface elevations drop in pools and side channel habitats be monitored after they are disconnected from the mainstem flow. To determine the rate at which isolated pools and side channels drain during drawdown events in Boundary Reservoir, up to ten stage recorder stations will be installed in selected areas prior to drawdown events. The information could aid in estimating how long pools retain water. The dewatering rate can be monitored during any daily flow fluctuations; however, it would be most useful to monitor the rate during periods of maximum extended drawdowns, if any occur in 2008.

8 REFERENCES

Arcement, George J., and Verne Schneider. 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. United States Geological Survey Water-Supply Paper 2339. United States Government Printing Office.

Barnes, Harry H. Jr. 1967. Roughness of Characteristics of Natural Channels. United States Geological Survey Water-Supply Paper 1849. United States Government Printing Office.

Bovee, K.D. 1986. Development and Evaluation of Habitat Suitability Criteria for Use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish & Wildlife Service, Biological Report 86(7). 235 pp.

Bovee, K.D. 1997. Data Collection Procedures for the Physical Habitat Simulation System. U.S. Geological Survey, Biological Resources Division, Ft. Collins, CO. 141 pp.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream Habitat Analysis Using the Instream Flow Incremental Methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Calder, P.D., D.M. Tammen, and C.M. Gleeson. 2004. Installing a Fourth Generating Unit at Seven Mile Dam. *Hydro Review*. 23(7): 4 pp.

CddHoward Consulting Inc. 2006. BOPT Technical Documentation (Rev.8 for BOPT June 1 Version).

Cooke, G.D. 1980. Lake level drawdown as a macrophyte control technique. *Water Resources Bulletin.* 16(2): 317-322.

Cummins, K.W. 1962. An Evaluation of Some Techniques for the Collection and Analysis of Benthic Samples with Special Emphasis on Lotic Waters. *American Midland Naturalist* 67:477-504.

DeGross. 2005. Aerial Photography from Flight Lines Taken in August 20, 2005.

Ecology (Washington State Department of Ecology). 2005. Online Long-term River Monitoring Home Page. Available online at: http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html.

Fisher, S.G., and A. LaVoy. 1972. Differences in Littoral Fauna Due to Fluctuating Water Levels Below a Hydroelectric Dam. *Journal of the Fisheries Research Board of Canada*. 29: 1472-1476.

Golder Associates Ltd. 2006. Columbia River Ramping Rate Assessment: Phase III and IV Investigations, Winter and Summer 2005. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 05-1480-039F: 55 p. + 5 app.

Golder Associates. 2007. Meso-Habitat Survey from the Canada-US Border Downstream to the Salmo River. Technical Memorandum dated June 13, 2007 from Dustin Ford (Golder Associates) to Bill Fullerton (Tetra Tech, Inc.).

Hedman, C.W., D.H. Van Lear, and W.T. Swank. 1996. In-stream Large Woody Debris Loading and Riparian Forest Seral Stage Associations in the Southern Appalachian Mountains. *Canadian Journal of Forest Resources*. 26: 1218-1227.

Higgins, P.S., and M.J. Bradford. 1996. Evaluation of a Large-Scale Fish Salvage to Reduce the Impacts of Controlled Flow Reduction in a Regulated River. *North American Journal of Fisheries Management*. 16: 666–673.

Hunter, Mark A. 1992. Hydropower Flow Fluctuations and Salmonids: A Review of the Biological Effects, Mechanical Causes, and Options for Mitigation. Technical Report No. 119. State of Washington Department of Fisheries. Olympia, WA.

McLellan, J.G., and D. O’Connor. 2001. Resident Fish Stock Status Above Chief Joseph and Grand Coulee Dams. Part 2. Baseline Assessment of Boundary Reservoir, Pend Oreille River, and its Tributaries. Washington Department of Fish and Wildlife. Spokane, WA.

Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's Guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper 11. United States Fish and Wildlife Service Report FWS/OBS-81/43.

National Water Information System, USGS 12396500 Pend Oreille River Below Box Canyon Near Ione, WA. Available online at: http://waterdata.usgs.gov/wa/nwis/dv

Pacific Geomatic Services (PGS). 2007. GPS Control in Support of Hydrographic Surveys of Boundary Reservoir. Survey report published August 14, 2007.

Payne, T.R. 2007. Alternative Conceptualization of the IFIM/PHABSIM Habitat Index. Paper presented to Sixth International Symposium on Ecohydraulics; Christchurch, New Zealand February 19–23, 2007.

Peck, D. V, J. M. Lazorcheck, and D. J. Klemm. 2003. Environmental Monitoring and Assessment Program: Surface Waters – Western Pilot Study Operations Manual for Wadeable Streams. U.S. Environmental Protection Agency, Corvallis, OR.

R.W. Beck and Associates. 1989. Skagit River Salmon and Steelhead Fry Stranding Studies. Prepared for Seattle City Light Environmental Affairs Division.

Rantz, S.E. 1982. Measurement and Computation of Streamflow: Volume 1. Measurements of Stage and Discharge. United States Geological Survey Water Supply Paper 2175. 284 pp.

Robison, G.E., and R.L. Beschta. 1990. Characteristics of Coarse Woody Debris for Several Coastal Streams of Southeast Alaska, USA. *Canadian Journal of Fisheries and Aquatic Sciences.* 47:1684-1693.

SCL (Seattle City Light). 2006. Proposed Study Plan for the Boundary Hydroelectric Project (FERC No. 2144). Seattle, Washington. October 2006. Available online at: http://www.seattle.gov/light/news/issues/bndryRelic/br_document.asp

SCL. 2007a. 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. 2007b. Methods Outline, Study 7 Fish HSI Task 4 Stranding and Trapping Surveys for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech and Golder Associates Ltd. May 2007.

SCL. 2008a. Study 1 – Erosion Study Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Watershed GeoDynamics under contract to Tetra Tech. March 2008.

SCL. 2008b. Study 2 – Analysis of Peak Flood Flow Conditions above Metaline Falls Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008c. Study 4 – Toxics Assessment: Evaluation of Contaminated Pathways Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008d. Study 6 – Evaluation of the Relationship of pH and Dissolved Oxygen to Macrophytes in Boundary Reservoir Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008e. Study 8 – Sediment Transport and Boundary Reservoir Tributary Delta Habitats Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech and Thomas R. Payne and Associates, Fisheries Consultants. March 2008.

SCL. 2008f. Study 9 – Fish Distribution, Timing and Abundance Study Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Terrapin Environmental and Golder Associates Inc., under contract to Tetra Tech. March 2008.

SCL. 2008g. Study 10 – Large Woody Debris Management Study Final Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008h. Study 11 – Productivity Assessment Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008i. Study 15 – Waterfowl/Waterbird Study Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

SCL. 2008j. Study 25 – Bathymetry Survey – Boundary Reservoir and Tailwater to Seven Mile Dam Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

Simpson M.R., and R.N. Oltmann. 1993. Discharge-Measurement System Using an Acoustic Doppler Current Profiler with Applications to Large Rivers and Estuaries. United States Geological Survey Water-Supply Paper 2395. United States Government Printing Office, WA.

Smith, C., and J.W. Barko. 1990. Ecology of Eurasian Watermilfoil. *Journal of Aquatic Plant Management*. 28: 55-64.

Terrapoint. 2005. Project Report, Metaline Falls (Contract #2354-H). Report presented to DeGross Aerial Mapping, Inc.

Trihey, E.W., and D.L. Wegner. 1981. Field Data Collection for Use with the Physical Habitat Simulation System of the Instream Flow Group. United States Fish and Wildlife Service Report. 151 pp.

USACE-HEC (U.S. Army Corps of Engineers – Hydrologic Engineering Center). 2006. HEC-RAS, River Analysis System User's Manual. Version 4.0 Beta.

USFWS (U.S. Fish and Wildlife Service). 1980. Habitat Evaluation Procedures (HEP). ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services. Washington, D.C.

Ward, J.V. 1992. Aquatic Insect Ecology: 1. Biology and Habitat. John Wiley and Sons. New York, NY.

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.

WSNWCB. Undated. Written Findings of the State Noxious Weed Control Board - Class B – B-designate Weed. Eurasian Watermilfoil (*Myriophyllum spicatum L.*). Available online at: http://www.nwcb.wa.gov/weed_info/Myriophyllum_spicatum.html. Olympia, Washington.

Appendix 1. Study No. 7.4.1 – Literature-Based HSI—Fish

1a. Study No. 7.4.1 –
Fish HSI for Target Species

1b. Study No. 7.4.1 –
Fish HSI Subtask 2: Interim Periodicity Tables for Target and Non-target Fish Species

Appendix 1a. Study No. 7.4.1 – Fish HSI for Target Species

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.1
Fish HSI for
Target Species

Prepared for
Seattle City Light

Prepared by
Mark Allen
Thomas R. Payne & Associates
(Under Contract to Tetra Tech)

March 2008

TABLE OF CONTENTS

List of Tables

List of Figures

This page is intentionally left blank.

Study No. 7.4.1: Fish HSI for Target Species Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

The following is a summary of existing Habitat Suitability Index (HSI) curves for various life stages of bull trout (*Salvelinus confluentus*), westslope cutthroat trout (*Oncorhynchus clarkii lewisii*), redband trout (*O. mykiss gairdneri*), mountain whitefish (*Prosopium williamsoni*), smallmouth bass (*Micropterus dolomieui*), and cyprinid forage species: northern pikeminnow, peamouth, redside shiner (*Ptychocheilus oregonensis*, *Mylocheilus caurinus*, *and Richardsonius balteatus*, respectively). Also initial judgment-based interim curves, using literature curves and available site specific habitat use measurements, are presented to represent the Boundary Project study area and to serve as a starting point in subsequent discussions with instream flow participants. Although each target species is represented by interim HSI curves for spawning, fry rearing, juvenile rearing, and adult rearing, some species and life stages are not expected to occur throughout the Boundary Project area. For example, redband trout are only expected to occur in the tailrace reach, and the spawning and fry rearing life-stages of westslope cutthroat trout are not known to occur in any Project reach to a significant degree (but rather if present are largely restricted to tributary habitats). Bull trout are not known to spawn either within the study area or in any of the adjacent tributaries, but are instead believed to occasionally recruit from locations farther upstream in the Pend Oreille watershed. Consequently, some of the following HSI curves will only be applied in specific reaches of the study area, and some will be proposed for deletion (see the recommendations portion of the Study 7.1.4.1 Interim Study Report for proposed changes to the current methodologies).

2 EXISTING LITERATURE-BASED HSI CURVES

The existing HSI data were obtained from published papers, white papers, state or federal curve libraries, and from the consultant's own HSI studies. Undoubtedly there are numerous other curve sets available that are not included, but may be added as they are acquired. The existing HSI curves include site-specific studies 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. 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.

For most species and life-stages all available curves were plotted in order to help identify overall trends in habitat suitability across the range of depths and velocities. 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).

3 BOUNDARY SITE-SPECIFIC HSI DATA

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 Study 9 electrofishing and biotelemetry efforts in the study area. The HSI data based on biotelemetry studies were intended to be the primary source of information for adult individuals of the target species, 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. The site-specific data are expected to help select the most appropriate HSI curve or to fine-tune a new judgment-based curve for use on the Boundary Project, however it should be noted 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,” therefore these site-specific data for rarer species are intended only to serve as general guidelines pertaining to the range of habitats utilized by the target species. Details describing the methodologies used to collect the HSI data by electrofishing and biotelemetry are presented in Study 9 (SCL 2008).

As of September 2007, site-specific data were non-existent for bull trout, and were very uncommon for all other salmonids. Actual sample sizes of fish observations for target species during HSI data collection are shown in Table 3.0-1 for electrofishing and in Table 3.0-2 for biotelemetry. Although additional target salmonids have been captured and/or tagged since September (total for October through December 2007 of 7 cutthroat trout and 25 mountain whitefish) (John Knutzen, Tetra Tech, personal communication, December 14, 2007) and additional site-specific data should be available prior to finalizing HSI curves, the rarity of many target species and the low sample sizes collected to date despite the significant effort expenditure suggests that final HSI will be largely based on existing, literature-based information. Given the unlikelihood of generating site-specific HSI for most target species, we recommend several changes in the HSI data collection efforts for 2008 (see the recommendations portion of the Study 7.2.4.1 Interim Study Report for proposed changes to the current methodologies)

4 DEVELOPMENT OF INTERIM AND FINAL HSI CURVES

A generally accepted “rule of thumb” is that 150-200 site-specific observations of habitat use by a target species and life-stage are usually needed to construct new and robust HSI curves (Bovee 1986). Although some smaller data sets may generate realistic and acceptable curves, some larger data sets do not. Consequently, new HSI curves are only proposed to be created for those target species and life-stages that have a minimum of 150 observations and show a biologically realistic distribution of utilization for depths, velocities, and substrate. Even for those species with abundant site-specific data, subjective decisions regarding habitat suitability will be 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. In addition to the site-specific habitat use data, habitat availability data will also be evaluated and, if appropriate, the habitat utilization data will be adjusted to account for habitat availability effects.

For species and life-stages that do not meet the sample size or distribution criteria, the existing site-specific data will be used to select or modify an existing HSI curve from among the candidate curves shown in the following figures. Because many (or most) of the target species and life-stages are not expected to be sufficiently abundant to meet the minimum sample size requirement, each curve set also contains and initial judgment-based interim curve to represent the Boundary Project study area and to serve as a starting point in subsequent discussions with instream flow participants. These interim curves are generally broad and encompass most of the available data sets, as well as the existing site-specific data, but it is important to recognize that broad HSI curves will typically yield very broad WUA relationships that may have limited value in assessing alternative flow regimes.

It is anticipated that each interim suitability curve, whether based on literature-only data, site specific-only data, or combination thereof, will be reviewed during spring 2008 by a workgroup composed of relicensing participants and experts on fish suitability and instream flow modeling techniques. This panel workgroup may modify the following interim curves and will through consensus select final fish HSI curves for use in the physical habitat modeling efforts. To assist with the discussion and evaluation of existing curves, a data table is shown for each species and life stage that describes the known characteristics of each curve set.

Note that substrate and cover criteria are not provided in this appendix. Substrate codes, and particularly cover codes, are highly variable among studies and thus they cannot be overlaid together on a common figure. For the target species in question, the substrate and cover criteria currently proposed for use in the Boundary Project area is consistent with the classification system used for the Washington fallback curves, although some refinements may yet occur due to the prominence of aquatic vegetation in the slow water areas. The Washington State HSI curves were developed by WDFW and WDOE (WDFW & WDOE 2004) and are available for use in flow studies *after* reasonable efforts at the study site do not provide enough data to verify or modify these agencies' provided species and life stage specific HSI curves. Consensus will be required to select appropriate substrate or cover HSI for target species. Consensus must also be reached regarding the application of spawning HSI curves for salmonids, given the limited availability of spawning habitat within the reservoir-influenced portions of the project area. 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 1b of Study 7) as fry <55 mm, juveniles 55-150 mm, and adults >150 mm.

5 SPECIES HSI CURVES

5.1. Bull Trout

Bull trout HSI data are very rare, and the data that are available are mostly from smaller streams (Table 5.1-1). 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 many 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 Boundary project area as of September 2007.

5.1.1. Spawning

Bull trout are not known to spawn in the mainstem Pend Oreille River and no bull trout have been collected in the reservoir during Study 9 surveys (one bull trout/brook trout hybrid was collected). Consequently, we recommend not conducting mainstem habitat modeling for the bull trout spawning life stage. An interim HSI curve for this species and life stage is provided for completeness of the curve sets until agreement can be achieved with relicensing participants.

Only four spawning HSI curves were located for bull trout, two (or maybe three) of which were based on actual measurements (Table 5.1-1, Figure 5.1-1). The four available curves show high variability in velocity and depth suitability. Given the paucity of curve data, the low or unknown sample sizes, and the expectation that bull trout in the project area might be larger, adfluvial individuals, the interim Boundary curve is broad and essentially envelopes the other data sets, except depth is not kept at 1.0 into deeper water (this could be modified if suitable gravel is available below the dam in deeper water).

5.1.2. Fry

Bull trout are not known to spawn in the mainstem Pend Oreille River or in tributaries draining to Boundary Reservoir and no bull trout fry have been collected during Study 9 surveys. Available life history information suggests that bull trout fry rearing in the region generally occurs in tributary streams (Scholz et al. 2005). Consequently, we recommend not conducting mainstem habitat modeling for the bull trout fry life stage. An interim HSI curve for this species and life stage is provided for completeness of the curve sets until agreement can be achieved with relicensing participants.

Microhabitat data describing bull trout fry are extremely rare, with only one of the two available curves based on actual data (Table 5.1-1, Figure 5.1-2). The interim Boundary curve for velocity is intermediate between the slower Prince of Wales curve (from actual field data on Dolly Varden trout) and the faster Saskatchewan curve. Although bull trout fry are largely benthic, the Saskatchewan curve appears unrealistically fast for a small salmonid fry. The interim depth curve is again intermediate, but most similar to the broader Saskatchewan curve.

5.1.3. Juvenile

Most microhabitat studies of bull trout appear to emphasize the juvenile life stage, and nine HSI curves are shown (Table 5.1-1, Figure 5.1-3). 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 interim 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 ft, except for the winter Flathead curve (that peaks at about 10 ft) and the Washington fallback curve that maintains suitability at 1.0 into deep water. The interim Boundary curve gives peak suitability for shallower depths (up to 4 ft) but also maintains intermediate suitability (0.5) into deep water.

5.1.4. Adult

Only the adult bull trout curve from the Hells Canyon portion of the Snake River is based on site-specific data from a telemetry study, which shows a narrower range of suitable velocities and higher suitability for deep water than the consensus curve from Alberta (Table 5.1-1, Figure 5.1-4). The interim Boundary curve essentially splits the difference between the two curves, based in part on the low sample size of the Hells Canyon data.

5.2. 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 5.2-1). An alternative to consider for cutthroat spawning and fry life stages, which are represented by relatively few available curves, is to use rainbow trout as a surrogate species. Very limited site-specific data are available for this species: as of September 2007 two radio-tagged adults have yielded only six depth observations and three velocity measurements.

5.2.1. Spawning

Westslope cutthroat trout are not known to spawn in Boundary Reservoir and few cutthroat trout have been collected during Study 9 surveys. Available life history information suggests that westslope cutthroat trout in the region usually display a resident life history pattern in tributary streams or an adfluvial life history pattern. McIntyre and Reiman (1995) report that spawning and early rearing occurs mostly in headwater streams. Consequently, we recommend not conducting mainstem habitat modeling for the westslope cutthroat trout spawning life stage. An interim HSI curve for this species and life stage is provided for completeness of the curve sets until agreement can be achieved with relicensing participants.

Only three HSI curves were available in our library for cutthroat spawning, but those curves showed highly similar (but narrow) depth and velocity suitability (Table 5.2-1, Figure 5.2-1). The interim Boundary curves enveloped the three available curves, but the resulting curves may remain too narrow to represent a larger river such as the Pend Oreille River below Boundary Dam. Consequently the spawning depth curve extends peak suitability into deeper water than the available curves, and then remains at intermediate suitability (0.5) at depth.

5.2.2. Fry

Westslope cutthroat trout are not known to spawn in Boundary Reservoir and no cutthroat trout fry have been collected in the reservoir during Study 9 surveys. Available life history information suggests that westslope cutthroat trout in the region usually display a resident life history pattern in tributary streams or an adfluvial life history pattern. McIntyre and Reiman (1995) report that spawning and early rearing occurs mostly in headwater streams. Consequently, we recommend not conducting mainstem habitat modeling for the westslope cutthroat trout fry life stage. An interim HSI curve for this species and life stage is provided for completeness of the curve sets until agreement can be achieved with relicensing participants.

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 5.2-1, Figure 5.2-2). The depth and velocity curves both show a fair range of suitability, most of which were encompassed by the interim Boundary curve for depth. For velocity, the interim 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.

5.2.3. Juvenile

As expected, HSI curves for juvenile cutthroat showed a wider range of suitable depths and velocities than did the fry curves (Table 5.2-1, Figure 5.2-3). 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 interim Boundary curve for velocity encompassed most of the curves except for the winter curve, which only showed positive suitability for near-zero velocity. The interim depth curve bracketed the majority of available curves, except for the very shallow end of the Washington winter curve, and except for the projected suitability into deeper water.

5.2.4. 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 5.2-1, Figure 5.2-4). The interim Boundary curve encompasses most of the available velocity curves, and gives an intermediate suitability (0.5) for zero velocity. The three velocity measurements taken at the estimated position of one radio tagged adult was well within the range of suitable velocities. For depth, the interim 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 suitability at 1.0 to 30 ft, then decreasing to zero suitability at 100 ft. The 30 ft depth is consistent with one of the radio-tagged adults that was observed on five separate occasions holding over water 10-30 ft in depth, with a focal depth (based on CART tag information) of approximately 5-10 ft. The other tagged adult was observed once at a water depth of approximately four feet.

5.3. Redband Trout

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 5.3-1). Because the complete list of candidate curves for rainbow trout is very large, the list was filtered down for juvenile and adult trout according to several criteria as described in the introduction, which included emphasis on redband populations and on large river data sets. However, this appendix will generally refer to HSI data sets as "rainbow trout" HSI, whereas description of site-specific data information will refer to "redband" trout.

Electrofishing during the spring months resulted in the capture of only three wild redband trout (none were radio-tagged), although stocked triploid trout (not a target species) were commonly encountered.

5.3.1. Spawning

Eleven spawning curves are presented, although more are certainly available in the gray literature (Table 5.3-1, Figure 5.3-1). The interim Boundary curve for spawning velocity is intermediate between several slower curves (two are TRPA curves based on very small adult trout) and several faster curves (two of which are judgment-based curves). The interim depth curve follows most curves up to maximum suitability at 0.75 ft, and then descends to intermediate suitability (0.5) into deeper water. The rainbow spawning curves are similar to the cutthroat curves, but are broader and extend into slightly deeper and faster water.

5.3.2. Fry

Rainbow fry are represented by 19 data sets, two of which are largely judgment-based (Category 1) curves (Table 5.3-1, Figure 5.3-2). Although most curves show high suitability only for velocities under 1 fps, the Saskatchewan consensus curve gives much higher suitability for faster velocities. The interim Boundary curve does not follow the consensus curve but instead follows most other curves to reflect low suitability for velocities over 1 fps. The interim Boundary depth curve essentially encompasses all of the available fry curves. The Boundary velocity curves for rainbow and cutthroat fry are almost identical, whereas the depth curves give slightly different suitability for depths over two feet.

5.3.3. 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 (≥100 observations), and stream size (flows ≥100 cfs). The interim Boundary curve for velocity brackets most of the available curves, with an intermediate suitability (0.5) for zero velocity (Table 5.3-1, Figure 5.3-3). The interim Boundary curve for depth likewise encompasses most available curves, and extends low suitability (0.25) into deep water. The Boundary velocity curve for juvenile rainbow trout is slightly faster than the cutthroat curve; likewise the depth curve is slightly deeper for rainbow trout than for cutthroats.

5.3.4. Adult

Forty-five HSI curves for adult rainbow trout were filtered down to a subset of 13 data sets according to the criteria listed for juvenile trout (Table 5.3-1, Figure 5.3-4). 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 rainbow 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 ft) are at the deepest range of most literature curves. The interim Boundary curves for adult rainbow trout are slightly deeper and faster than the cutthroat curves, and are likewise deeper and faster than the juvenile rainbow curves.

5.4. Mountain Whitefish

HSI curves for mountain whitefish are extremely rare, and most available data sets are derived from studies in Alberta (Table 5.4-1). Site-specific habitat use observations are available (as of September 2007) from one adult captured by electrofishing in May, and from one radio-tagged adult that was relocated on two separate occasions.

5.4.1. Spawning

Mountain whitefish are suspected of spawning in Boundary Reservoir, but has not yet been confirmed during Study 9 sampling. Of the three spawning data sets available for review, one is a consensus curve and another was based on the observation of only two spawning locations (Table 5.4-1, Figure 5.4-1). The interim 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.

5.4.2. Fry

The whitefish fry HSI curves show high variability in velocity suitability, but are more consistent for depth (Table 5.4-1, Figure 5.4-2). The consensus-based Saskatchewan curve envelopes all other data, but the interim Boundary curve is more intermediate in nature.

5.4.3. Juvenile

The available HSI curves for juvenile whitefish also show high variability in both velocity and depth (Table 5.4-1, Figure 5.4-3). The interim Boundary curves are relatively broad and only exclude the fastest velocities and sets deep water suitability to an intermediate value.

5.4.4. 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 interim 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 5.4-1, Figure 5.4-4). The site-specific electrofishing and biotelemetry data fall within the interim curves, with the deepest observation (at approximately 20 ft) illustrating the positive suitability for deeper water.

5.5. 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. Smallmouth bass were the most numerous of the target species that were captured by electrofishing, and several adult bass were implanted with telemetry tags (Table 5.5-1).

5.5.1. 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 5.5-1, Figure 5.5-1). 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 interim 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 interim velocity curves may over represent suitable spawning habitat. For depth, the interim Boundary curve brackets most other curves (except for the extremely shallow West Virginia curve), and then descends to zero suitability along the Brownlee Reservoir curve. Bass biologists have suggested that maximum depths of bass nests are dictated by light penetration, probably through effects on egg incubation and/or fry food availability.

5.5.2. Fry

Most of the fry data appear to represent fish after leaving the nest, but wide variability exists in the velocity curves, where some show suitability only at velocities <0.5 fps, and others give high suitability for higher velocities (Table 5.5-1, Figure 5.5-2). The interim Boundary curve for velocity brackets the bulk of the data, except for the two fastest curves that seem excessive for small fry. The interim depth curve for fry also brackets most of the data sets, but brings suitability to zero at 10 ft instead of maintaining positive suitability into deeper water. Twelve smallmouth bass <6 cm were captured by electrofishing, mostly in areas with near zero velocity and depths <4 ft deep, which is consistent with the interim HSI curves and most literature-based curves.

5.5.3. Juvenile

HSI data for juvenile bass are abundant, but fairly variable for fast and deep water (Table 5.5-1, Figure 5.5-3). The interim Boundary curve for velocity encompasses most of the available curves except for faster portions of the Huron, Virginia, and Minnesota curves. The Boundary depth curve brackets all of the other curves except the very shallowest curves and the narrow peak of the Bain curve. Unlike some other curves, the interim Boundary curve does not maintain suitability at 1.0 into deeper water (as it does for adults), but rather assumes a lower suitability of

0.20. Electrofishing yielded the capture of 93 juvenile bass from 58 point samples (HSI electrofishing cells). Most of the juveniles occurred at velocities <0.2 fps, which is much slower than velocities suggested by most literature-based curves and is at the low end of the interim curve. The depths where juveniles were captured were mostly between one foot and seven feet, which is deeper than most literature-based curves but consistent with the interim curve. It should be recognized that the capture efficiency of smaller fish by electrofishing is expected to decline as depths exceed five feet or so, therefore the decline in catch for depths over seven feet may be due in part to sampling limitations.

5.5.4. Adult

Sixteen HSI curves are available for adult smallmouth bass, most of which are encompassed by the interim Boundary curves for velocity and depth (Table 5.5-1, Figure 5.5-4). Not bracketed by the Boundary curves are the initial limbs of the shallowest curves, nor portions of the Bovee curve. Also, the interim curve maintains maximum suitability to depths of 15 ft, with intermediate and declining suitability over 25 ft. The adult bass Boundary curve is deeper and faster than the interim curves for juvenile bass. Forty-eight adult bass were captured in 40 electrofishing cells, with the majority of fish in velocities <0.5 fps and at depths from 2-7 ft. These observations are consistent with most literature-based HSI curves and are well within the interim curves. Additional site-specific data are available from 15 radio- and CART-tagged bass, which yielded approximately 30 velocity measurements and 40 depths measurements (as of September 2007). The telemetry data show a more even distribution among velocities from near zero fps to almost four fps, and illustrates a much greater utilization of depths over 10 ft than does the electrofishing data, which was largely ineffective at those depths. Smallmouth bass were also regularly observed at depths between 15-40 ft 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 ft of the substrate.

5.6. 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 5.6-1). 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 and fry HSI are not considered here, only juvenile or adult (for smaller species) rearing data are included. Site-specific data are included for cyprinids up to about 10 cm in length, although capture efficiency of smaller individuals is likely 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.

5.6.1. 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 (<1.5 ft) water (Table 5.6-1, Figure 5.6-1). Because of the high uncertainty of microhabitat requirements for the project species, and because of the wide range in available depths in the project area, the interim Boundary curve for depth is broad and encompasses most of the available HSI curves. However, the interim curve for velocity excludes many of the midwestern curve sets and shows higher suitability for slower velocities in concert with most pikeminnow data and with the site-specific observations. Site-specific data through September 2007 includes the capture of 96 forage cyprinids from 30 sampling cells. Over 95 percent of the captured forage cyprinids were northern pikeminnow and peamouths, which occurred in similar numbers. Redside shiners were rarely observed. Most cyprinid forage fish were captured in velocities <0.5 fps, and only one capture occurred at velocities >1 fps. Relatively few forage cyprinids were captured from depths >5 ft; however, the efficiency of electrofishing for such small fish in deep water at night is undoubtedly low, consequently the interim curve includes higher suitability for depths over five feet than would be expected solely from the electrofishing samples.

6 REFERENCES

Aadland, L.P., and A. Kuitunen. 2006. Habitat suitability criteria for stream fishes and mussels of Minnesota. Minnesota Department of Natural Resources, Ecological Services Division, Fergus Falls and St. Paul, MN. 167pp.

Addley, C., G.K. Clipperton, T. Hardy, and A.G.H. Locke. 2003. South Saskatchewan River Basin, Alberta, Canada – fish habitat suitability criteria (HSI) curves. Alberta Fish & Wildlife Division, Alberta Sustainable Resource Development. Edmonton, Alberta. 63pp. ISBN 0-7785-359-4.

Allen, M.A. 1996. Equal area line-transect sampling for smallmouth bass habitat suitability criteria in the Susquehanna River, Pennsylvania. Pages B119-132 in M. LeClerc, C. Herve, S. Valentin, A. Boudreault, and Y. Cote, editors. Ecohydraulics 2000: Second international symposium on habitat hydraulics. Institut National de la Recherche Scientifique-Eau, Quebec, Canada.

Baltz, D.M., and P.B. Moyle. 1984. Segregation by species and size class of rainbow trout, *Salmo gairdneri*, and Sacramento sucker, *Catastomus occidentalis*, in three California streams. Environmental Biology of Fishes 10:101-110.

Baltz. D.M., and B. Vondracek. 1985. Pit 3, 4, and 5 Project Bald Eagle and Fish Study, Appendix I-D suitability and microhabitat preference curves. Prepared for Pacific Gas & Electric Company by Biosystems Analysis, Inc. and University of California, Davis.

Bovee, K.D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. Cooperative Instream Flow Service Group, U.S. fish & Wildlife Service, Fort Collins, CO.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream flow Incremental Methodology. Instream Flow Information Paper 21. U.S. Fish & Wildlife Service, Biological Report 86(7). 235pp.

Bovee, K.D., T.J. Newcomb, and T.G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. National Biological Survey, Biological Report 21. 63pp.

Bozek, M.A., and F.J. Rahel. 1991. Assessing habitat requirements of young Colorado River cutthroat trout by use of macrohabitat and microhabitat analysis. Transactions of the American Fisheries Society 120:571-581.

Brown, R.S., and W.C. Mackay. 1995. Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta. Transactions of the American Fisheries Society 124:873-885.

Bugert, R.M., T.C. Bjornn, and W.R. Meehan. 1991. Habitat use by young salmonids and their responses to cover and predators in a small southeast Alaska stream. Transactions of the American Fisheries Society 120:474-485.

Chandler, J.A., editor. 2003. Redband trout and bull trout associated with the Hells Canyon Complex. Idaho Power Technical Report Appendix E.3.1-7.

Cochnauer, T. and T. elms-Cockrum. 1986. Probability-of-use curves for selected Idaho fish species. Idaho Department of Fish and game Project F-71-R-10, Subproject II, Job No. 1-a. Idaho Department of Fish and Game. 50pp.

Corning, R.V., and G. Elliott. 1987. An evaluation of IFIM curves developed for the Swanson River rainbow trout populations. Draft report to USFWS, Alaska Investigation Field Office, Anchorage, AK. 24pp.

Courtney, R.F., G.L. Walder, and R.L. Vadas. 1998. Instream flow requirements for fish in the Kananaskis River. Report by EnviResource Consulting, Ltd. and Sirius Aquatic Sciences to Fisheries and Recreation Enhancement Working Group.

Edwards, E.A., G. Gebhart, and O.E. Maughan. 1983. Habitat suitability information: smallmouth bass. United States Fish and Wildlife Service FWS/OBS-82/10.36 47pp.

Fernet, D.A., R.F. Courtney, and C.P. Bjornson. 1990. Instream flow requirements for fishes downstream of the Oldman River Dam. Report by Environmental Management Associates for Alberta Public Works, Supply and Services, Edmonton, Alberta.

Golder Associates, Ltd. 1999. Red Deer River instream flow needs study. Report to Fisheries Management Division, Alberta Environmental Protection, Cochrane, Alberta.

Groshens, T.P., and D.J. Orth. 1994. Transferability of habitat suitability criteria for smallmouth bass, Micropterus dolomieu. Rivers 4:194-212.

Heggenes, J., T.G. Northcote, and A. Peter. 1991. Spatial stability of cutthroat trout (Oncorhynchus clarki) in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:757-762.

Joy, E.T., R. Menendez, K.D. Bledsoe, and C.W. Stihler. 1981. An evaluation of instream flow methods for use in West Virginia. WV Dept. Natl. Res., Div. Wildlife Res., Elkins, WV. 163pp.

Knight, N.J. 1985. Microhabitats and temperature requirements of hardhead (*Mylopharodon conocephalus*) and Sacramento squawfish (*Ptychocheilus grandis*), with notes for some other native California stream fishes. Ph D. University of California, Davis.

Larimore, R.W., and D.D. Garrels. 1982. Seasonal and daily microhabitat selection by Illinois fishes. Final Report, Illinois Natural History Survey, Champain, IL. 113pp.

Leclerc, J. 1983 (date approximate). Unpublished data cited from Instream Flow Group HSC database files.

Locke, A.G.H. 1987. Microhabitat utilization and preference curve development for rainbow trout fry in four creeks in southwestern Alberta. Alberta Forestry, Lands, & Wildlife, Fish & Wildlife Division.

Locke, A.G.H. 1988. IFIM-microhabitat criteria development: Data pooling considerations. Pages 31-54 in K. Bovee and J.R. Zuboy, editors. Proceedings of a workshop on the development and evaluation of habitat suitability criteria. A compilation of papers and discussions presented at Colorado State University, Fort Collins, Colorado, December 8-12, 1986. United States Fish and Wildlife Service, Biological Report 88(11). Fort Collins, CO. 408pp.

McIntyre, J.D., and B.E. Rieman. 1995. Westslope Cutthroat Trout. Chapter 1 in Young, M.K. (ed). Conservation Assessment for Inland Cutthroat Trout. USDA Forest Service. General Technical Report RM-GTR-256. Fort Collins, Colorado, 80526.

Monahan, J.T. 1991. Development of habitat suitability data for smallmouth bass (*Micropterus dolomieui*) and rock bass (*Ambloplites rupestris*) in the Huron River, Michigan. M.S. Thesis, Michigan State University, East lansing. 130pp.

Moyle, P. B. and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: Developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Muhlfeld, C.C., D.H. Bennett, and B. Marotz. 2001. Summer habitat use by Columbia River redband trout in the Kootenai River drainage, Montana. North American Journal of Fisheries Management 21:223-235.

Muhlfeld, C.C., S. Glutting, R. Hunt, D. Daniels, and B. Marotz. 2003. Winter diel habitat use and movement by subadult bull trout in the Upper Flathead River, Montana. North American Journal of Fisheries Management 23:163-171.

Nehring, R.B., and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4(1):1-19.

Newcomb, T.J., S.A. Perry, and W.B. Perry. 1995. Comparison of habitat suitability criteria for smallmouth bass (*Micropterus dolomieu*) from three West Virginia Rivers. Rivers 5:170-183.

Orth, D.J., R.N. Jones, and O. Eugene Maughan. 1982. Considerations in the development of curves for habitat suitability criteria. Pages 124-133 in N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Proceedings of a symposium organized by the Western Division, American Fisheries Society. 28-30 October 1981, Portland, Oregon. 376pp.

Peters, E.J., R.S. Holland, M.A. Callam, and D.L. Bunnell. 1989. Platte River suitability criteria… Habitat utilization, preference and suitability index criteria for fish and invertebrates in the lower Platte River. Nebraska Game and Parks Commission, Nebraska Technical Series Publication No. 17. 134p.

Pflieger, W.L. 1975. The fishes of Missouri. Missouri Department of Conservation.

Pratt, K.L. 1984. Habitat use and species interaction of juvenile cutthroat (Salmo clarki lewisi) and bull trout (*Salvelinus confluentus*) in the Upper Flathead River basin. M.S. Thesis, University of Idaho, Moscow, ID. 95p.

Pruitt, T.A., and R.L. Nadeau. 1978. Recommended stream resources maintenance flows on seven Idaho streams. Instream Flow Information Paper Number 8. Cooperative Instream Flow Service Group, Fort Collins, Colorado. FWS/OBS-78/68. 58pp.

Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. Habitat suitability information: Rainbow trout. United States Fish and Wildlife Service FWS/OBS-82/10.60. 64pp.

Richter, T.J. 2003. Hells Canyon Complex resident fish study. Idaho Power, Technical Report Appendix E.3.1-5.

Sando, S.K. 1981. The spawning and rearing habitats of rainbow trout and brown trout in two rivers in Montana. MT State U, Bozeman, MT. 55pgs.

Sanford, R.A. 1984. PHABSIM error analysis: Techniques and case studies. M.S. Thesis, University of Washington. Seattle, Washington.

Scholz, A., H.J. McLellan, D.R. Geist, and R.S. Brown. 2005. Investigations of Migratory Bull Trout (*Salvelinus confluentus*) on Relation to Fish Passage at Albeni Falls Dam. Final Report prepared for U.S. Dept. of the Army, Corps of Engineers, Seattle District. Contract No. DACW68-02-D-001. 204 pp.

Schrader, W.C. and R.G. Griswold. 1992. Winter habitat availability and utilization by juvenile cutthroat trout, brown trout, and mountain whitefish in the South Fork Snake River, Idaho. Idaho Department of Fish & Game, Final Progress Report, Project No. 0-AG-10-10920.

SCL (Seattle City Light). 2008. Study 9 – Fish Distribution, Timing, and Abundance Study Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Terrapin Environmental and Golder Associates Inc. under contract to Tetra Tech. March 2008.

Smith, G.E. and M.E. Aceituno. 1987. Habitat preference criteria for brown, brook, and rainbow trout in Eastern Sierra Nevada streams, final report. California Department of Fish and Game Stream Evaluation Report 87-2. Sacramento, California. 103pp.

Studley, T.K., J.E. Baldrige and T.R. Lambert. 1986. Micro habitat of smallmouth bass in four California rivers. MS presented at Pacific Fishery Biologists conference, April 1986, Eureka, California.

Thomas, J.A., and K.D. Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research and Management 8:285-294.

Thomas R. Payne & Associates. 1991. Instream flow study for Milk Ranch, Bucks, and Grizzly Creeks, Bucks Creek Project (FERC 619). Document prepared for Pacific Gas and Electric Company by Thomas R. Payne & Associates, Arcata, California.

Thomas R. Payne & Associates. 1993. North Fork Stanislaus River Hydroelectric Development Project (FERC 2409) Article 37 adequacy of minimum flow study McKays Point Diversion Dam. Document prepared for Calaveras County Water District and Northern California Power Agency by Thomas R. Payne & Associates and Aquatic Systems Research, Arcata, California. 69pp+apps.

Thomas R. Payne & Associates. 2000. Determining appropriate HSI for use in the South Fork American River Basin. Testing the transferability of generic and California-specific HSI. Report submitted to El Dorado Irrigation District, Placerville, California. 100pp.

Thomas R. Payne & Associates. 2001. Development of habitat suitability criteria for the Poe Project (FERC No. 2107), North Fork Feather River, California. Report prepared for Pacific Gas and Electric Company, San Ramon, California. 103pp.

Thomas R. Payne & Associates. 2002. Habitat suitability criteria for rainbow trout and Sacramento suckers in the Upper North Fork Feather River Project (FERC No. 2105). Report prepared for Pacific Gas and Electric Company, San Ramon, California. 86pp.

Thomas R. Payne & Associates. 2002. Selection of habitat suitability criteria for use in the Middle Fork and South Fork Stanislaus Rivers, California. Spring Gap – Stansilaus Project (FERC No. 2130) and Beardsley/Donnells Project (FERC 2005). Report prepared for Pacific Gas and Electric Company, San Ramon, California, and Tri-Dam Project, Pinecrest, California. 93pp.

Thomas R. Payne & Associates. 2004. Klamath Hydroelectric Project (FERC NO. 2082). Habitat suitability criteria. Report to PacifiCorp, Portland, Oregon. 64pp. + appendices.

Thompson, G.E., and R.W. Davies. 1976. Observations on the age, growth, reproduction, and feeding of mountain whitefish in the Sheep River, Alberta. Transactions of the American Fisheries Society 105:208-219.

Tuolomne County and Turlock Irrigation District. 1993. Clavey River Project. Project No. 10081-002-California. Applicants response to the Commission's information request of 31 March 1993. Item No. 6 Habitat suitability criteria.

Underwood, K.D., S. W. Martin, M.L. Schuck, and A.T. Scholz. 1995. Investigations of bull trout (*Salvelinus confluentus*), steelhead trout (*Oncorhynchus mykiss*), and spring chinook salmon (*O. tshawytscha*) interactions in southeast Washington streams. 1992 final Report. BPA Project No. 90-053, DOE/BP-17758-2. Bonneville Power Administration, Portland, Oregon. 173p.

Valdez, R.A. 1978. The Central Utah Project and cutthroat trout stream habitat. Department of Wildlife Sciences, Utah State University, Logan, UT. 24pp.

Voos, K.A., and W.S. Lifton. 1988. Development of a bivariate depth and velocity suitability function for Dolly Varden (*Salvelinus malma*) juveniles. Pages 307-319 in K. Bovee and J.R. Zuboy, editors. Proceedings of a workshop on the development and evaluation of habitat suitability criteria. A compilation of papers and discussions presented at Colorado State University, Fort Collins, Colorado, December 8-12, 1986. United States Fish and Wildlife Service, Biological Report 88(11). Fort Collins, CO. 408pp.

WDFW & WDOE. 2004. Instream flow study guidelines: Technical and habitat suitability issues. Updated April 5, 2004.

Wise, L.M., W.S. Lifton, and K.A. Voos. 1997. Trout habitat utilization criteria for the Response of Fish Populations to Altered Flows Project. Report prepared for Pacific Gas and Electric Company by Entrix, Inc., Walnut Creek, California. March 13, 1997. 9pp + apps.

Wydoski, R.S., and R.R. Whitney. 2003. Inland fishes of Washington. 2nd Edition, Revised and Expanded. University of Washington Press. Seattle, WA. 322pp.

Table 3.0-1. The number of HSI cells sampled by electrofishing from March-September 2007, including the number of cells containing the target species and the number of individuals of each species, by month.

Month	# Cells Sampled	Bull Trout	Cutthroat Trout	Rainbow Trout (wild)	Whitefish	SM Bass <55mm	SM Bass 55-150mm	SM Bass >150mm	Forage Cyprinids <120mm
March	11	0	0	1	0	0	0	0	1
April	103	0	0	1	0	0	2	3	4
May	87	0	0	1	1	0	5	10	4
June	0	0	0	0	0	0	0	0	0
July	60	0	0	0	0	1	4	4	0
August	97	0	0	0	0	9	28	13	14
September	96	0	0	0	0	2	19	4	7
Total # Cells	454	0	0	3	1	12	58	34	30
Total # Fish	-	0	0	3	1	12	93	44	92

Table 3.0-2. The number of adult fish tagged with radio or CART telemetry tags as of September 2007, and the total number of individual HSI measurements for those fish, by target species.

Data	Bull Trout	Cutthroat Trout	Rainbow Trout (wild)	Whitefish	SM Bass
# Fish Tagged	0	2	0	1	15
# HSI Observations	0	6	0	2	44

Table 5.1-1. Literature-based 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
Idaho	S			ID	7 streams?								Pruitt et al 78
WA DOE	S,J+A			WA	?						Cat I?	1	Rittmeuller pers com
WA Fallback	S,J+A		34,39	WA	2,4 streams							2	WDFW & WDE 04
Saskatchewan	S,F,J,A			Alberta	Sask Basin streams						Cat I	3	Addley et al 03
Prince Wales	F,J	<8,8+	78,72	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	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:
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 vels??, other position data recorded
5 curves presented in Slauson 1988
6 includes fry, curves drawn from Pratt 1984 thesis, figs 10 & 11
7 incl fry and adults, nose vels only
8 daytime curve pts taken from histograms, cover data also collected but histograms not presented
9 bottom vels estimated with formula for 0.2m above the btm (but fish depth not known), dist to bank also recorded

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, 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.

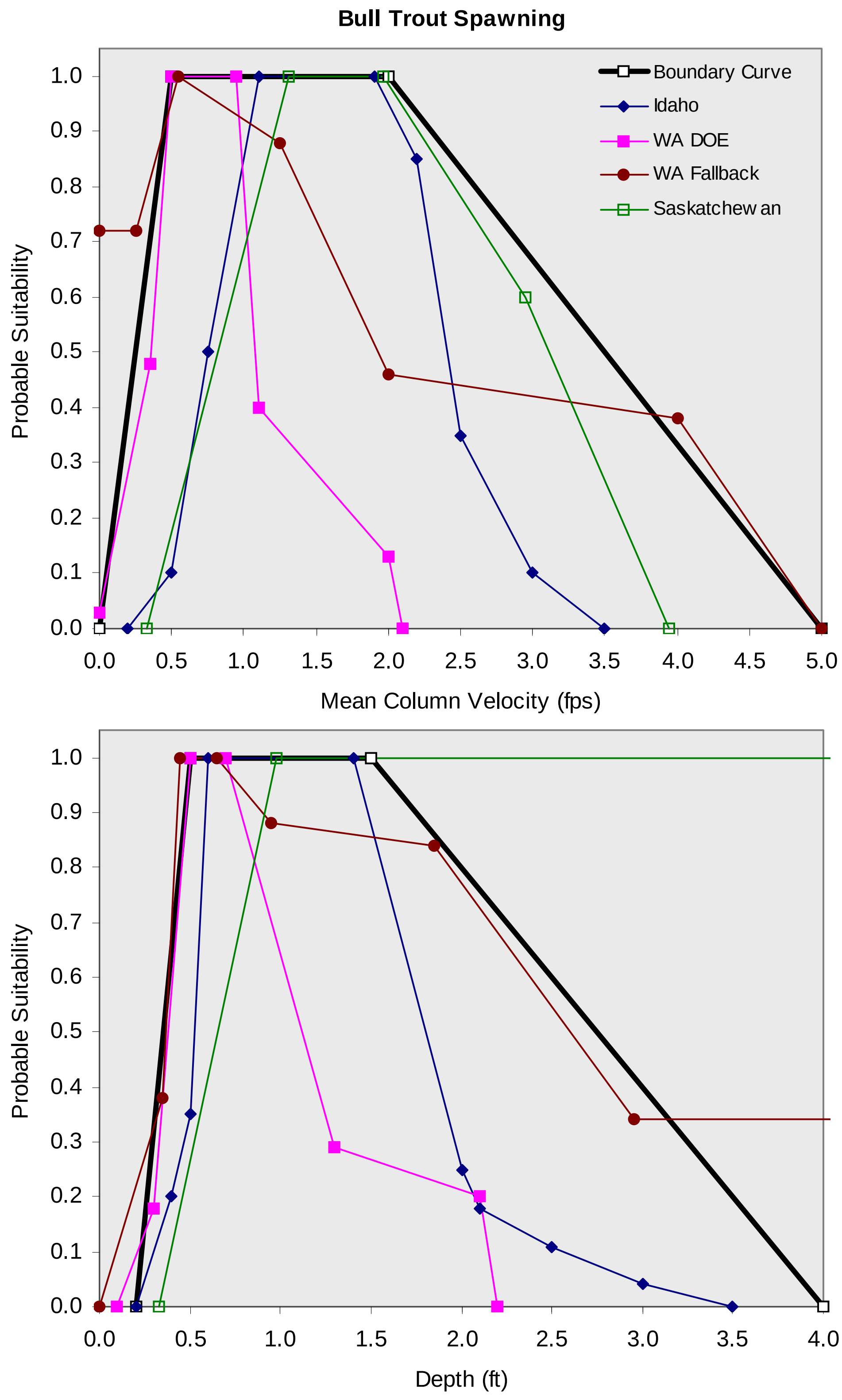


Figure 5.1-1. Available HSI curves for bull trout spawning, along with interim Boundary curves.

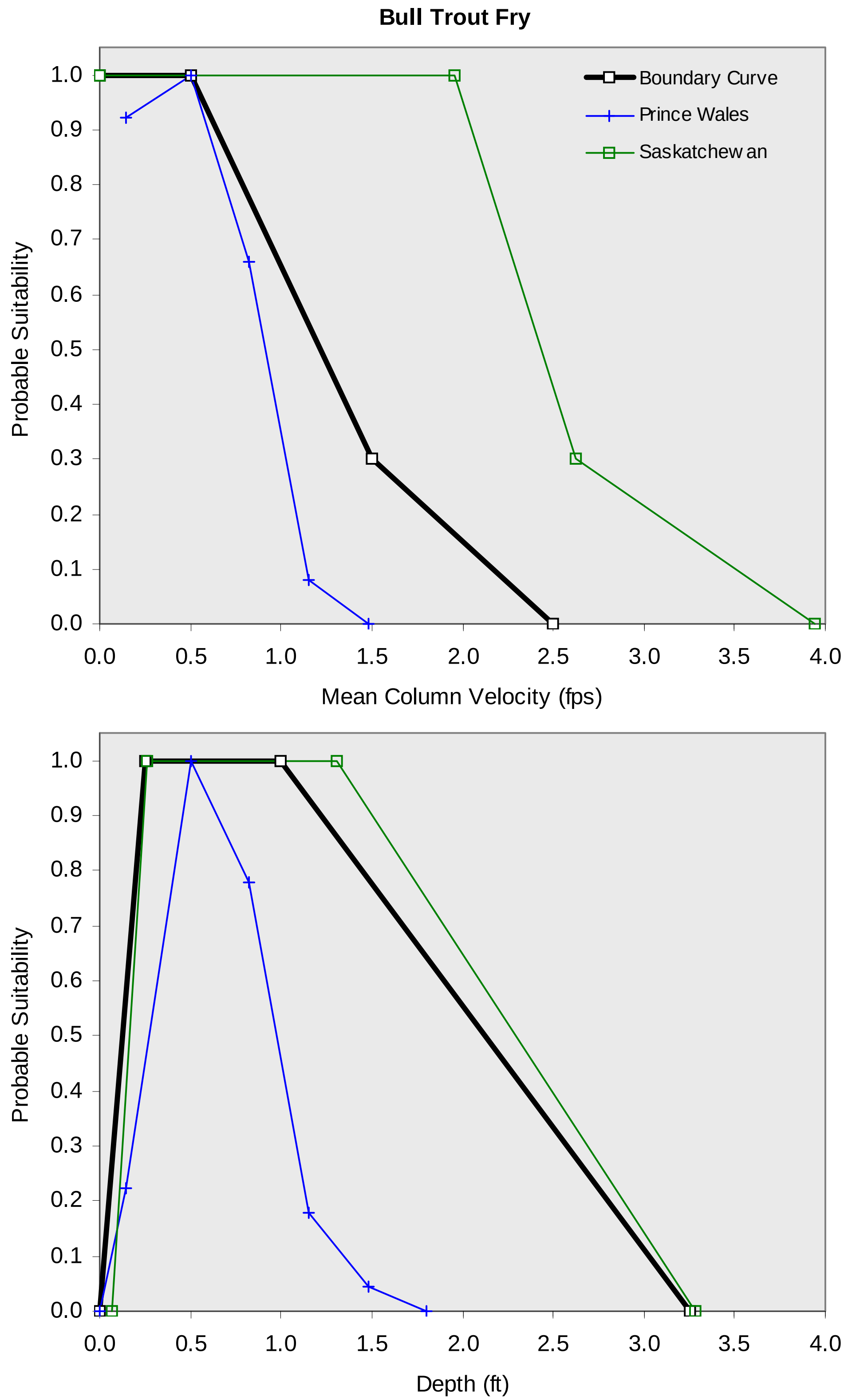


Figure 5.1-2. Available HSI curves for bull trout fry, along with interim Boundary curves.

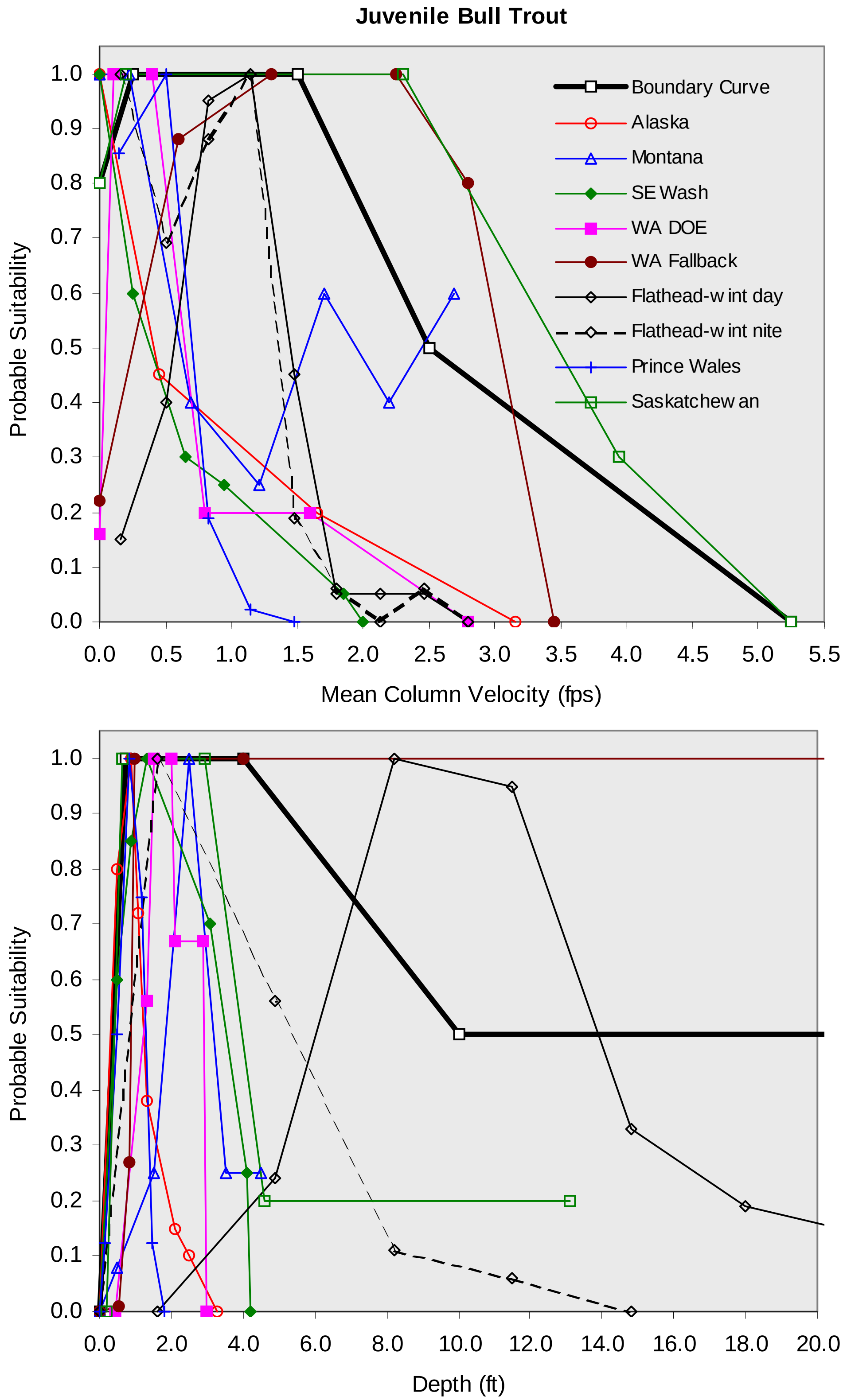


Figure 5.1-3. Available HSI curves for juvenile bull trout, along with interim Boundary curves.

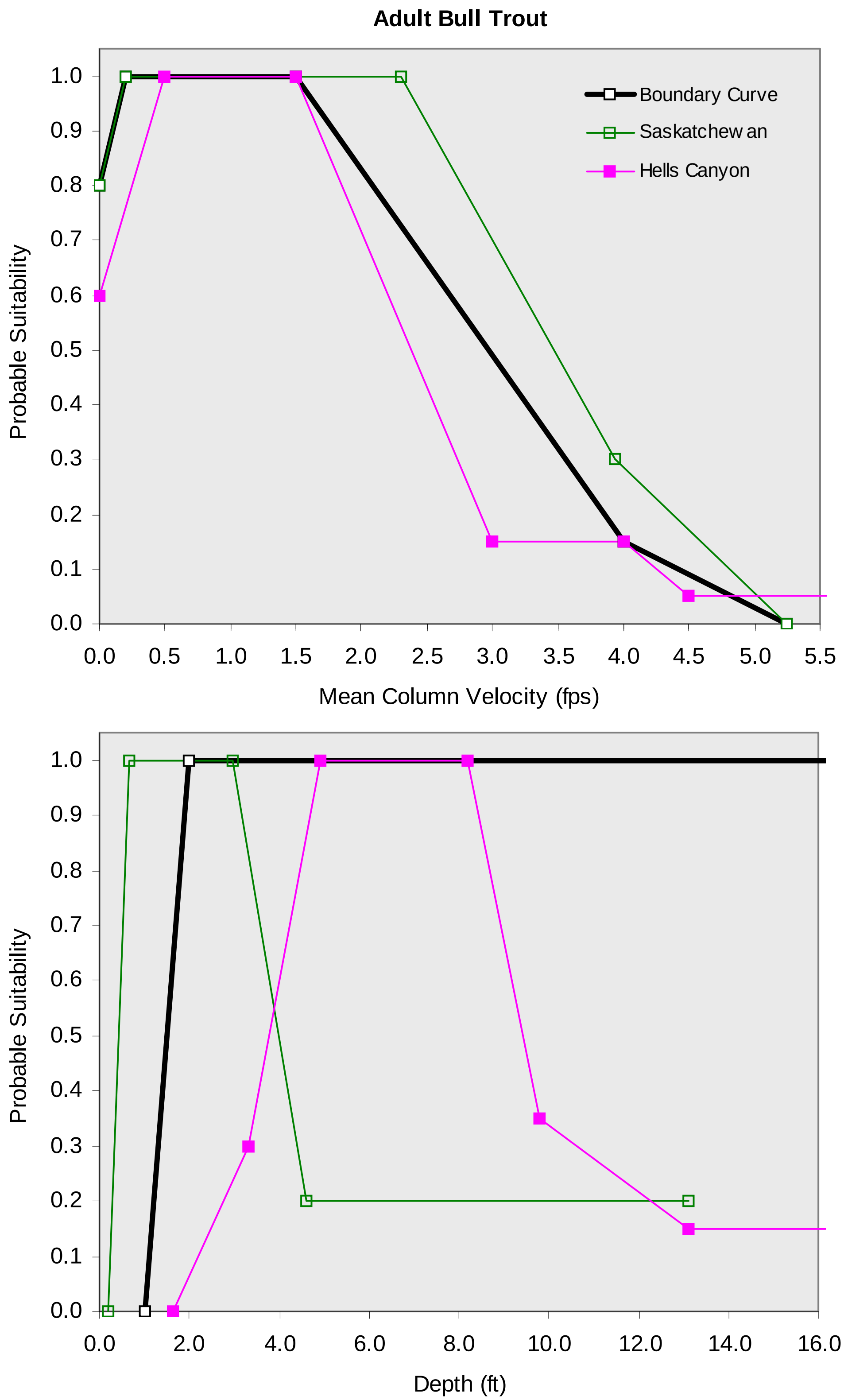


Figure 5.1-4. Available HSI curves for adult bull trout, along with interim Boundary curves.

Table 5.2-1. Literature-based 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	S,J+A		69,251	WA	6,5 studies						III?	1	WDFW & WDE 04
WA Fallback-wint	J+A			WA							II?	1,7	WDFW & WDE 04
Bovee	S,F,J,A			OR/WA									Bovee 78
Utah	S,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: 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 pts 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 cutts
8 no vels, data combined from 2 streams, ratios calced from use/avail histograms (fall ratios not calced but very similar to summerl)

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, 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.

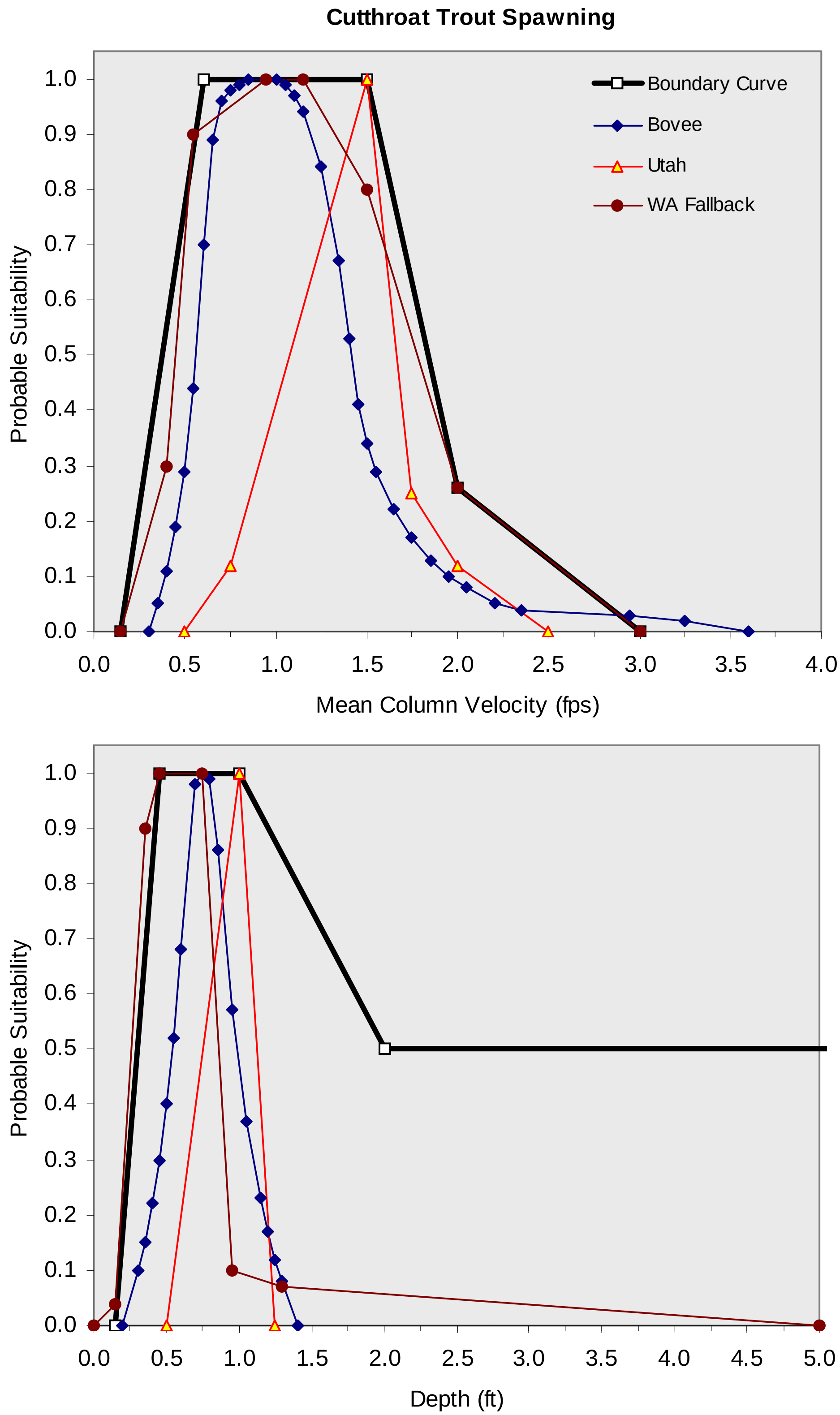


Figure 5.2-1. Available HSI curves for cutthroat trout spawning, along with interim Boundary curves.

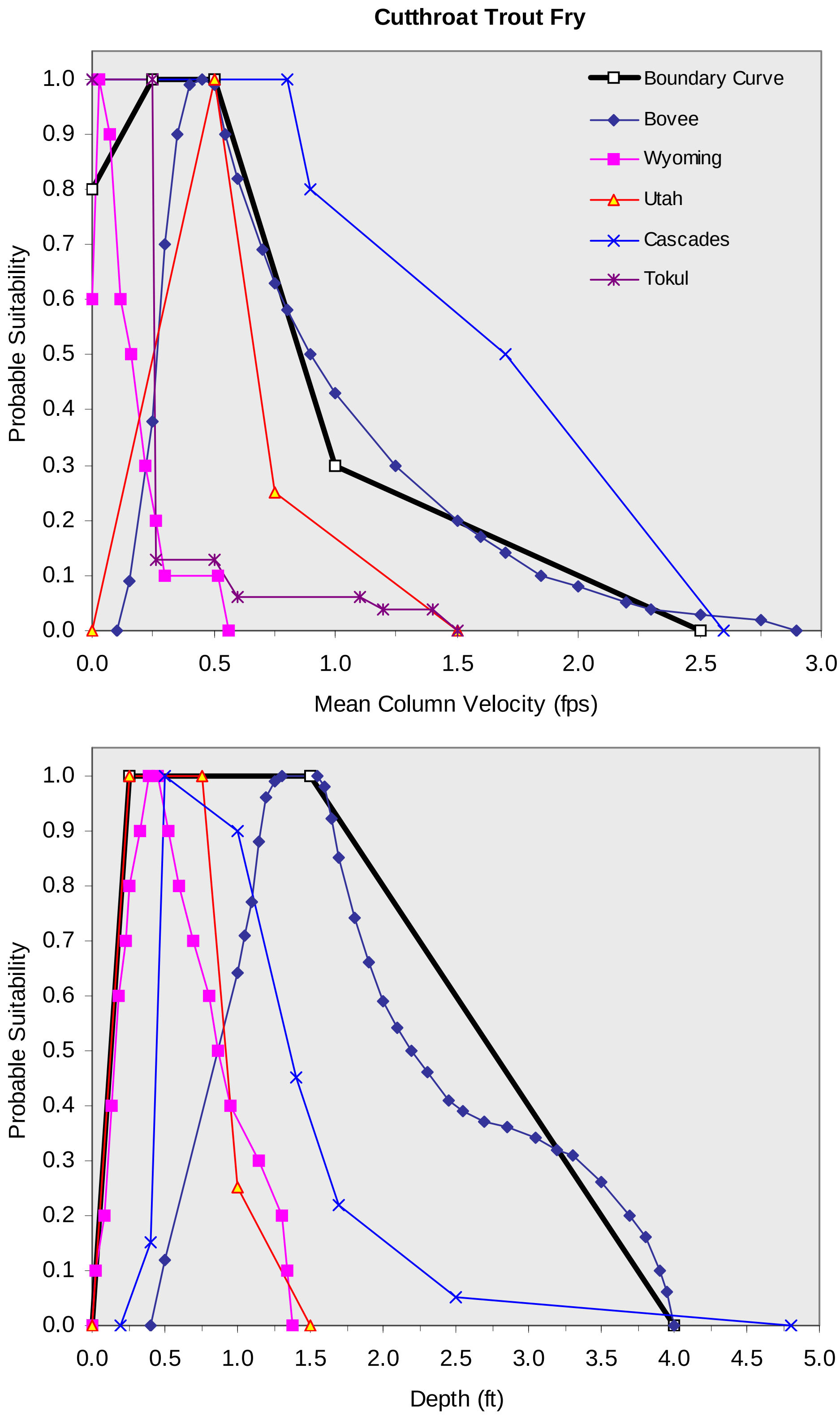


Figure 5.2-2. Available HSI curves for cutthroat trout fry, along with interim Boundary curves.

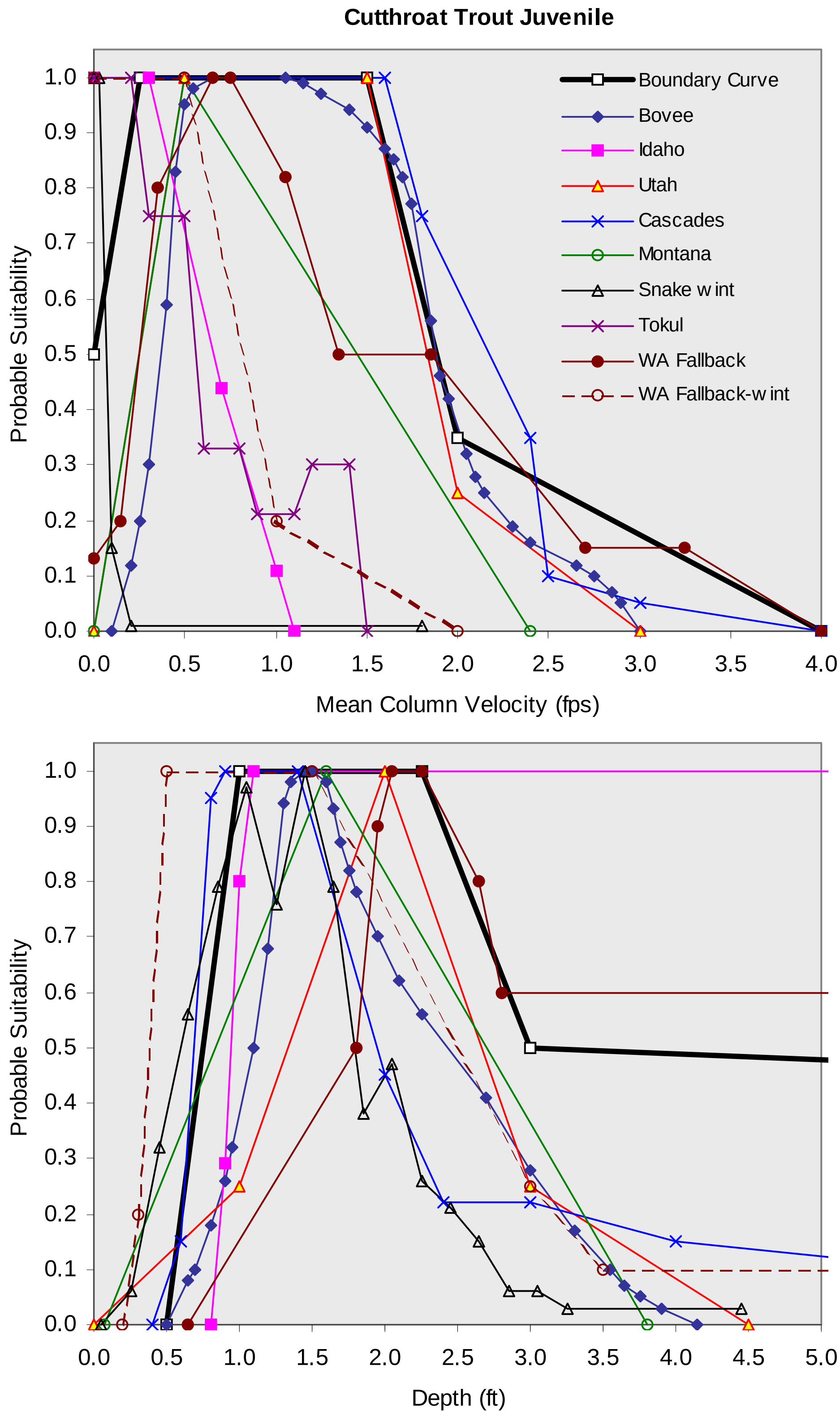


Figure 5.2-3. Available HSI curves for juvenile cutthroat trout, along with interim Boundary curves.

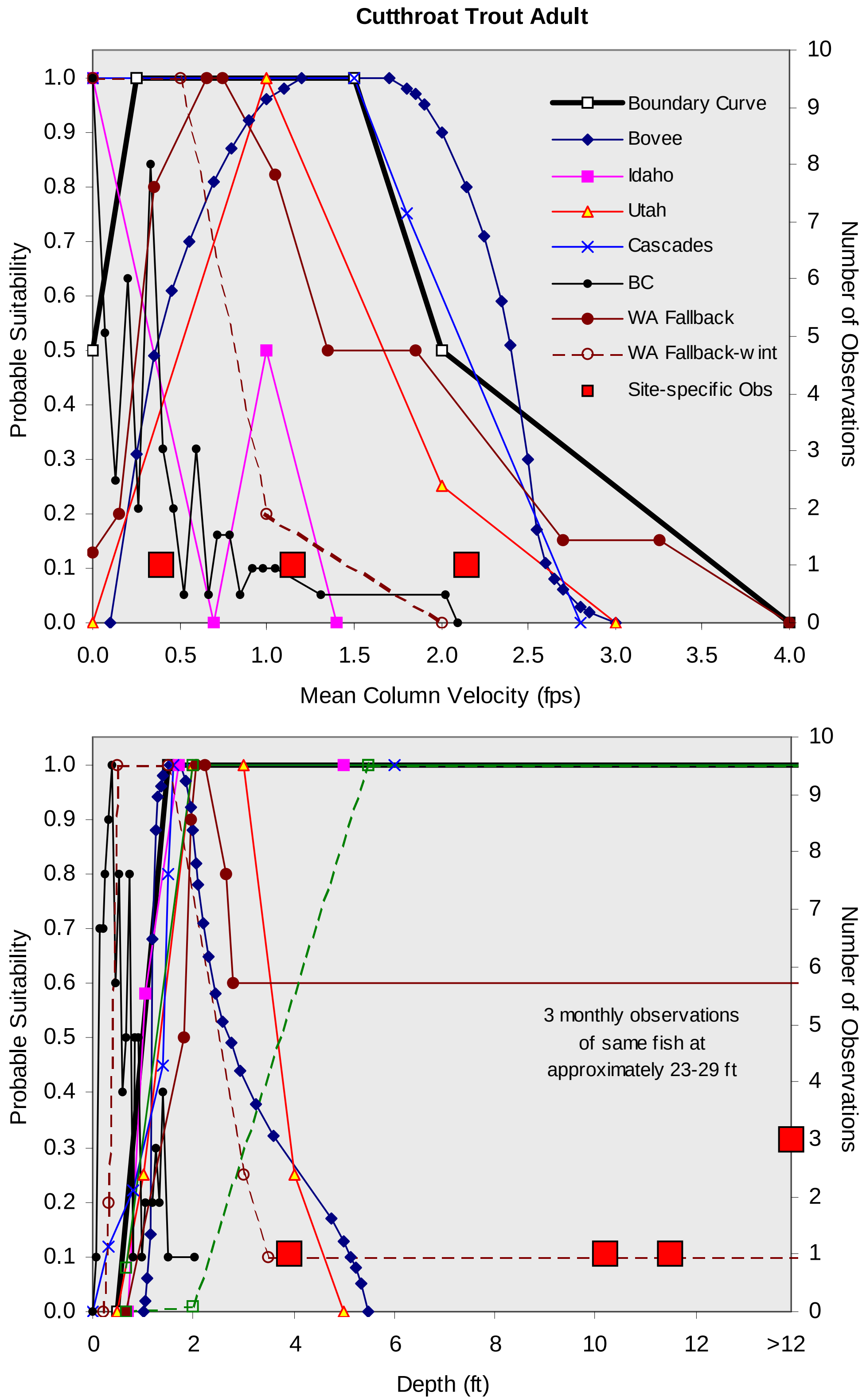


Figure 5.2-4. Available HSI curves for adult cutthroat trout, along with interim Boundary curves and biotelemetry observations from the Boundary project area.

Table 5.3-1. Literature-based HSI datasets for rainbow 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
Roaring	S	13-30	73	CA	Roaring	30-40	40	45-50	total	DO uw	Cat II		TRPA unpub
Up NF Feather	S,J,A	<15,16-42	172437, 179	CA	upper NF Feather	40-60	35-150	46-72	RCH,EA	DO uw	Cat II, III	18	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,A	14-30	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
Alaska	S	14-38		AK	Swanson River		100				Cat II	1,4	Corning & Elliott 87
UpKlamath	S,F,J,A	<4,5-15	66,173,501,164	OR	Upper Klamath	87	325	50-62	RCH	DO uw/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	406301, 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	212822, 164	CA	Battle	14-29	4-108	36-73	EA	DO uw	Cat II		TRPA 98
Alberta U/A	F	3.6-6.8		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	106442,332	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 micro	DO uw	Cat III	14,15	TRPA 02
SF Amer Basin	J,A	5-15,16-60	169,145	CA	SF Amer + tribs	13-90	10-154	46-71	EA	DO uw	Cat II	17	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 Sult	J,A	7-17,18+	188,163	CO	So Platte		250-600		EA	DO uw	Cat II	19	Thomas & Bovee 93
Oldman	A	25+?	151	Alberta	Oldman,Crowsnest					DO uw/EF	Cat III?	8,24	Fernet et al 90
Hells Canyon	A	26-46	75	ID	Snake res		7282-32420			TEL	Cat II	25	Chandler 03

Notes:
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 availability data also given
5 enveloped use HSC by expert panel
6 adjacent velocity and bioenergetics data also collected
7 data reweighted to simulate equal-area sampling
8 curve points approximated from graphs
9 U/A curves derived from data from a single study site in one stream using PHABSIM output to estimate habitat availability
10 these HSC curves were not presented in the cited report (i.e., curves were fit to the raw data at a later date)
11 curve pts normalized from electivity index (avg'ed between 2 streams for juv and adults), substrate data not entered here
12 most (86%) of juveniles were 5-9cm, adjacent velocity and bioenergetics data also collected
14 these HSC curves were not presented in the cited report (i.e., curves were fit to the raw data at a later date)
15 equal-area sampling according to mesohabitat type and microhabitat type (deep v shallow, fast v slow)
17 a variety of substrate and cover codes were used in a transferability test, but HSC curves were not developed from them
18 use, U/A, and density curve-types were averaged to develop the composite curve, cover curves are U/A
19 optimal habitat was defined as the central 50% of observations, suitable was defined as the central 95%
24 juvenile curves based on earlier study in Oldman River (Fernet & Matkowski 1986)-we don't have that report
25 bottom vels estimated with formula for 0.2m above the btm (but fish depth not known), dist to bank also recorded

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, 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.

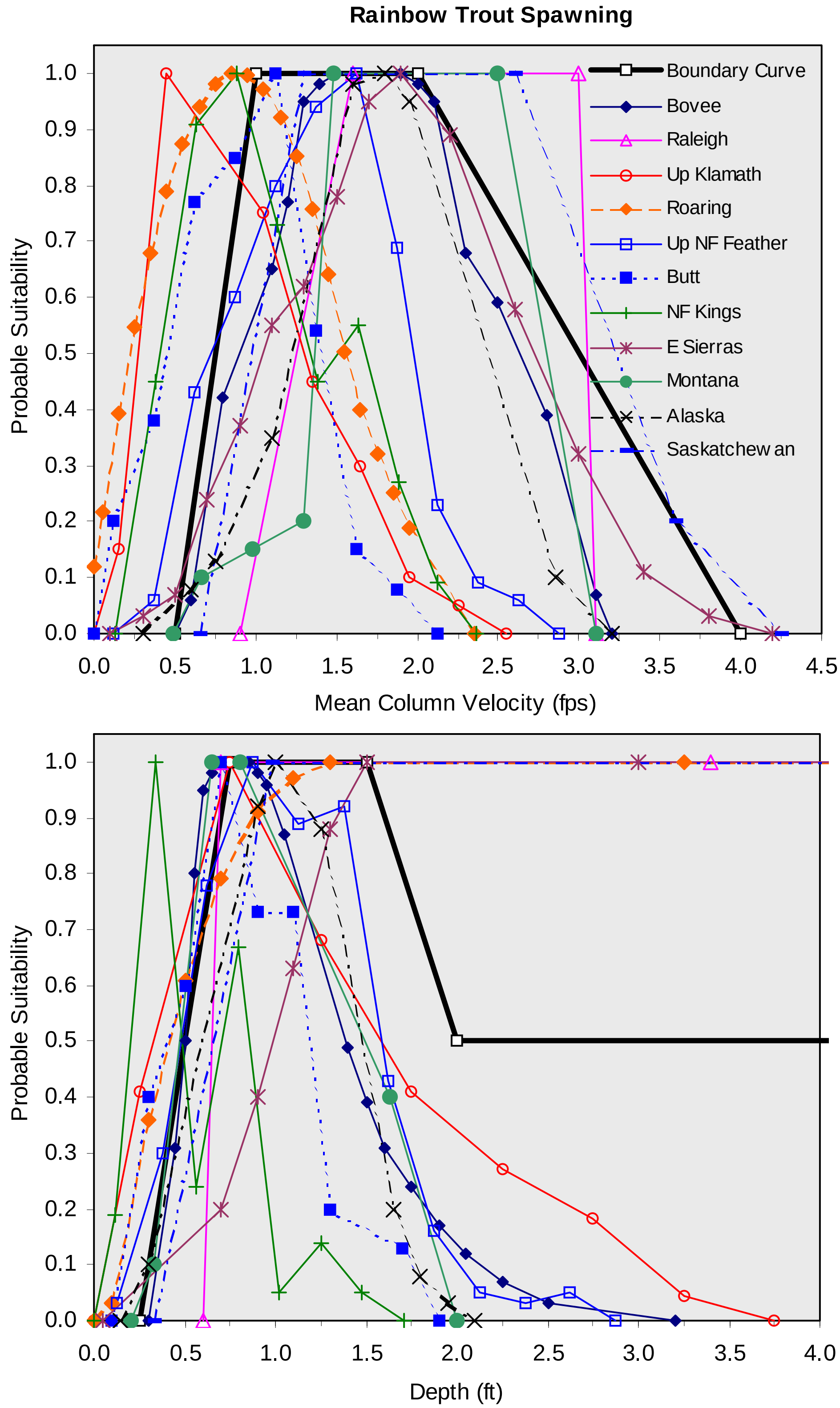


Figure 5.3-1. Available HSI curves for rainbow trout spawning, along with interim Boundary curves.

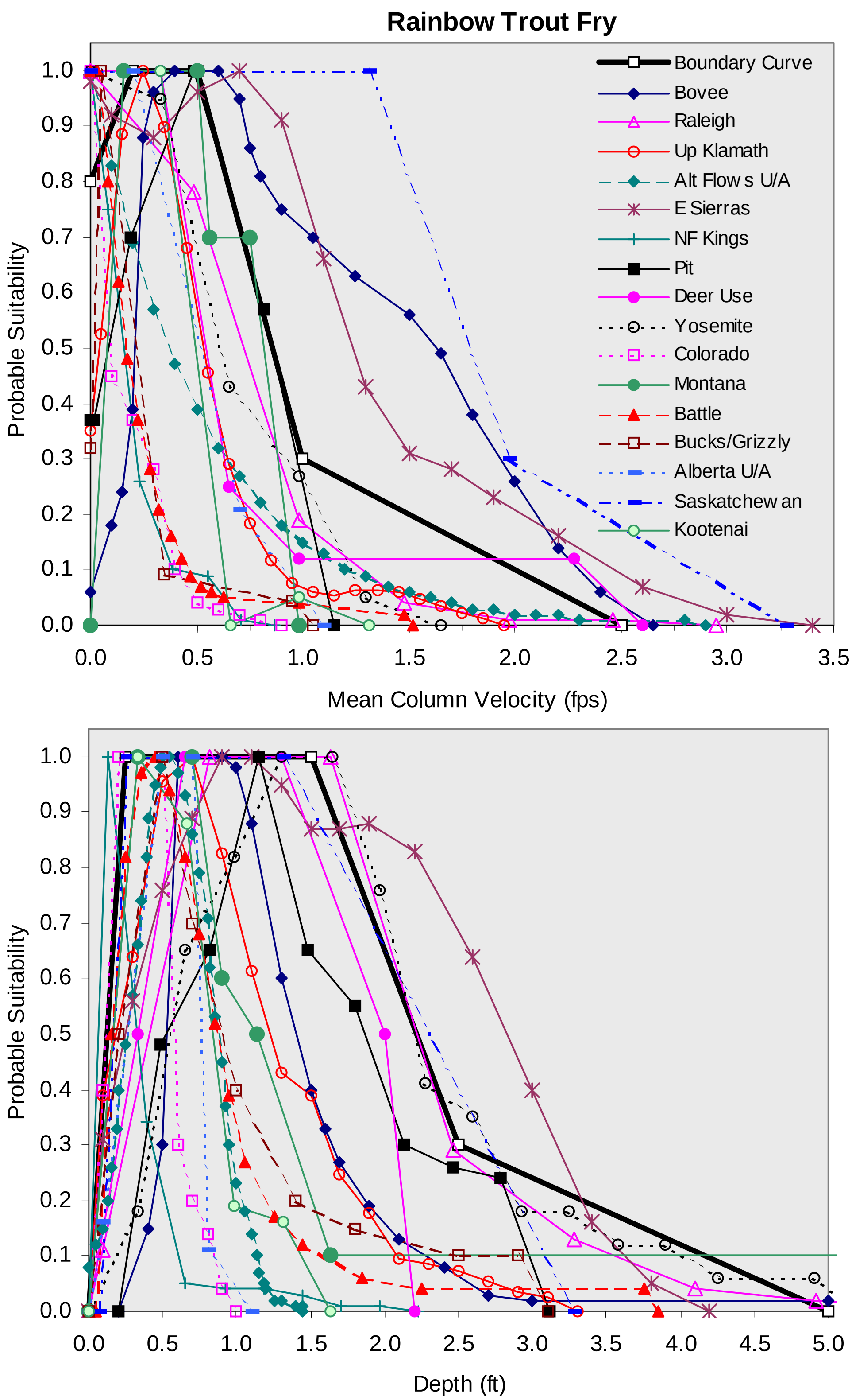


Figure 5.3-2. Available HSI curves for rainbow trout fry, along with interim Boundary curves.

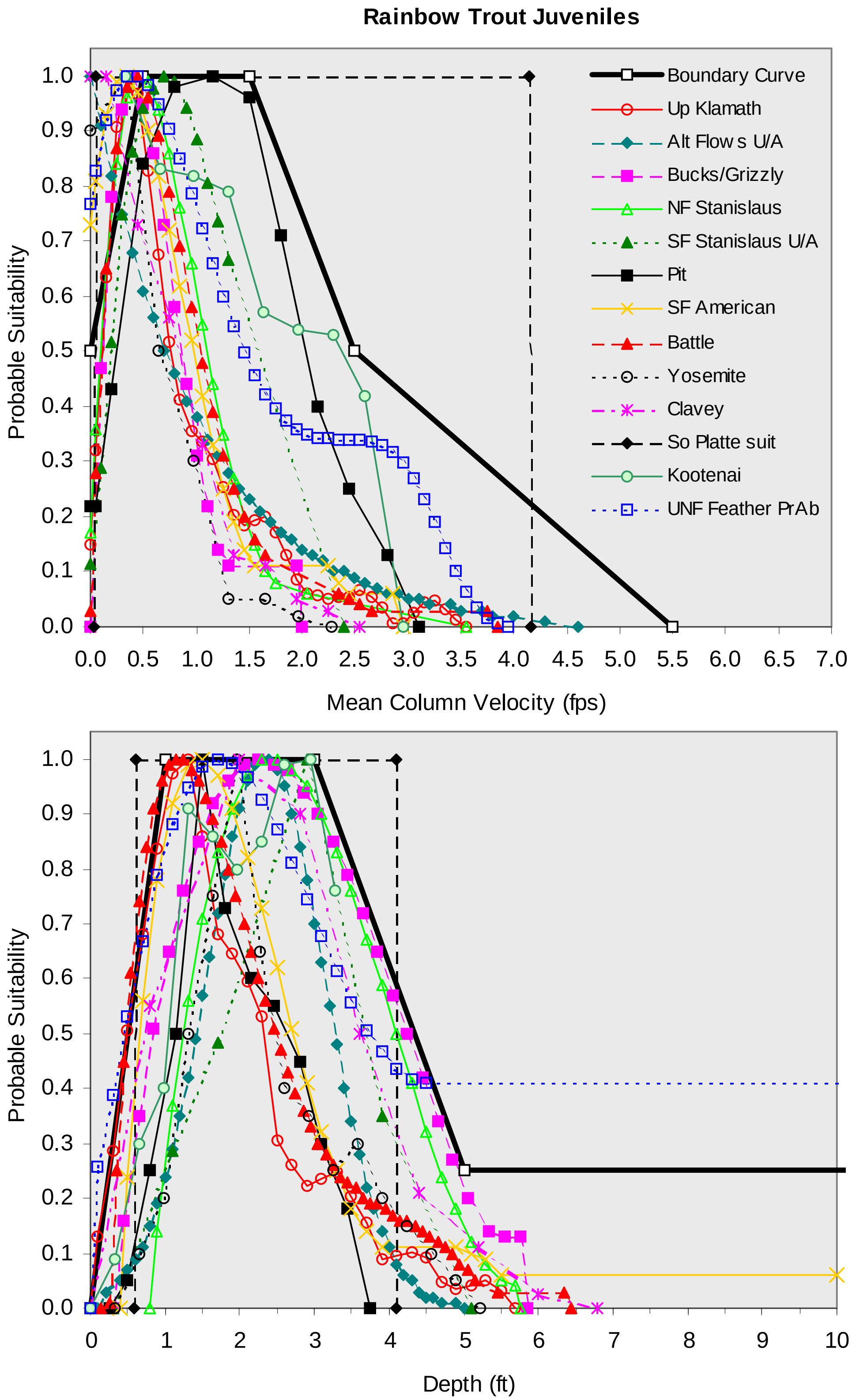


Figure 5.3-3. Available HSI curves for rainbow trout fry, along with interim Boundary curves.

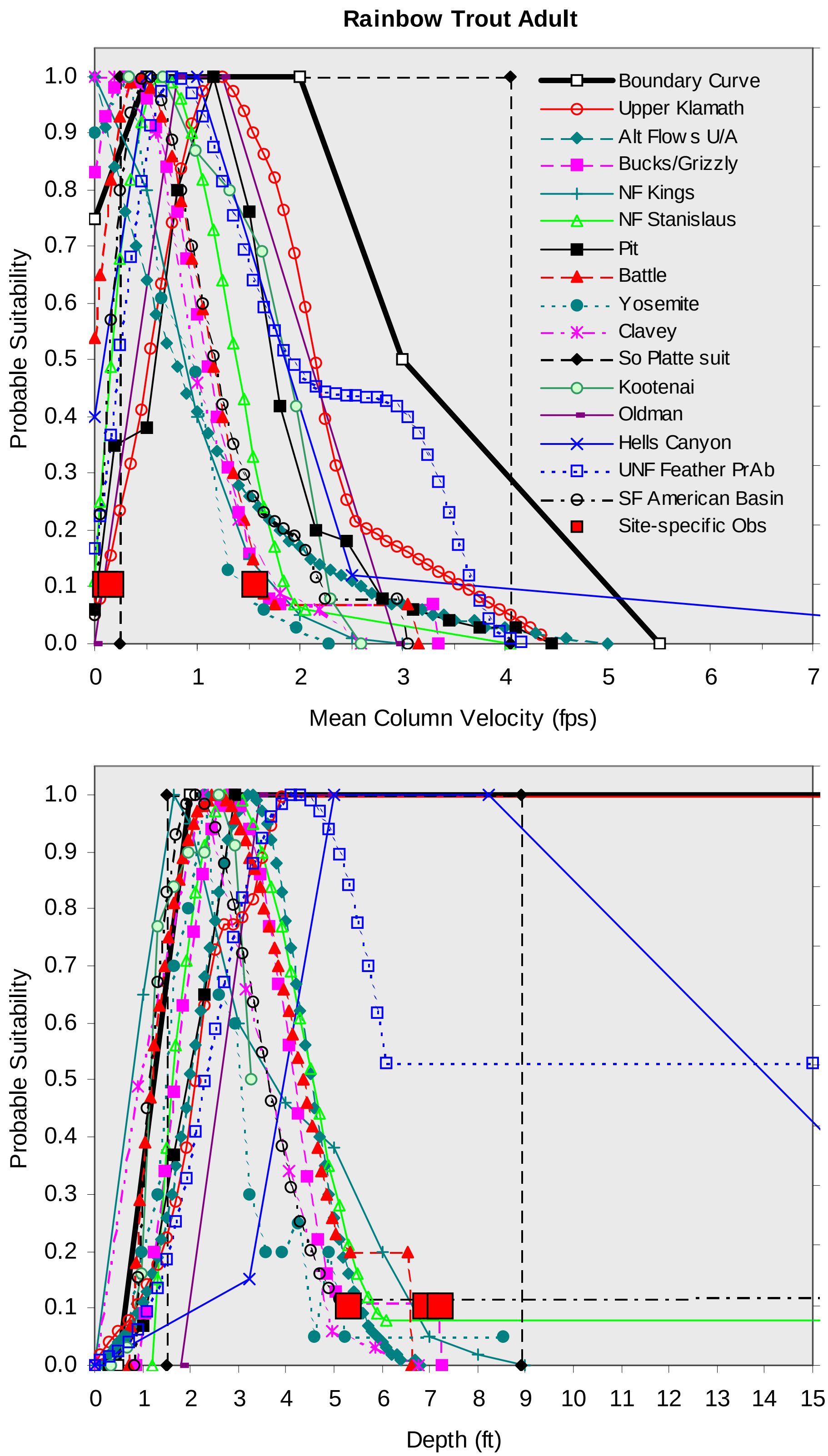


Figure 5.3-4. Available HSI curves for adult rainbow trout, along with interim Boundary curves and electrofishing observations from the Boundary project area (wild trout only).

Table 5.4-1. Literature-based HSI datasets for mountain 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	DO uw	Cat I,III,III	3	Courtney et al 98
Red Deer	F,J,A			Alberta	Red Deer		base ~700				Cat I	4	Golder 99
WA Fallback	J,A			WA								5	WDFW & WDE 04
Sheep	A			Alberta	Sheep River					DO uw	Cat III	6,7	Locke 88
Misc	A			PacNW								8	Wydoski & Whitney 03

Notes:
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 vel data is presented in symposium paper, orig 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 trib deltas

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, EF-electrofishing, 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.

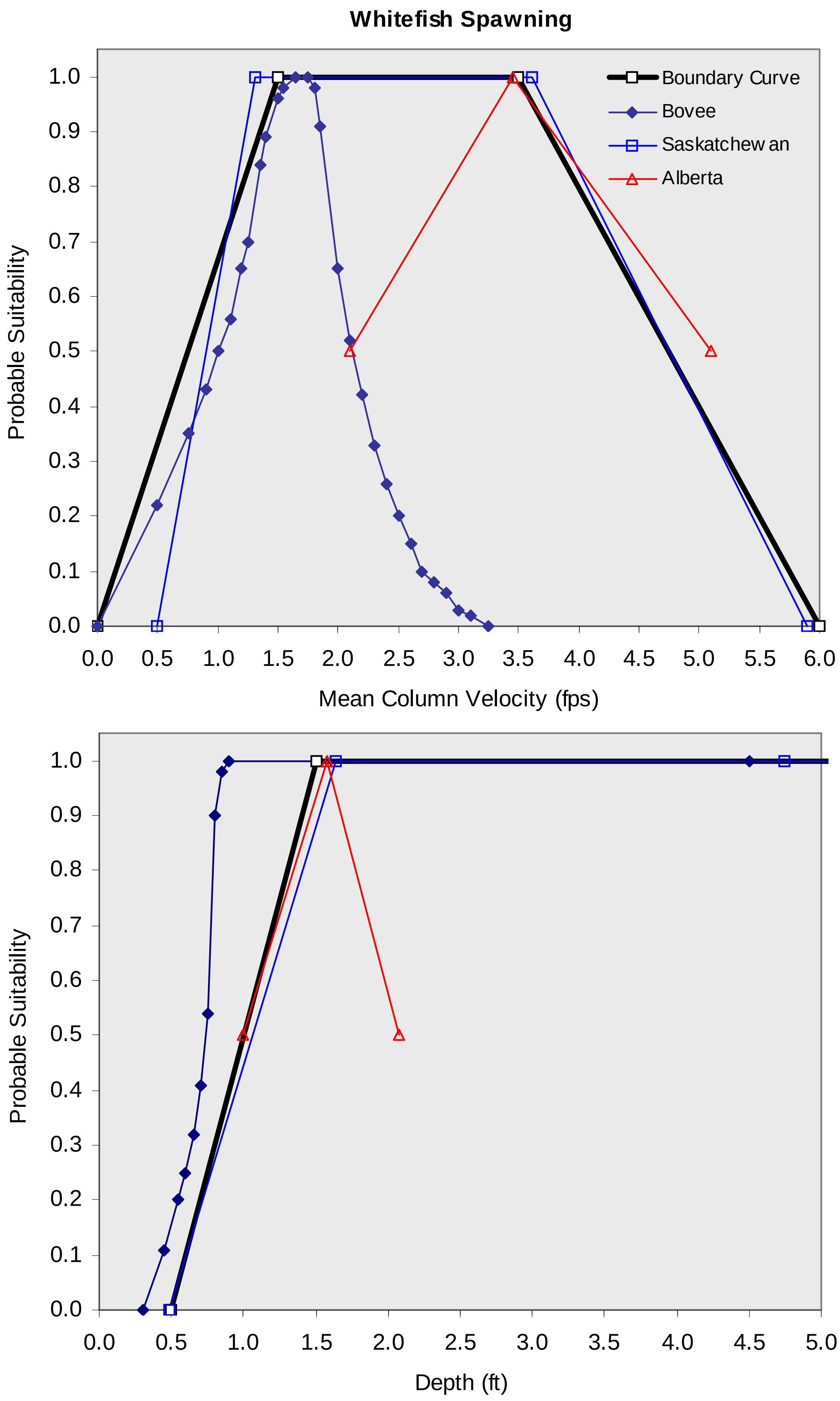


Figure 5.4-1. Available HSI curves for whitefish spawning, along with interim Boundary curves.

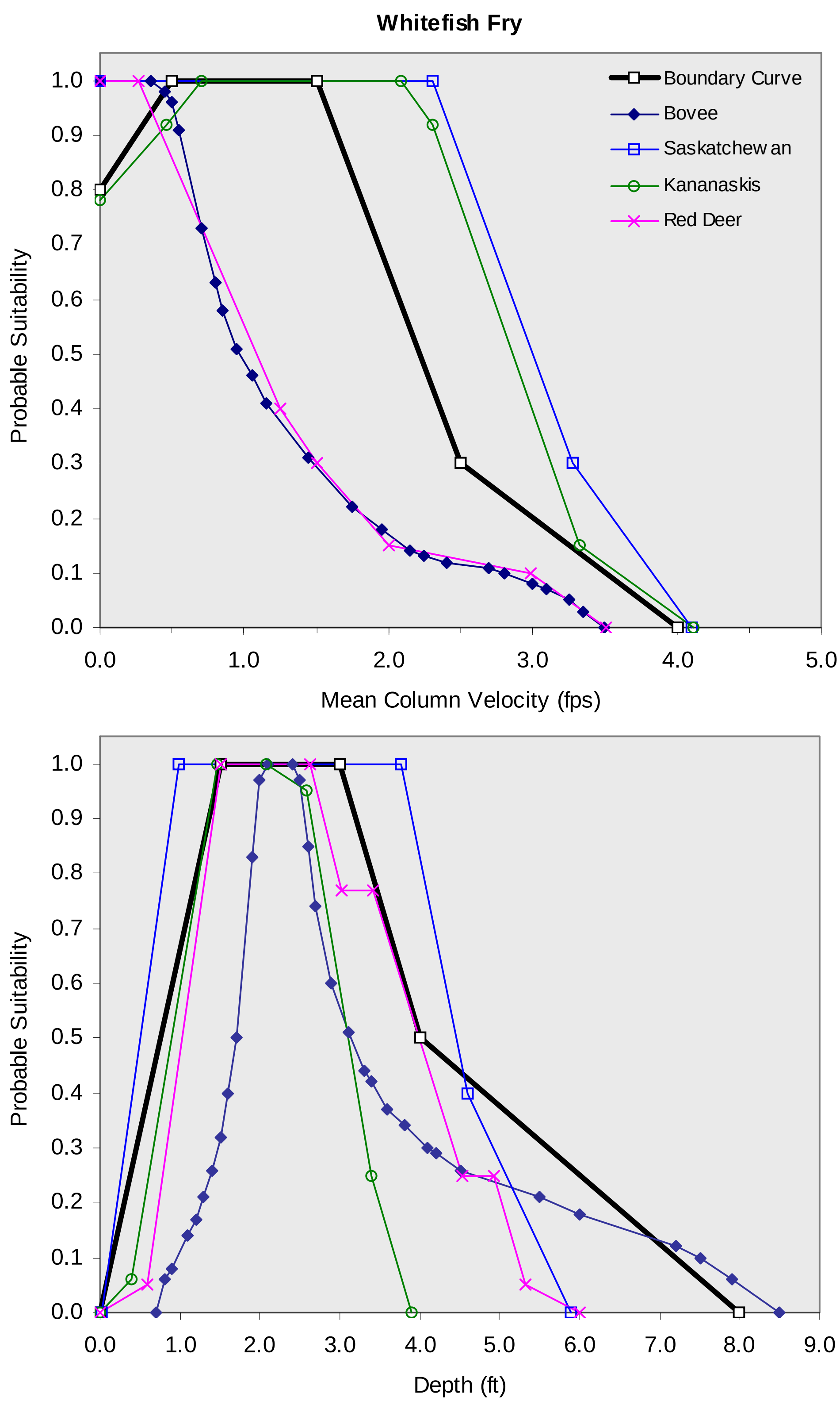


Figure 5.4-2. Available HSI curves for whitefish fry, along with interim Boundary curves.

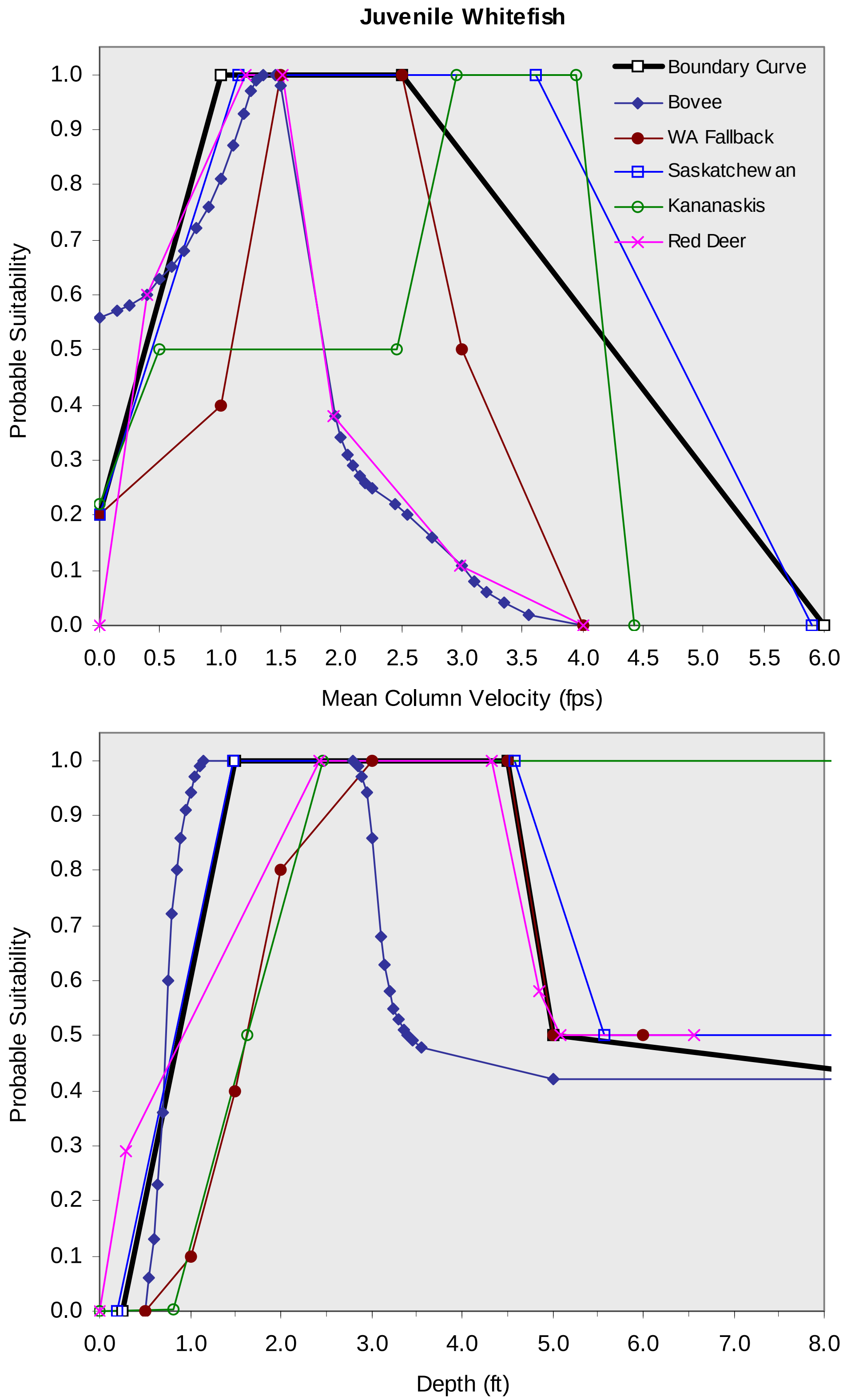


Figure 5.4-3. Available HSI curves for juvenile whitefish, along with interim Boundary curves.

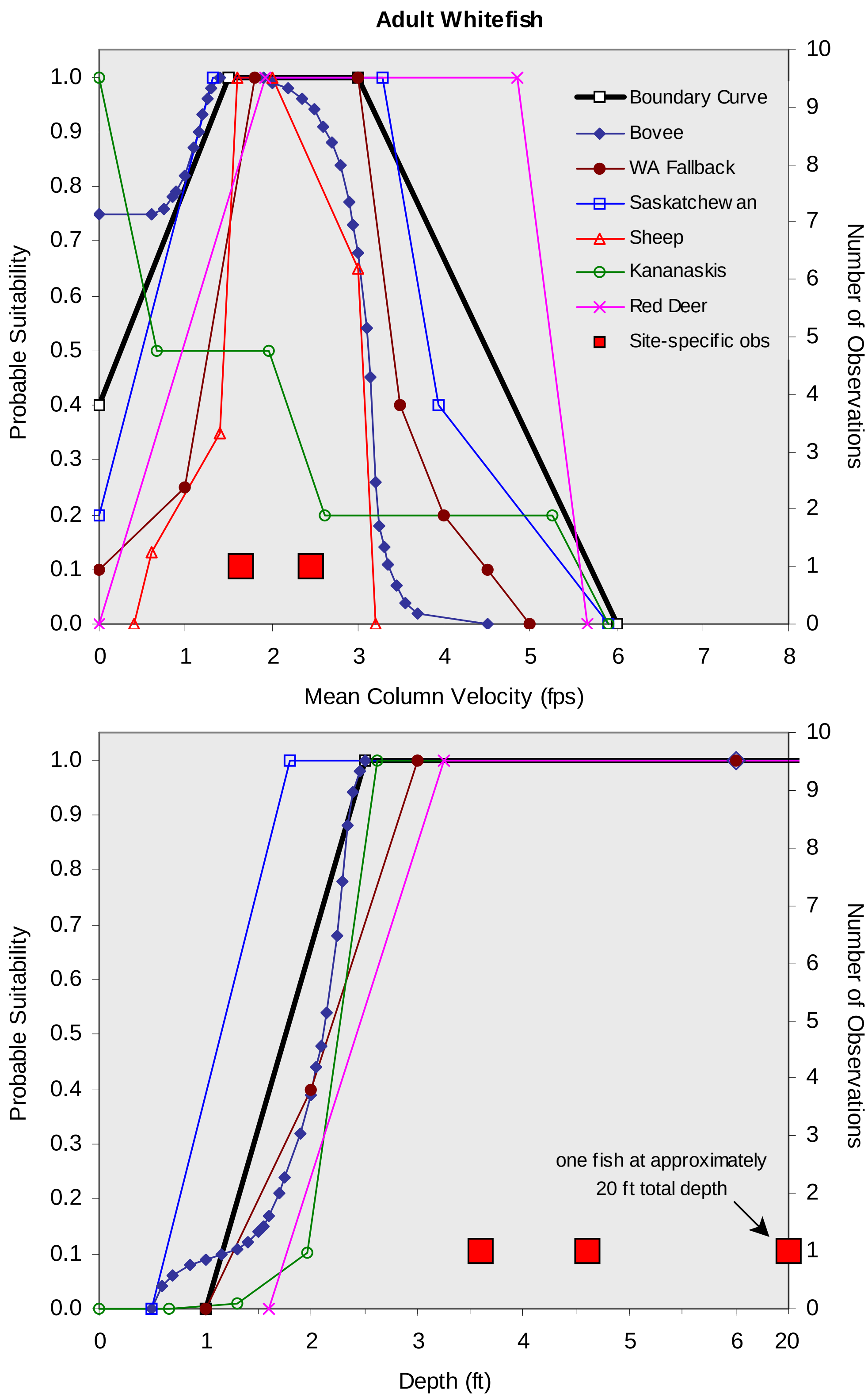


Figure 5.4-4. Available HSI curves for adult whitefish, along with interim Boundary curves and site-specific observations from the Boundary project area.

Table 5.5-1. Literature-based 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:
1 from "clear" curve, USFWS essentially equivalent (therefore not entered)
2 HSC curves later derived from frequency histograms, used Bovee curve for spwn depth
3 curve points from Instream Flow Group HSC summary
4 no sample size or stream size/flow information found, winter and summer-nighttime HSC data also available in paper
5 data combined among streams for adults & spwning, separate by rivers for fry & juvs
6 not sure how Cat III curves or poisson regression was performed for spawning lifestage
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 spwn depth
10 0.5 curve pts taken from graph, others from table, cover for juv/adlt based only on juvs (adults showed less cover use), values based on normalized rel 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 & spwning, separate by rivers for fry & juvs
13 substrate code arranged from smoothest to roughest (most cover)
14 from "turbid" curve (no clear curve available)
15 based on data by 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

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, PPS-pre-positioned area shocker, EF-electrofishing, NET-netting, 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.

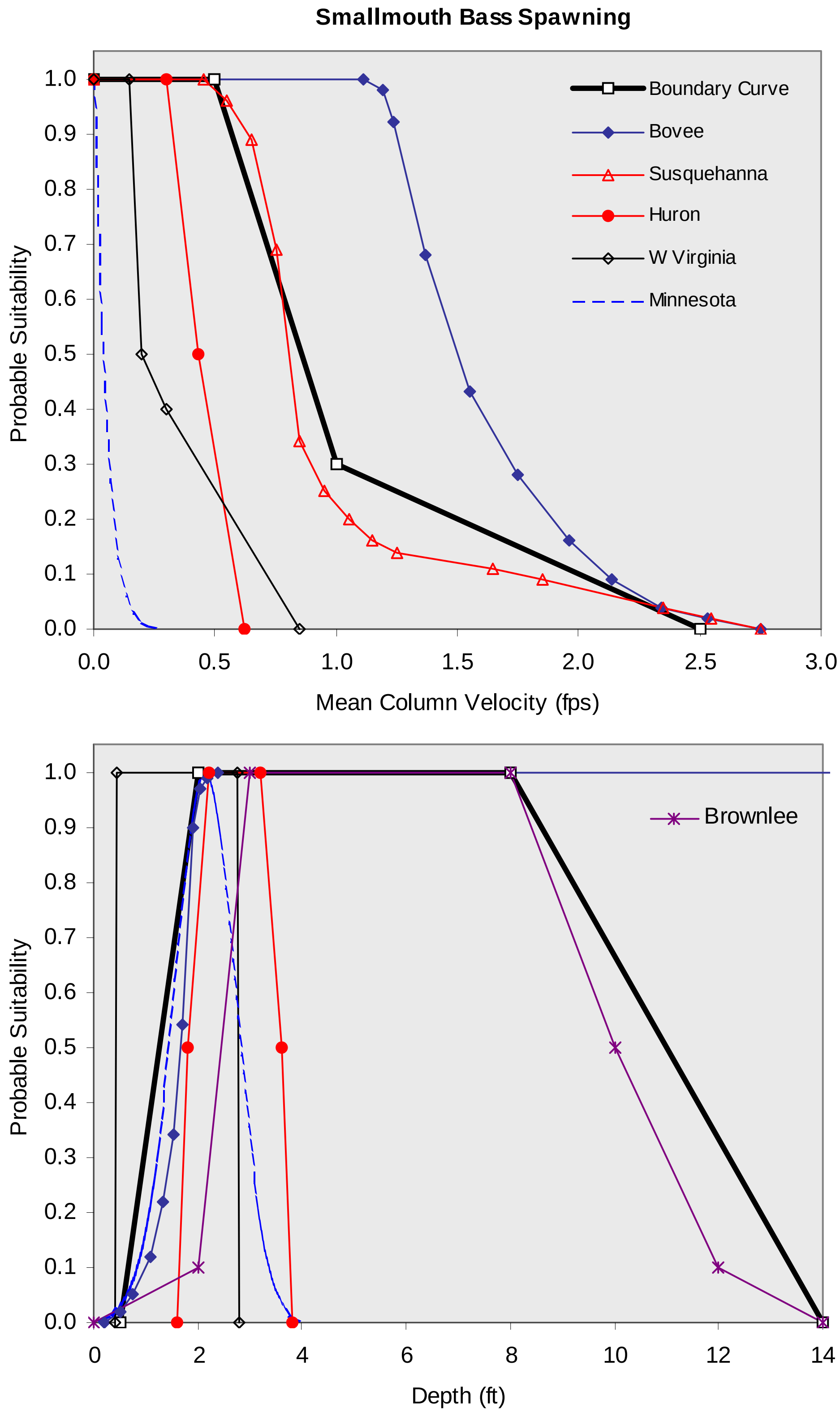


Figure 5.5-1. Available HSI curves for smallmouth bass spawning, along with interim Boundary curves.

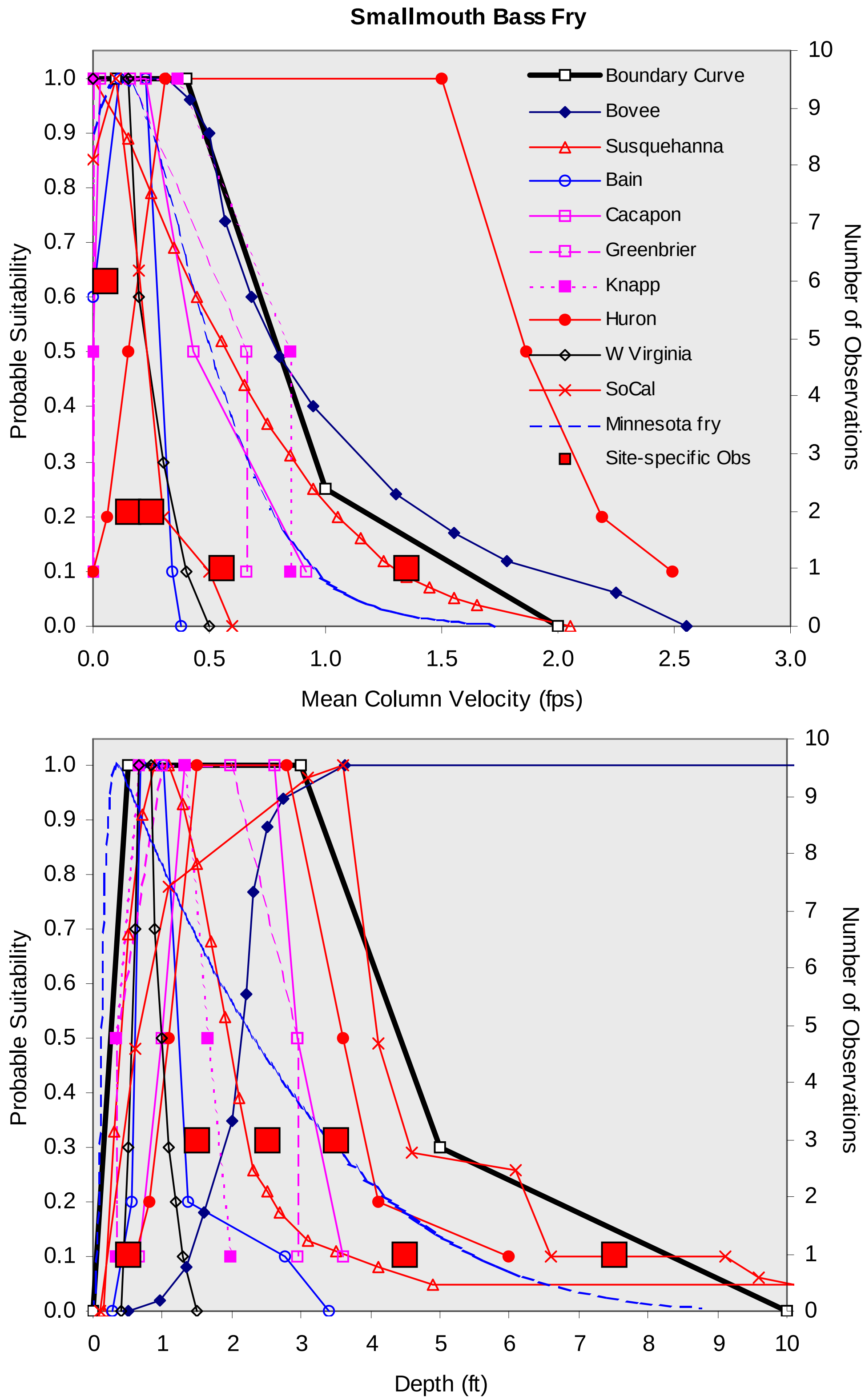


Figure 5.5-2. Available HSI curves for smallmouth bass fry, along with interim Boundary curves and electrofishing observations from the Boundary project area.

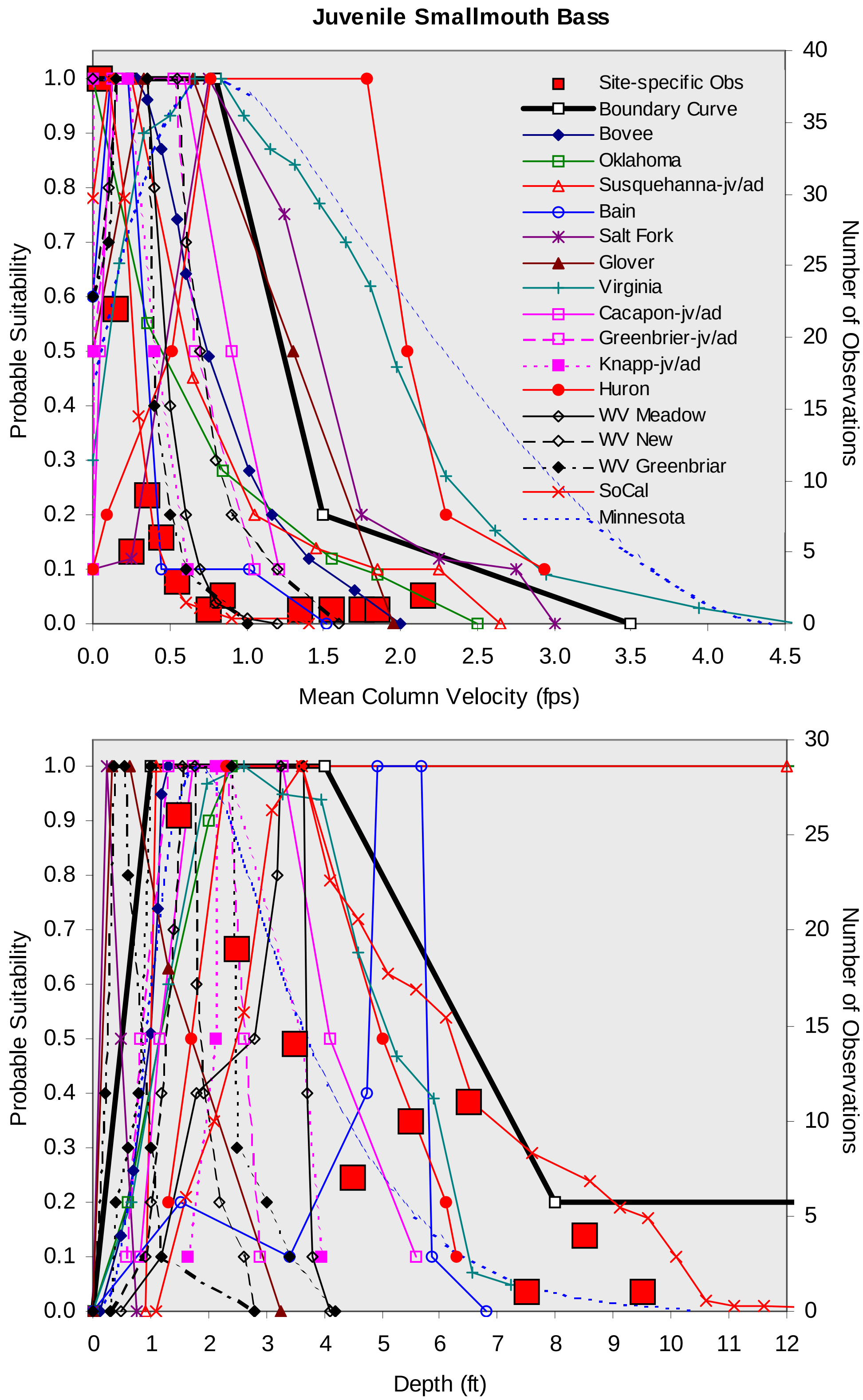


Figure 5.5-3. Available HSI curves for juvenile smallmouth bass, along with interim Boundary curves and electrofishing observations from the Boundary project area.

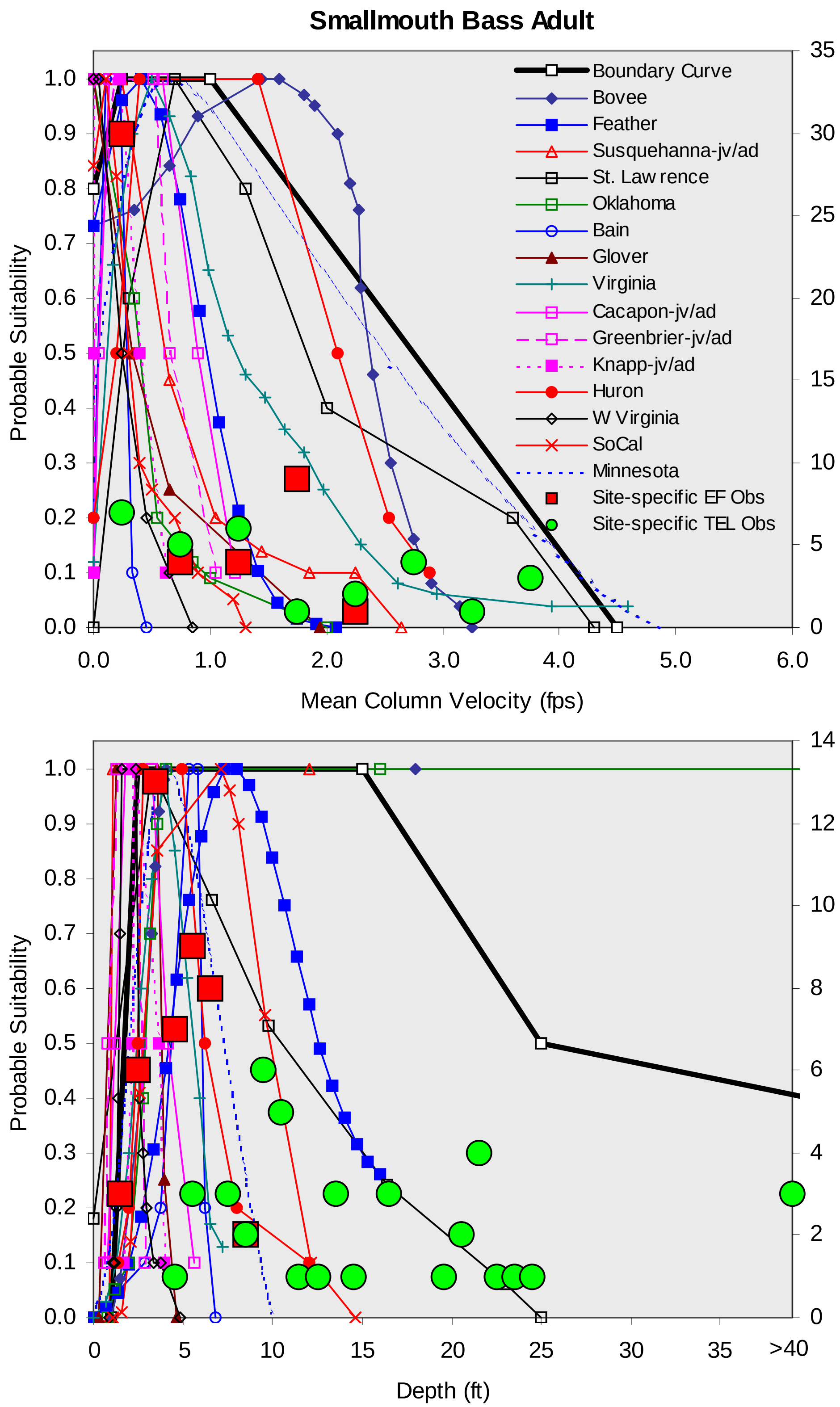


Figure 5.5.4. Available HSI curves for adult smallmouth bass, along with interim Boundary curves, electrofishing and biotelemetry observations from the Boundary project area.

Table 5.6-1. Literature-based 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:
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 4 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

Lifestages are: S-spawning, F-fry, J-juvenile, A-adult. Survey designs include: methods include: DOuw-direct observation underwater, DOow-direct observation out-of-water, PPS-pre-positioned area shocker, EF-electrofishing, NET-netting, 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.

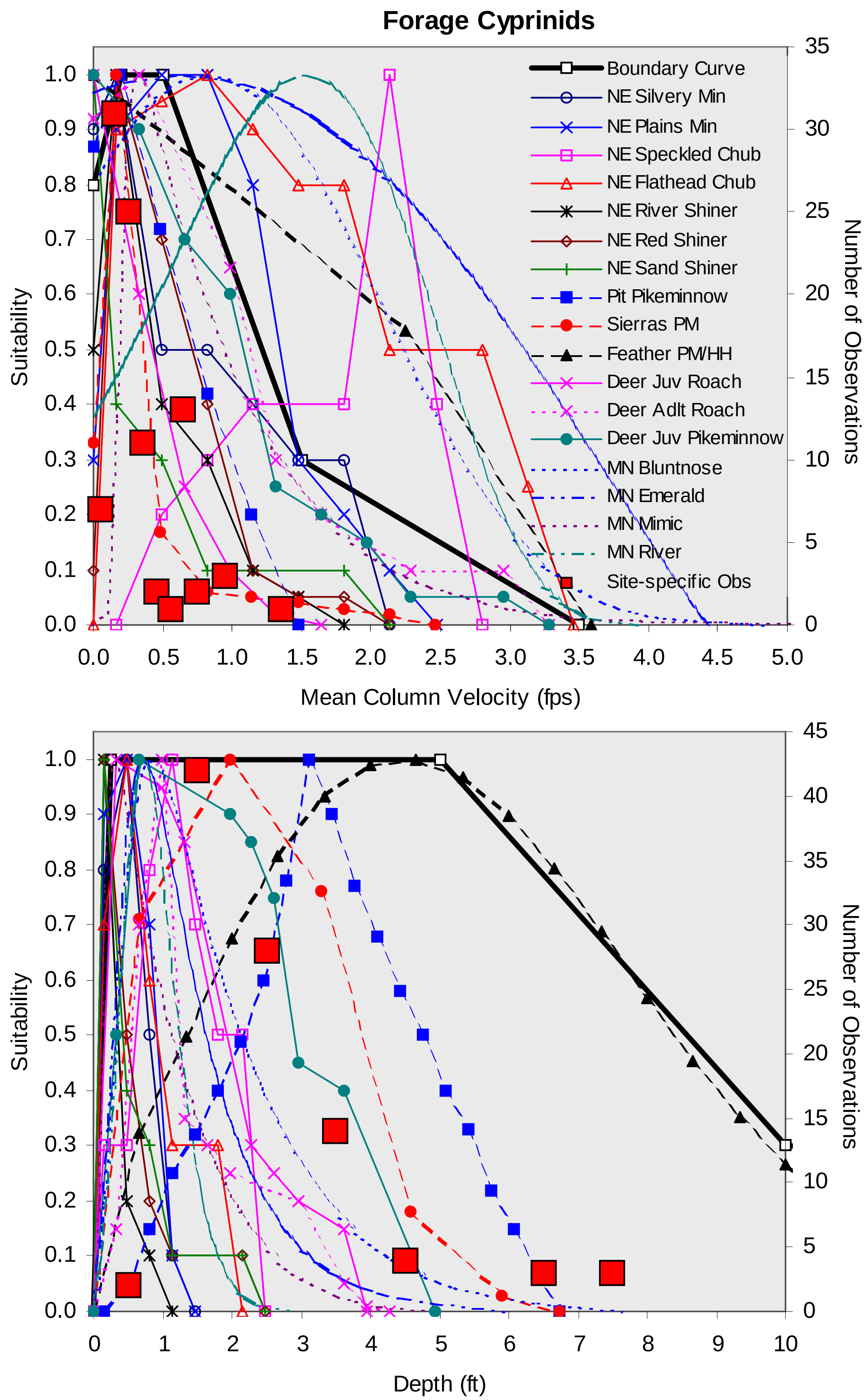


Figure 5.6-1. Available HSI curves for cyprinid forage species, along with interim Boundary curves and electrofishing observations from the Boundary project area.

This page is intentionally left blank.

Appendix 1b. Study No. 7.4.1 – Fish HSI Subtask 2: Interim Periodicity Tables for Target and Non-target Fish Species

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.1

Fish HSI

Subtask 2: Interim Periodicity Tables for Target and Non-target Fish Species

Prepared for
Seattle City Light

Prepared by
Mark Allen
Thomas R. Payne & Associates
(Under Contract to Tetra Tech)

March 2008

List of Tables

List of Figures

This page is intentionally left blank

Study No. 7.4.1: Fish HSI
Subtask 2: Interim Periodicity
Tables for Target and Non-target Fish Species
Boundary Hydroelectric Project (FERC No. 2144)

The following pages present interim periodicity information for target species in the Boundary Reservoir project area. Target species and life-stages 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 bass (*Micropterus dolomieui*), and a guild of cyprinid species (to represent forage for piscivorous species). Periodicity dates are also presented for spawning and fry life-stages of non-target species, including suckers (mostly largescale, *Catostomus snyderi*), yellow perch (*Perca flavescens*), largemouth bass (*M. salmoides*), and sunfishes (mostly black crappie [*Pomoxis nigromaculatus*] and pumpkinseed [*Lepomis gibbosus*]), that may be susceptible to stranding during Project operations.

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 black lines) are denoted by letters that correspond to the data source listed in the associated table. The thick red lines with diamond symbols and displayed dates are the interim periodicities. The interim dates shown here were not calculated using a mathematical formula, but instead were subjectively chosen based on the literature information with generally greater weight to site-specific data from geographically similar locations, and less weight to literature reviews (which tend to cover broad geographic areas with broader life history characteristics). On the following figures, the literature-based periodicities that immediately surround (above and below) the interim periodicities were given most weight, whereas those lines farther from the interim line were given less weight. Finally, actual site-specific data from the Study 9 electrofishing and stranding efforts were also plotted with the literature periodicities and were used to help select the starting and ending dates for the interim periodicities. New site-specific data will be added to these figures as they become available.

In producing these provisional periodicities, several assumptions and comments should be noted:

1. Periodicity dates are intended for use in modeling the flow:habitat relationship for fish species and life-stages in the project area (for the target species only), and for defining the temporal period when spawning and fry life-stages are most vulnerable to stranding during project operations (for all species).
2. Actual dates listed for literature data in the 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 15-May; in similar manner “late-August” may be interpreted in the figures and tables as 25-August, and so on.
3. Spawning periodicities are based solely on literature dates; addition of site-specific observations or analysis of temperature modeling results may be used to further adjust the interim dates.

4. Not all listed life stages are expected to be included in the habitat modeling in all study reaches. For example, spawning, incubation, and fry rearing are not known to occur in Boundary Reservoir for some species (e.g., westslope cutthroat trout, and possibly mountain whitefish), and redband trout are only expected to occur in the tailrace reach. Bull trout are not known to spawn or rear in the project area or tributaries, but are thought to occasionally immigrate from locations higher in the Pend Oreille watershed. Consequently, some periodicities contained in this appendix may be proposed for deletion.
5. It is assumed that incubation times begin at the onset of spawning, even though the incubation lines (dotted lines in figures) only extend from the cessation of spawning.
6. It is assumed that the division between "fry" and "juvenile" life stages for salmonids occurs at a length of approximately 5 to 6 centimeters (cm), which is consistent with most of the salmonid HSC 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 6 cm, based on data from Pennsylvania (Allen 1996), Michigan (Monahan 1991), California (Studley et al. 1986), and West Virginia (Newcomb et al. 1995); therefore, we also propose to use a criterion length of 55 mm 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, and for juveniles up to 10 cm to represent forage base when modeling the flow:habitat relationship. The use of cyprinid species $\leq$10 cm in length as forage was not contained in the RSP, but was agreed by consensus of the relicensing participant in subsequent workshop meetings (March 23, 2007, and June 7, 2007).
7. 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 are largely based on site-specific electrofishing data (where available) or from additional local expert or literature information.
8. 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). The size range for cyprinid forage species (up to 10 cm) includes juveniles and (for shiners) adults, and available data and literature suggest that year-round periodicity is also appropriate for this target species group.

These interim periodicities are anticipated to be reviewed and potentially modified during a future meeting (e.g., the proposed Habitat Suitability Criteria subgroup meeting during spring 2008), based on additional literature data, input from agency participants and local experts, and new site-specific observations from fish sampling in the Project area.

REFERENCES

Allen, M.A. 1996. Equal area line-transect sampling for smallmouth bass habitat suitability criteria in the Susquehanna River, Pennsylvania. Pages B119-132 in M. LeClerc, C. Herve, S. Valentin, A. Boudreault, and Y. Cote, editors. Ecohydraulics 2000: Second international symposium on habitat hydraulics. Institut National de la Recherche Scientifique-Eau, Quebec, Canada.

Ashe, B.L., and A.T. Scholz. 1992. Assessment of the fishery improvement opportunities on the Pend Oreille River: recommendations for fisheries enhancement. Final Report 1989-1991. BPA Report DOE/BP-39339-6

Behnke, R.J. 2002. Trout and salmon of North America. The Free Press. New York.

Bennett, D.H., and M. Liter. 1991. Water quality, fish and wildlife characteristics of Box Canyon Reservoir, Washington, Section 3: Fish, Completion Report 1989-1990. Dept of Fish and Wildlife Resources, College of Forestry, Wildlife and Range Sciences. University of Idaho, Moscow, ID. 94p.

Clipperton, G.K., C. W. Koning, Q.G.H. Locke, J.M. Mahoney, and B. Quazi. 2003. Instream flow needs determinations for the South Saskatchewan River Basin, Alberta, Canada. Alberta Environment, Alberta.

Craig, S.D. 1997. Habitat conditions affecting bull trout, *Salvelinus confluentis*, spawning areas within the Yakima River Basin, Washington. M.S. thesis, Central Washington University.

Daily, M.K. 1971. The mountain whitefish: a literature review. University of Idaho Forest, Wildlife and Range Experiment Station Paper 8. Moscow, Idaho.

Fernet, D.A., R.F. Courtney, and C.P. Bjornson. 1990. Instream flow requirements for fishes downstream of the Oldman River Dam. Report by Environmental Management Associates for Alberta Public Works, Supply and Services. Edmonton, Alberta.

Goetz, F. 1989. Biology of the bull trout, *Salvelinus confluentus*, a literature review. U.S. Forest Service, Willamette National Forest. Eugene, Oregon.

Golder Associates. 1999. Red Deer River instream flow needs study. Report to Fisheries Management Division, Alberta Environmental Protection, Cochran, Alberta.

Griffith, J.S., Jr. 1972. Comparative behavior and habitat utilization of brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Salmo clarki*) in small streams in northern Idaho. *Journal Fisheries Research Board of Canada* 29:265-273.

Henderson, C., and R.F. Foster. 1957. Studies of smallmouth black bass (*Micropterus dolomieu*) in the Columbia River near Richland, Washington. *Transactions of the American Fisheries Society* 86:112-127.

James, P.W., and H.M. Sexauer. 1997. Spawning behavior, spawning habitat and alternative mating strategies in an adfluvial population of bull trout. In: Friends of the Bull Trout Conference. Edited by W.C. Mackay, M.K. Brewin, and M. Monita. Pp. 325-329.

Knight, C.A., R.W. Orme, and D.A. Beauchamp. 1999. Growth, survival, and migration patterns of juvenile adfluvial Bonneville cutthroat trout in tributaries of Strawberry Reservoir, Utah. Transactions of the American Fisheries Society 128:553-563.

Monahan, J.T. 1991. Development of habitat suitability data for smallmouth bass (*Micropterus dolomieui*) and rock bass (*Ambloplites rupestris*) in the Huron River, Michigan. M.S. Thesis, Michigan State University, East Lansing. 130pp.

Montgomery, J.C., D.H. Fickeisen, and C.D. Becker. 1980. Factors influencing smallmouth bass production in the Hanford area, Columbia River. *Northwest Science* 54:296-305.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Co. Anchorage, Alaska.

Muhlfeld, C.C. 2002. Spawning characteristics of redband trout in a headwater stream in Montana. North American Journal of Fisheries Management 22:1314-1320.

Nehring, R.B., and R.M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4(1):1-19.

Newcomb, T.J., S.A. Perry, and W.B. Perry. 1995. Comparison of habitat suitability criteria for smallmouth bass (Micropterus dolomieu) from three West Virginia Rivers. Rivers 5:170-183.

Northcote, T.G., and G.L. Ennis. 1994. Mountain whitefish biology and habitat use in relation to compensation and improvement possibilities. Reviews in Fisheries Science 2(4):347-371.

Pearsons, T.N., S.R. Phelps, S.W. Martin, E.L. Bartrand and G.A. McMichael. 2003. Gene flow between resident and anadromous *Oncorhynchus mykiss* in the Yakima Basin: ecological and genetic evidence. In Proceedings of the Inland Rainbow Trout Workshop. Edited by P. Howell and D. Buchanan. Oregon Chapter, American Fisheries Society. Princeton, Oregon. Pp. 1-9.

Petit, S.W., and R.L. Wallace. 1975. Age, growth, and movement of mountain whitefish, *Prosopium williamsoni* (Girard), in the North Fork Clearwater River, Idaho. Transactions of the American Fisheries Society 104:68-76.

Pillipow, R., and C. Williamson. 2004. Goat River bull trout (*Salvelinus confluentus*) biotelemetry and spawning assessments 2002-03. BC Journal of Ecosystems and Management, Extension Note 4(2).

Pratt, K.L. 1992. A review of bull trout life history. In Proceedings of the Gearheart Mountain bull trout workshop. Edited by P.J. Howell and D.V. Buchanan. Oregon Chapter of the American Fisheries Society. Corvallis, Oregon. Pp. 5-9.

R.L. & L. environmental Services, LTD (RL&L). 1999. Lower Columbia River whitefish monitoring program. 1997-1998 investigations. Data report prepared for B.C. Hydro, Castlegar, B.C.

RL&L. 2000. Lower Columbia River whitefish monitoring program. 1998-1999 investigations. Data report prepared for B.C. Hydro, Castlegar, B.C.

RL&L. 2000b. Brilliant expansion project: prediction and assessment of project related flow variations on the aquatic environment. Final Report to Columbia Power Corporation, Castlegar, B.C.

Ratliff, D.E., S.L. Theisfeld, W.G. Weber, A.M. Stuart, M.D. Riehle, and D.V. Buchanan. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-94. Oregon Department of Fish and Wildlife, Information Report Number 96-7.

Rawson, D.S. 1945. The experimental introduction of smallmouth bass into lakes of the Prince Albert National Park, Saskatchewan. Transactions of the American Fisheries Society 73:19-31.

Reiser, D.W., E. Conner, K. Binkley, K. Lynch, and D. Paige. [no date]. Evaluation of spawning habitat used by bull trout in the Cedar River watershed, Washington. Unpublished Manuscript.

Richter, T.J. 2003. Hells Canyon Complex resident fish study. Idaho Power, Technical Report Appendix E.3.1-5.

Schill, D., R. Thurow, and P. Kline. 1994. Seasonal movement and spawning mortality of fluvial bull trout in Rapid River, Idaho. Idaho Department of Fish and Game, Wild Trout Evaluations. Job Performance Report, IDFG 94-13. Boise, Idaho.

Seattle City Light. 2007. Draft Angler Interviews memos.

Scott, W.B., and E.J. Crossman. 1998. Freshwater fishes of Canada. Galt House Publications, Ltd., Oakville, Ontario.

Studley, T.K., J.E. Baldrige and T.R. Lambert. 1986. Micro habitat of smallmouth bass in four California rivers. MS presented at Pacific Fishery Biologists conference, April 1986, Eureka, California.

Thompson, G.E., and R.W. Davies. 1976. Observations on the age, growth, reproduction, and feeding of mountain whitefish () in the Sheep River, Alberta. Transactions of the American Fisheries Society 105:208-219.

Vadas, R.L., and H.A. Beecher. 2007. Variations in fish spawning-flow timing in Washington desert streams of the mid-Columbia. Online Powerpoint presentation www.gwpc.org/meetings/meetings_forum/AF07/Proceedings/GW%20Dependent%20Ecosystems/Vadas,%20Bob.pdf

Wydoski, R.S., and R.R. Whitney. 2003. Inland fishes of Washington. 2nd Ed., revised and expanded. University of Washington Press. Seattle.

Zimmerman, C.E., and G.H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss*: evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Science 57:2152-2162.

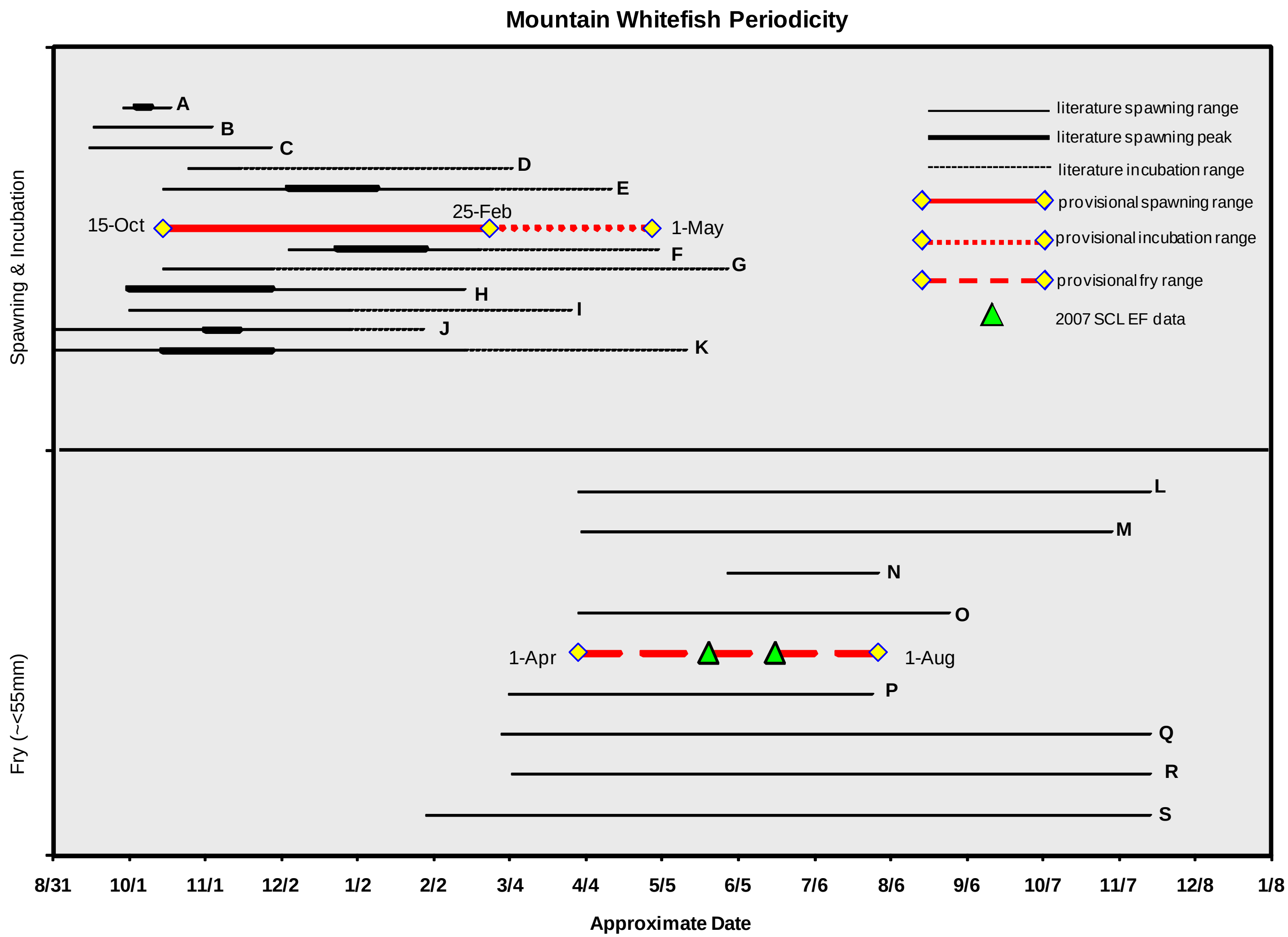


Figure 1. Provisional Boundary Periodicity – Mountain Whitefish
(see Table 1 for source data)

Table 1. Boundary Provisional 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° 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	spawning	start	15-Sep	1.75			Clipperton et al. 2003	represents several South Saskatchewan Basin streams
C	So Saskatch Basin	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	B.C. Brilliant	spawning	start	15-Oct	1.65	5-Dec	1.65	RL&L 2000	
E	B.C. Brilliant	spawning	end	25-Feb	1.65	10-Jan	1.65	RL&L 2000	
E	B.C. Brilliant	incubation	end	15-Apr	1.65			RL&L 2000	
F	Columbia&Kootenay	spawning	start	5-Dec	1.50	25-Dec	1.50	RL&L 1999,2000	spawning from 33-46°F, peaks ranged from 34-42°F
F	Columbia&Kootenay	spawning	end	20-Feb	1.50	30-Jan	1.50	RL&L 1999,2000	
F	Columbia&Kootenay	incubation	end	5-May	1.50			RL&L 1999,2000	
G	NF Clearwater	spawning	start	15-Oct	1.45			Pettit & Wallace 1975	
G	NF Clearwater	spawning	end	28-Nov	1.45			Pettit & Wallace 1975	
G	NF Clearwater	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° 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 (<5-6cm)	start	1-Apr	0.90			Thompson & Davies 1976	
L	Sheep R, AB	fry (<5-6cm)	end	20-Nov	0.90			Thompson & Davies 1976	end date unknown, but fish averaged 81mm by end of year
M	Red R AB	fry (<5-6cm)	start	2-Apr	0.80			Golder 1999	
M	Red R AB	fry (<5-6cm)	end	4-Nov	0.80			Golder 1999	
N	NF Clearwater	fry (<5-6cm)	start	1-Jun	0.70			Pettit & Wallace 1975	
N	NF Clearwater	fry (<5-6cm)	end	1-Aug	0.70			Pettit & Wallace 1975	end date unknown, but fish averaged 86mm by September
O	Northcote lit review	fry (<5-6cm)	start	1-Apr	0.60			Northcote & Ennis 1994	
O	Northcote lit review	fry (<5-6cm)	end	30-Aug	0.60			Northcote & Ennis 1994	
P	Daily lit review	fry (<5-6cm)	start	4-Mar	0.40			Daily 1971	
P	Daily lit review	fry (<5-6cm)	end	30-Jul	0.40			Daily 1971	time when fry mean length=55mm in Yellowstone River
Q	Behnke's Salmonids	fry (<5-6cm)	start	1-Mar	0.30			Behnke 2002	
Q	Behnke's Salmonids	fry (<5-6cm)	end	20-Nov	0.30			Behnke 2002	unknown end date
R	FW Fish of Canada	fry (<5-6cm)	start	5-Mar	0.20			Scott & Crossman 1998	
R	FW Fish of Canada	fry (<5-6cm)	end	20-Nov	0.20			Scott & Crossman 1998	unknown end date
S	Fish of WA	fry (<5-6cm)	start	30-Jan	0.10			Wydoski & Whitney 2003	eggs hatch 1+ months after spawning
S	Fish of WA	fry (<5-6cm)	end	20-Nov	0.10			Wydoski & Whitney 2003	unknown end date

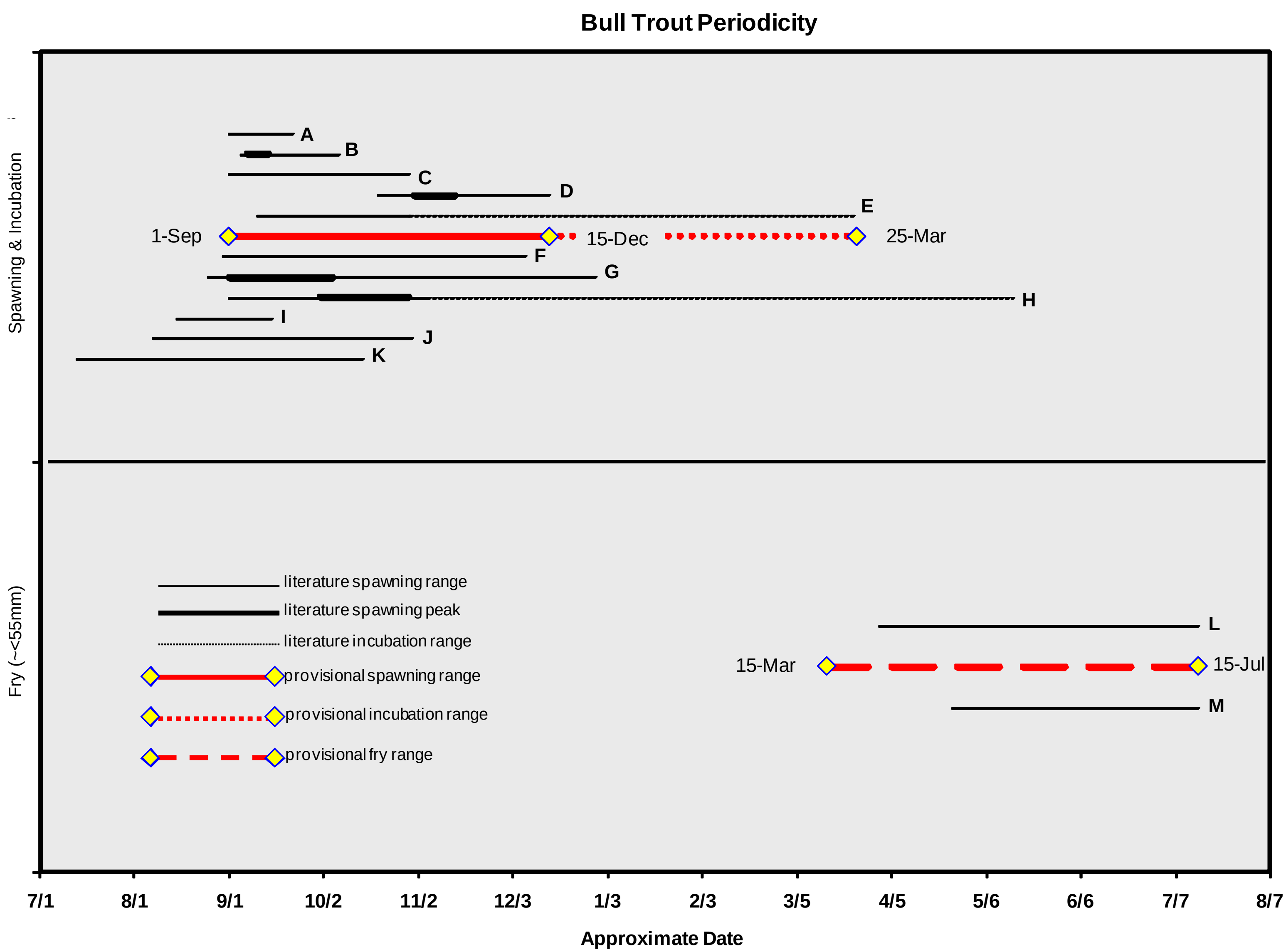


Figure 2. Provisional Boundary Periodicity – Bull Trout
(see Table 2 for source data)

Table 2. Boundary Provisional Periodicity – Bull Trout

	Periodicity Dataset	Lifestage		Range	code	Peak	code	Source	Notes
A	Goat BC	spawning	start	1-Sep	1.80			Pillipow & Williamson 2004	headwater tributary to Fraser River
A	Goat BC	spawning	end	22-Sep	1.80			Pillipow & Williamson 2004	
B	Rimrock	spawning	start	5-Sep	1.75	7-Sep	1.75	James & Sexauer 1997	spawning peaked at 42-46° F
B	Rimrock	spawning	end	7-Oct	1.75	14-Sep	1.75	James & Sexauer 1997	
C	Flathead tribs	spawning	start	1-Sep	1.70			Pratt 1992	literature review, spawning as temperatures decreased to 48° F
C	Flathead tribs	spawning	end	30-Oct	1.70			Pratt 1992	
D	Cedar WA	spawning	start	20-Oct	1.65	1-Nov	1.65	Reiser et al. no date	
D	Cedar WA	spawning	end	15-Dec	1.65	14-Nov	1.65	Reiser et al. no date	end date unknown, but new redds observed on 7 December
E	B.C. Brilliant	spawning	start	10-Sep	1.60			RL&L 2000	
E	B.C. Brilliant	spawning	end	30-Oct	1.60			RL&L 2000	
E	B.C. Brilliant	incubation	end	25-Mar	1.60			RL&L 2000	
F	Yakima	spawning	start	30-Aug	1.50			Craig 1997	6 Yakima basins, spawning as temperatures decreased to 48° F
F	Yakima	spawning	end	7-Dec	1.50			Craig 1997	
G	Fish of WA	spawning	start	25-Aug	1.45	1-Sep	1.45	Wydoski & Whitney 2003	peak spawning as temperatures declined from 48-41° F
G	Fish of WA	spawning	end	30-Dec	1.45	5-Oct	1.45	Wydoski & Whitney 2003	
H	FW Fish of Canada	spawning	start	1-Sep	1.40	1-Oct	1.40	Scott & Crossman 1998	spawning began at temperatures ~46° F
H	FW Fish of Canada	spawning	end	5-Nov	1.40	30-Oct	1.40	Scott & Crossman 1998	
H	FW Fish of Canada	incubation	end	15-May	1.40			Scott & Crossman 1998	
I	Rapid ID	spawning	start	15-Aug	1.35			Schill et al. 1994	
I	Rapid ID	spawning	end	15-Sep	1.35			Schill et al. 1994	
J	Goetz lit review	spawning	start	7-Aug	1.30			Goetz 1989	spawning begins as temperatures drop below 48° F
J	Goetz lit review	spawning	end	31-Oct	1.30			Goetz 1989	
K	Metolius	spawning	start	13-Jul	1.25	15-Aug		Ratliff et al 1996	spawning began as temperatures dropped below 48° F
K	Metolius	spawning	end	15-Oct	1.25	1-Oct		Ratliff et al 1996	
L	Flathead tribs	fry (<5-6cm)	start	1-Apr	0.60			Pratt 1992	fry may remain in gravel up to 3 weeks prior to emergence
L	Flathead tribs	fry (<5-6cm)	end	15-Jul	0.60			Pratt 1992	end date unknown
M	FW Fish of Canada	fry (<5-6cm)	start	25-Apr	0.40			Scott & Crossman 1998	
M	FW Fish of Canada	fry (<5-6cm)	end	15-Jul	0.40			Scott & Crossman 1998	unknown end date

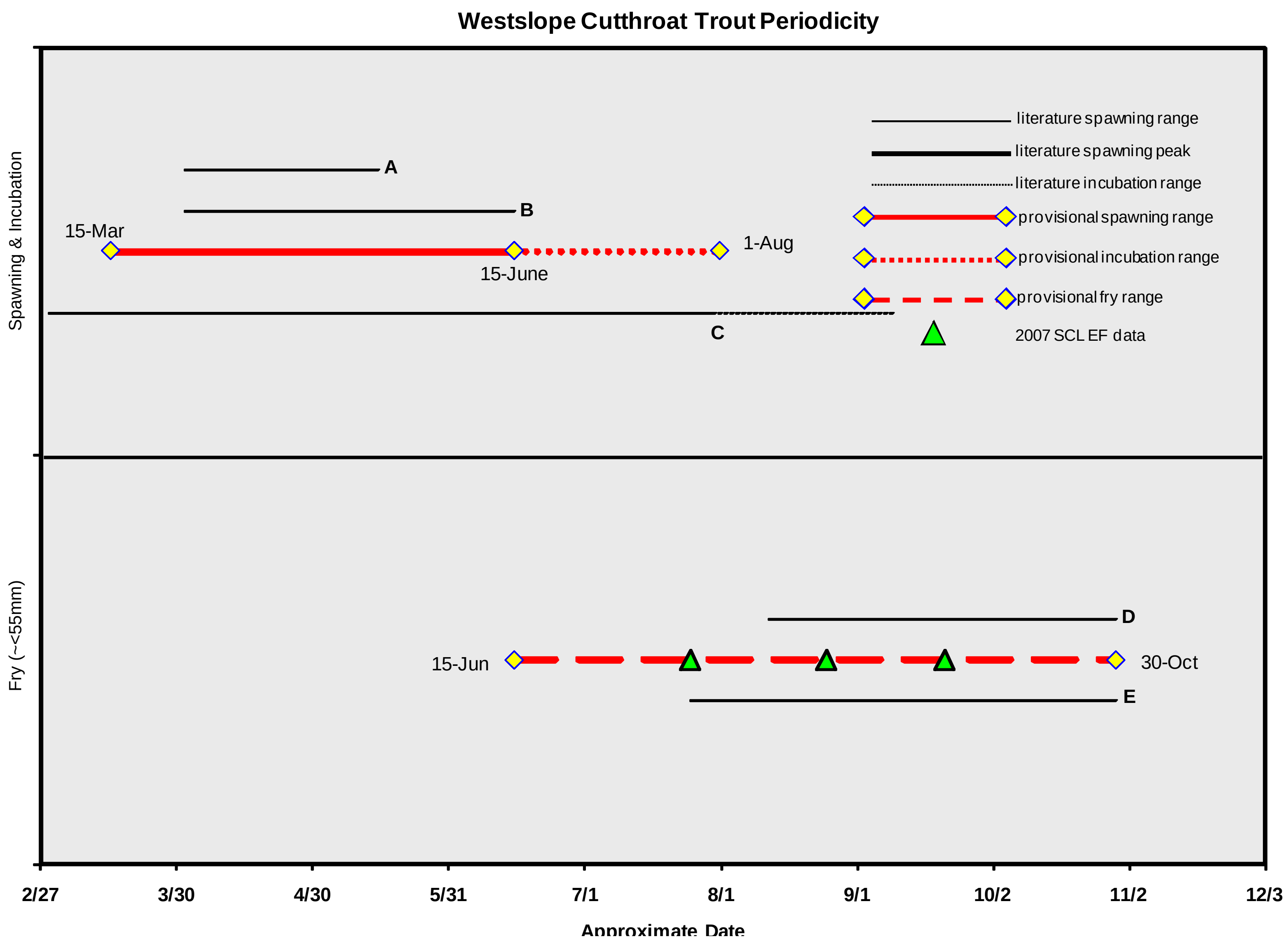


Figure 3. Provisional Boundary Periodicity – Westslope Cutthroat Trout
(see Table 3 for source data)

Table 3. Boundary Provisional Periodicity – 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° F
B	Behnke's Salmonids	spawning	end	15-Jun	1.60			Behnke 2002	
C	Fish of WA	spawning	start	1-Mar	1.40			Wydoski & Whitney 2003	spawning at 43-63° F
C	Fish of WA	spawning	end	30-Jul	1.40			Wydoski & Whitney 2003	
C	Fish of WA	incubation	end	10-Sep	1.40			Wydoski & Whitney 2003	6 wk incubation time added
D	Utah	fry (<5-6cm)	start	12-Aug	0.60			Knight et al 1999	Bonneville cutthroat
D	Utah	fry (<5-6cm)	end	30-Oct	0.60			Knight et al 1999	end date unknown
E	Northern ID	fry (<5-6cm)	start	25-Jul	0.40			Griffith 1972	first emergence of fry in northern Idaho tributaries over 2 years
E	Northern ID	fry (<5-6cm)	end	30-Oct	0.40			Griffith 1972	end date unknown

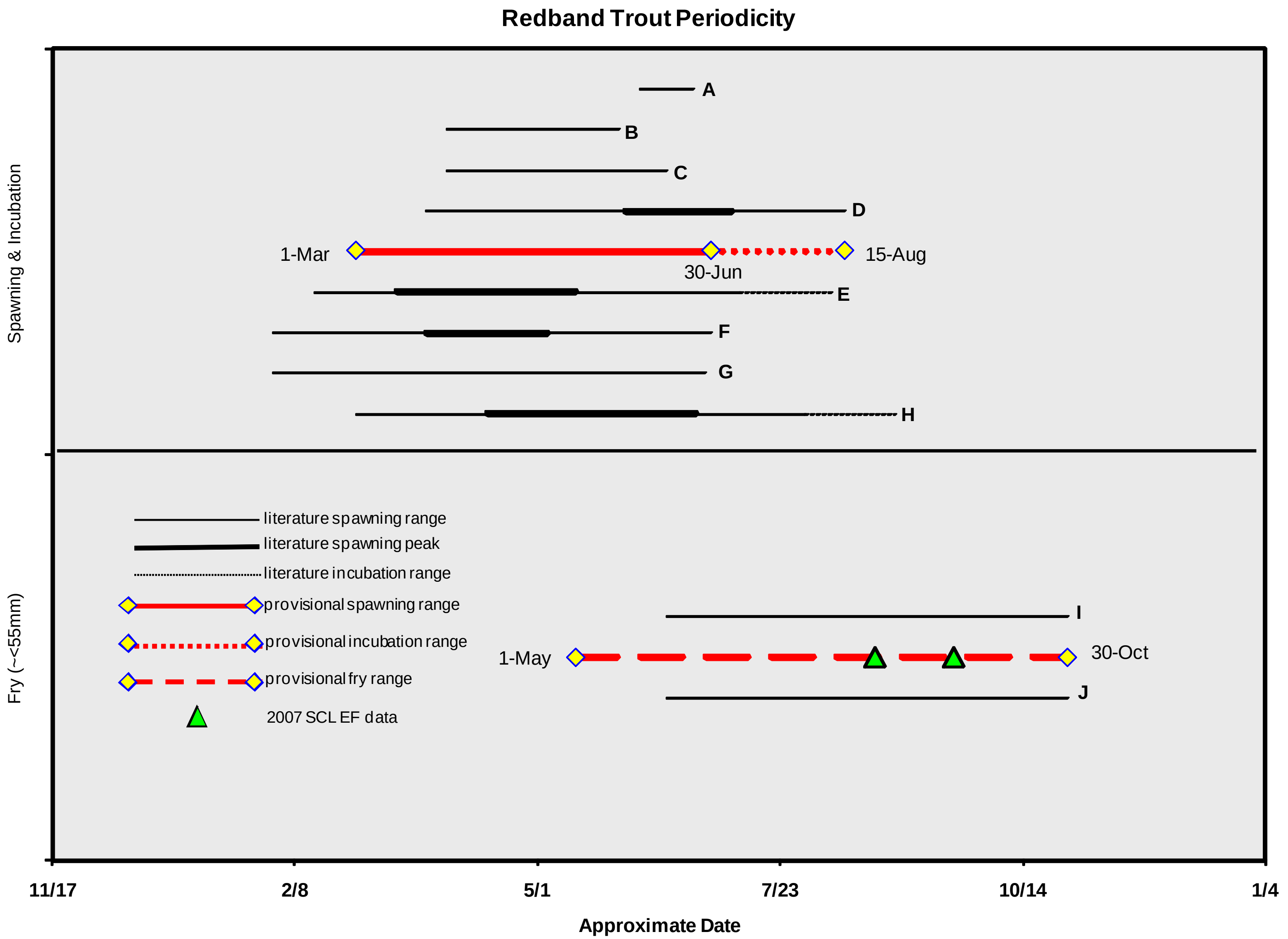


Figure 4. Provisional Boundary Periodicity – Redband Trout (see Table 4 for source data)

Table 4. Boundary Provisional Periodicity – Rainbow Trout

	Periodicity Dataset	Lifestage		Range	code	Peak	code	Source	Notes
A	Montana	spawning	start	6-Jun	1.90			Muhlfeld 2002	
A	Montana	spawning	end	24-Jun	1.90			Muhlfeld 2002	
B	Colorado	spawning	start	1-Apr	1.80			Nehring & Anderson 1993	
B	Colorado	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	spawning	start	25-Mar	1.60	1-Jun	1.60	Zimmerman & Reeves 2000	our visual estimate of peak time
D	Deschutes	spawning	end	15-Aug	1.60	7-Jul	1.60	Zimmerman & Reeves 2000	
E	B.C. Brilliant	spawning	start	15-Feb	1.40	15-Mar	1.40	RL&L 2000	
E	B.C. Brilliant	spawning	end	10-Jul	1.40	15-May	1.40	RL&L 2000	
E	B.C. Brilliant	incubation	end	10-Aug	1.40			RL&L 2000	
F	Fish of WA	spawning	start	1-Feb	1.30	25-Mar	1.30	Wydoski & Whitney 2003	
F	Fish of WA	spawning	end	30-Jun	1.30	5-May	1.30	Wydoski & Whitney 2003	
F	Fish of WA	incubation	end	20-Aug	1.30			Wydoski & Whitney 2003	6 wk incubation time added
G	Yakima	spawning	start	1-Feb	1.20			Pearsons et al. 2003	
G	Yakima	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	
I	Colorado	fry (<5-6cm)	start	15-Jun	0.60			Nehring & Anderson 1993	
I	Colorado	fry (<5-6cm)	end	30-Oct	0.60			Nehring & Anderson 1993	end date unknown
J	FW Fish of Canada	fry (<5-6cm)	start	15-Jun	0.40			Scott & Crossman 1998	
J	FW Fish of Canada	fry (<5-6cm)	end	30-Oct	0.40			Scott & Crossman 1998	end date unknown

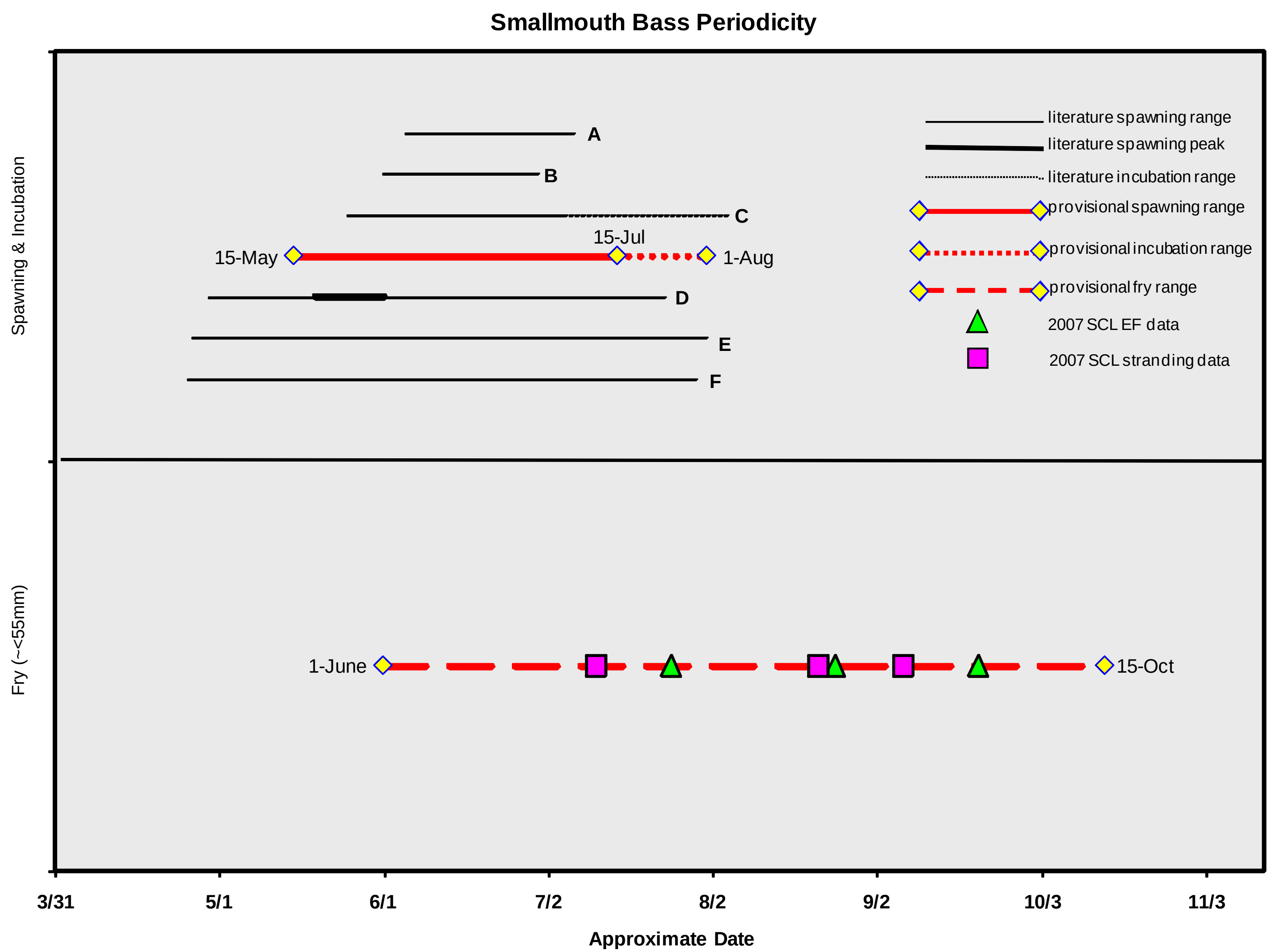


Figure 5. Provisional Boundary Periodicity – Smallmouth Bass
(see Table 5 for source data)

Table 5. Boundary Provisional Periodicity – Smallmouth 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	spawning	1	1-Jun	1.70			SCL 2007	based on SCL angler interviews
B	Boundary Anglers	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, 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, 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, Columbia R	spawning	start	25-Apr	1.20			Montgomery et al. 1980	
F	Hanford, Columbia R	spawning	end	30-Jul	1.20			Montgomery et al. 1980	

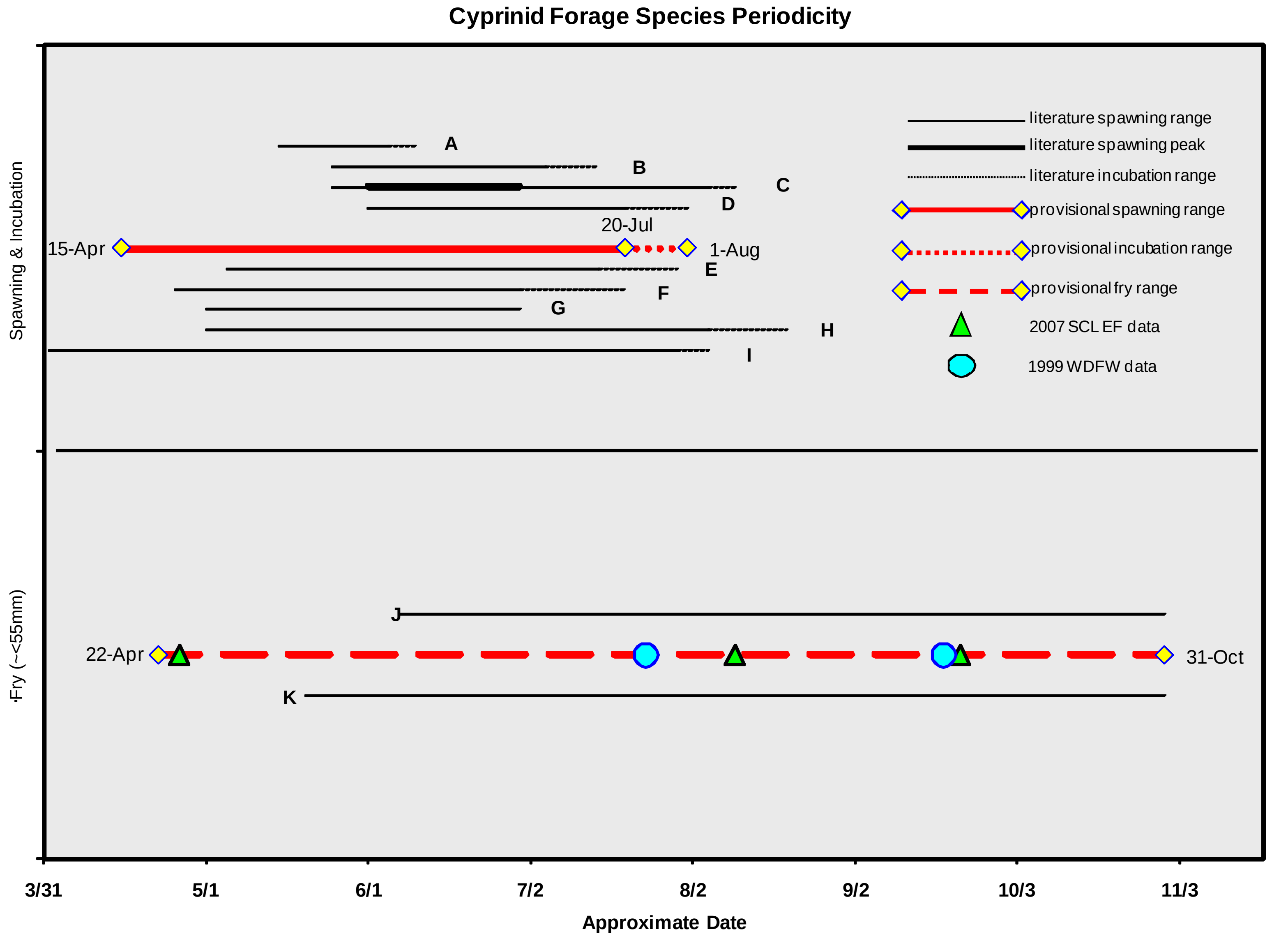


Figure 6. Provisional Boundary Periodicity – Cyprinid Forage Species
(see Table 6 for source data)

Table 6. Boundary Provisional 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° 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° 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	B.C. Brilliant-Pikeminnow	spawning	start	1-Jun	1.60			RL&L 2000	
D	B.C. Brilliant-Pikeminnow	spawning	end	20-Jul	1.60			RL&L 2000	
D	B.C. Brilliant-Pikeminnow	incubation	end	1-Aug	1.60			RL&L 2000	
E	B.C. Brilliant-Redside Shiner	spawning	start	5-May	1.45			RL&L 2000	used incubation start date to represent start of spawning
E	B.C. Brilliant-Redside Shiner	spawning	end	15-Jul	1.45			RL&L 2000	
E	B.C. Brilliant-Redside Shiner	incubation	end	30-Jul	1.45			RL&L 2000	
F	B.C. Brilliant-Peamouth	spawning	start	25-Apr	1.40			RL&L 2000	
F	B.C. Brilliant-Peamouth	spawning	end	30-Jun	1.40			RL&L 2000	
F	B.C. 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	V Fish Canada-Redside Shiner	spawning	start	1-May	1.30			Scott & Crossman 1998	
H	V Fish Canada-Redside Shiner	spawning	end	5-Aug	1.30			Scott & Crossman 1998	
H	V 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° 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° F
J	Fish of WA-Pikeminnow	fry/juv (<10cm)	start	7-Jun	0.60			Wydoski & Whitney 2003	swimming 1 week after hatching
J	Fish of WA-Pikeminnow	fry/juv (<10cm)	end	30-Oct	0.60			Wydoski & Whitney 2003	end date unknown
K	Fish of WA-Peamouth	fry/juv (<10cm)	start	20-May	0.40			Wydoski & Whitney 2003	eggs hatch in ~7-8 days
K	Fish of WA-Peamouth	fry/juv (<10cm)	end	30-Oct	0.40			Wydoski & Whitney 2003	end date unknown

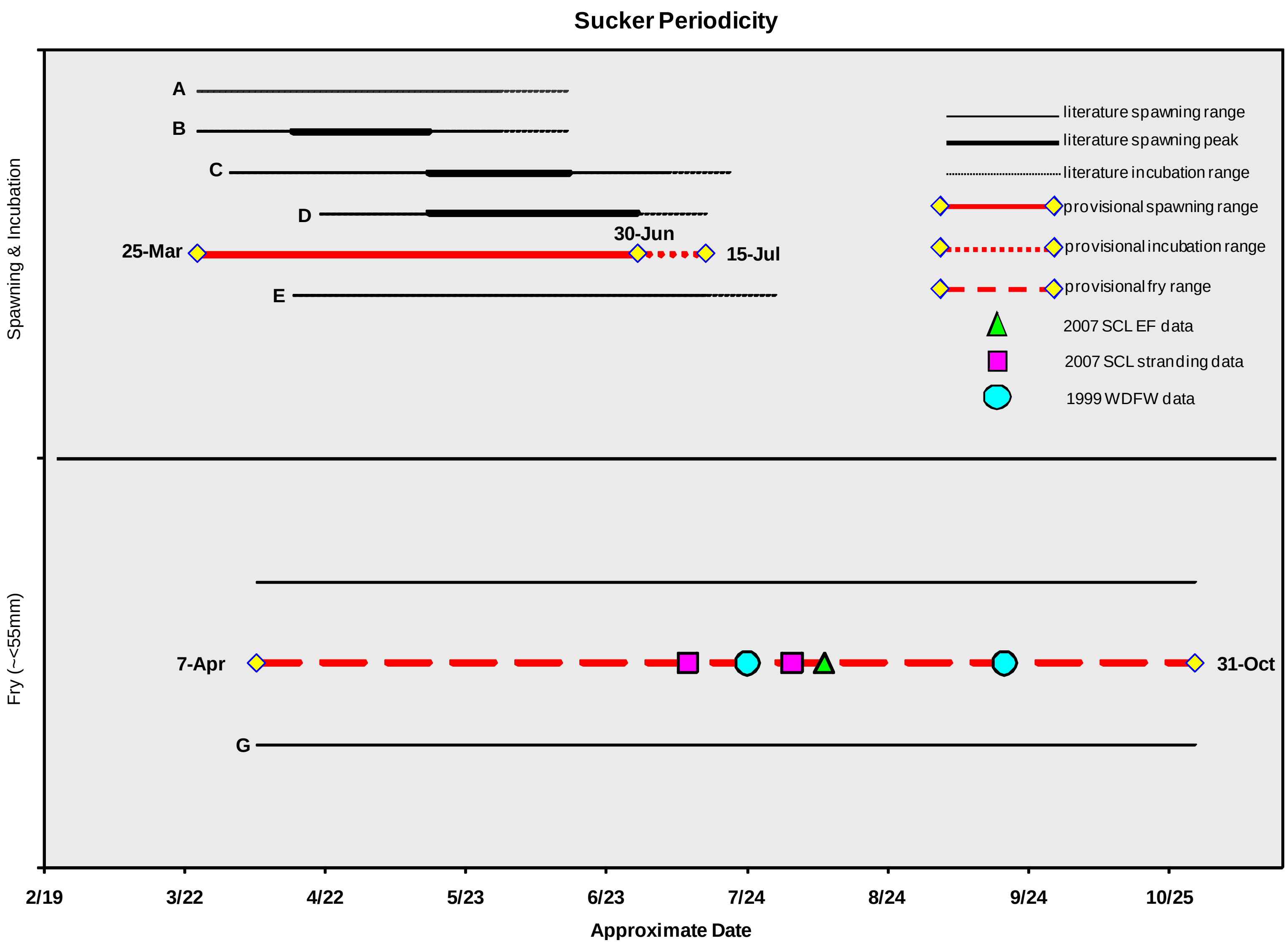


Figure 7. Provisional Boundary Periodicity – Largescale and Longnose Suckers (see Table 7 for source data)

Table 7. Boundary Provisional Periodicity – Largescale & Longnose Suckers

	Periodicity Dataset	Lifestage		Range	code	Peak	code	Source	Notes
A	Fish of WA	longnose-spwn	start	25-Mar	1.90			Wydoski & Whitney 2003	spawning @ water temps >41° F
A	Fish of WA	longnose-spwn	end	31-May	1.90			Wydoski & Whitney 2003	by late March temps in Boundary>41° F (5.0°C)
A	Fish of WA	longnose-inc	start	25-Mar	1.90			Wydoski & Whitney 2003	eggs usually hatch in ~2-3 weeks
A	Fish of WA	longnose-inc	end	15-Jun	1.90			Wydoski & Whitney 2003	
B	FW Fish Canada	longnose-spwn	start	25-Mar	1.80	15-Apr	1.80	Scott & Crossman 1998	spawn in the "spring" when @ water temps >41° F
B	FW Fish Canada	longnose-spwn	end	31-May	1.80	15-May	1.80	Scott & Crossman 1998	by late March temps in Boundary>41° F (5.0°C)
B	FW Fish Canada	longnose-inc	start	25-Mar	1.80			Scott & Crossman 1998	eggs usually hatch in ~14 days
B	FW Fish Canada	longnose-inc	end	15-Jun	1.80			Scott & Crossman 1998	
C	Fish of WA	largescale-spwn	start	1-Apr	1.70	15-May	1.70	Wydoski & Whitney 2003	in Pend Oreille when temps 46-55°F (7.8-12.8°F)
C	Fish of WA	largescale-spwn	end	7-Jul	1.70	15-Jun	1.70	Wydoski & Whitney 2003	
C	Fish of WA	largescale-inc	start	1-Apr	1.70			Wydoski & Whitney 2003	
C	Fish of WA	largescale-inc	end	21-Jul	1.70			Wydoski & Whitney 2003	
D	FW Fish Canada	largescale-spwn	start	21-Apr	1.60	15-May	1.60	Scott & Crossman 1998	
D	FW Fish Canada	largescale-spwn	end	30-Jun	1.60	30-Jun	1.60	Scott & Crossman 1998	
D	FW Fish Canada	largescale-inc	start	21-Apr	1.60			Scott & Crossman 1998	eggs usually hatch in ~14 days
D	FW Fish Canada	largescale-inc	end	15-Jul	1.60			Scott & Crossman 1998	
E	Foster Creek (Douglas Co.)	largescale-spwn	start	15-Apr	1.40			Vadas and Beecher 2007	
E	Foster Creek (Douglas Co.)	largescale-spwn	end	15-Jul	1.40			Vadas and Beecher 2007	
E	Foster Creek (Douglas Co.)	largescale-inc	start	15-Apr	1.40			Vadas and Beecher 2007	
E	Foster Creek (Douglas Co.)	largescale-inc	end	31-Jul	1.40			Vadas and Beecher 2007	assume 14 days
F	Fish of WA	fry (<55mm)	start	7-Apr	0.70			Wydoski & Whitney 2003	25 March + 14 days
F	Fish of WA	fry (<55mm)	end	31-Oct	0.70			Wydoski & Whitney 2003	end date unknown
G	FW Fish Canada	fry (<55mm)	start	7-Apr	0.30			Scott & Crossman 1998	25 March + 14 days
G	FW Fish Canada	fry (<55mm)	end	31-Oct	0.30			Scott & Crossman 1998	end date unknown

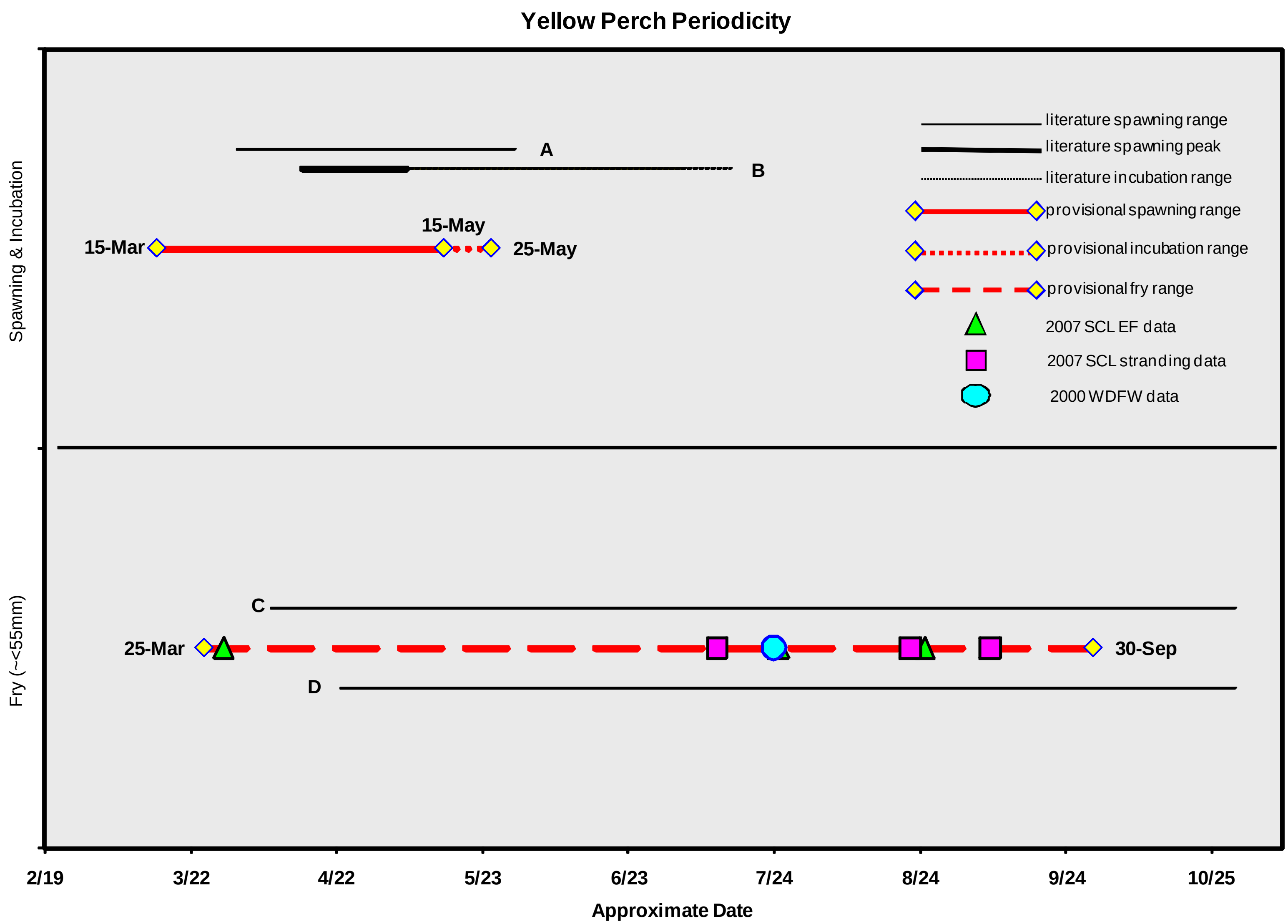


Figure 8. Provisional Boundary Periodicity – Yellow Perch
(see Table 8 for source data)

Table 8. Boundary Provisional 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° F
A	Fish of WA	spawning	end	30-May	1.75			Wydoski & Whitney 2003	
B	FW Fish Canada	spawning	start	15-Apr	1.70	15-Apr	1.70	Scott & Crossman 1998	spawning @ water temps of 44-54° F
B	FW Fish Canada	spawning	end	5-Jul	1.70	7-May	1.70	Scott & Crossman 1998	
B	FW Fish Canada	incubation	start	15-Apr	1.70			Scott & Crossman 1998	eggs hatch in ~8-10 days (but up to 27d @ 47° F)
B	FW Fish Canada	incubation	end	15-Jul	1.70			Scott & Crossman 1998	by mid-May temps in Boundary>55° F
C	Fish of WA	fry (<55mm)	start	8-Apr	0.60			Wydoski & Whitney 2003	eggs usually hatch in ~8-10 days
C	Fish of WA	fry (<55mm)	end	30-Oct	0.60			Wydoski & Whitney 2003	end date unknown
D	FW Fish Canada	fry (<55mm)	start	23-Apr	0.40			Scott & Crossman 1998	eggs usually hatch in ~8-10 days
D	FW Fish Canada	fry (<55mm)	end	30-Oct	0.40			Scott & Crossman 1998	end date unknown

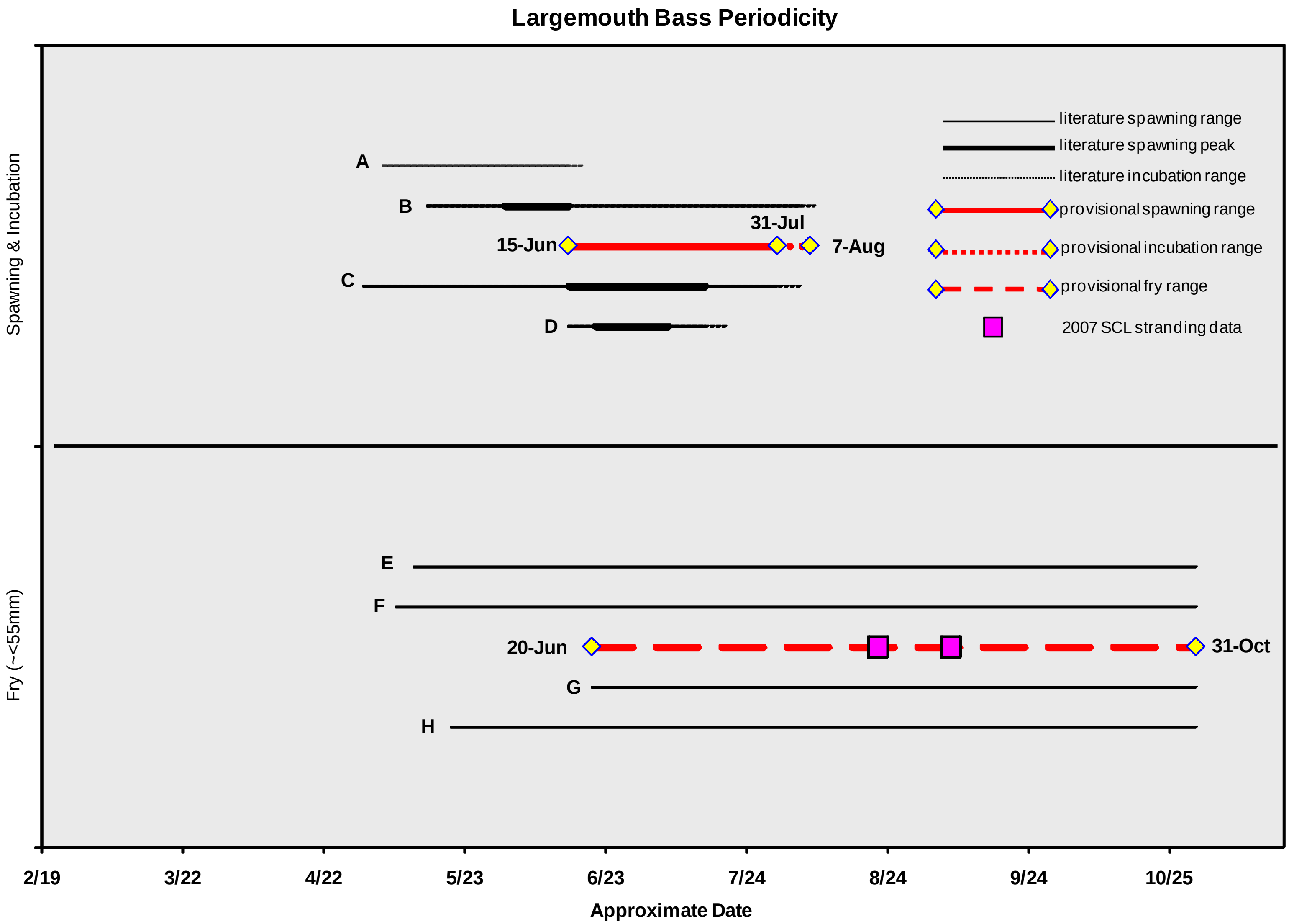


Figure 9. Provisional Boundary Periodicity – Largemouth Bass (see Table 9 for source data)

Table 9. Boundary Provisional Periodicity – Largemouth Bass

	Periodicity Dataset	Lifestage		Range	code	Peak	code	Source	Notes
A	Fish of WA	spawning	start	5-May	1.70			Wydoski & Whitney 2003	spawning @ water temps of 60-65° F
A	Fish of WA	spawning	end	15-Jun	1.70			Wydoski & Whitney 2003	
A	Fish of WA	incubation	start	5-May	1.70			Wydoski & Whitney 2003	eggs usually hatch in ~3-7 days
A	Fish of WA	incubation	end	18-Jun	1.70			Wydoski & Whitney 2003	
B	FW Fish Canada	spawning	start	15-May	1.60	1-Jun	1.60	Scott & Crossman 1998	late spring when water temps >60° F
B	FW Fish Canada	spawning	end	5-Aug	1.60	15-Jun	1.60	Scott & Crossman 1998	to mid-summer as late as August
B	FW Fish Canada	incubation	start	15-May	1.60			Scott & Crossman 1998	eggs usually hatch in ~3-5 days
B	FW Fish Canada	incubation	end	8-Aug	1.60			Scott & Crossman 1998	by late June temps in Boundary>60° F (15.6° C)
C	Box Canyon Reservoir	spawning	start	1-May	1.40	15-Jun	1.40	Ashe & Scholz 1992	
C	Box Canyon Reservoir	spawning	end	31-Jul	1.40	15-Jul	1.40	Ashe & Scholz 1992	
C	Box Canyon Reservoir	incubation	start	1-May	1.40			Ashe & Scholz 1992	
C	Box Canyon Reservoir	incubation	end	5-Aug	1.40			Ashe & Scholz 1992	
D	Box Canyon Reservoir	spawning	start	15-Jun	1.30	21-Jun	1.30	Bennett and Liter 1991	spawning @ water temps of 62-65° F
D	Box Canyon Reservoir	spawning	end	15-Jul	1.30	7-Jul	1.30	Bennett and Liter 1991	
D	Box Canyon Reservoir	incubation	start	15-Jun	1.30		1.30	Bennett and Liter 1991	
D	Box Canyon Reservoir	incubation	end	20-Jul	1.30		1.30	Bennett and Liter 1991	
E	Fish of WA	fry (<55mm)	start	12-May	0.70			Wydoski & Whitney 2003	eggs usually hatch in ~3-7 days
E	Fish of WA	fry (<55mm)	end	31-Oct	0.70			Wydoski & Whitney 2003	end date unknown
F	Box Canyon Reservoir	fry (<55mm)	start	8-May	0.60			Ashe & Scholz 1992	assume 3-7 day hatch
F	Box Canyon Reservoir	fry (<55mm)	end	31-Oct	0.60			Ashe & Scholz 1992	length at age 1 annulus was 66mm in 1988 and 65mm in 1990
G	Box Canyon Reservoir	fry (<55mm)	start	20-Jun	0.40			Bennett and Liter 1991	
G	Box Canyon Reservoir	fry (<55mm)	end	31-Oct	0.40			Bennett and Liter 1991	captured numerous bass fry <2 inches in "October" 89/90
H	FW Fish Canada	fry (<55mm)	start	20-May	0.30			Scott & Crossman 1998	eggs usually hatch in ~3-5 days
H	FW Fish Canada	fry (<55mm)	end	31-Oct	0.30			Scott & Crossman 1998	end date unknown

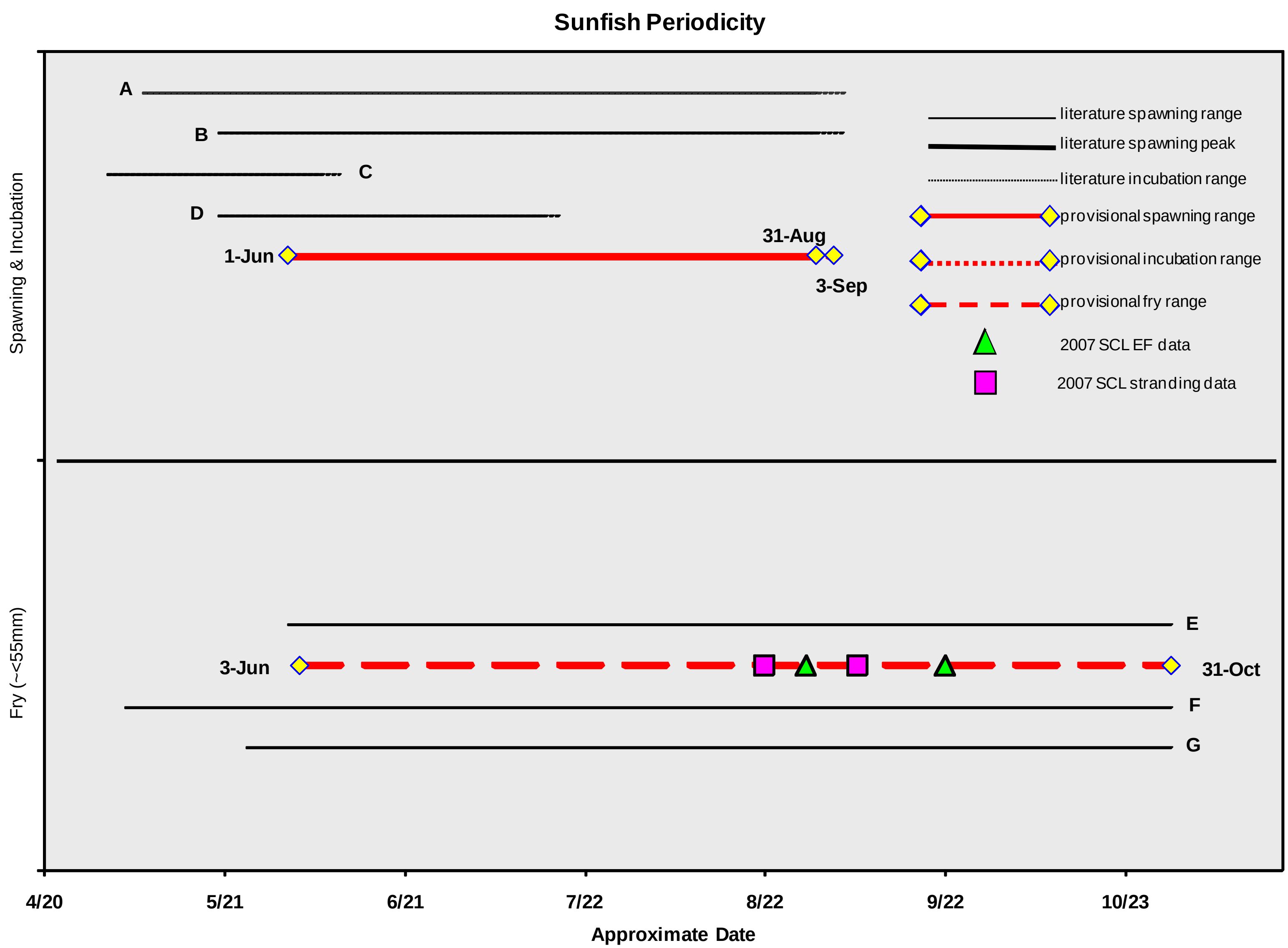


Figure 10. Provisional Boundary Periodicity – Sunfish spp.
(see Table 10 for source data)

Table 10. Boundary Provisional 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 (<55mm)	start	1-Jun	0.60			Bennett and Liter 1991	captured 1 inch pumpk fry in the "spring" of 1989&90
E	Box Canyon Reservoir	fry (<55mm)	end	31-Oct	0.60			Bennett and Liter 1991	captured 1 inch pumpk fry in the "fall" of 1989&90
F	Fish of WA	fry (<55mm)	start	4-May	0.40			Wydoski & Whitney 2003	1 May + 3 days
F	Fish of WA	fry (<55mm)	end	31-Oct	0.40			Wydoski & Whitney 2003	end date unknown
G	FW Fish Canada	fry (<55mm)	start	25-May	0.30			Scott & Crossman 1998	20 May + 5 days
G	FW Fish Canada	fry (<55mm)	end	31-Oct	0.30			Scott & Crossman 1998	end date unknown

Appendix 2. Study No. 7.4.2 – Mainstem Aquatic Habitat Modeling: Macrophyte Habitat Suitability Index

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.2
Mainstem Aquatic Habitat Modeling: Macrophyte Habitat Suitability Index

Interim Report

Prepared for
Seattle City Light

Prepared by
Darlene Siegel, Shannon Brattebo, Merri Martz, Harry Gibbons, and Robert Plotnikoff
Tetra Tech

March 2008

TABLE OF CONTENTS

Appendix

List of Tables

List of Figures

This page is intentionally left blank.

Study No. 7.4.2: Mainstem Aquatic Habitat Modeling: Macrophyte Habitat Suitability Index Interim Report Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 7.4.2, Mainstem Aquatic Habitat Modeling: Macrophyte Habitat Suitability Index (HSI) 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) 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 an interim report for the 2007 study efforts of the Mainstem Aquatic Habitat Modeling: Macrophyte Monitoring.

1.1. Study Background

Macrophytes are included in the mainstem aquatic habitat model in the form of Habitat Suitability Curves (HSC) and Habitat Suitability Indices (HSI) to estimate aquatic macrophyte productivity under various reservoir management scenarios. Provisional literature-based HSC and HSI have been developed that will describe the response of macrophytes to cyclic inundation and dewatering that may change physical parameters that the macrophytes are exposed to, such as, water depth, water velocity, light, etc. The literature-based HSC and HSI are presented in Appendix 1. These literature-based HSC and HSI will be supplemented by site-specific information developed through field studies described in the Interim Report for Study 7 Methods section 4. This report describes data collected through field studies conducted from June through August 2007.

Aquatic macrophytes comprise a diverse assemblage of macroscopic flora that have 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. 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 (Washington State Noxious Weed Control Board [WSNWCB] [undated]). 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

In order to assess the impact of operations scenarios on the growth and distribution of macrophytes within Boundary Reservoir, literature-based HSI models (curves) were developed and will be field validated. These curves will then be used in the Mainstem Aquatic Habitat and Tributary Delta Aquatic Habitat modeling to evaluate the potential distribution of macrophytes under operations scenarios.

First, a literature review was conducted to develop HSI curves for macrophyte growth within the Pend Oreille River. HSI curves were developed for macrophyte growth as a function of depth, velocity, substrate, and duration of inundation and dewatering (rates of macrophyte colonization and dewatering mortality).

Second, 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. Field surveys consisted of measurements of macrophyte abundance, depth, velocity, substrate, and the reservoir routing model will provide duration of inundation and dewatering data.

Finally, literature-based information from the first task and field data from the second task will be used to validate HSI curves for depth, velocity, substrate, and duration of inundation as a function of macrophyte abundance.

2 STUDY OBJECTIVES

The goal of the macrophyte component of the Mainstem Aquatic Habitat Modeling Study is to provide quantitative indices of the effects of existing Project operations and operations scenarios on the habitat of aquatic macrophytes.

The objectives of the macrophyte component study include:

- Develop new, or modify existing, Habitat Suitability Indices for macrophytes.
- Map the current aquatic macrophyte habitat in Boundary Reservoir and tailrace.
- Field validate the Habitat Suitability Indices through a survey of aquatic plant distribution and abundance 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.

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 Study No. 7, Sub-study 7.3.

4 METHODS

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. HSI curves were developed for macrophyte growth as a function of 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. HSI curves were then developed to address habitat conditions expected to exist in Boundary Reservoir. Further details of the HSI development methodology are outlined in Appendix 1.

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 Physical Habitat Model Development (see Study 7, Sections 4.3.3 and 4.3.4 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 m or when macrophytes were encountered. When macrophytes were present, GPS points were taken at the boundaries of these beds and every 100 m 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.

Literature-based information from the HSI development and the field data will be used to validate HSI curves for depth, velocity, substrate, and duration of inundation as a function of macrophyte abundance. This will be conducted through the development of a histogram (i.e., bar chart) for each of the habitat parameters (e.g., depth, velocity, substrate, frequency of inundation and dewatering) using the site-specific field observations. A histogram developed using field observations will then be compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve 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.

Measurements of macrophyte density in these areas will then be correlated with the duration of inundation and dewatering associated with antecedent Boundary Project operations.

Following comparison of literature-based HSI curves with field data, potential habitat indices for macrophytes will be calculated for operations scenarios using the Aquatic Habitat Model and the Scenario Tool. Data describing the physical and hydraulic characteristics of the Pend Oreille River were collected during the 2007 field season along transects coincident with macrophyte monitoring locations. Potential habitat conditions are to be modeled under the Aquatic Habitat Modeling study once all available information becomes available. Information on the response of macrophytes to changes in hydraulic conditions will be developed as part of the HSI study (SCL 2008). Habitat suitability information (i.e., HSI curves) represents a functional relationship between the independent variables depth, velocity, substrate, and frequency of inundation/dewatering and the response of organisms to a gradient of the independent variable (suitability), which is expressed over a scale of 0.0 (poor) to 1.0 (best). Output from the Scenario Tool and the Hydraulic Routing Model (SCL 2008) will predict hourly flow and water surface elevations at transects within the Project area. The Aquatic Habitat Model will be used to predict depth and velocities within cells, or transect subdivisions. The HSI curves will be used in the aquatic habitat model to quantify the area of Pend Oreille River channel containing potentially suitable habitat. This process will be repeated to determine an index of potential habitat for each of the macrophyte indices for operations scenarios.

Once the HSI model is finalized, the HSI curve and colonization information will be provided for use in conjunction with the Mainstem Aquatic Habitat Modeling Study (Study No. 7) and the Tributary Delta Habitat Modeling Study (Study No. 8).

5 PRELIMINARY RESULTS

This section presents the results of the literature-based HSI for macrophytes, the results of the macrophyte mapping, and preliminary results of the existing macrophyte habitat conditions in Boundary Reservoir. Limited interpretation of the data will be conducted until the study is finalized and all data have been collected.

5.1. Literature-Based HSI

The literature-based 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 5.1-1). 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 5.1-1. Boundary 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 Vo_i = Velocity S_i = Substrate DI_i = Duration of Inundation DD_i = Duration of Dewatering

1 See Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, Varial Zone Analysis for details on integrating inundation and dewatering factors.

The methods used to determine provisional values for each of the five variables and the results for literature review are described in further detail in Appendix 1.

The literature-based HSI for macrophytes will be verified with field collected data as these data become available (see Section 5.3).

5.2. 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. As a result of the macrophyte mapping effort, macrophyte distribution, abundance, and species present in upper and lower Boundary Reservoir are presented in Figure 5.2-1. Table 5.2-1 also summarizes the Macrophyte species found in upper and lower Boundary Reservoir.

Table 5.2-1. Macrophyte species in Boundary Reservoir.

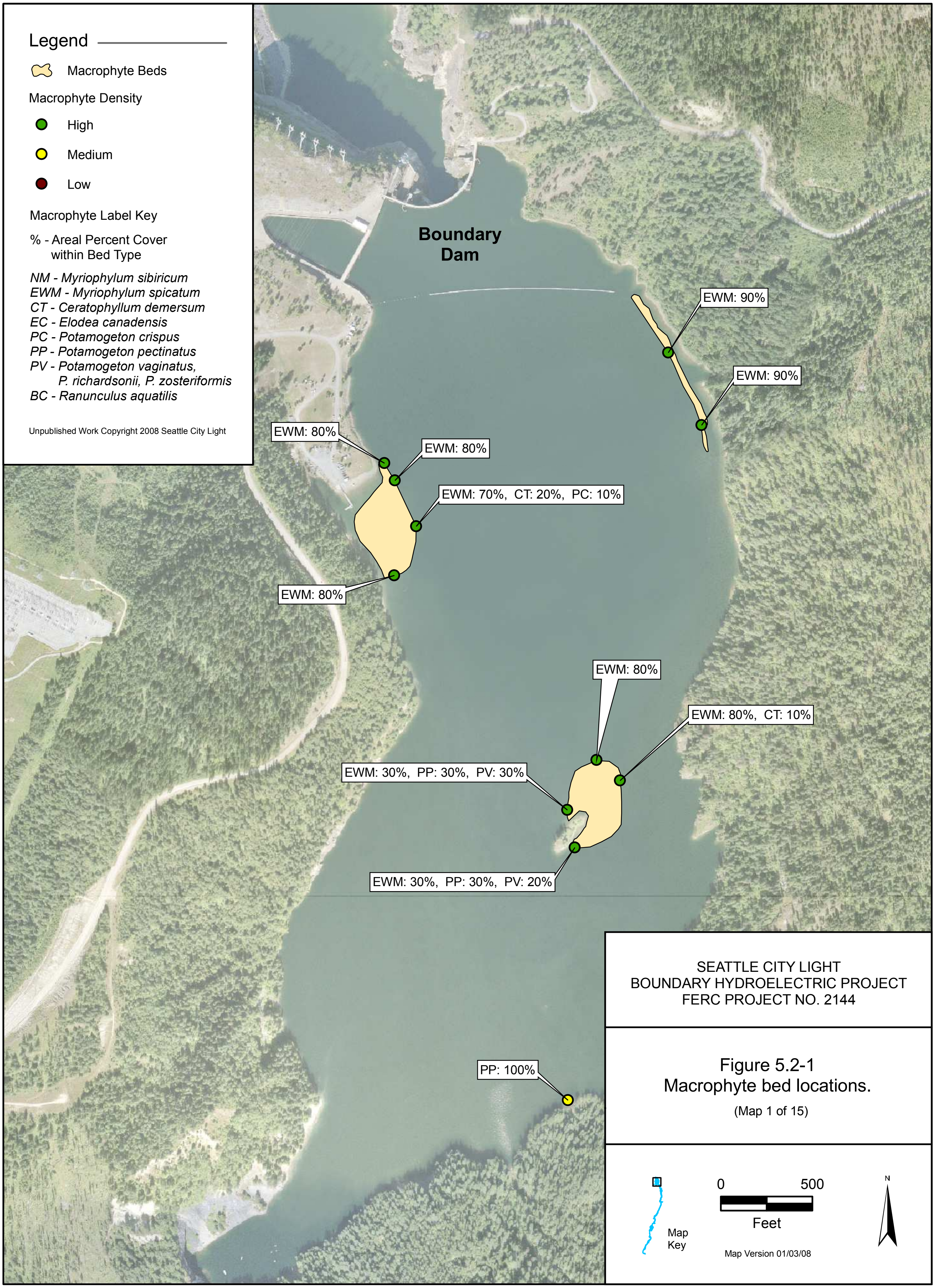
Scientific Name	Common Name	Status
Myriophyllum sibericum	Northern Milfoil	Native
Myriophyllum spicatum	Eurasian Watermilfoil	Non-native
Ceratophyllum demersum	Coontail	Native
Elodea canadensis	Common Waterweed	Native
Potamogeton crispus	Curly Pondweed	Non-native
Potamogeton pectinatus	Sago Pondweed	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 covered 18.6 acres in Lower Boundary Reservoir and 137.6 acres in Upper Boundary Reservoir. Eurasian watermilfoil, potamogeton species, and coontail were the dominant plant species found in Boundary Reservoir (Figure 5.2-1). Table 5.2-2 summarizes the relative number of macrophyte beds found in 2007 August survey by above and below Metaline Falls.

Table 5.2-2. Date and locations of macrophyte bed sampling during 2007 and scheduled sampling for 2008.

Collection Date	Reservoir Zone	No. of Macrophyte Beds	Macrophyte Bed Size Range (acres)	2008 Additional Mapping
August 25-27, 2007	Box Canyon Tailrace	0	0	None
August 25-27, 2007	Above Metaline Falls	25	0.017-55.66	Fish Stranding and Trapping Areas
August 25-27, 2007	Canyon Reach	28	0.0006-5.34	None
August 25-27, 2007	Boundary Forebay	4	0.008-2.83	None
August 25-27, 2007	Boundary Tailrace	0	0	None

The distribution and abundance measures will be correlated with habitat features in the reservoir including depth, velocity, substrate, and duration of inundation and dewatering as these data become available (see Section 5.3). Depths at which macrophytes were found in the 2007 August survey calculated using GPS and bathymetry will be crossed-checked with actual depth data collected at habitat transects in August 2007 (see Section 5.3). This cross-check will ensure a more accurate determination of macrophyte habitat is achieved.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.2-1
Macrophyte bed locations.
(Map 1 of 15)

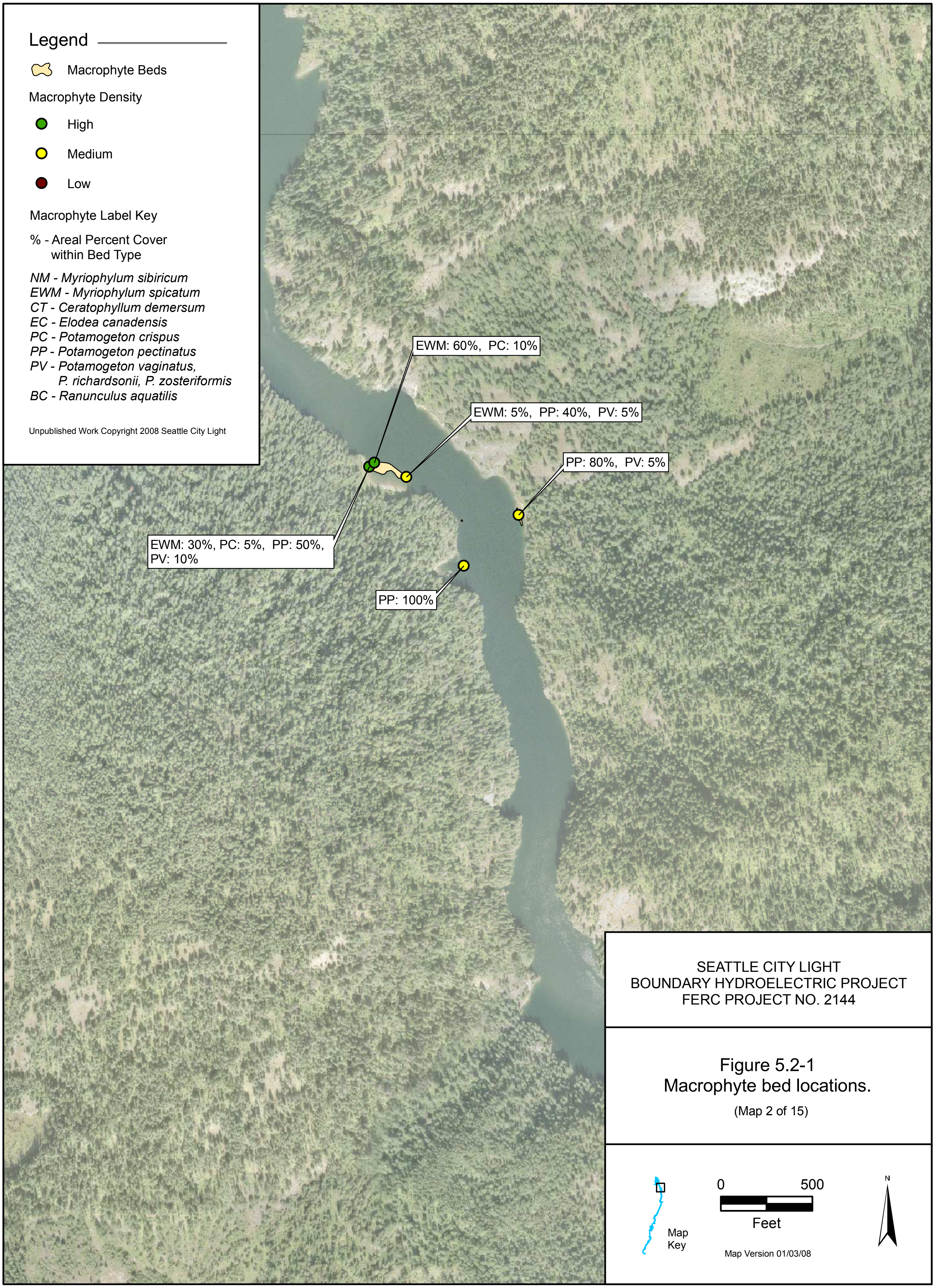


Figure 5.2-1
Macrophyte bed locations.
(Map 2 of 15)

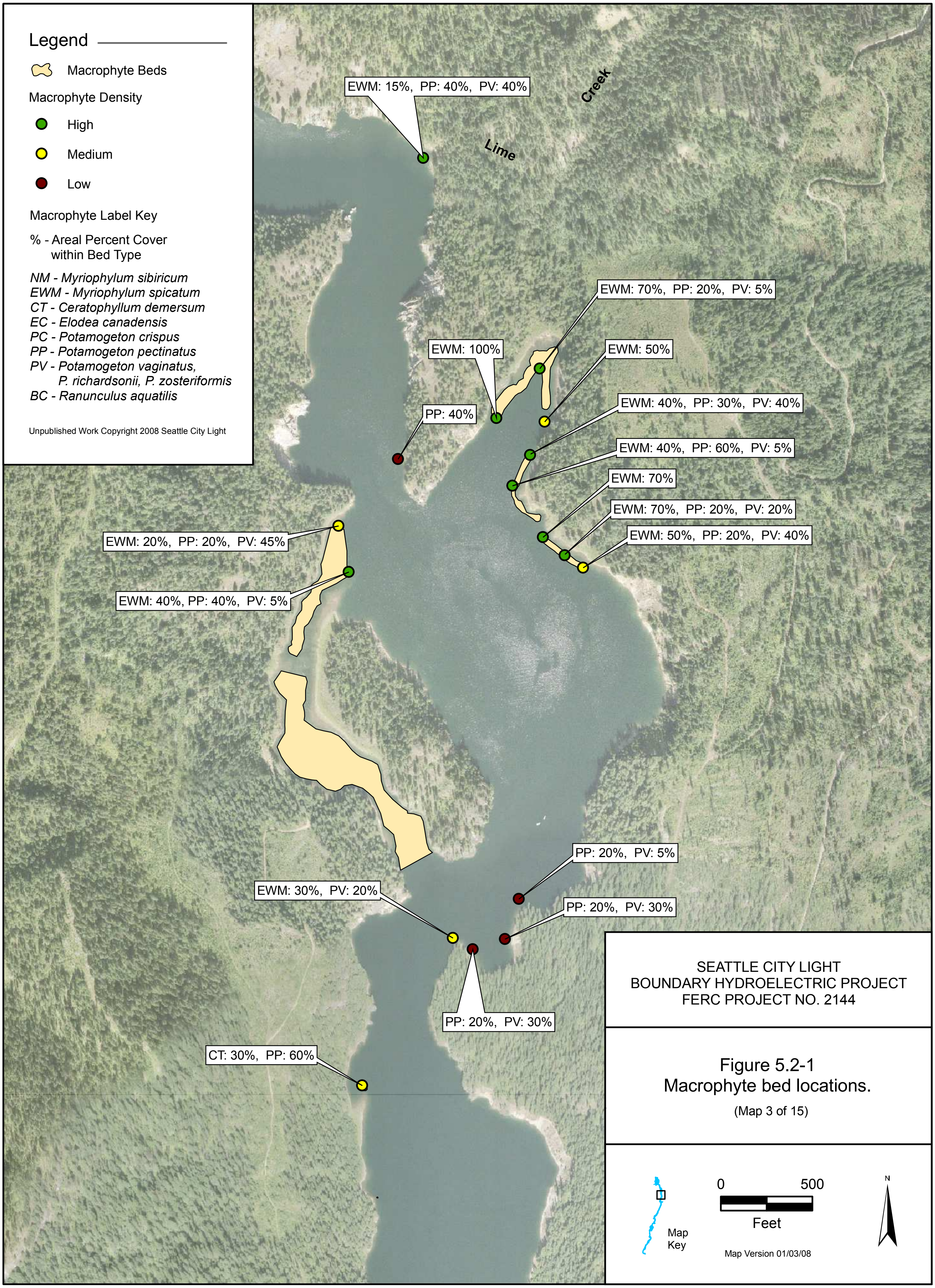


Figure 5.2-1
Macrophyte bed locations.
(Map 3 of 15)

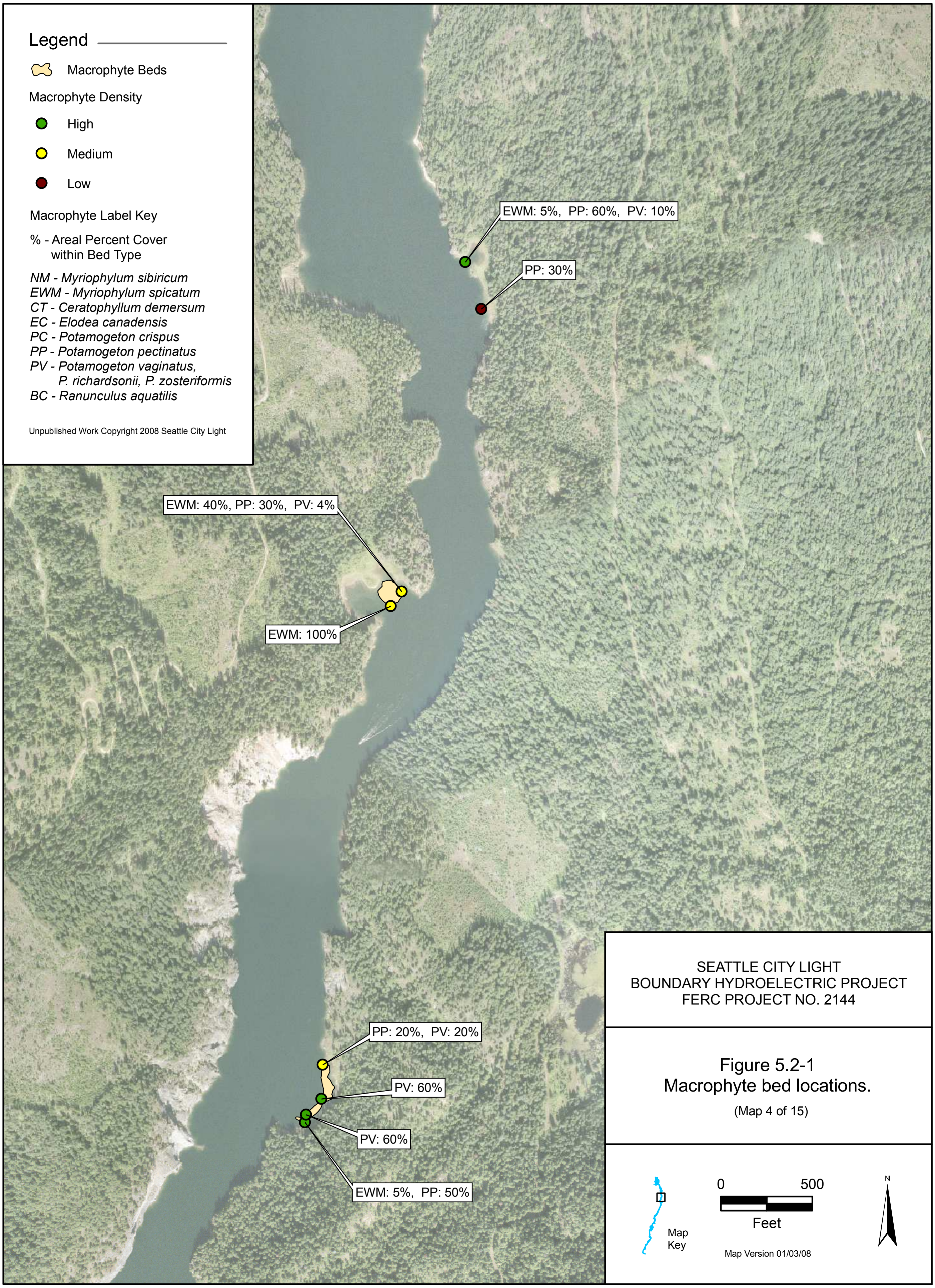


Figure 5.2-1
Macrophyte bed locations.
(Map 4 of 15)

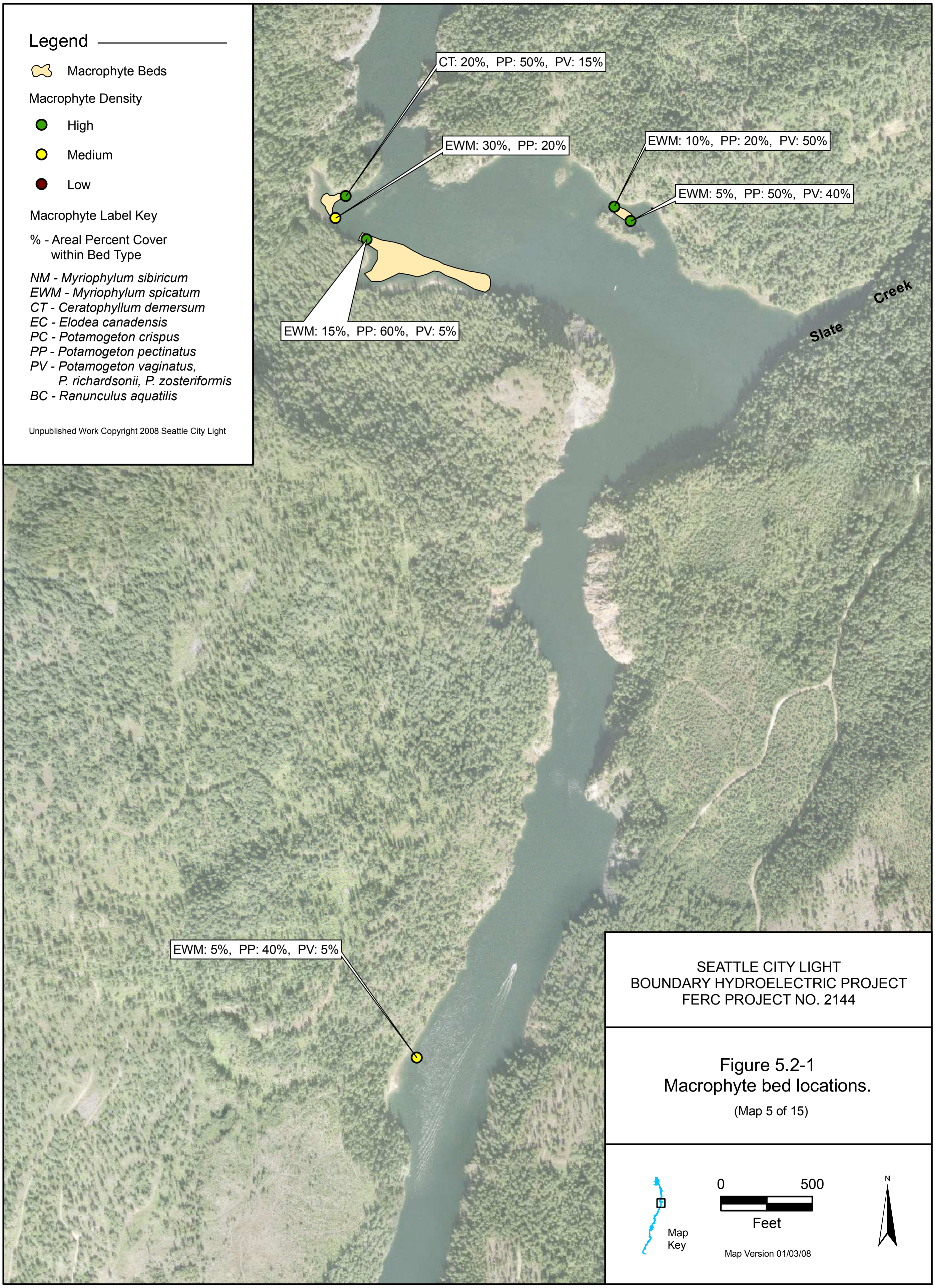


Figure 5.2-1
Macrophyte bed locations.
(Map 5 of 15)

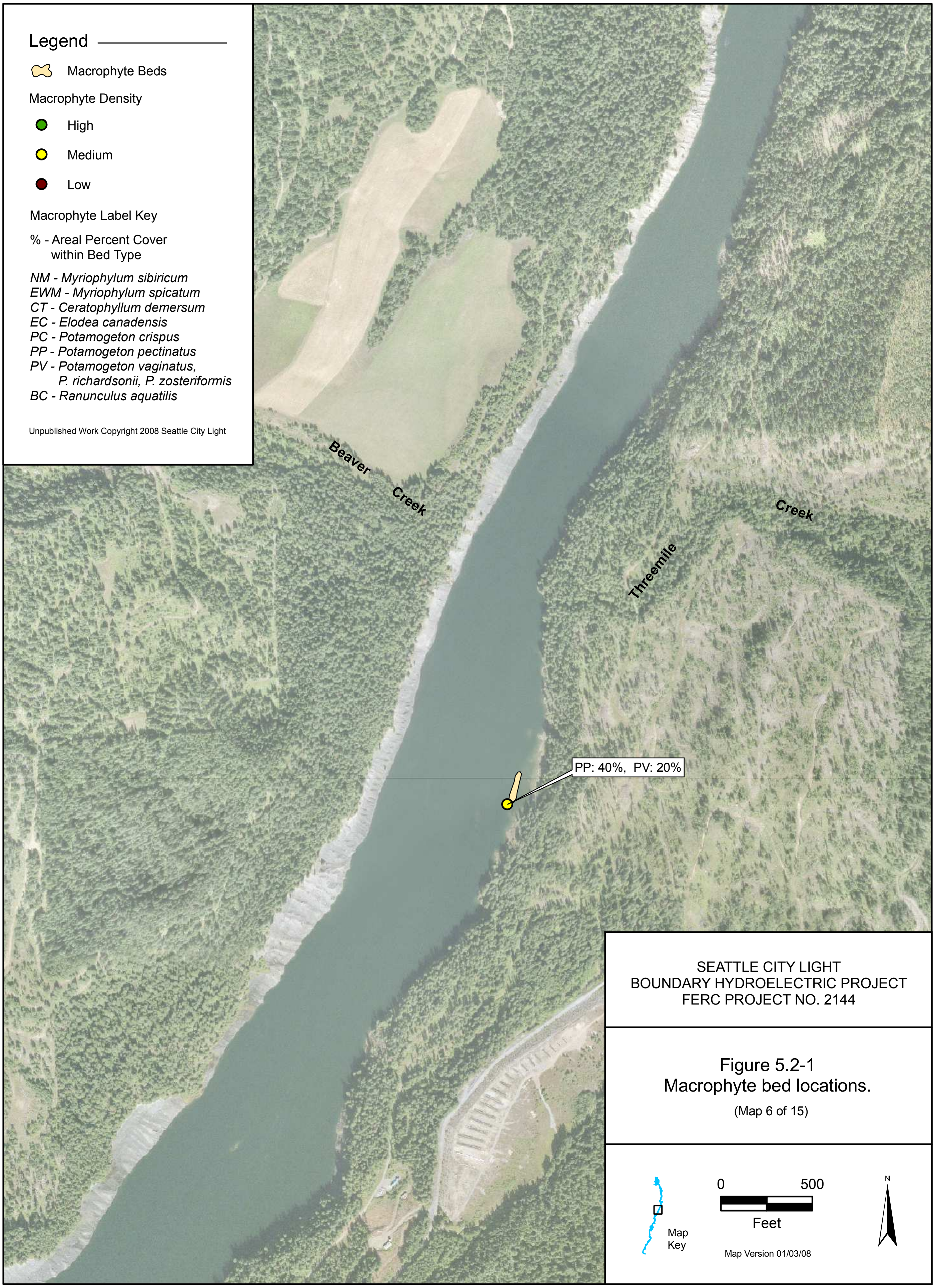


Figure 5.2-1
Macrophyte bed locations.
(Map 6 of 15)

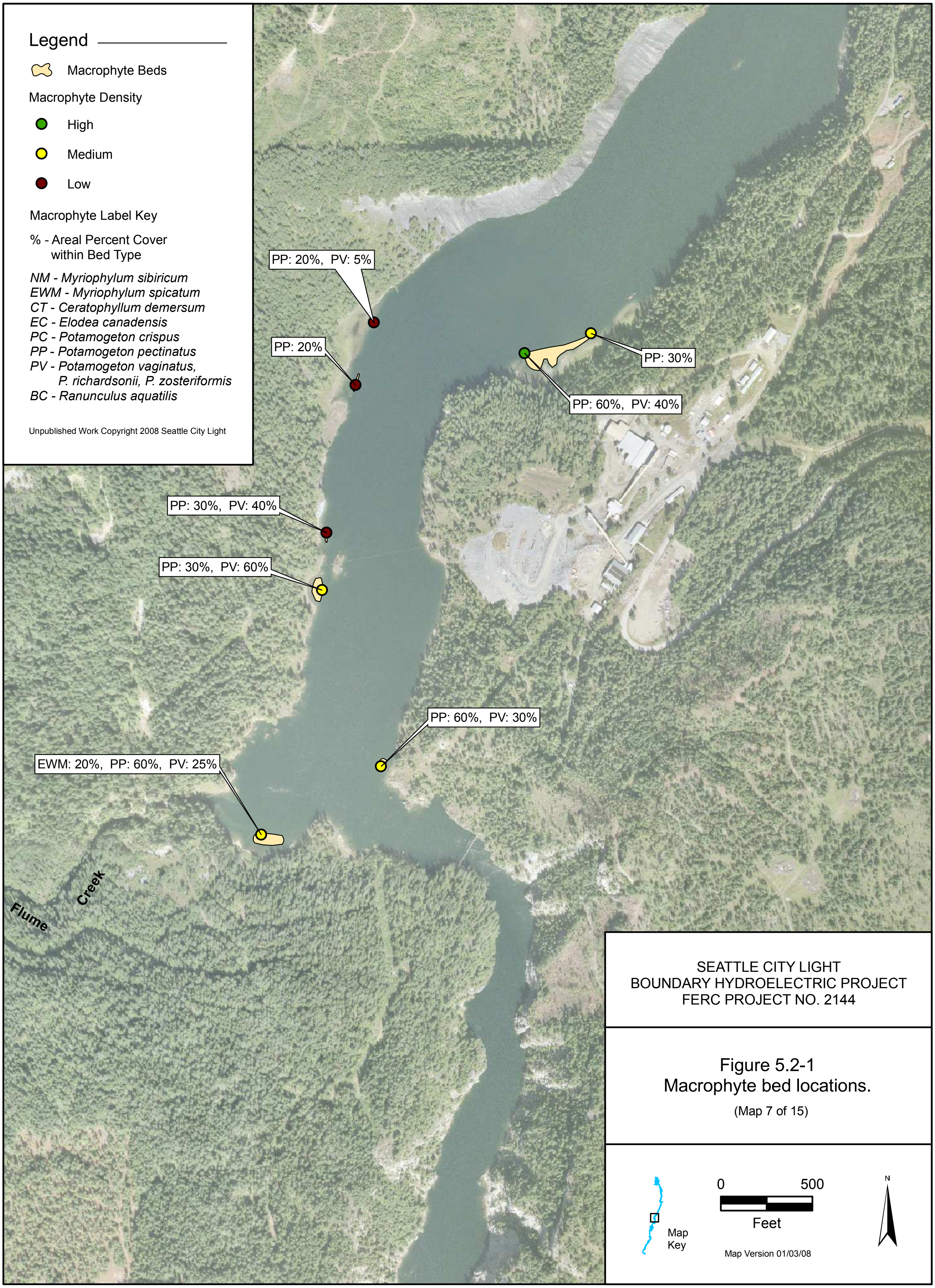


Figure 5.2-1
Macrophyte bed locations.
(Map 7 of 15)

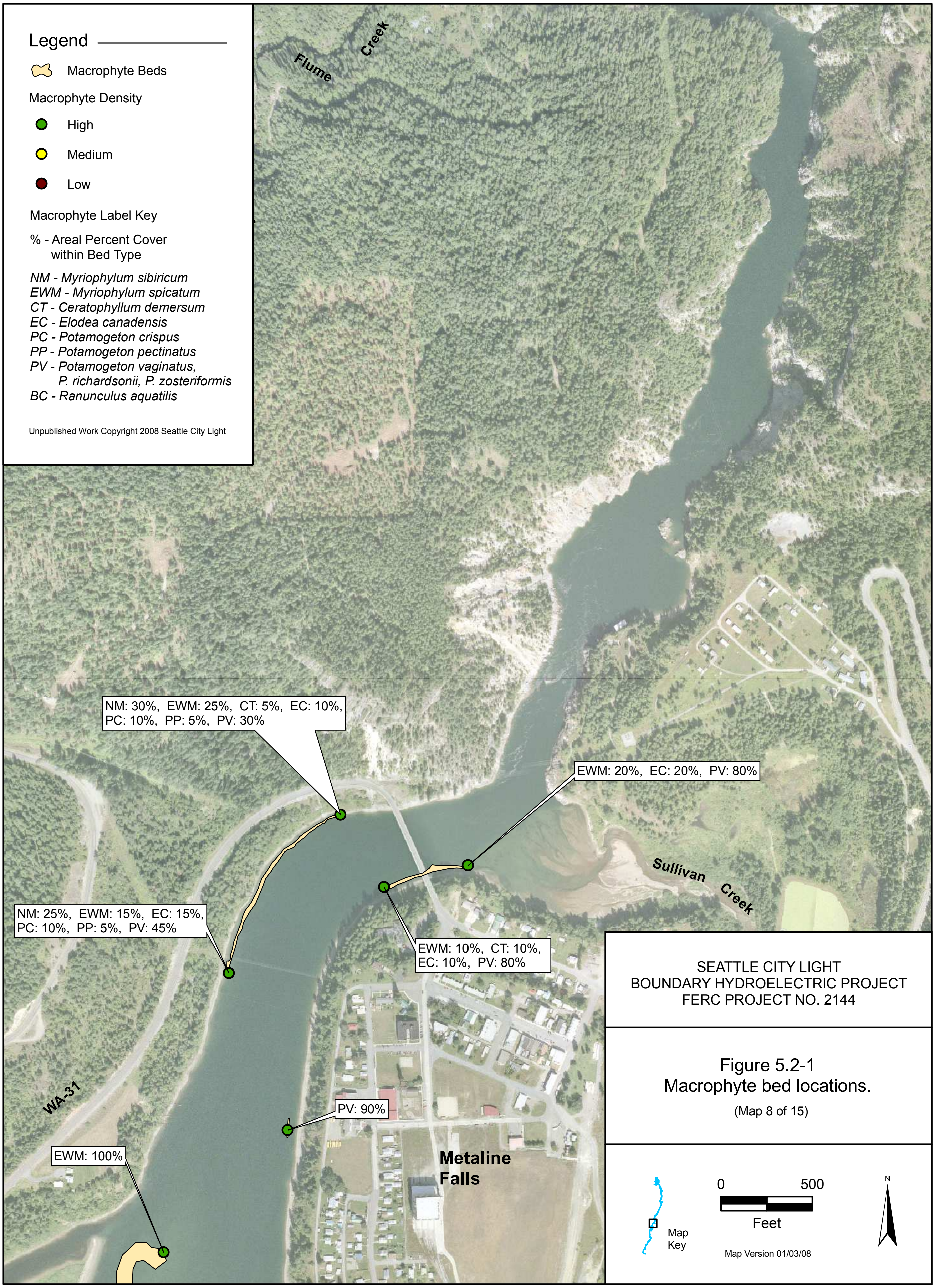


Figure 5.2-1
Macrophyte bed locations.
(Map 8 of 15)

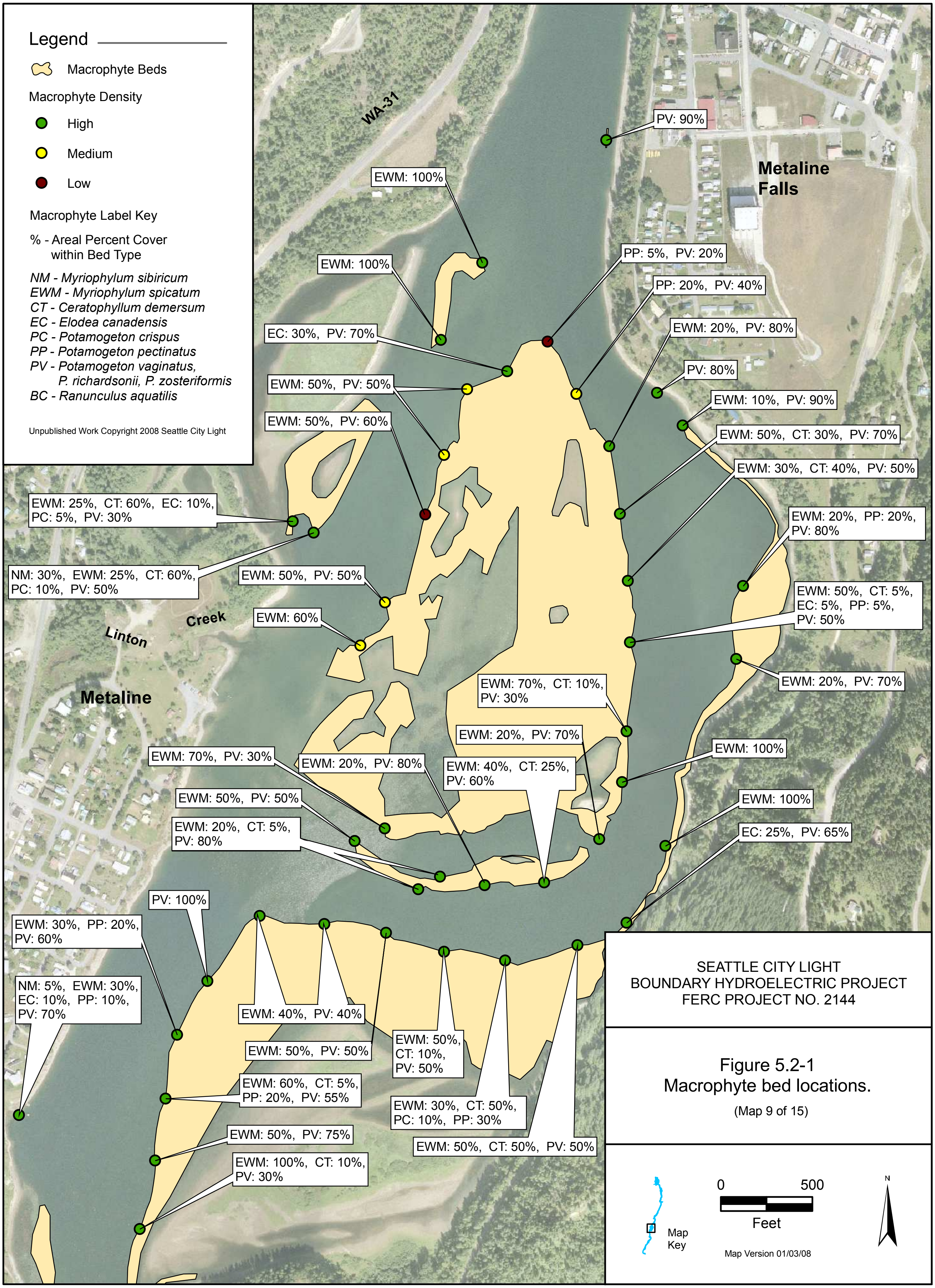
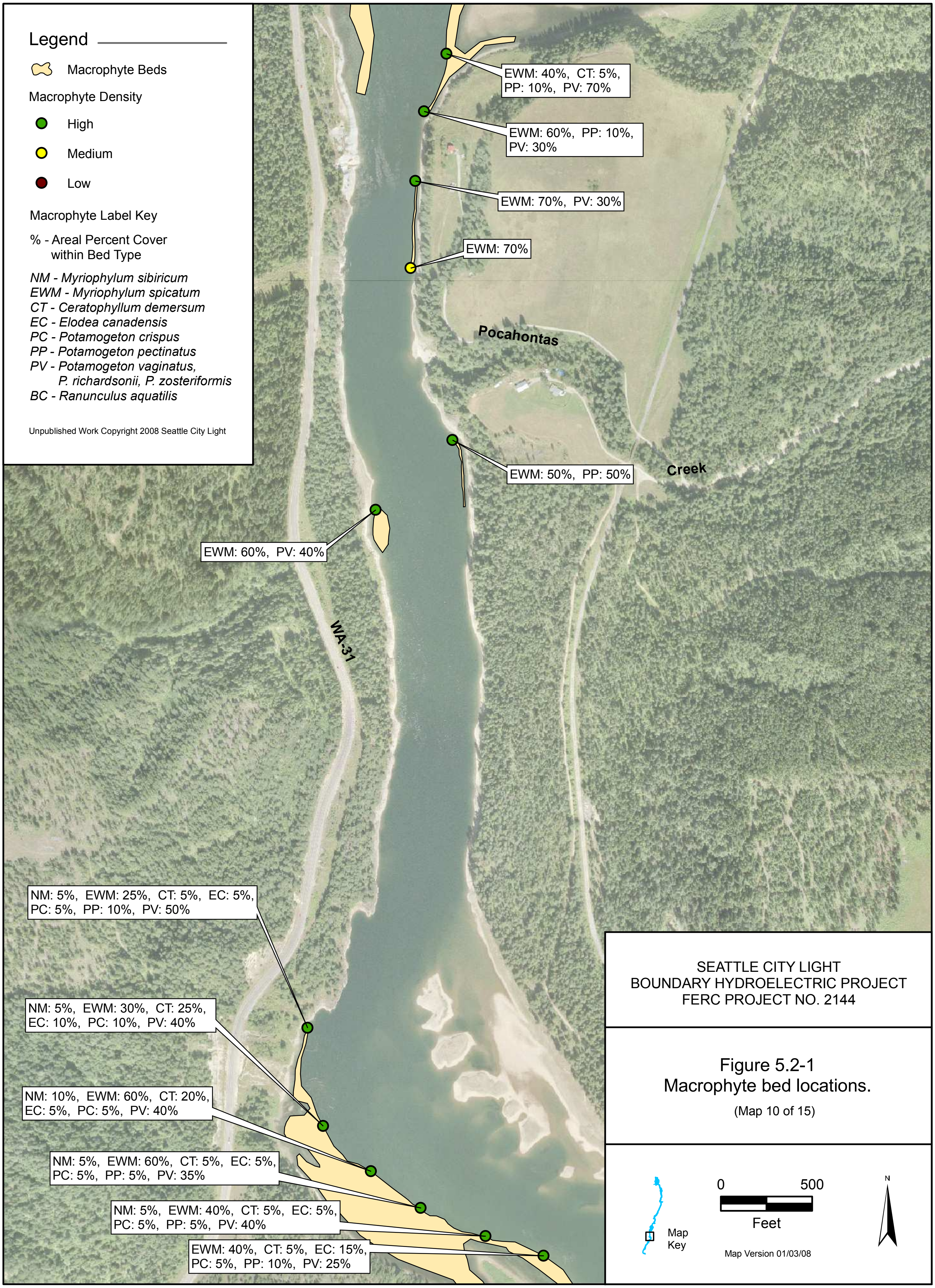


Figure 5.2-1
Macrophyte bed locations.
(Map 9 of 15)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.2-1
Macrophyte bed locations.
(Map 10 of 15)

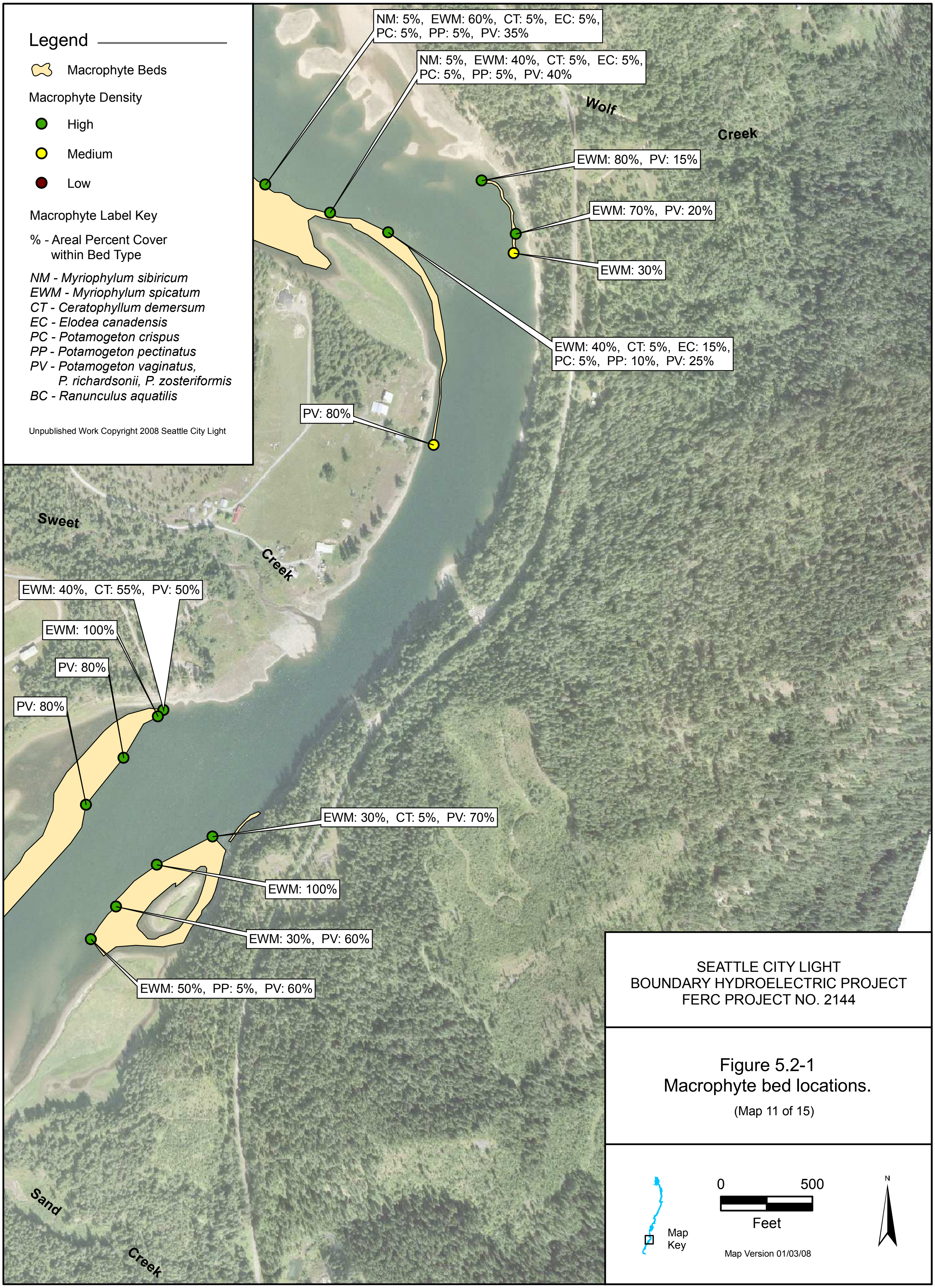


Figure 5.2-1
Macrophyte bed locations.
(Map 11 of 15)

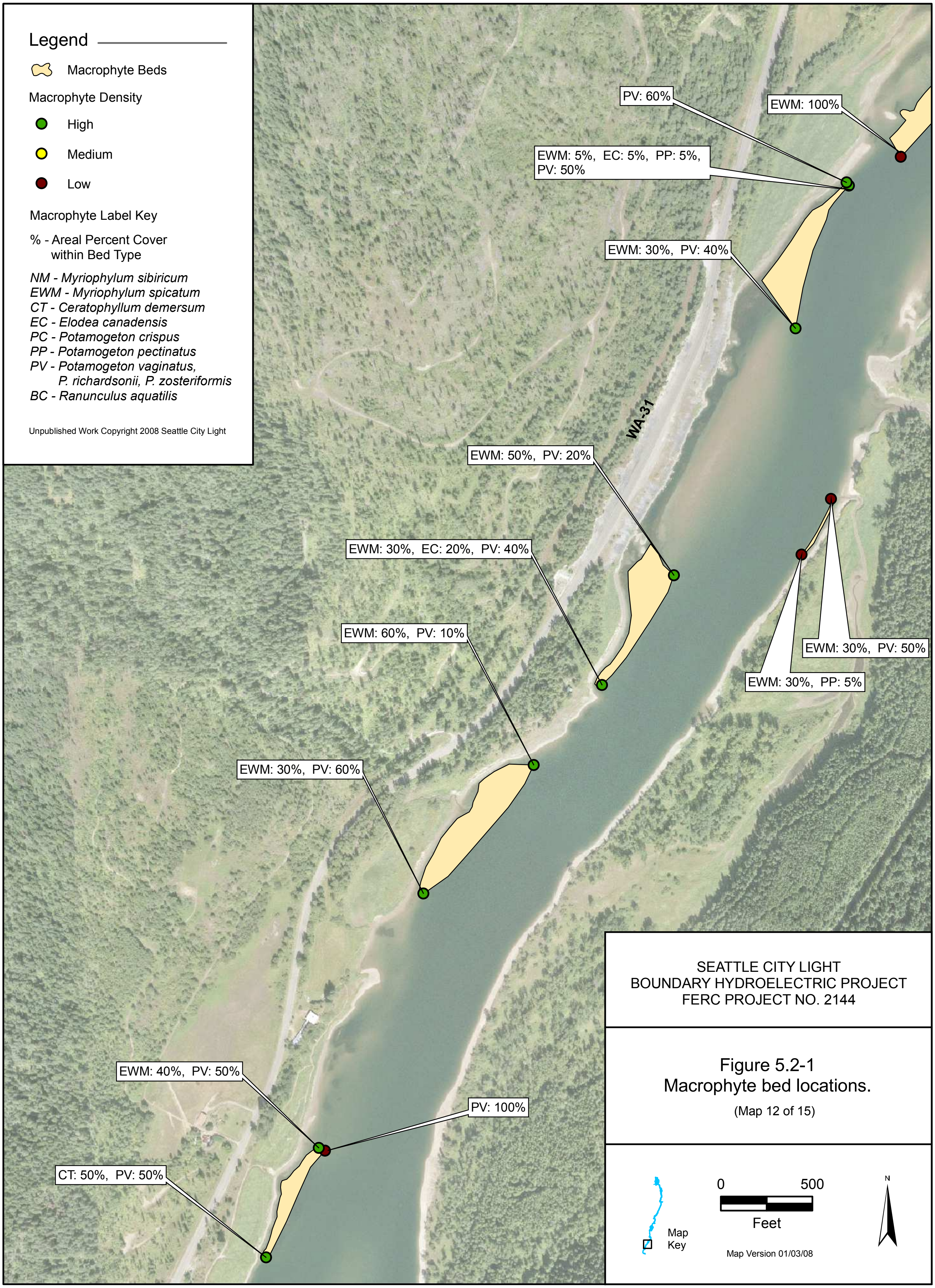


Figure 5.2-1
Macrophyte bed locations.
(Map 12 of 15)

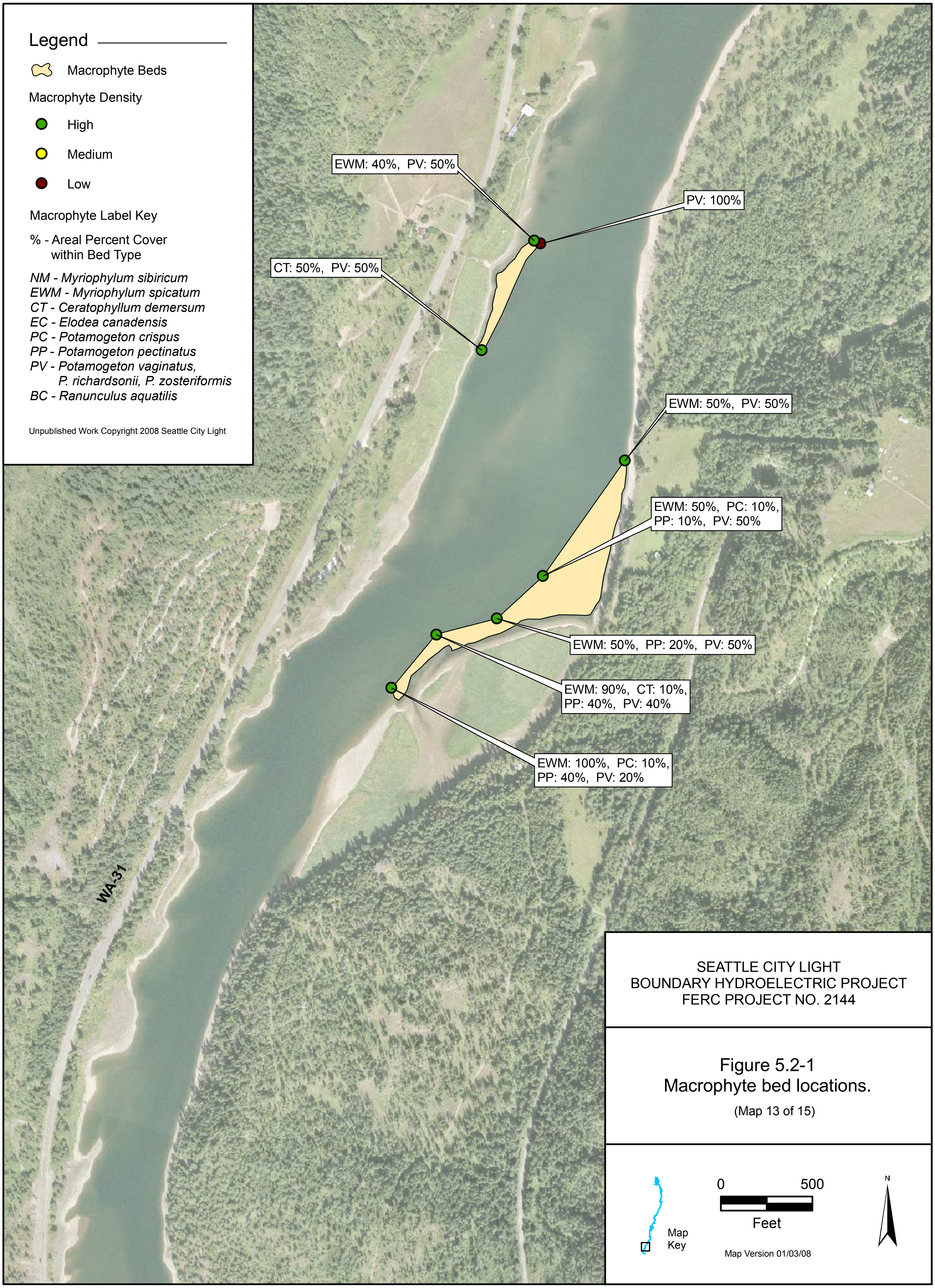
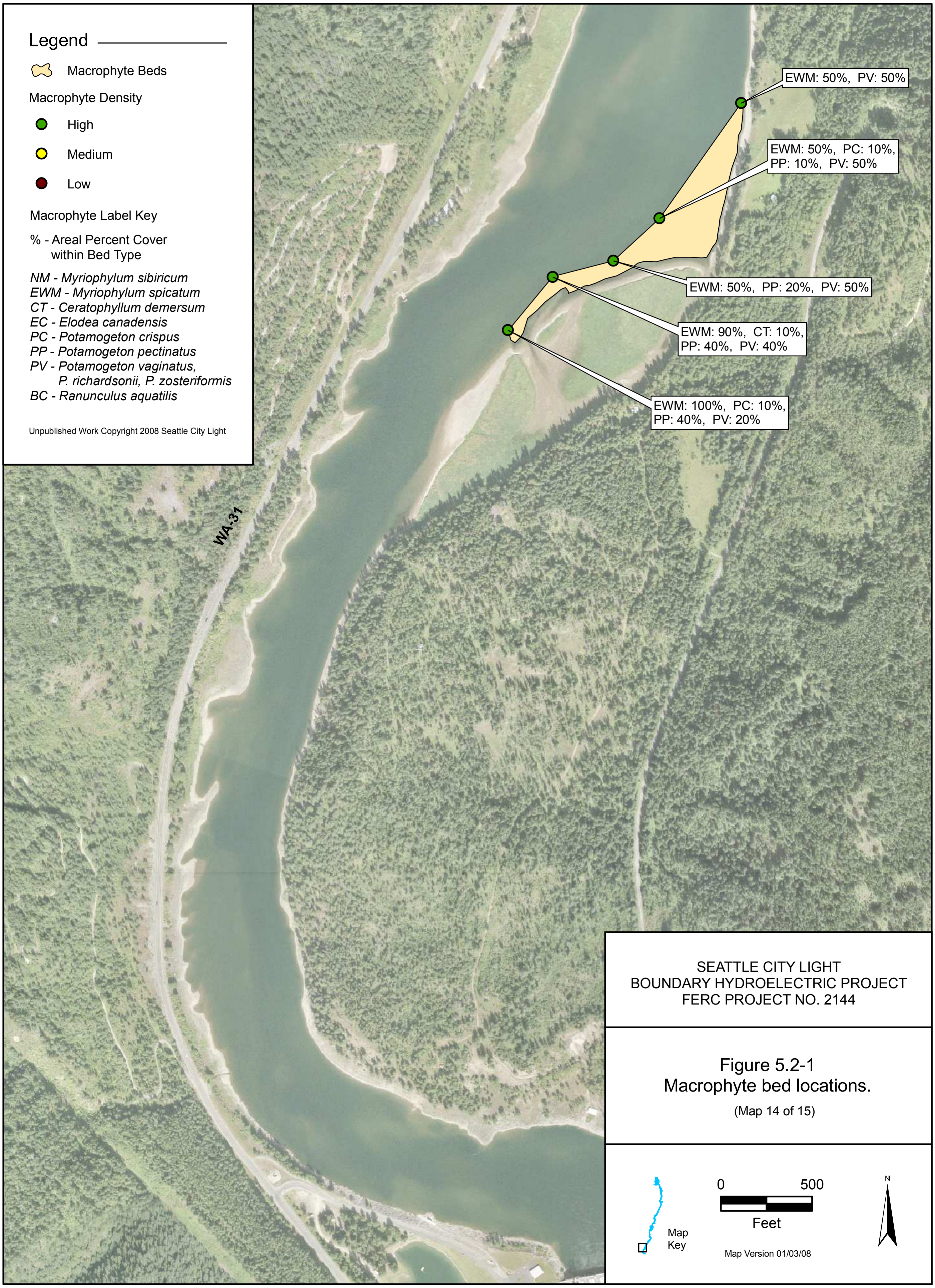


Figure 5.2-1
Macrophyte bed locations.
(Map 13 of 15)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.2-1
Macrophyte bed locations.
(Map 14 of 15)

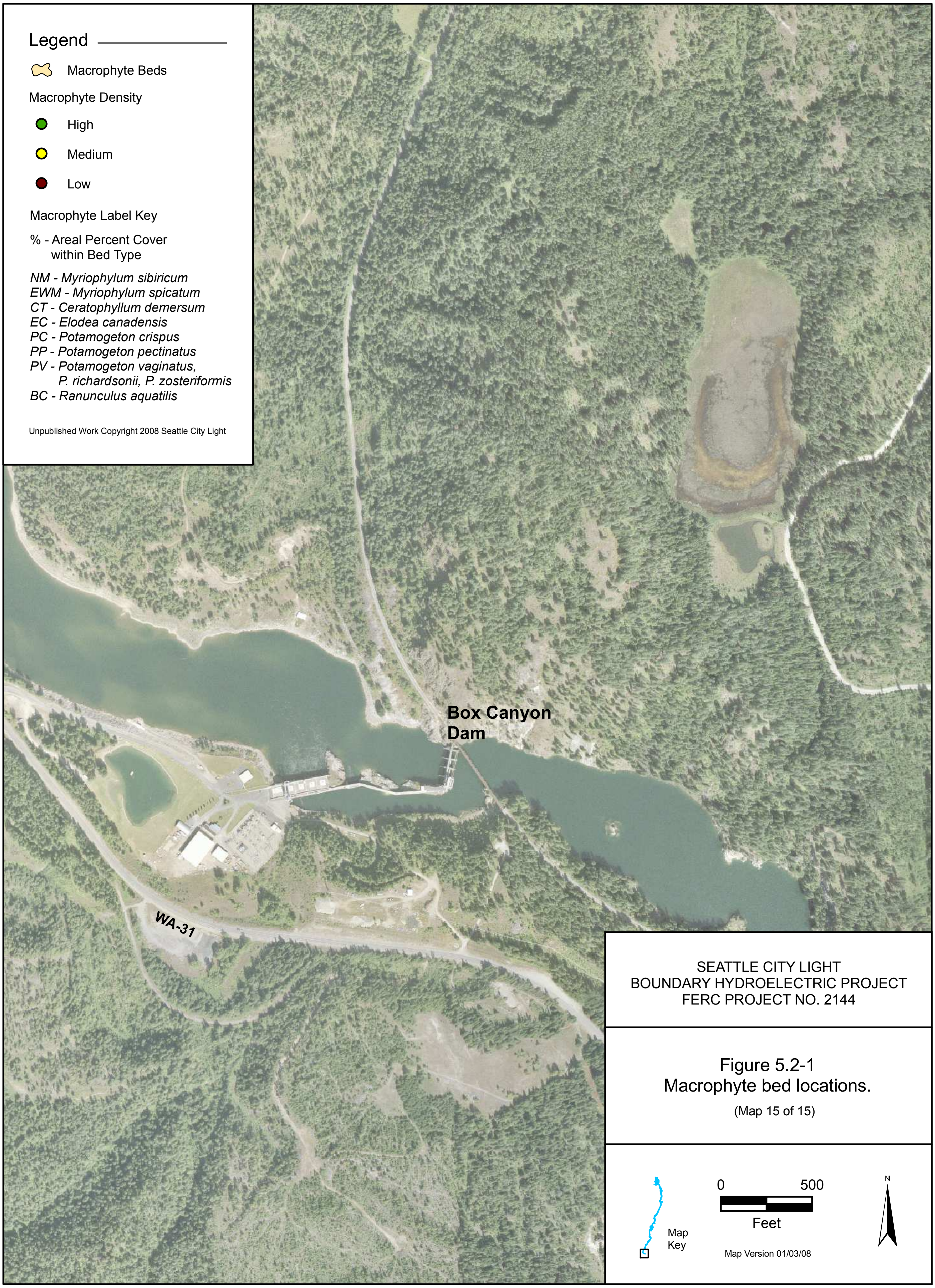


Figure 5.2-1
Macrophyte bed locations.
(Map 15 of 15)

5.3. 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 were 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]) 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 were collected during August 2007 as per the RSP (SCL 2007) and are currently undergoing a QA/QC process and at the time of this report were not available for inclusion. Macrophyte habitat data (depth, velocity, and substrate) along with the duration of inundation and dewatering calculated from the Hydraulic Routing Model Study will be sufficient to validate and refine macrophyte HSI curves for Boundary Reservoir. Macrophyte distribution and abundance mapping efforts in August 2007 (see Section 5.2) will also be used to further refine macrophyte HSI curves for Boundary Reservoir.

5.4. Aquatic Macrophyte Provisional HSI Model Refinement

Based on the data collected to date, existing conditions within Boundary Reservoir, and the biological growth requirements of aquatic macrophytes, the following adjustments to the provisional macrophyte HSI model will be defined:

- 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 is calculated to be 39.4 feet (12 meters). Although species-dependent, in general hydrostatic pressure limitation is between 26.3 feet (8 meters) and 39.4 feet (12 meters).
    - Therefore, aerial coverage of aquatic submersed macrophyte beds is 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. 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 factors 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 cannot be exposed to desiccation. Second, light has to be available to support

photosynthesis. Third, the substrate must be stable to allow seeds, turions, roots, or tubers to remain in place during spring growth. 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. The subsequent increase in reservoir water level and daily fluctuation do not influence the aquatic plant bed expansion after spring growth begins.

  - o When the reservoir water levels increase to the summertime 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.

- 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. However, the community dominance of non-native species such as Eurasian watermilfoil (EWM) has shown that it is still expanding coverage within the reservoir. It is taking advantage of micro-velocity environments that allow it to establish beds on steep rocky banks within the canyon reach, as demonstrated by the small pioneering beds. Hence, velocity is not a major consideration for habitat suitability.
- Substrate type is both a reflection of sedimentation areas and the ability of EWM to build sediment by organic deposition and trapping suspended solids from the water column through filtration.

The macrophyte coverage map along with the cross section and routing model data will be used to refine the provisional HSI model.

6 SUMMARY

At this time, literature-based HSI curves have been developed for macrophytes within Boundary Reservoir. The HSI curve developed addresses macrophyte response to changes in depth, velocity, substrate, and duration of inundation and dewatering. During the literature review no appropriate suitability curves were found for macrophytes, so other literature information were used to develop professional judgment-based suitability values. In addition, macrophyte characteristics and density data have been collected along depth, velocity, and substrate gradients both through physical habitat transect data collection efforts and a separate river-wide aquatic vegetation mapping effort. Although the depth, velocity, and substrate data from cross-sectional habitat transects has been collected, these data at the time of preparation of this report are currently undergoing analysis that includes their association with biological observations. These analyses are not yet complete relative to use in refinement of the literature-based HSI curves. This analysis will continue in order to complete this process. However, preliminary assessment of cross-sectional data would indicate that there is adequate data to complete the HSC/HSI validation. This is based, in part, by the fact that the habitat cross sections were located upstream, downstream, and within some of the Macrophyte beds. Using this information along with the mapping of macrophyte beds in the reservoir will allow us to evaluate the complete range of reservoir conditions. The more intensive mapping effort (see Section 4, Methods) to characterize location and composition of beds resulted in the description of all settings in Boundary reservoir where macrophytes were established.

Many factors influence the growth of aquatic macrophytes such as light, turbidity, nutrients, water temperature, substrate type, and substrate stability. Factors that are operationally dependent are water depth (light), water column velocity (substrate stability and colonization), and substrate. Therefore, the HSI addresses macrophyte responses to changes in depth, velocity, substrate, and duration of inundation and dewatering as another component of the Boundary Reservoir habitat resources.

Macrophyte bed establishment under a low fluctuation condition was not observed in the Box Canyon tailrace. Consequently, information from past studies describing macrophyte beds in the Box Canyon Reservoir was used to understand the low fluctuation scenario and effects on macrophyte bed occurrence and characteristics. These studies were conducted on the Box Canyon Reservoir macrophyte distribution by the investigators from 1982 through 1992 (Gibbons et al. 1983a; 1983b; Gibbons 1984; Gibbons 1986; Verhalen et al. 1985).

Macrophytes that have established colonies in distinct areas of the reservoir are determined by water inundation and the amount of light available in the water column during the spring season (personal communication, Eugene Welch and Mark Sytsma). Hydrologic conditions during the spring define the wetted margin of the shoreline which limits the establishment of root crowns for macrophytes. Advantageous root establishment in the substrate is limited by desiccation from exposure to sunlight and freezing temperatures. Established root crowns from previous year's macrophyte bed are influenced by exposure in the same way. The low reservoir water surface elevation in the pre-runoff period therefore defines the shoreline limit of macrophyte bed establishment. Subsequently, high flow runoff carries turbid water in the reservoir that limits light penetration thereby presenting a limitation for viability of new and/or previous year's established macrophytes at depth due to their inability to photosynthesize effectively. Diurnal low pool fluctuation is a secondary factor limiting establishment and maintenance of macrophyte beds within the Pend Oreille River. The combination of spring inundation and light limitation defines the extent of distribution for macrophytes within the reservoir. Carry-over expansion of macrophyte beds due to summer and fall shoreline area colonization are subsequently limited by the following spring hydraulic conditions.

7 REFERENCES

Falter, C.M., C. Baines and J.W. Carlson. 1991. Water Quality, Fish and Wildlife Characteristics of Box Canyon Reservoir. Completion Report 1989-1990. Section 2: Water Quality. Department of Fish and Wildlife Resources. College of Forestry, Wildlife and Range Sciences, University of Idaho.

Fox, A.M. 1996. Macrophytes, p. 27-44. In. G. Petts and P. Calow [eds.], River Biota: Diversity and Dynamics. Blackwell Science Ltd.

Gibbons, H.L. 1983a. Refinement of control and management methodology for Eurasian Watermilfoil in the Pend Oreille River, Washington. State of Washington Research Center, Report No. 56. Washington State University, Pullman, WA.

Gibbons, H.L. 1983b. Investigation and control of Myriopyllum spicatum in the Pend Oreille River, Washington. State of Washington Research Center, Report No. 47. Washington State University, Pullman, WA.

Gibbons, H.L. 1984. Control of Eurasian Watermilfoil – Part I & Part II. State of Washington Research Center, Report No. 59. Washington State University, Pullman ,WA.

Gibbons, H.L. 1986. Control and management of Eurasian Watermilfoil in the Pend Oreille River, Washington. Proceedings of the First International Symposium on Eurasian Watermilfoil (Myriophyllum spicatum) and related Haloragaceae species. July 23-24, 1985. Vancouver, B.C., Canada. APMS 116-125.

Hamel, K. 1990. Milfoil – An Aggressive Water Weed. Department of Ecology Doc No. 90-br-002. Olympia, WA.

Pelletier, G., and R. Coots. 1990. Progress Report No. 1 - Pend Oreille River Water Quality Study. Washington Department of Ecology. Environmental Investigations and Laboratory Services Program. Surface Water Investigation Section. Olympia, Washington.

Seattle City Light (SCL). 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. 2008. Study 7 – Mainstem Aquatic Habitat Modeling Study Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech, Thomas R. Payne & Associates, Golder Associates, and Terrapin Environmental. March 2008.

U.S. Environmental Protection Agency (EPA). 1993. Clark Fork - Pend Oreille Basin water quality study: A summary of findings and a management plan. United States Environmental Protection Agency Regions VIII and X. Report for Section 525 of the Clean Water Act of 1987.

Verhalen, F.A., H.L. Gibbons, and W.H. Funk. 1985. Implications for control of Eurasian Watermilfoil in the Pend Oreille River. Lake and Watershed Management: Practical Applications. NALMS. p. 361-364.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, Third Edition. Academic Press, San Diego, California.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water

Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

Washington State Noxious Weed Control Board (WSNWCB). 2004. Written findings of the State Noxious Weed Control Board - Class B - B-designate Weed. Curly-leaf pondweed (*Potamogeton crispus* L.). Available online at: http://www.nwcb.wa.gov/weed_info/Written_findings/Potamogeton_crispus.html. Olympia, Washington.

WSNWCB. Undated. Written Findings of the State Noxious Weed Control Board - Class B – B-designate Weed. Eurasian Watermilfoil (Myriophyllum spicatum L.). Available online at: http://www.nwcb.wa.gov/weed_info/Myriophyllum_spicatum.html. Olympia, Washington.

Appendix 1. Macrophyte Literature-Based HSI Report

Boundary Hydroelectric Project (FERC No. 2144)

Study 7.4.2
Macrophyte Habitat Suitability Index

Prepared for
Seattle City Light

Prepared by
Darlene Siegel, Merri Martz, Gene Welch, and Harry Gibbons
Tetra Tech

March 2008

Table of Contents

Appendix

List of Tables

List of Figures

Study 7.4.2 – Macrophyte Habitat Suitability Index

Interim Report

Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Macrophytes are included in the mainstem aquatic habitat model in the form of Habitat Suitability Curves (HSC) and Habitat Suitability Indices (HSI) to estimate aquatic macrophyte production under various reservoir management scenarios. This report describes provisional literature-based HSC and HSI that will describe the response of macrophytes to cyclic inundation and dewatering that may change physical parameters that the macrophytes are exposed to, such as, water depth, water velocity, light, etc. These literature-based HSC and HSI will be supplemented by site-specific information developed through field studies. The response of macrophytes to operations scenarios will be evaluated as part of Fish and Aquatic Study 11: Productivity Assessment to provide information on the effects of operations on primary and secondary production.

The abbreviation HSI is used in this document to refer to either HSI models or a combination of HSI and HSC, depending on the context. HSI models provide a quantitative relationship between 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 life stage, under to structure of Habitat Evaluation Procedures (USFWS 1980). Alternatively, HSC are designed for use in the Instream Flow Incremental Methodology to quantify changes in habitat under various flow regimes (Bovee et al. 1998). HSC describes the instream suitability of habitat variables related only to stream hydraulics and channel structure (i.e., depth, velocity, and substrate). Both HSC and HSI models are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Both HSI and HSC are hypotheses of species-habitat relationships and are intended to provide indicators of habitat change. For the Boundary Project aquatic habitat studies, HSC (i.e., depth, velocity, and substrate) and HSI (i.e., duration of inundation and dewatering) models will be integrated to analyze the effects of operations scenarios on macrophytes.

The aquatic macrophytes comprise a diverse assemblage of macroscopic flora that have 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 exotic species are especially severe.

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).

An additional concern in Boundary Reservoir is the presence of non-native invasive species, such as Eurasian water milfoil (*Myriophyllum spicatum*) and curly pondweed (*Potamogeton crispus*). Those taxa have spread in the shallow, low-velocity 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. 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 (Washington State Noxious Weed Control Board [WSNWCB] [undated]). Each fragment 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 other areas. Another non-native invasive species of, curly pondweed, is found in the project vicinity, begins growth in early spring and spreads by vegetative turions or seeds (WSNWCB 2004).

The combined depth, velocity, and substrate HSC will be used to identify optimal habitats for macrophyte production. HSI describing the rate of macrophyte growth and effects of dewatering will then be used to estimate the effects of operations scenarios on macrophyte productivity. Data provided in this report are provisional estimates of suitability curves that can be used to estimate macrophyte productivity for operations scenarios. Once field data from the Boundary and Box Canyon reservoirs have been collected and analyzed, the HSC/HSI will be adjusted, if needed, to accommodate this information.

2 STUDY OBJECTIVES

The objective for the development of a Boundary macrophyte model is to help assess the effect of operations scenarios on aquatic production. Developing a macrophyte model for the Boundary Project will help in evaluating how differences in depth, velocity, and substrate and the frequency, duration, and magnitude of inundation and dewatering can influence macrophyte biomass. The Boundary macrophyte evaluation process will use estimates of physical and hydraulic conditions for operations scenarios coupled with HSC and HSI information to provide a comparative index of macrophyte production.

3 STUDY METHODS

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 3.0-1). 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 3.0-1. Boundary 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 Vo_i = Velocity S_i = Substrate DI_i = Duration of Inundation DD_i = Duration of Dewatering

1 See Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, 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 for 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: 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 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 Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, 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.

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. 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. Section 4 includes a summary of the information from literature sources and the provisional suitability curves.

4 HSI MODEL VARIABLES

4.1 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 4.1-1 [e.g., for May SD (4.8/3 = 1.6 meters) gives a colonization depth of 7.9 feet (2.4 m). 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).

For Eurasian water milfoil (*Myriophyllum spicatum)*, abundant growth appeared between depths of 1.6 to 11.5 feet (0.5 meter to 3.5 meters), 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).

Provisional suitability values were selected based on secchi depth and estimates of euphotic zone depth in Boundary Reservoir (Table 4.1-1). 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 4.1-2. Figure 4.1-2 displays the provisional depth of light suitability curve for macrophytes which is based on literature and professional judgment and will later be refined based on field data.

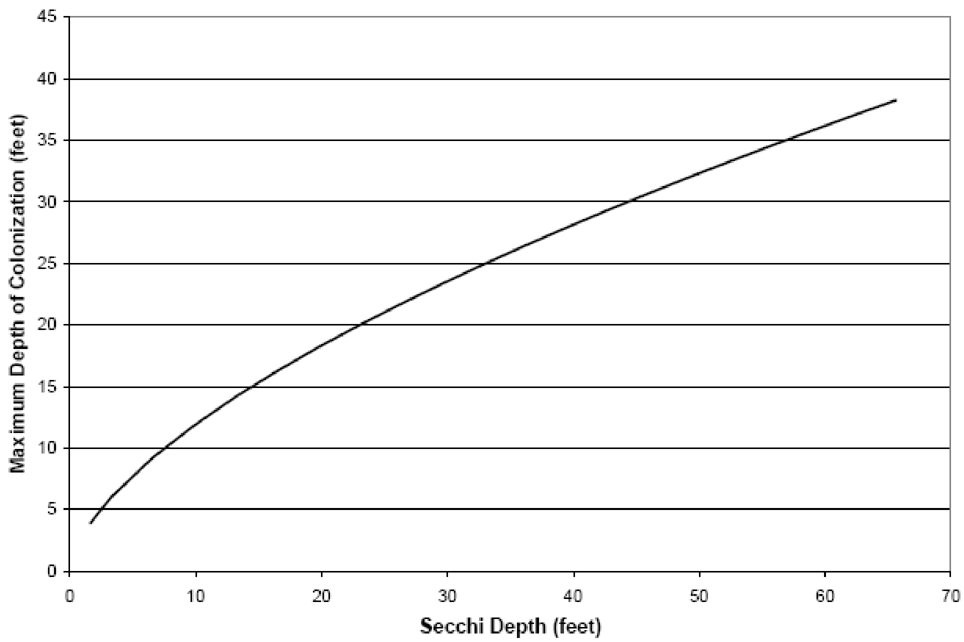


Figure 4.1-1. Regression model relationship developed by Canfield et al. (1985) between Secchi depth and the maximum depth of colonization.

Table 4.1-1. 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*	16.7*	28.5*	44.3*	39.7*	34.5*	34.5	34.5

* Estimated euphotic depth based on three times the Secchi disk readings reported by McLellan and O'Conner (2001).

Table 4.1-2. Depth of light ranges and provisional suitability values for macrophytes (Falter, et al. 1991, Nichols 2001, Canfield et al. 1985, Riis and Bigg 2003).

Depth of Light Feet (m)	Provisional Suitability Values
0 (maximum)	0.5
0.33 ft (0.1m)	0.6
0.66 ft (0.2 m)	1.0
3.28 ft (1.0 m)	0.75
6.6 ft (2.0 m)	0.3
>16.5 ft (5.0 m)	0.01

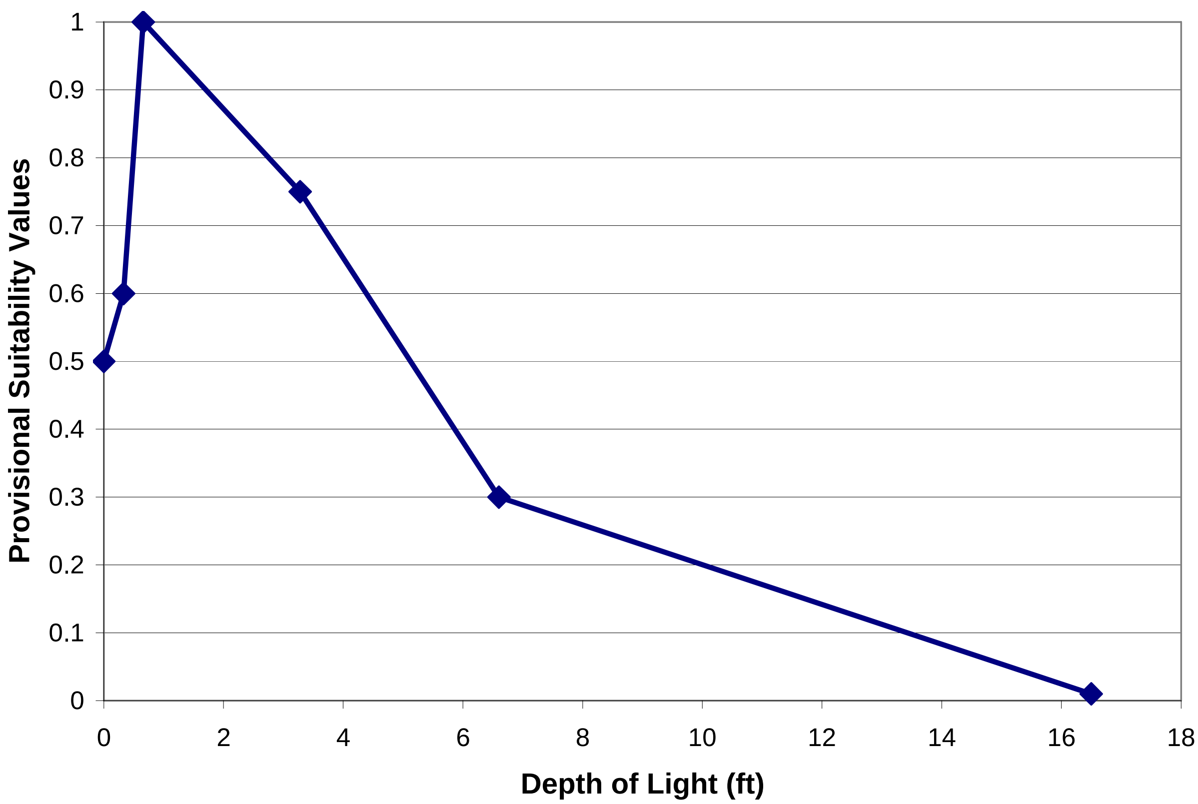


Figure 4.1-2. Provisional depth of light suitability curve for macrophytes.

4.2 Velocity

Henriques (1987) found that at velocities less than 0.66 feet per second (ft/s) (0.2 meters 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 ft/s (0.9 m/s). However, macrophytes were recorded in velocities of up to 3.9 ft/s (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 ft/s (0.05 m/s), it increased steadily to approximately 1.3 ft/s (0.4 m/s), and decreased slightly up to 1.97 ft/s (0.6 m/s) (Riis and Biggs 2003). In addition, this study found a threshold velocity of 2.6 ft/s (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 4.2-1). 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 4.2-1 displays the provisional velocity suitability curve for macrophytes. The velocity suitability curve is based on literature and professional judgment and will be refined further based on data collected in the field to determine ranges of suitable velocities for macrophyte growth in Boundary Reservoir.

Table 4.2-1. Velocity ranges and provisional suitability values for macrophytes *(Henriques 1987, Riis and Biggs 2003).*

Velocity feet/second (m/s)	Provisional Suitability values
0	0.1
0.164 ft/s (0.05 m/s)	1.0
1.31 ft/s (0.4 m/s)	0.75
1.97 ft/s (0.6 m/s)	0.3
2.62 ft/s (0.8 m/s)	0.1
7.7 ft/s (2.4 m/s)	0.0

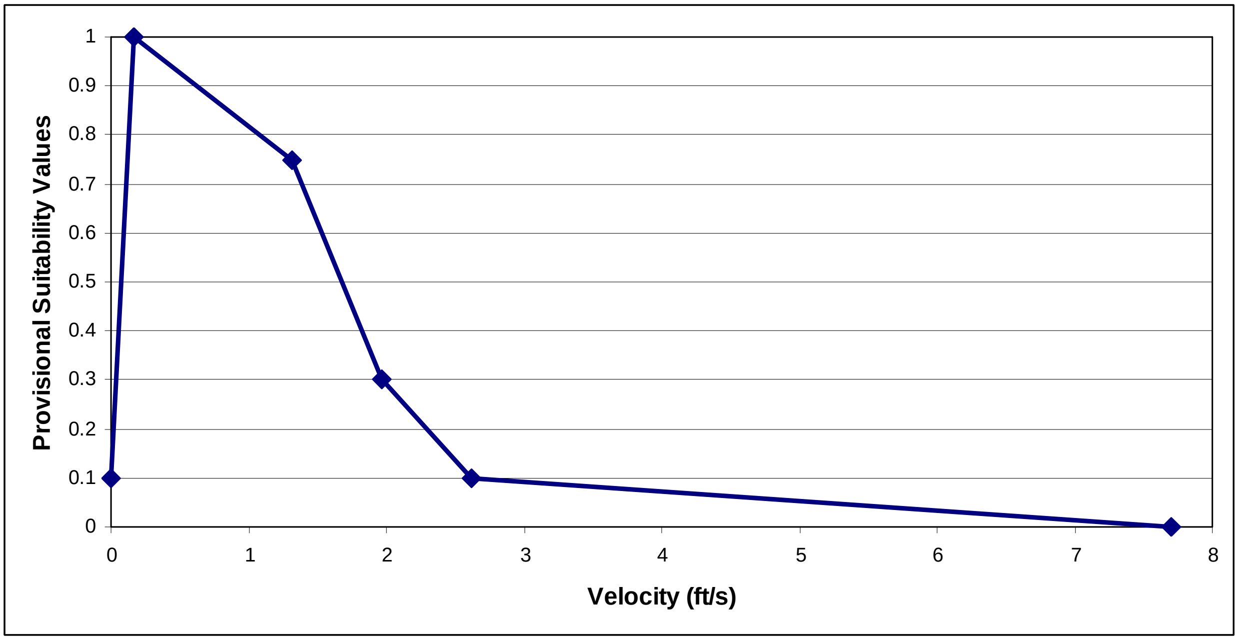


Figure 4.2-1. Provisional velocity suitability curve for macrophytes.

4.3 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 [undated], 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 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 4.3-1). Figure 4.3-1 displays the provisional substrate suitability curve for macrophytes.

Table 4.3-1. 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

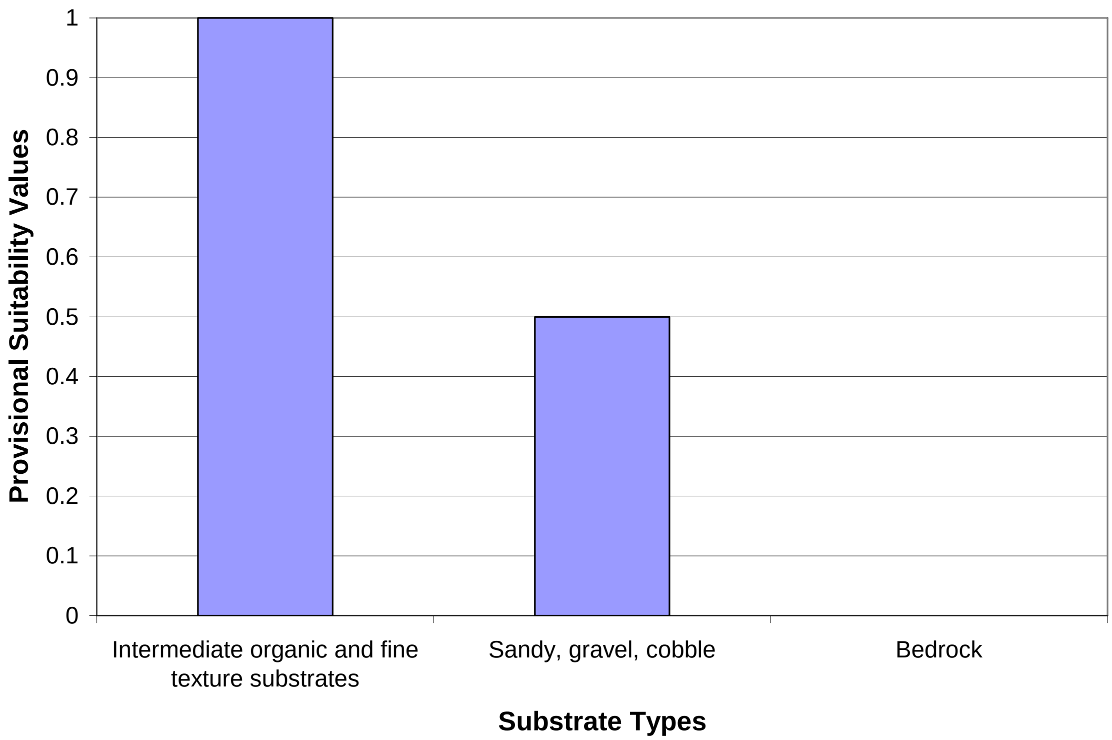


Figure 4.3-1. Provisional substrate suitability values for macrophytes.

4.4 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 (WSNWCB [undated]), 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 m 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 meters 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 water milfoil 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 [undated]).

Figure 4.4-1 displays the provisional duration of dewatering suitability curves for submergent macrophytes. The provisional duration of dewatering suitability curve in Figure 4.4-1 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 4.4-1. Duration of dewatering provisional suitability values for submergent macrophytes.

$HSI_{Submergent}$
(WSNWCB undated)

Time (hours)	Provisional Suitability Values
0	1.0
6	0.8
12	0.6
24	0.4
72	0.1
720	0.0

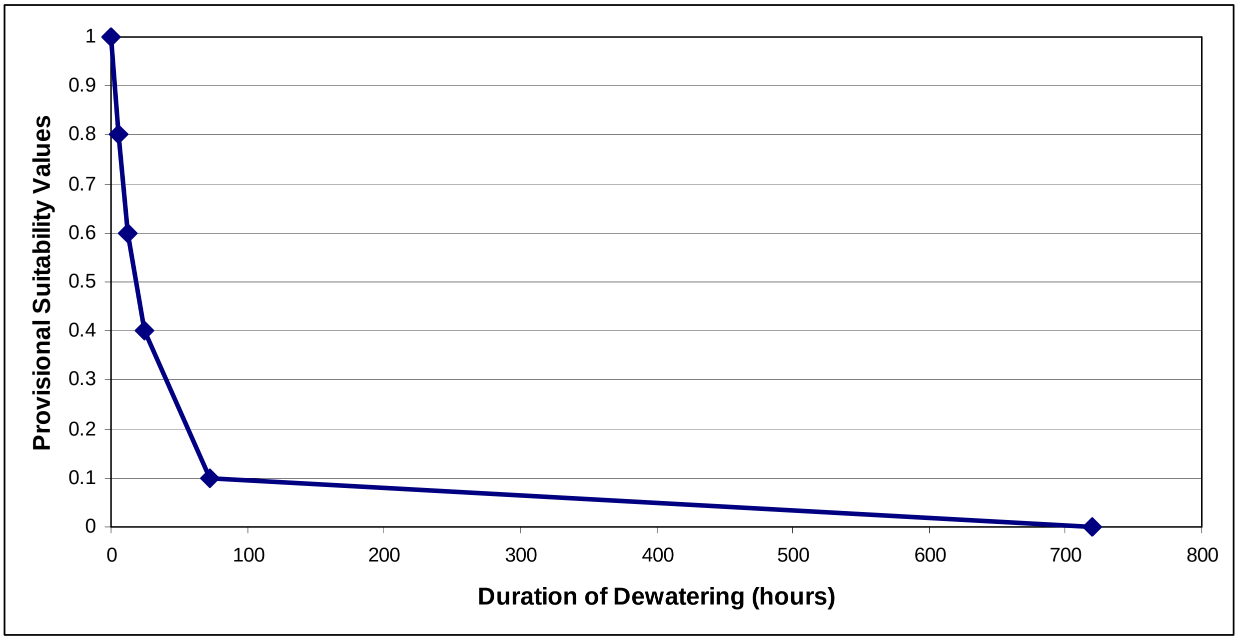


Figure 4.4-1. Provisional duration of dewatering suitability curve for submergent macrophytes.

4.5 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 4.5-1). The duration of inundation HSI factor will only be included during spring time steps in the Boundary Reservoir Physical Habitat Model.

Table 4.5-1. Duration of inundation provisional suitability values for macrophytes.

Constant Inundation	Provisional Suitability Values
yes	1.0
no	0

5 CONCLUSION

A review of available literature has provided general information regarding the habitat suitability of macrophyte related to depth, velocity, substrate type, duration of exposure, and duration of inundation. Provisional suitability curves have been developed based on this information. Field studies are currently underway to gather data specific to macrophyte communities in the Boundary Reservoir, which will be used to calibrate and revise the provisional suitability curves. Once the suitability curves for macrophytes at the Boundary Reservoir have been refined and finalized with field data, they will be incorporated into the larger HSI model, along with the benthic macroinvertebrate, macrophyte, and fish data, to gain a broader understanding of the biotic response to operations scenarios at the Boundary Dam. This information will enable

Seattle City Light and other stakeholders to evaluate the effects of operations scenarios to support relicensing decisions.

6 LITERATURE CITED

Barko, J.W. and R.M. Smart. 1986. Sediment-relates mechanisms of growth limitation in submersed macrophytes. Ecology 67:1328-1340.

Biggs, B.J.F. and S. Stokseth. 1996. Hydraulic habitat suitability for periphyton in rivers. *Regulated Rivers: Research and Management*. 12:251-261.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Paper No. 12. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-82/26).

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Washington, DC: U.S. Fish and Wildlife Service (Biological Report 86[7]). 235pp.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131pp.

Canfield, D.E. Jr., K.A. Langeland, S.B. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. *Journal of Aquatic Plant Management* 23: 25-28.

Chambers, P.A. and J. Kalff. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Canadian Journal of Fisheries and Aquatic Sciences. 42: 701-709.

Cooke, G.D. 1980. Lake level drawdown as a macrophyte control technique. *Water Resources Bulletin.* 16(2): 317-322.

Engel, S. 1995. Eurasian water milfoil as a fishery management tool. *Fisheries* 20(3): 20-27.

Falter, C.M., C. Baines and J.W. Carlson. 1991. Water Quality, Fish and Wildlife Characteristics of Box Canyon Reservoir. Completion Report 1989-1990. Section 2: Water Quality. Department of Fish and Wildlife Resources. College of Forestry, Wildlife and Range Sciences, University of Idaho.

Fox, A.M. 1996. Macrophytes, p. 27-44. In. G. Petts and P. Calow [eds.], River Biota: Diversity and Dynamics. Blackwell Science Ltd.

Hamel, K. 1990. Milfoil – An Aggressive Water Weed. Department of Ecology Doc No. 90-br-002. Olympia, WA.

Haslam, S.M. 1978. *River Plants*. Cambridge University Press.

Henriques, J. 1987. Aquatic macrophytes, p. 207-222. In. P. R. Henriques [ed.], Aquatic Biology and Hydroelectric Power Development in New Zealand. Oxford Univ. Press.

McLellan, J.G., and D. O'Connor. 2001. Resident fish stock status above Chief Joseph and Grand Coulee Dams. Part 2. Baseline Assessment of Boundary Reservoir, Pend Oreille River, and its Tributaries. Washington Department of Fish and Wildlife. Spokane Washington.

Nichols, S. 2001. Macrophytes: Where they grow and why. Lakeline. pp 38-41.

Pelletier, G., and R. Coots. 1990. Progress Report No. 1 - Pend Oreille River Water Quality Study. Washington Department of Ecology. Environmental Investigations and Laboratory Services Program. Surface Water Investigation Section. Olympia, Washington.

Pend Oreille County. 2003. Interim Aquatic Plant Management Plan for the Pend Oreille River (RM 34.4-90.1). Newport, Washington.

Riis, T. and B.J.F. Biggs. 2003. Hydrologic and hydraulic control of macrophyte establishment and performance in streams. Limnology and Oceanography. 48(4): 1488-1497.

Riis. T. and I. Hawes. 2002. Relationships between water level fluctuations and vegetation diversity in shallow water of New Zealand lakes. Aquatic Botany. 74: 133-148.

Smith, C. and Barko, J.W. 1990. Ecology of Eurasian Watermilfoil. Journal of Aquatic Plant Management. 28: 55-64.

U.S. Environmental Protection Agency (EPA). 1993. Clark Fork - Pend Oreille Basin water quality study: A summary of findings and a management plan. United States Environmental Protection Agency Regions VIII and X. Report for Section 525 of the Clean Water Act of 1987.

USFWS (U.S. Fish and Wildlife Service). 1980. Habitat evaluation procedures (HEP). ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C. March 31, 1980.

Van Geest, F.J., H. Wolters, F.C.J.M. Roozen, H. Coops, R.M.M. Roijackers, A.D. Biujse and M. Scheffer. 2005. Water-level fluctuations affect macrophyte richness in floodplain lakes. Hydrobiologia. 539: 239-248.

Wilxoc, D.A. and J.E. Meeker. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Canadian Journal of Botany. 69(7):1542-1551.

Welch, E.B. and J.M. Jacoby. 2004. Polluted Effects in Freshwater; Applied Limnolgy. 3rd edition, Taylor and Francis, London.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, Third Edition. Academic Press, San Diego, California.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

Washington State Noxious Weed Control Board (WSNWCB). 2004. Written findings of the State Noxious Weed Control Board - Class B - B-designate Weed. Curly-leaf pondweed (*Potamogeton crispus* L.). Available online at: http://www.nwcb.wa.gov/weed_info/Written_findings/Potamogeton_crispus.html. Olympia, Washington.

WSNWCB. Undated. Written Findings of the State Noxious Weed Control Board - Class B – B-designate Weed. Eurasian watermilfoil (*Myriophyllum spicatum* L.). Available online at: http://www.nwcb.wa.gov/weed_info/Myriophyllum_spicatum.html. Olympia, Washington.

This page is intentionally left blank.

Appendix A: Macrophyte HSI Annotated Bibliography

Annotated Bibliography

Barko, J.W. and R.M. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67:1328-1340.

Two macrophyte species were found to decline in growth with increasing organic sediment matter and in inorganic sediments with a sand fraction exceeding 75% dry mass. Growth and nutrient accumulation were highly correlated with sediment nutrient concentrations based on volume. Mechanisms of growth limitation on both sands and organic sediments appear to involve nutrition.

Biggs, B.J.F. 1998. Hydraulic habitat of plants in streams. Regulated Rivers: Research and Management. 12(2-3): 131-144.

The hydraulic stability among streams was reviewed to determine the effects on periphyton, bryophytes, and macrophytes. Periphyton and macrophyte colonization was determined to be enhanced by low velocities. However, for mature communities, the peak biomass of periphyton and macrophytes can be negatively correlated with velocity.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Paper No. 12. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-82/26).

This guide describes the overall approach of the methodology for collecting and interpreting data using the Instream Flow Incremental Methodology. The protocol addresses both macrohabitat and microhabitat characteristics. Total habitat availability and suitability can be calculated from this methodology.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Washington, DC: U.S. Fish and Wildlife Service (Biological Report 86[7]). 235pp.

The Instream Flow Incremental Methodology (IFIM) is a habitat-based tool used to evaluate the environmental consequences of various water and land use practices. This paper discusses the development and evaluation of habitat suitability criteria required for successful implementation of the IFIM.

Canfield, D.E. Jr., K.A. Langeland, S.B. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. Journal of Aquatic Plant Management ***23****: 25-28.*

This study identifies a significant positive relationship between water transparency as measured by a Secchi disc and the maximum depth of colonization by aquatic macrophytes. This model is to be used to provide a first approximation of the potential extent of aquatic weed problems in lakes, including a measure of how much of the lake is suitable for colonization. Variability in the maximum depth of colonization and Secchi depth relationship is likely based on the different light requirements for each species of macrophytes.

Chambers, P.A. and J. Kalff. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Canadian Journal of Fisheries and Aquatic Sciences. 42: 701-709.

This study examines how macrophyte biomass and depth of colonization shifts with increased nutrient loading of lakes. The depth distribution of macrophytes was found to be primarily controlled by irradiance, but other environmental parameters were found to be factors including nutrients, wave action, currents, substrate particle size and stability, and temperature.

Cooke, G.D. 1980. Lake level drawdown as a macrophyte control technique. Water Resources Bulletin. 16(2): 317-322.

The response of 63 nuisance species to lake drawdown was reviewed. These case histories suggest that the technique may be species specific; that the invasion of resistant species may be rapid; and that undesirable changes may occur in the system, including algal blooms and low dissolved oxygen. The technique appeared successful, at least for short term control of 1 to 2 years. It can achieve control at relatively low cost without the introduction of chemicals or use of machinery.

Canadian Wildlife Service (CWS). 2003. Eurasian Watermilfoil. http://www.cws-scf.ec.gc.ca/publications/inv/p1_e.cfm

The Canadian Wildlife Service provides a taxonomic overview of Eurasian watermilfoil. The ecology, distribution, biology, current status, potential threat and control measures are also described for the species.

Engel, S. 1995. Eurasian water milfoil as a fishery management tool. Fisheries ***20****(3): 20-27.*

Eurasian watermilfoil can be detrimental to fisheries, especially when native plant communities are replaced with invasive, dense mats of watermilfoil. However, in other lakes Eurasian watermilfoil can improve fish production, especially in waters too turbid to support native plant growth. In these cases watermilfoil creates a dynamic littoral zone creating habitat and a food base for benthivores and piscivores that would otherwise be non-existent.

U.S. Environmental Protection Agency (EPA). 1993. Clark Fork - Pend Oreille Basin water quality study: A summary of findings and a management plan. United States Environmental Protection Agency Regions VIII and X. Report for Section 525 of the Clean Water Act of 1987.

In response to concerns and complaints about the growing presence of algae and water weeds in the Clark Fork-Pend Oreille Basin, a comprehensive water quality study was conducted to characterize water quality problems, identify sources and recommend actions for maintaining and enhancing water quality throughout the basin. The study concluded that excessive levels of algae caused water use impairment in up to 250 miles of the Clark Fork River. The primary water quality concern on the Pend Oreille River is the proliferation of Eurasian watermilfoil, an invasive and adaptable plant.

Falter, C. M., C. Baines and J. W. Carlson. 1991. Water Quality, Fish and Wildlife Characteristics of Box Canyon Reservoir. Completion Report 1989-1990. Section 2: Water Quality. Department of Fish and Wildlife Resources. College of Forestry, Wildlife and Range Sciences, University of Idaho.

A study was conducted to assess the water quality, and the fish and wildlife characteristics of Box Canyon Reservoir, Pend Oreille River. The results of the aquatic macrophyte analysis, biomass has been found to be greatest in the littoral regions of the Pend Oreille River at depths of less than 10 feet.

Fox, A.M. 1996. Macrophytes, p. 27-44. In. G. Petts and P. Calow [eds.], River Biota: Diversity and Dynamics. Blackwell Science Ltd.

This book provides a review of river biota as taken from a selection of chapters of The Rivers Handbook. The chapter on macrophytes describes the biology, distributional ecology, quantitative ecology, and interaction with human activities.

Hamel, K. 1990. Milfoil – An Aggressive Water Weed. Department of Ecology Doc No. 90-br-002. Olympia, WA.

A fact sheet published by the Washington State Department of Ecology and the U.S. Army Corps of Engineers to educate the public about Eurasian watermilfoil. Methods of controls and ways to reduce the spreading of watermilfoil are discussed.

Haslam, S.M. 1978. River Plants. Cambridge University Press.

The effects on the distribution so f riverine plants are discussed in detail. Variables considered include river morphology, depth, flow, substrate, light, shading, siltation, nutrients, and pollution.

Henriques, J. 1987. Aquatic macrophytes, p. 207-222. In. P. R. Henriques [ed.], Aquatic Biology and Hydroelectric Power Development in New Zealand. Oxford Univ. Press.

This chapter describes the various effects of hydroelectric power development on freshwater macrophytes. Potential problems of noxious species, rare macrophyte species and habitat, and beneficial aspects of macrophyte presence are discussed.

Nichols, S. 2001. Macrophytes: Where they grow and why. Lakeline. pp 38-41.

This fact-sheet defines macrophytes and the littoral zone. It also discusses characteristics of the littoral zone and species specific requirements for habitat.

Pelletier, G., and R. Coots. 1990. Progress Report No. 1 - Pend Oreille River Water Quality Study. Washington Department of Ecology. Environmental Investigations and Laboratory Services Program. Surface Water Investigation Section. Olympia, Washington.

The Washington State Department of Ecology conducted a study to address water quality concerns of the Pend Oreille River between Albeni Falls and box Canyon dams. Water quality was found to be generally good and below thresholds of eutrophic conditions. Phytoplankton and periphyton and macrophytes were also assessed. Macrophytes were found to be responsible for water quality violations for pH and total dissolved gasses.

Pend Oreille County. 2003. Interim Aquatic Plant Management Plan for the Pend Oreille River (RM 34.4-90.1). Newport, Washington.

An aquatic plan management plan was developed for the Pend Oreille River between river miles 34.4 and 90.1 due to the dense and nuisance growth in this portion of the river. The plan describes the aquatic plant communities in the river, describes management strategies considered for minimizing negative impacts by reducing overall aquatic plant density. The suggested management strategy is the continued use of rotovation.

Riis, T. and B.J.F. Biggs. 2003. Hydrologic and hydraulic control of macrophyte establishment and performance in streams. Limnology and Oceanography. 48(4): 1488-1497.

Fifteen streams were studied in New Zealand to test the hypotheses that the presence and development of macrophytes is primarily controlled by the hydraulic regime and in stable systems, strongly influenced by local hydraulic conditions. The results of the study show that that the abundance and diversity of macrophytes decreased as flood disturbance Duration increased. Four species of macrophytes did not show overlapping preferences for velocity, depth, and substrate suggesting coexistence by physical niche separation.

Riis. T. and I. Hawes. 2002. Relationships between water level fluctuations and vegetation diversity in shallow water of New Zealand lakes. Aquatic Botany. 74: 133-148.

Twenty-one New Zealand lakes were assessed to determine how water level fluctuations affected the diversity of the littoral plant community. Water level range, Duration of variation, and duration of low water level events was found to affect species diversity. It was found that a diverse littoral community occurred within a 1 m monthly water level range, with a mean duration of low level events lasting up to 1 month in lakes with low inter-annual water level fluctuation.

Smith, C. and Barko, J.W. 1990. Ecology of Eurasian Watermilfoil. Journal of Aquatic Plant Management. 28: 55-64.

The habitat preferences and ecology of Eurasian watermilfoil was summarized through a literature review. Effects of environmental factors on watermilfoil, effect of watermilfoil invasions, and other management issues were addressed.

Van Geest, F.J., H. Wolters, F.C.J.M. Roozen, H. Coops, R.M.M. Roijackers, A.D. Biujse & M. Scheffer. 2005. Water-level fluctuations affect macrophyte richness in floodplain lakes. Hydrobiologia. 539: 239-248.

One hundred floodplain lakes in the active floodplain of the Lower Rhine, Netherlands were analyzed for factors determining water level fluctuations and the affect on macrophytes. Species richness was reduced for all macrophytes at all fluctuation levels, except, submersed macrophytes were not affected by large level fluctuations. Shallow, moderately isolated, lakes with occasional bottom exposure were found to have the highest potential for creating macrophyte-rich floodplain lakes.

Wilxoc, D.A. and J.E. Meeker. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Canadian Journal of Botany. 69(7):1542-1551.

Two regulated lakes in northern Minnesota were compared to an unregulated lake to identify the effects of water-level regulation on aquatic macrophyte communities. Natural annual fluctuations of about 1.8 m were replaced with fluctuations of 1.1 and 2.7 m in the regulated lakes, and the timing of water-level changes was also altered. The natural hydrologic regime at the unregulated lake resulted in intermediate disturbance and high diversity. Water-level fluctuation in the regulated lakes caused either too little or too much disturbance, resulting in reduced structural diversity.

Welch, E.B. and J.M. Jacoby. 2004. Polluted Effects in Freshwater; Applied Limnolgy. 3rd edition, Taylor and Francis, London.

This text provides an introduction to the ecological consequences of water pollution in aquatic ecosystems. This book reviews limnological and water pollution literature to describe how pollutants in wastewater affect populations of organisms in freshwater environments.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems, Third Edition. Academic Press, San Diego, California.

This limnology text describes the structural and functional interrelationships of organisms of inland waters as they are affected by their dynamic physical, chemical, and biotic environments.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

This report identifies the impacts of water level fluctuation on the biological characteristics of reservoirs. The definition and the effects of the littoral zone biology is discussed. Potential impacts in reservoir biota include habitat destruction, partial or total loss of aquatic species, changes in habitat quality and shifts in species diversity.

Washington State Noxious Weed Control Board (WSNWCB). 2004. Written findings of the State Noxious Weed Control Board - Class B - B-designate Weed. Curly-leaf pondweed (Potamogeton crispus L.). URL: http://www.nwcb.wa.gov/weed_info/Written_findings/Potamogeton_crispus.html. Olympia, WA.

Curly-leaf pondweed, a Washington state noxious weed, is described. The habitat, distribution, economic importance, and the control of this species are also addressed.

WSNWCB. Undated. Written Findings of the State Noxious Weed Control Board - Class B – B-designate Weed. Eurasian Watermilfoil (Myriophyllum spicatum L.) URL:http://www.nwcb.wa.gov/weed_info/Myriophyllum_spicatum.html. Olympia, Washington.

Eurasian watermilfoil, a Washington state noxious weed, is described. The habitat, distribution, economic importance, and the control of this species are also addressed.

Appendix 3. Study No. 7.4.3 – Mainstem Aquatic Habitat Modeling: Periphyton HSI

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.3
Mainstem Aquatic Habitat Modeling: Periphyton HSI

Interim Report

Prepared for
Seattle City Light

Prepared by
Shannon Brattebo, Darlene Siegel, Kari Kimura, Harry Gibbons,
Robert Plotnikoff, Gene Welch, Merri Martz, and Adam Baines
Tetra Tech

March 2008

TABLE OF CONTENTS

Appendices

List of Tables

List of Figures

Study No. 7.4.3: Mainstem Aquatic Habitat Modeling: Periphyton HSI Interim Report Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 7.4.3, Mainstem Aquatic Habitat Modeling: Periphyton HSI 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) 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 an interim report for the 2007 study efforts of the Mainstem Aquatic Habitat Modeling: Periphyton Monitoring.

1.1. Study Background

A Habitat Suitability Index (HSI) has been 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 is based upon a literature addressing the species' habitat requirements and preferences.

Because periphyton communities are comprised of numerous taxa, the HSI for the Boundary Project will not be specific to any individual species, but will be developed for the commonly used chlorophyll *a* [periphyton] metric selected to represent the communities.

Periphyton are organisms that live on the benthic 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 algae portion of which are primary producers. Primary production 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 benthic macroinvertebrates and some fish, birds, and/or mammals.

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). 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 two components, a literature-based HSI and site-specific field data to validate the literature-based HSI. Field data generation includes periphyton data with depth and cross-sectional data with depth, velocity, and substrate measurements. Site-specific periphyton monitoring consisted of two different components, artificial substrate sampling on hard substrate surfaces and determination of seasonal colonization rates.

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 Physical 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 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 Upper Reservoir 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, autumn, and will be carried out in the winter for 8-week periods. 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, November 5–10, and are to be retrieved on February 2–6, weather and reservoir conditions permitting.

The second component of the study included the determination of seasonal periphyton colonization rates within the reservoir. For summer and winter periods, 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. 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 colonization study were used for periphyton HSI development and validation.

2 STUDY OBJECTIVES

The goal of this study is 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 will be used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for periphyton for operations scenarios. The information collected during this study will also be used to support the Aquatic Productivity Study.

3 STUDY AREA

Periphyton monitoring and sample collection was conducted in Boundary Reservoir and Box Canyon Reservoir. 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 lower reservoir upstream of Boundary Forebay but not in the upper reservoir 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. A site map indicating where periphyton were sampled is provided in Figure 3.0-1. The sampling sites were chosen based on type of substrate, depth, and geographic area.

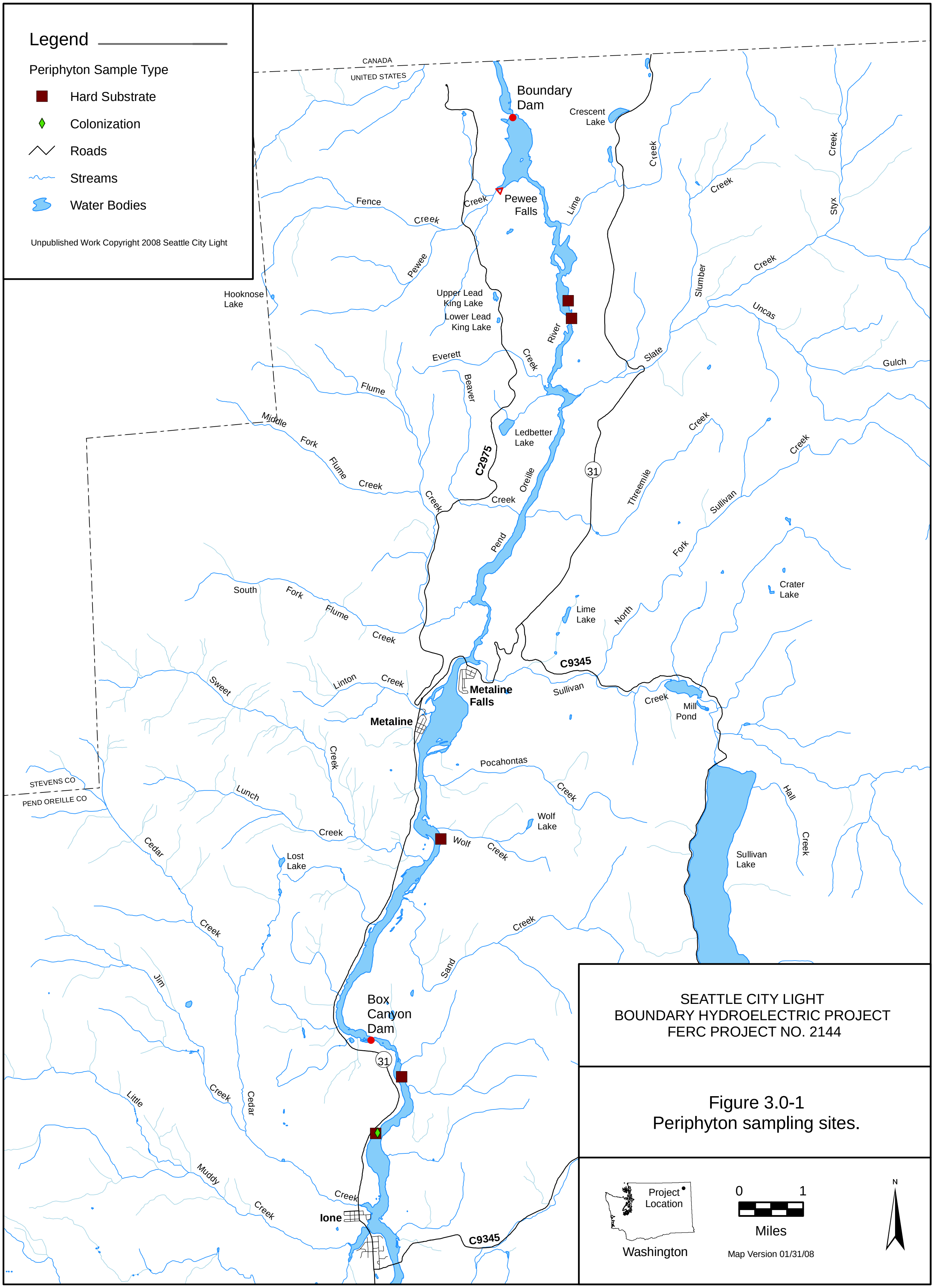


Figure 3.0-1
Periphyton sampling sites.

4 METHODS

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 few appropriate suitability curves were found for periphyton, so other literature information were used to develop suitability values. A more detailed explanation of the methodology used to create the literature-based periphyton HSI curves can be found within the literature-based HSI report in Appendix 1.

Periphyton site-specific monitoring consisted of two different components, artificial substrate sampling on hard substrate surfaces and determination of seasonal colonization rates. 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. 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 lower Boundary Reservoir and upper Boundary Reservoir will be determined once the hydraulic model is complete. The 2007 water elevation records from Box Canyon Dam have been obtained and will be adjusted to ensure that they are reported in the same datum as the records from Boundary Dam. Once this process is complete and the records have been reviewed for quality assurance/quality control, analysis will be conducted to determine depth and duration of inundation and exposure at sampling sites. It will be necessary to obtain additional water elevation records for samples collected in 2008. 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 4.0-1 and 4.0-2. All hard substrate samples (shoreline and vertical face sites) were retrieved 8 weeks

Table 4.0-1. 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	February*
Total				**216**	
Treatments/Sites					
A) High Fluctuation-Downstream of Metaline Falls					
B) Moderate Fluctuation-Upstream of Metaline Falls					
C) Low Fluctuation-Box Canyon Reservoir					

*Weather permitting.

Table 4.0-2. 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	February*
Total				**144**	
Treatments/Sites					
A) High Fluctuation-Canyon Reach					
B) Low Fluctuation-Box Canyon Reservoir					

*Weather permitting.

Table 4.0-3. Colonization sample deployment and retrieval schedule.

Season	Colonization Period	Deployment Date	Retrieval Date
Summer	8 weeks	July 6th	September 1st
	6 weeks	July 20th	September 1st
	4 weeks	August 3rd	September 1st
	2 weeks	August 16th	September 1st
	1 week	August 23rd	September 1st
	3 days	August 28th	September 1st
Winter*	8 weeks	December 8th	February 2nd
	6 weeks	December 21st	February 2nd
	4 weeks	January 4th	February 2nd
	2 weeks	January 18th	February 2nd
	1 week	January 25th	February 2nd
	3 days	January 30th	February 2nd

*Winter colonization baskets deployment and retrieval is depending on weather and reservoir conditions.

following deployment. 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 in millimeters with calipers and recorded in a field notebook. These measurements were used to determine 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*.

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 4.0-3. For summer and winter periods, 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. Colonization samples were placed at elevation intervals of 5, 15, and 25 feet. The same deployment and retrieval procedures were used for the colonization samples as for the hard substrate shoreline samples.

5 PRELIMINARY RESULTS

All collected periphyton data were preliminarily analyzed to address the objectives of the study and are presented below. The literature-based HSI curve and model are briefly discussed below with more detail found in Appendix 1. Site-specific periphyton data are presented by treatment site, elevation interval, and season. Periphyton monitoring data are presented as observations until all data are collected and the hydraulic model is complete. Once the hydraulic model is complete, model results (water surface elevations and water velocity) along with periphyton monitoring data will be used to further refine the literature-based periphyton HSI curves. In addition, water surface elevation data for Box Canyon Reservoir were recently obtained from the Pend Oreille Utility District. These data are being reviewed and will be used with the complete set of periphyton data collected in Box Canyon to validate the HSI curves. Preliminary analysis indicates that this data set is complete and will allow refinement of the HSI curves for periphyton for depth under minimum water surface elevation fluctuation.

5.1. Literature-Based Periphyton HSI Curves

A literature-based HSI was created for Boundary Reservoir. The HSI developed addresses 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 5.1-1 and each variable is described in further detail in Appendix 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.

Table 5.1-1. Boundary reservoir literature-based periphyton HSI Model.

Periphyton Composite Suitability Index	**$CSI_i = HSC_i * HSI_i$**
Periphyton HSC	$HSC_i = D_i * Vo_i * S_i$
Periphyton HSI	$HSI_i = f(DI_i, DD_i)^1$
Periphyton Variables	D_i = Depth Vo_i = Velocity S_i = Substrate DI_i = Duration of Inundation DD_i = Duration of Dewatering

1 See Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, Varial Zone Analysis for details on integrating inundation and dewatering factors.

The methods used to determine provisional values for each of the five variables and the results for literature review are described in further detail in Appendix 1. The literature-based HSI for periphyton will be verified with field collected data as these data become available (see Section 5.4).

5.2. Periphyton Communities on Hard Substrate

The Interim Report for Study 7.4.3 includes information and preliminary results for sampling events conducted up to September 1, 2007. Periphyton monitoring on hard substrate to this date has been conducted during two different seasons: spring and summer. Periphyton artificial substrate baskets were retrieved from both Boundary Reservoir and Box Canyon Reservoir after 8 weeks of incubation. Spring periphyton samples were retrieved at the end of May and summer samples retrieved the first of September.

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 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. Once the hydraulic routing model is complete, the model will be used to determine the length of time the baskets were dry. This information will be used in validating the HSI curves for duration of inundation and duration of dewatering.

Site-specific periphyton data have also been collected for the fall season in Boundary and Box Canyon reservoirs. Hard substrate baskets were retrieved the first week of November 2007 and lab analysis is currently under way. Artificial hard substrate baskets were deployed for the winter season sampling event the first week of December and are scheduled to be retrieved at the beginning of February 2008 or as weather and reservoir conditions permit. Periphyton data collected during 2007 and 2008 will be used along with results from the hydraulic model to further refine the literature-based HSI curves. The hydraulic model being developed will provide information on water surface elevations, water velocities, and duration of inundation and dewatering that will be used in conjunction with the site-specific periphyton data collected to validate the periphyton HSI model for Boundary Reservoir.

Figures presenting water surface elevations at each Boundary Reservoir treatment site during the sampling period will be incorporated into the report once the data becomes available. Hourly water surface elevations in Box Canyon Reservoir during sampling periods will also be presented in graphical form. Recently, hourly water surface elevation data for Box Canyon Reservoir were obtained from the Pend Oreille Public Utility District. The water surface elevation obtained for Box Canyon Reservoir is from a gage located in the Box Canyon Forebay. The water surface elevations are currently being reviewed and analyzed. The hydraulic model, which is currently being developed, will provide information on site-specific water surface elevations in Boundary Reservoir. Once the model is completed, the water surface elevations at each treatment site over the course of each deployment will be used to calculate the depth of water at each sample over time. The hydraulic model will also enable the calculation of the duration of inundation and dewatering at each treatment site over the colonization period. For each sample, the time of inundation and dewatering will be calculated on an hourly basis from the water surface elevations generated by the model with respect to the fixed elevation of each sample. This information (depth of samples and duration of inundation and dewatering) will then be used in the periphyton HSI validation. Site-specific water surface elevations will also be used to help better understand periphyton responses to fluctuating water surface elevations and enable the validation of HSI curves for duration of inundation and duration of dewatering.

5.2.1. Vertical Treatment Sites

Figures 5.2-1 through 5.2-2 graphically present the average periphyton biomass measured by chlorophyll *a* (mg/m^2) at each vertical treatment site and elevation interval for samples collected in May and September respectively. Tables 5.2-1 through 5.2-2 summarize the periphyton chlorophyll *a* found in vertical treatment samples collected in May and September.

Average spring periphyton chlorophyll *a* biomass concentrations at vertical treatment sites ranged from 1.44 to 3.86 mg/m^2 for all elevation intervals. Due to water fluctuation, hard substrate baskets placed at the 2 foot and 5 foot elevation intervals in Lower Boundary reservoir were dewatered at the time of spring retrieval. Average spring periphyton chlorophyll *a* appears to be similar at vertical treatment sites in Lower Boundary and Box Canyon Reservoirs. Both vertical treatment sites show a decrease (48 percent and 63 percent, respectively) in spring periphyton chlorophyll *a* as the elevation interval increases from 10 feet to 40 feet (Figure 5.2-1).

There was a larger variability in summer periphyton chlorophyll *a* at vertical treatment sites in Boundary and Box Canyon reservoirs than spring chlorophyll *a*. Average summer periphyton chlorophyll *a* at vertical treatment sites ranged from 0.55 to 22.85 mg/m^2 for all elevation intervals. Baskets placed at the 2 foot elevation interval in Box Canyon were dewatered at the time of retrieval. The highest summer periphyton chlorophyll *a* for vertical treatment sites was seen at the 5 foot elevation interval in lower Boundary and Box Canyon reservoirs (Figure 5.2-2). Summer periphyton chlorophyll *a* is higher at the lower Boundary Reservoir vertical site for all elevation intervals than at the vertical site in Box Canyon (Figure 5.2-2). There also appears to be a decreasing trend (95 percent reduction) in summer periphyton chlorophyll *a* at the vertical site in Lower Boundary with the exception of chlorophyll *a* found at the 10-foot elevation interval.

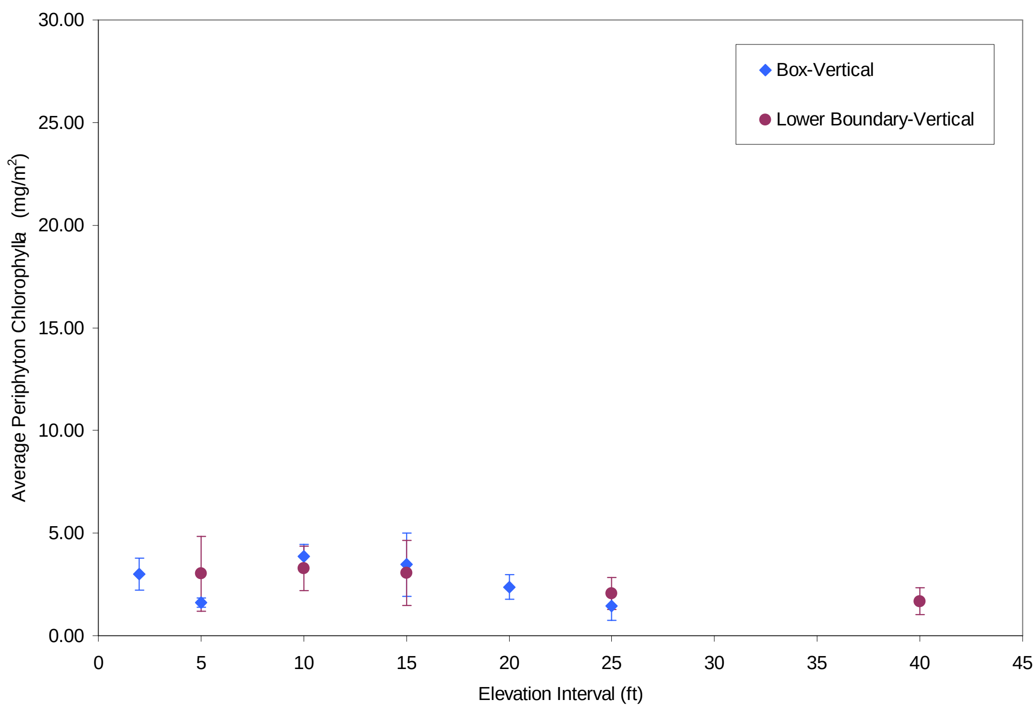


Figure 5.2-1. Spring average periphyton biomass as represented by chlorophyll *a* for vertical sites retrieved May 2007.

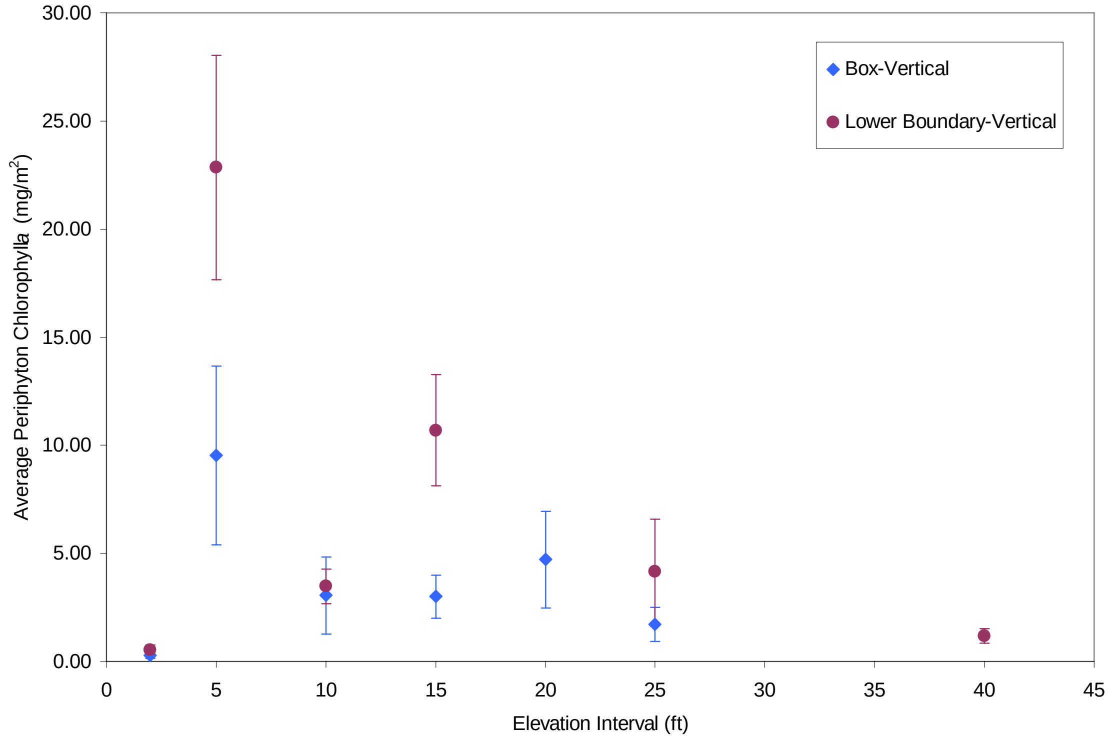


Figure 5.2-2. Summer average periphyton biomass as represented by chlorophyll *a* for vertical sites retrieved September 2007.

Table 5.2-1. Summary of spring average periphyton chlorophyll *a* (standard deviations) for vertical treatment sites in Boundary and Box Canyon reservoirs, May 2007.

Date	Elevation Interval	Average Periphyton Chlorophyll *a* (mg/m^2) with (Standard Deviations)	
		Lower Vertical	Box Vertical
May	2	0*	3.00 (0.79)
	5	3.02 (1.81)	1.62 (0.22)
	10	3.28 (1.07)	3.86 (0.58)
	15	3.05 (1.59)	3.47 (1.55)
	20	-	2.37 (0.59)
	25	2.06 (0.78)	1.44 (0.69)
	40	1.68 (0.65)	-

*The samples were retrieved dry. Dewatered samples retrieved in the summer were analyzed for verification that there were no viable periphyton cells as indicated by active chlorophyll *a* from dry samples (see Section 5.2.2).

Table 5.2-2. Summary of summer average periphyton chlorophyll *a* (standard deviations) for vertical treatment sites in Boundary and Box Canyon reservoirs, September 2007.

Date	Elevation Interval	Average Periphyton Chlorophyll *a* (mg/m^2) with (Standard Deviations)	
		Lower Vertical	Box Vertical
September	2	0.55 (0.21)	0.28 (0.13)*
	5	22.85 (5.19)	9.53 (4.13)
	10	3.48 (0.79)	3.05 (1.79)
	15	10.70 (2.57)	3.00 (0.99)
	20	-	4.71 (2.22)
	25	4.16 (2.43)	1.71 (0.78)
	40	1.19 (0.33)	-

*The samples were retrieved dry. Dewatered samples retrieved in the summer were analyzed for verification that there were no viable chlorophyll *a* cells on dry samples (see Section 5.2.2).

5.2.2. Shoreline Treatment Sites

Figures 5.2-3 and 5.2-4 graphically present the average periphyton chlorophyll *a* (mg/m^2) at each shoreline treatment site and elevation interval for samples collected in May and September respectively. Tables 5.2-3 through 5.2-4 summarize the average periphyton chlorophyll *a* found in shoreline treatment samples collected in May and September.

Average spring periphyton chlorophyll *a* for shoreline sites ranged from 0.68 to 5.46 mg/m^2. Baskets placed at the 2-foot and 5-foot elevation intervals in Lower Boundary were dewatered at the time of retrieval. Baskets placed at the 2 foot elevation interval in Upper Boundary were also dewatered at the time of retrieval in May. 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 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 to no viable chlorophyll *a* present and laboratory results were near detection limits. Once the hydraulic routing model is complete, the model will be used to determine the length of time the baskets were dry. This information will be used in validating the HSI curves for duration of inundation and duration of dewatering.

Upper Boundary Reservoir shoreline sites were slightly higher in periphyton chlorophyll *a* than lower Boundary and Box Canyon shoreline sites at elevation intervals of 10, 15, and 25 feet (Figure 5.2-3). Spring periphyton chlorophyll *a* at upper Boundary and Box Canyon shoreline sites decreased (88 percent and 74 percent reduction, respectively) with increasing elevation interval 10 to 40 feet. Spring periphyton chlorophyll *a* appears to stabilize at lower Boundary shoreline sites deeper than the 10-foot elevation interval (Figure 5.2-3 and Table 5.2-3).

Average summer periphyton chlorophyll *a* ranged from 0.81 to 12.81 mg/m^2 for shoreline sites. Hard substrate baskets deployed at the 2-foot elevation interval in upper Boundary and Box Canyon reservoirs were dewatered at the time of retrieval at the end of August. Baskets deployed at the 5-foot elevation interval in upper Boundary were also dewatered at the time of retrieval.

Overall summer periphyton chlorophyll *a* levels was larger and much more variable than chlorophyll *a* levels seen during the spring. This is especially true for periphyton chlorophyll *a* on baskets placed at the 5-foot elevation interval at shoreline sites in lower Boundary and Box Canyon reservoirs (Figure 5.2-4). The highest periphyton chlorophyll *a* at the Upper Boundary shoreline site was seen at the 15-foot elevation interval. Some of this variability may be due to temporal exposure from artificial drawdowns in support of other studies during August 2007 limiting periphytic growth at the 5-foot and 10-foot elevation intervals. Some variability expressed as a bimodal pattern in the summer chlorophyll *a* concentrations indicate that periphyton growth is being affected by other factors and potential seasonal conditions beyond light (Figure 5.2-4 and Table 5.2-4). Additional analysis of the data will be attempted to try to isolate controlling factors once all of the periphyton data have been collected and are available for comprehensive analysis relative to validation of the HSI curves.

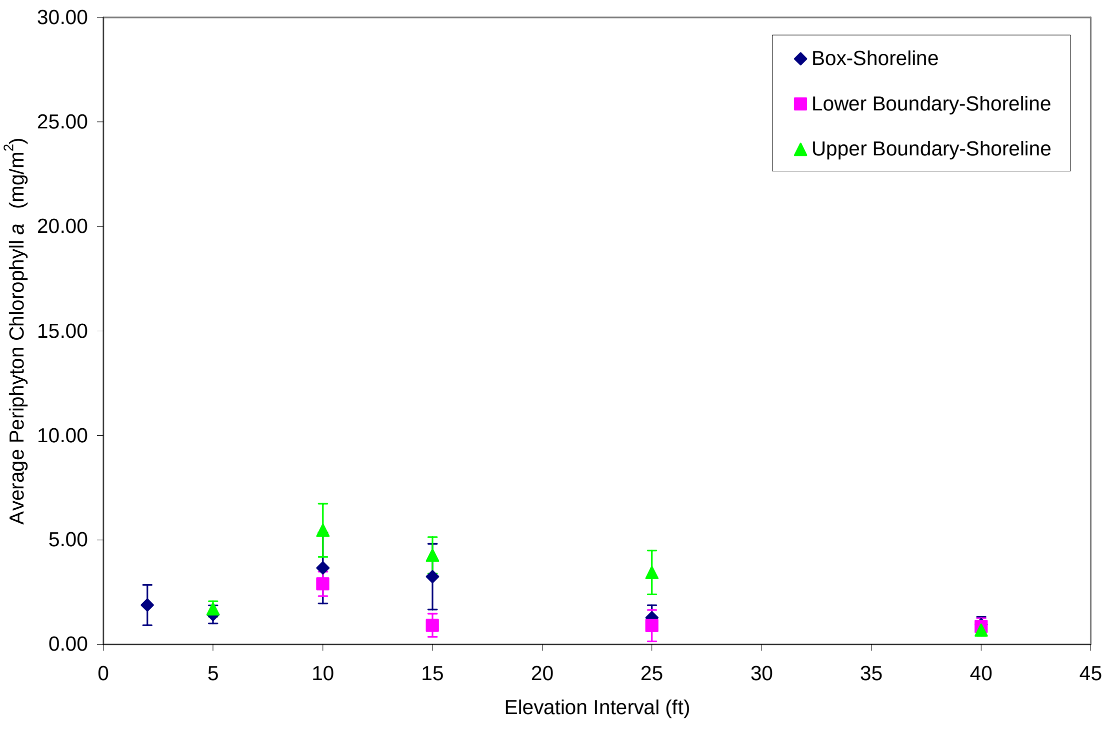


Figure 5.2-3. Spring average periphyton chlorophyll *a* for shoreline sites retrieved May 2007.

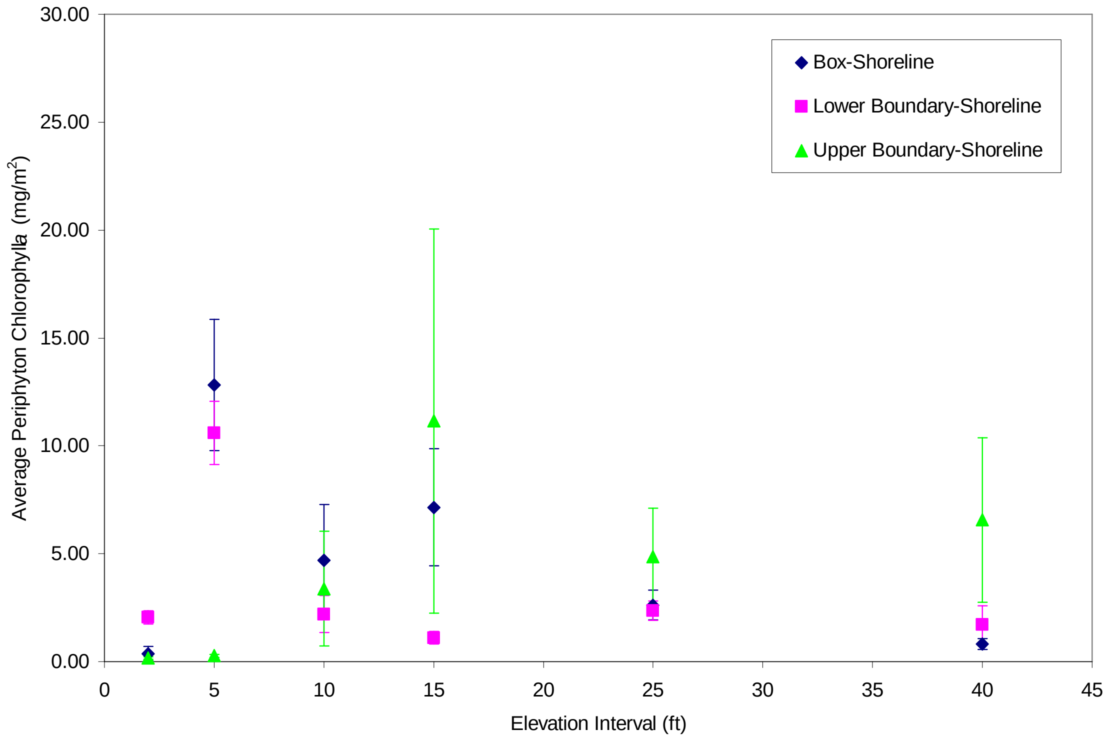


Figure 5.2-4. Summer average periphyton chlorophyll *a* for shoreline sites retrieved September 2007.

Table 5.2-3. Summary of spring average periphyton chlorophyll *a* (standard deviations) for shoreline treatment sites in Boundary and Box Canyon reservoirs, May 2007.

Date	Elevation Interval	Average Periphyton Chlorophyll *a* (mg/m^2) with (Standard Deviations)		
		Lower Shoreline	Upper Shoreline	Box Shoreline
May	2	0*	0*	1.88 (0.96)
	5	0*	1.70 (0.37)	1.43 (0.43)
	10	2.89 (0.59)	5.46 (1.27)	3.65 (1.70)
	15	0.91 (0.56)	4.26 (0.88)	3.24 (1.57)
	20	-	-	-
	25	0.89 (0.75)	3.44 (1.05)	1.28 (0.59)
	40	0.85 (0.41)	0.68 (0.28)	0.95 (0.36)

*The samples were retrieved dry. Dewatered samples retrieved in the summer were analyzed for verification that there were no viable chlorophyll *a* cells on dry samples.

Table 5.2-4. Summary of summer average periphyton chlorophyll *a* (standard deviations) for shoreline treatment sites in Boundary and Box Canyon reservoirs, September 2007.

Date	Elevation Interval	Average Periphyton Chlorophyll *a* (mg/m^2) with (Standard Deviations)		
		Lower Shoreline	Upper Shoreline	Box Shoreline
September	2	2.05 (0.32)	0.17* (0.05)	0.38* (0.33)
	5	10.61 (1.46)	0.27* (0.07)	12.81 (3.03)
	10	2.20 (0.85)	3.38 (2.65)	4.71 (2.58)
	15	1.11 (0.30)	11.15 (8.90)	7.14 (2.71)
	20	-	-	-
	25	2.37 (0.45)	4.86 (2.24)	2.62 (0.70)
	40	1.71 (0.88)	6.57 (3.82)	0.81 (0.25)

*The samples were retrieved dry. Dewatered samples retrieved in the summer were analyzed for verification that there were no viable chlorophyll *a* cells on dry samples.

5.3. 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 sampling has begun with the first colonization basket deployed during the first week of December 2007. Winter colonization baskets will continue to be deployed until January 30, 2008, weather and reservoir conditions permitting.

Average summer periphyton chlorophyll *a* collected from colonization baskets in Box Canyon reservoir are shown in Figure 5.3-1 and summarized in Table 5.3-1. Average summer periphyton colonization rates were calculated by depth and are presented in Figure 5.3-2. A figure presenting hourly water surface elevations in Box Canyon Reservoir during the time colonization baskets were deployed will be inserted into the report once the data are reviewed. Water surface elevation data were acquired from Pend Oreille Public Utility District and are currently being reviewed.

Average summer periphyton chlorophyll *a* collected from colonization baskets ranged from 0.80 to 17.02 mg/m^2 at all elevation intervals (5, 15, and 25 feet). The highest periphyton chlorophyll *a* was seen at the 5 foot elevation interval and after 42 days (6 weeks) of incubation. The lowest periphyton chlorophyll *a* was seen at the 25 foot elevation interval after only 3 days of incubation. Summer periphyton colonization rates varied from 0.24 to 0.55 mg/m^2-day for baskets at the 5 foot elevation interval, 0.11-0.35 mg/m^2-day for baskets at the 15 foot elevation interval, and 0.04 to 0.27 mg/m^2-day for baskets at the 25 foot elevation interval. There was a decrease in periphyton colonization at Day 28. This decrease will be investigated further to determine whether fluctuating water surface elevations in Box Canyon Reservoir or other factors (weather, light, nutrients) are influencing periphyton colonization. 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.

Once the complete data set is collected for periphyton colonization, the HSI for duration of inundation will be refined. Preliminary results show that the optimal colonization rates may be slower than suggested in the literature-based HSI curve. This may be a result of conditions specific to the Boundary and Box Canyon reservoirs, such as low nutrient concentrations and light limitations. Further analyses of the colonization rates of periphyton will be conducted and the HSI curves will be adjusted accordingly. Contrary to longer periods of time to reach peak colonization is a possibility that artificial substrate allows for greater accumulation of biomass as measured by chlorophyll *a* resulting from summer low velocities compounded by artificially reduced velocities in the baskets. This testing is recommended by employing baskets and sampling of natural substrate using a side-by-side design over time and depth intervals. After completing this recommended data collection, refinement of HSI curves will be conducted.

The average colonization rates determined for summer and winter spring periods for Box Canyon Reservoir will be used along with water surface elevations obtained from the Pend Oreille Public Utility District to refine the literature-based HSI model. Specifically, the colonization data collected will be used to validate the duration of inundation and dewatering portion of the periphyton HSI model.

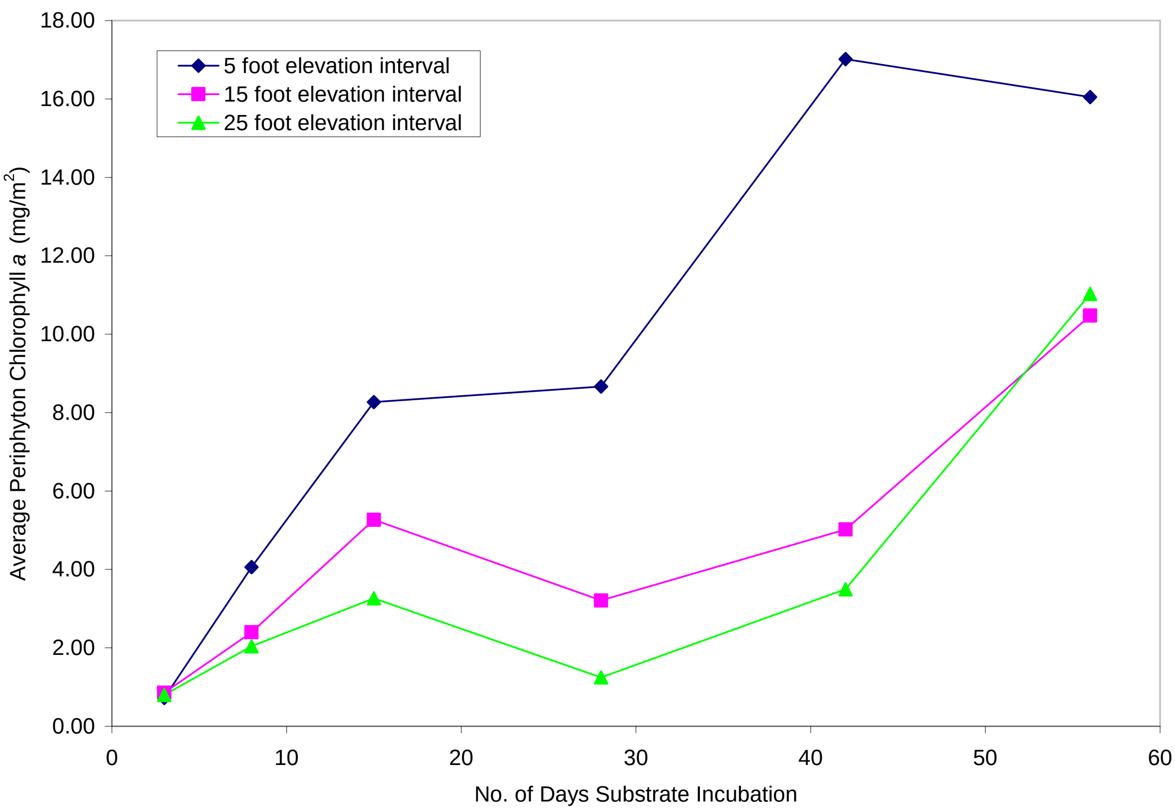


Figure 5.3-1. Average summer periphyton chlorophyll *a* collected at elevation intervals 5, 15, and 25 feet in Box Canyon reservoir after various days of incubation.

Table 5.3-1. Average summer periphyton chlorophyll *a* and colonization rates per elevation interval and number of days incubated in Box Canyon Reservoir.

Date Retrieved	No. of Days Exposed	Elevation Interval	Average Periphyton Chlorophyll *a* (mg/m²)	Periphyton Colonization Rate (mg/m²-day)
September	56	5	16.05	0.29
		15	10.47	0.19
		25	11.03	0.20
	42	5	17.02	0.41
		15	5.02	0.12
		25	3.50	0.08
	28	5	8.67	0.31
		15	3.21	0.11
		25	1.25	0.04
	15	5	8.27	0.55
		15	5.26	0.35
		25	3.27	0.22
	8	5	4.06	0.51
		15	2.40	0.30
		25	2.04	0.26
	3	5	0.72	0.24
		15	0.85	0.28
		25	0.80	0.27

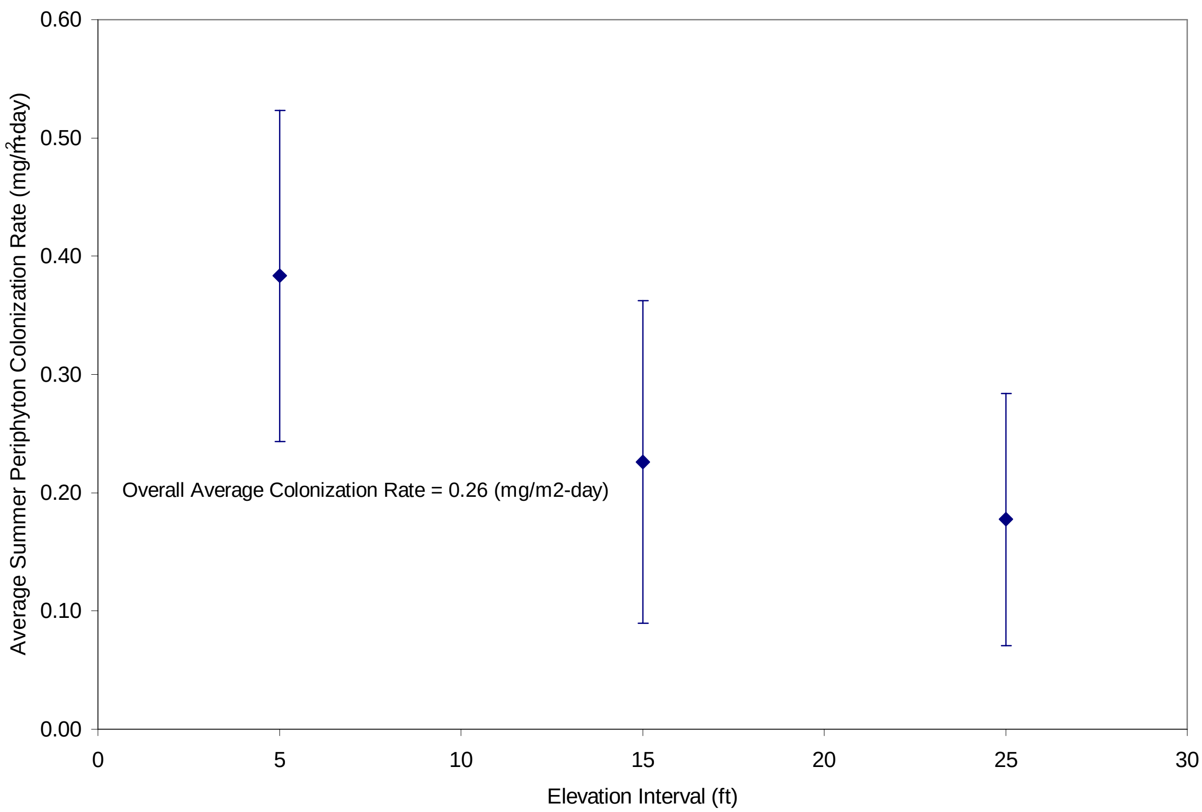


Figure 5.3-2. Average summer periphyton colonization rate, 2007.

5.4. Validation of Periphyton HSI Curves

Once all periphyton monitoring data are collected, field data along with results from the hydraulic model will be used to further refine and validate HSI curves for depth, velocity, substrate, and duration of inundation and dewatering. The hydraulic routing model will provide information concerning site-specific water surface elevations during the sampling period so the depth of each sample and the duration of inundation and dewatering can be determined. The hydraulic model will also provide information on the water velocity at each treatment site. Using the information provided by the hydraulic model, 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 can be refined and validated for Boundary Reservoir. A histogram will be developed for each of the habitat parameters using site-specific periphyton field data and then compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve for aquatic habitat modeling. Validated HSI curves will be presented in the final report.

5.5. Final Periphyton HSI Curves

A panel of relicensing participants and regional experts (agency, tribal, industry and university researchers) will convene to confirm the periphyton HSI curves that were validated with site-specific data. A roundtable discussion format is proposed, where the panel members will review literature-based periphyton community information and site-specific data to develop a final set of HSI curves. These curves will then be used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for operations scenarios.

6 SUMMARY

At this time, a literature-based HSI curve has been developed for periphyton within Boundary Reservoir. The HSI curve developed addresses periphyton responses to changes in depth, velocity, substrate, and duration of inundation and dewatering. During the literature review no appropriate suitability curves were found for periphyton, so other literature information was used to develop suitability values. These suitability values will be refined based on site-specific field data collected in 2007 and 2008.

Site-specific periphyton data have been collected in Boundary and Box Canyon reservoirs for spring, summer, and fall seasons. Fall periphyton samples are currently being analyzed by the laboratory and will be presented along with winter data in the final report. Winter periphyton data samples and periphyton colonization samples are to be collected in February 2008, weather and reservoir conditions permitting. Retrieval of winter periphyton samples and colonization baskets may not occur until March due to adverse weather and reservoir conditions (i.e., ice). The site-specific data collected from field efforts along with results from the hydraulic model will be used to calibrate and validate the literature-based HSI curve.

Initial analysis of data indicates that periphyton responses in Boundary and Box Canyon reservoirs are responding to select environmental variables as per experimental design which will lead to refinement of the HSI periphyton literature-based model. At all treatment sites and seasons with the exception of the shoreline treatment sites in the summer, periphyton chlorophyll *a* is decreasing with decreasing elevation intervals after reaching maximum. The variability in the summer chlorophyll *a* concentrations at the shoreline treatment sites indicates that periphyton growth is being affected by other factors such as study drawdown and potential seasonal conditions. A comparative analysis of the periphyton data with outputs from the hydraulic model and habitat transect data will take place in 2008 and will allow for deciphering these conditions for further validation of the HSI curves. Specifically, chlorophyll *a* data in combination with cross-sectional data of depth, velocity, and substrate combined with the output for reservoir water surface elevation and velocities from the hydraulic routing model will result in a Boundary Reservoir definition that supports any refinement of the periphyton HSI.

The effects of pool fluctuations can be seen on periphyton communities at 2- and 5-foot elevation intervals at shoreline sites in upper Boundary and Box Canyon reservoirs in spring and at 2-foot elevation interval at all sites in Boundary and Box Canyon reservoirs in the summer. Baskets at these elevation intervals were dry or partially dry at the time of retrieval and no viable periphyton chlorophyll *a* cells were found. The time these samples were dewatered will be calculated using the water surface elevations from the hydraulic model and will be used to refine the HSI curve for duration of dewatering.

Results from the summer colonization samples confirm the original experimental design of an 8 week incubation time. Colonization baskets placed at 15- and 25-foot elevation intervals had peak periphyton growth after 8 weeks of incubation. Although baskets placed at the 5-foot elevation interval experienced peak periphyton growth after 6 weeks of incubation, there was only a slight difference in periphyton growth between 8 and 6 weeks of incubation.

The artificial baskets and suspended platforms used to collect periphyton create an environmental condition that diverges from velocity gradients present in hard rock substrate within the Boundary Reservoir. This reduction in velocity may result 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. This reduction in velocity may be one of the factors that are responsible for the high variation in summer periphyton chlorophyll *a* at shoreline treatment sites along with inundation and dewatering, and solar aspect. A direct comparison between colonization within artificial baskets and *in situ* communities is proposed to verify the influence of velocity on periphyton accumulation within the substrate relative to periphyton removal from substrate. An additional study is recommended for 2008 to compare the periphyton found in the artificial substrate samplers with periphyton on natural hard substrate at shoreline sites in all three reservoir locations. The study will evaluate 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 will be used to verify the validation of HSI curves and to test the hypothesis that the influence of velocity on periphyton growth is being under-expressed by the geometry of the baskets. Data from the baskets would be corrected by applying a correction factor developed through comparison of artificial and natural substrate.

Once the HSI curves for periphyton in Boundary Reservoir have been validated and finalized, they will be used to define the relationship between habitat quantity and quality for periphyton for operations scenarios. The final periphyton HSI curve will also be incorporated into the larger HSI model, along with benthic invertebrate, macrophyte, and fish data, to gain a broader understanding of the biotic response to operations scenarios of Boundary Dam.

7 REFERENCES

Angradi, T.R. and D.M. Kubly. 2006. Effects of atmospheric exposure on chlorophyll *a*, biomass and productivity of the epilithon of a tailwater river. *Regulated Rivers: Research and Management* 8(4): 345-358.

Blinn, D.W., and J.P. Shannon, L.E. Stevens, J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. *Journal of the North American Benthological Society*. 14(2): 233-248.

Brusven, M.A., C. MacPhee, and R. Biggam. 1974. Chapter 5 Benthic Insects (Effects of Water Fluctuation on Benthic Insects). University of Idaho: Moscow, Idaho.

Chisholm, I.M., M.E. Hensler, B. Hansen, and D. Skaar. 1989. Quantification of Libby Reservoir levels needed to maintain or enhance reservoir fisheries. Methods and Data Summary 1983-1987. Prepared for Bonneville Power Administration by Montana Department of Fish, Wildlife and Parks. Kalispell, Montana.

DeVries, P., B. Kvam, S. Beck, D. Reiser, M. Ramey, C. Huang, and C. Eakin. 2001. Kerr Hydroelectric Project, Lower Flathead River ramping rate study. Prepared by R2 Resource Consultants, for Confederated Salish and Kootenai Tribes of the Flathead Nation, Montana.

Fillion, D.B. 1967. The abundance and distribution of benthic fauna of the three mountain reservoirs on the Kananaskis River in Alberta. *Journal of Applied Ecology* 4: 1-11.

Fisher, S.G. and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. *Journal of the Fisheries Research Board of Canada* 29: 1472-1476.

Furey, P.C., R.N. Nordin, and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. *Journal of the North American Benthological Society* 25(1): 19-31.

Gislason, J.C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. *North American Journal of Fisheries Management* 5: 39-46.

Grzybkowska, M. and M. Dukowska. 2002. Communities of Chironomidae (Diptera) above and below a reservoir on a lowland river: long-term study. *Annales Zoologici* (Warszawa) 52:235-247.

Horner, R.R., E.B. Welch, M.R. Seeley, and J.M. Jacoby. 1990. Responses of periphyton to changes in current velocity, suspended sediment and phosphorus concentration. *Freshwater Biology*. 24(2): 215-232.

Kaster, J.L. and Jacobi, G.Z. 1978. Benthic macroinvertebrates in a fluctuating reservoir. *Freshwater Biology*. 8(3): 283-290.

May, B., S. Glutting, T. Weaver, G. Michael, B. Morgan, P. Suek, J. Wachsmuth, and C. Weichler. 1988. Quantification of Hungry Horse Reservoir levels needed to maintain or enhance reservoir fisheries. Methods and data summary technical report for 1983-1987. Prepared for Bonneville Power Administration by Montana Department of Fish, Wildlife and Parks. Kalispell, Montana.

Paterson, C.G. and C.H. Fernando. 1969. The effect of winter drainage on reservoir benthic fauna. *Canadian Journal of Zoology* 47: 589-595.

Perry, S.A. and W.B. Perry. 1986. Effects of experimental flow regulation on invertebrate drift and stranding in the Flathead and Kootenai rivers, Montana, USA. Hydrobiologia. 134:171-182.

Thorp, J.H., and A.P. Covich. 2001. An overview of freshwater habitats. In: J.H. Thorp and A.P. Covich, editors. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, California. Pp. 19-41.

Troelstrup, Jr., N.H. and G.L. Hergenrader. 1990. Effects of hydropower peaking flow fluctuations on community structure and feeding guilds of invertebrates colonizing artificial substrates in a large impounded river. *Hydrobiologia* 199: 217-228.

Ward, J.V. 1992. Aquatic insect ecology: 1. biology and habitat. John Wiley and Sons, New York.

Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems*. Academic Press, San Diego. 1006 pp.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

Appendix 1. Periphyton Literature-Based HSI Curve Report

Boundary Hydroelectric Project (FERC No. 2144)

Study 7.4.3

Periphyton and Benthic Macroinvertebrate HSI

Subtask 1 (Part): Periphyton Literature-Based HSI

Prepared for
Seattle City Light

Prepared by
Darlene Siegel, Merri Martz, Gene Welch, and Harry Gibbons
Tetra Tech

March 2008

Table of Contents

Appendices

List of Tables

List of Figures

Study 7.4.3 – Periphyton Habitat Suitability Index Interim Report Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Periphyton is included in the mainstem aquatic habitat model in the form of Habitat Suitability Curves (HSC) and Habitat Suitability Indices (HSI) to estimate periphyton productivity under various reservoir management scenarios. This report describes provisional literature-based HSC and HSI that will describe the response of periphyton to cyclic inundation and dewatering that may change physical parameters that the periphyton are exposed to, such as, water depth, water velocity, light, etc. These literature-based HSC and HSI will be supplemented by site-specific information developed through field studies. The response of periphyton to operations scenarios will be evaluated as part of Fish and Aquatic Study 11: Productivity Assessment to provide information on the effects of operations scenarios on primary and secondary production.

The abbreviation HSI is used in this document to refer to either HSI models or a combination of HSI and HSC, depending on the context. HSI models provide a quantitative relationship between 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 life stage, under to structure of Habitat Evaluation Procedures (USFWS 1980). Alternatively, HSC are designed for use in the Instream Flow Incremental Methodology to quantify changes in habitat under various flow regimes (Bovee et al. 1998). HSC describes the instream suitability of habitat variables related only to stream hydraulics and channel structure (i.e., depth, velocity, and substrate). Both HSC and HSI models are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Both HSI and HSC are hypotheses of species-habitat relationships and are intended to provide indicators of habitat change. For the Boundary Project aquatic habitat studies, HSC (i.e., depth, velocity, and substrate) and HSI (i.e., duration of inundation and dewatering) models will be integrated to analyze the effects of operations scenarios on periphyton.

Because periphyton communities are comprised of numerous taxa, the HSI for the Boundary Project will not be specific to any individual species, but will be developed for the commonly used chlorophyll *a* [periphyton] metric selected to represent the communities.

Periphyton are organisms that live on the benthic 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 algae portion of which are primary producers. Primary production 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 benthic macroinvertebrates and some fish, and/or birds.

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). 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 surface elevation or flow. 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 in the varial zone is reduced (Fisher and LaVoy 1972, Ward 1992).

Varial zone habitats may be subjected to regular exposure to ultraviolet light, 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 production (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).

The combined depth, velocity, and substrate HSC will be used to identify optimal habitats for periphyton production. HSI describing the describing the rate of periphyton colonization and effects of dewatering will then be used to estimate the effects of operations scenarios on periphyton production. Data provided in this report are provisional estimates of suitability curves that can be used to estimate periphyton production under operations scenarios. Once field data from the Boundary and Box Canyon reservoirs have been collected and analyzed, the HSC/HSI will be adjusted, if needed, to accommodate this information.

2 STUDY OBJECTIVE

The objective for the development of a Boundary periphyton model is to help assess the effect of operations scenarios on aquatic production. Developing a periphyton model for the Boundary Project will help in evaluating how differences in depth, velocity, and substrate and the frequency, duration, and magnitude of inundation and dewatering can influence periphyton biomass. The Boundary periphyton evaluation process will use estimates of physical and hydraulic conditions under operations scenarios coupled with HSC and HSI information to provide a comparative index of periphyton production.

3 STUDY METHODS

The Boundary Project 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 3.0-1). During 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 3.0-1 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 3.0-1. Boundary periphyton model

Periphyton Composite Suitability Index	$CSI_i = HSC_i * HSI_i$
Periphyton HSC	$HSC_i = D_i * Vo_i * S_i$
Periphyton HSI	$HSI_i = f(DI_i, DD_i)$[1]
Periphyton Variables	D_i = Depth Vo_i = Velocity S_i = Substrate DI_i = Duration of Inundation DD_i = Duration of Dewatering

[1] See Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, 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 for 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: 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 will be 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 will be 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 is 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 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 Fish and Aquatic Study 7: Mainstem Aquatic Habitat Model, 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 periphyton production 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.

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 is to determine the response of periphyton as a whole. As such, the HSC and HSI curves provided here focus on the suitability for periphyton as a group based, in part, on information from literature and professional experience and judgment. Section 4 includes a summary of the information from literature sources and the provisional suitability curves.

4 HSI MODEL VARIABLES

4.1. 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 4.1-1).

Another procedure that may be used to estimate euphotic zone depth is to assume that the Secchi disk disappears at 10 percent of surface I_o (100 percent) and this value is then used in the equation for light attenuation $I_z = I_o e^{-KZ}$. Under this procedure, the euphotic zone depth would equate to 4 meters for April and 3.2 meters for May. Further calibration of the euphotic zone depths will be conducted with data collected in the field.

Provisional suitability values (Table 4.1-2) 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. Further calibration of the index values will be supported with data collected in the field evaluating the differences in periphyton biomass at varying water depths. Figure 4.1-1 displays the provisional depth suitability curve for periphyton.

Table 4.1-1. 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*	16.7*	28.5*	44.3*	39.4*	34.5*	34.5	34.5

* Estimated euphotic depth based on three times the Secchi disk readings reported by McLellan and O'Connor (2001).

Table 4.1-2. Depth ranges and provisional suitability values for periphyton.

Depth (feet)	Provisional Suitability Values
0	0.75
3.28 ft (1m)	1.0
16.4 ft (5m)	1.0
32.8 ft (10m)	0.6
49.2 (15m)	0.01
98.4 ft (30m)	0.0

Source: Wright and Szluha 1980, Ward 1992, Thorp and Covich 2001, Wetzel 2001, McLellan and O'Connor 2001

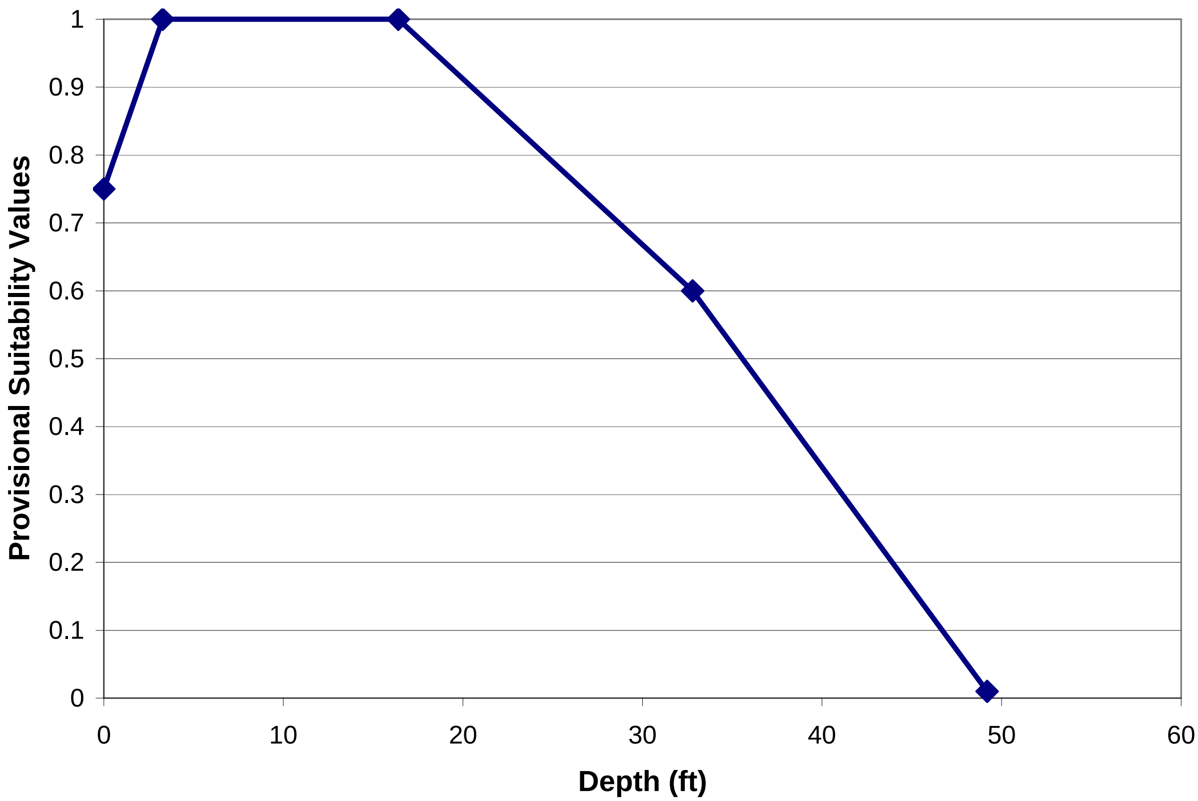


Figure 4.1-1. Provisional depth suitability curve for periphyton, note value is zero at 98 ft where light is insufficient for photosynthesis.

4.2. 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 1996).

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 [ft/s]) to lowest biomass at highest velocities (greater than 2.30 ft/s). 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 ft/s (0.5 to 0.7 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 ft/s (0.5 m/s). In laboratory flumes Horner et al. (1990) found the maximum biomass at 1.97 ft/s (0.6 m/s). However, abrupt increases to higher velocities especially with suspended solids can detach periphyton and cause sloughing.

Provisional suitability values (Table 4.2-1) 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). Further calibration of the index values will be supported with data collected in the field evaluating the differences in periphyton biomass and the associated water velocity and potential correlation with nutrient data. This relationship emphasizes scouring loss and ignores nutrients, which are more stimulatory as velocity increases (Welch and Jacoby 2004). Figure 4.2-1 displays the provisional velocity suitability curve for periphyton.

Table 4.2-1. Velocity ranges and provisional suitability values for periphyton.

Velocity (feet/second)	Provisional Suitability Values
0 ft/s	0.9
0.82 ft/s (0.25m/s)	1.0
1.64 ft/s (0.5m/s)	1.0
2.46 ft/s (0.75m/s)	0.5
3.28 ft/s (1m/s)	0

Source: Biggs 1996, Biggs and Stokseth 1996, Biggs and Gerbeaux 1993

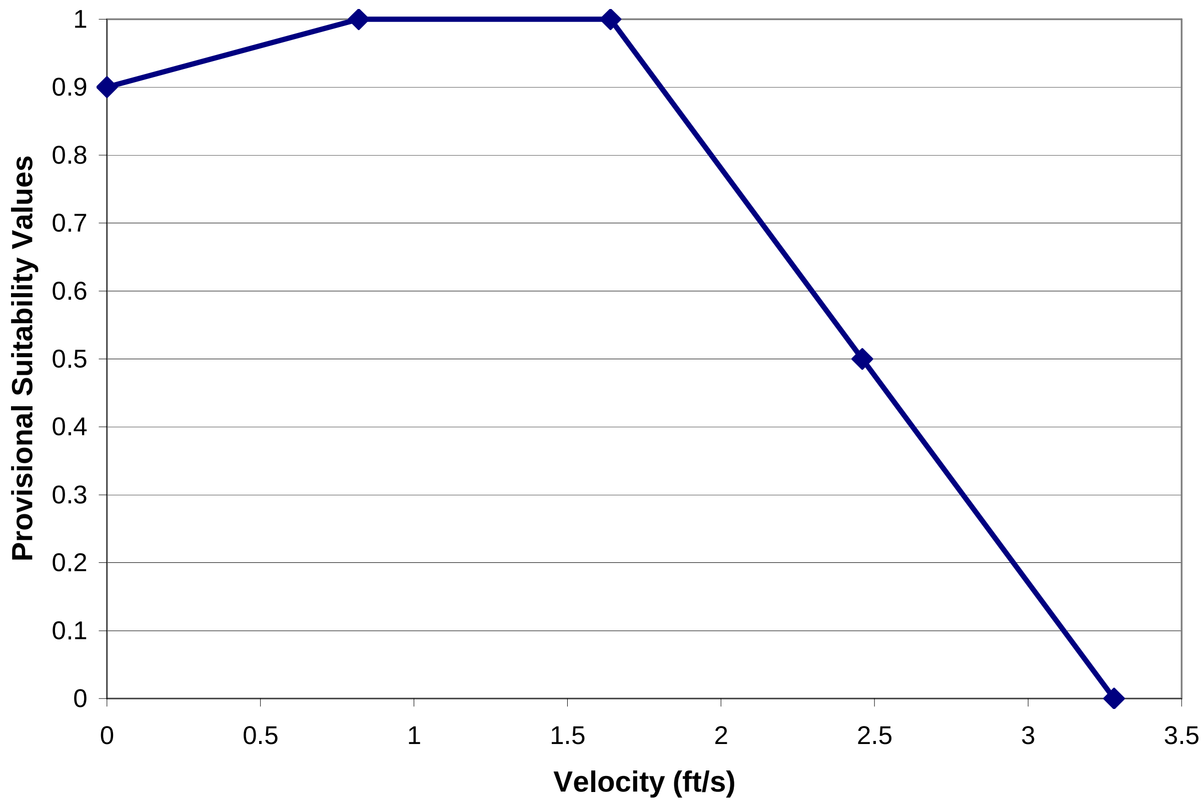


Figure 4.2-1. Provisional velocity suitability curve for periphyton.

4.3. 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, we assume 1 (Table 4.3-1). Figure 4.3-1 displays the provisional substrate suitability curve for periphyton.

Table 4.3-1. Substrate types and provisional suitability values for periphyton.

Substrate Type	Provisional Suitability Values
Hard Substrates	1.0
Silt or Organic Substrate	0

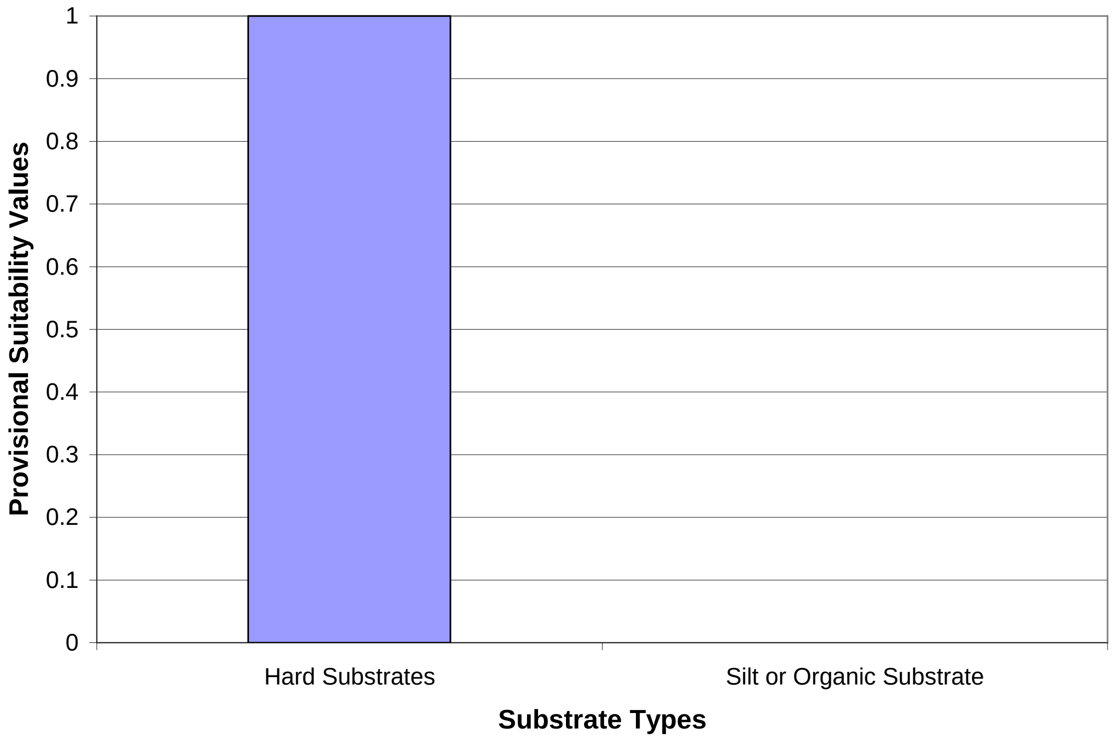


Figure 4.3-1. Provisional substrate suitability values for periphyton.

4.4. 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 4.4-1). Further calibration of the index values will be supported with data collected in the field evaluating the response of periphyton communities to the dewatering cycle found in Boundary Reservoir over multiple seasons. Figure 4.4-1 displays the provisional duration of dewatering suitability curve for periphyton.

Table 4.4-1. 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

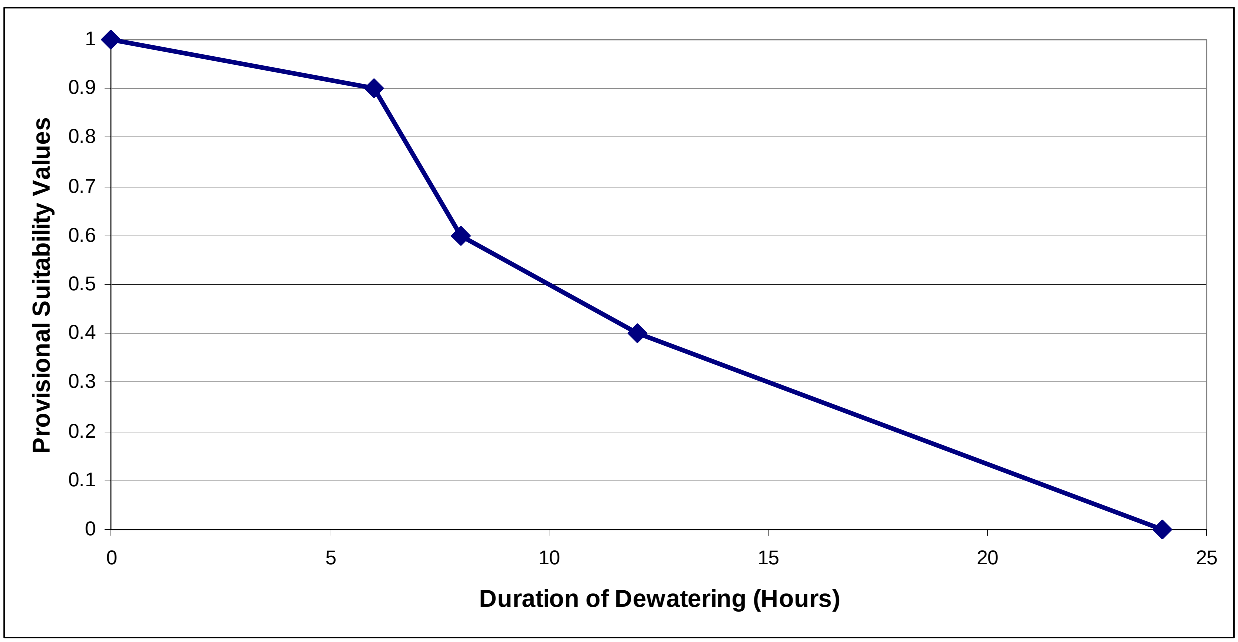


Figure 4.4-1. Provisional duration of dewatering suitability curve for periphyton, note at 24 hours of exposure it is assumed that viable periphyton is zero.

4.5. 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 un-enriched 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. If observations show nutrient conditions to play a role they will be included in the final version of this model.

Provisional suitability values for duration of inundation were selected based on the effects of varying colonization rates found in the literature (Table 4.5-1). Further calibration of the index values will be supported with data collected in the field evaluating the response of periphyton communities to the inundation cycle found in Boundary Reservoir over multiple seasons. Figure 4.5-1 displays the provisional duration of inundation suitability curve for periphyton.

Table 4.5-1. Duration of inundation provisional suitability values for periphyton.

Duration of Inundation (Time)	Provisional Suitability Values
0 hours	0.0
1 day	0.1
3 days	0.5
7 days	0.8
>21 days	1.0

Source: Blinn et al. 1995, Biggs 1998, Falter 2004

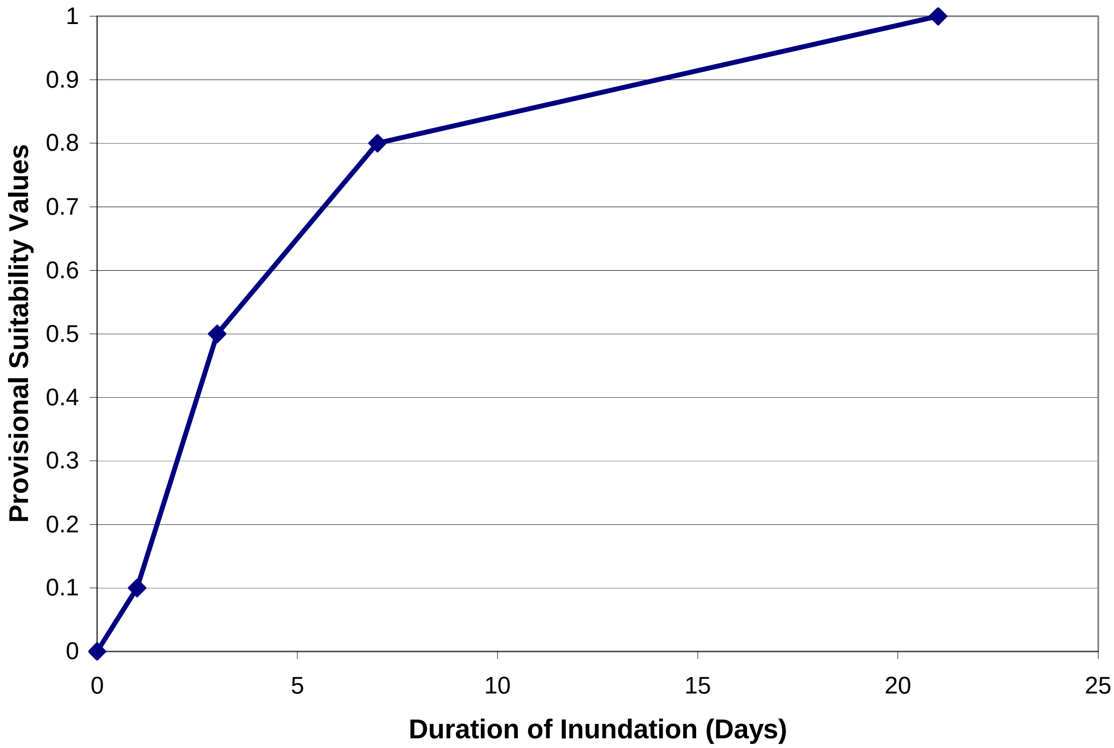


Figure 4.5-1. Provisional duration of inundation suitability curve for periphyton.

5 REFERENCES

Angradi, T.R. and D.M. Kubly. 2006. Effects of atmospheric exposure on chlorophyll *a*, biomass and productivity of the epilithon of a tailwater river. *Regulated Rivers: Research and Management* 8(4): 345-358.

Biggs, B.J.F. 1998. Hydraulic habitat of plants in streams. *Regulated Rivers: Research and Management*. 12(2-3): 131-144.

Biggs, B.J.F. and Gerbeaux, P. 1993. Periphyton development in relation to macro-scale (geology) and micro-scale (velocity) limiters in two gravel-bed rivers, New Zealand. *New Zealand Journal of Marine and Freshwater Research*. 27:39-53.

Biggs, B.J.F. and S. Stokseth. 1996. Hydraulic habitat suitability for periphyton in rivers. *Regulated Rivers: Research and Management*. 12:251-261.

Blinn, D.W., and J.P. Shannon, L.E. Stevens, J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. *Journal of the North American Benthological Society*. 14(2): 233-248.

Falter, C.M. 2004. Lake Pend Oreille littoral periphyton community: an updated trophic status assessment, 2003. Final report submitted to the Tri-State Water Quality Council. Moscow, Idaho.

Fillion, D.B. 1967. The abundance and distribution of benthic fauna of the three mountain reservoirs on the Kananaskis River in Alberta. *Journal of Applied Ecology* 4: 1-11.

Fisher, S.G. and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. *Journal of the Fisheries Research Board of Canada* 29: 1472-1476.

Furey, P.C., R.N. Nordin, and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. *Journal of the North American Benthological Society* 25(1): 19-31.

Gislason, J.C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. *North American Journal of Fisheries Management* 5: 39-46.

Horner, R.R. and Welch, E.B. 1981. Stream periphyton development in relation to current velocity and nutrients. *Canadian Journal of Fisheries and Aquatic Sciences*. 38: 449-457.

Horner, R.R., E.B. Welch, M.R. Seeley, and J.M. Jacoby. 1990. Responses of periphyton to changes in current velocity, suspended sediment and phosphorus concentration. *Freshwater Biology* 24(2): 215-232.

Kaster, J.L. and Jacobi, G.Z. 1978. Benthic macroinvertebrates in a fluctuating reservoir. *Freshwater Biology* 8(3): 283-290.

Larson, G.L., C.D. McIntire and R.W. Jacobs, eds. 1993. Crater Lake Limnological Studies Final Report. Technical Report NPS/PNROWU-93/03. National Park Services, Pacific Northwest Region, Seattle, Washington. 722 pp.

McLellan, J.G. and D. O'Connor. 2001. 2000 WDFW Annual Report for the Project, Resident Fish Stock Status Above Chief Joseph and Grand Coulee Dams. Part I. Baseline Assessment of Boundary Reservoir, Pend Oreille River, and its Tributaries. Report to Bonneville Power Administration, Contract No. 00004619, Project No. 199700400.

Perry, S.A. and W.B. Perry. 1986. Effects of experimental flow regulation on invertebrate drift and stranding in the Flathead and Kootenai rivers, Montana, USA. *Hydrobiologia*. 134:171-182.

Reynolds, C.S. 1996. Algae. Pp 6-26 in Petts, G. and P. Calow, eds., *River Biota: Diversity and Dynamics*. Blackwell Science, Oxford, England.

Stevenson, R.J. 1983. Effects of current and conditions simulating autogenically changing microhabitats on benthic diatom immigration. *Ecology* 64: 1514-1524.

Stevenson, R.J. 1990. Benthic algal community dynamics in a stream during and after a spate. *Journal of the North American Benthological Society* 9:277-288.

Tri-State Water Quality Council. 2004. Voluntary Nutrient Reduction Report. http://www.tristatecouncil.org/pages/vnrp3yr.htm.

Troelstrup, Jr., N.H. and G.L. Hergenrader. 1990. Effects of hydropower peaking flow fluctuations on community structure and feeding guilds of invertebrates colonizing artificial substrates in a large impounded river. *Hydrobiologia* 199: 217-228.

U.S. Environmental Protection Agency (EPA). 1998. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. Available online at http://www.epa.gov/owow/monitoring/tech/lakes.html

Usher, H.D. and D.W. Blinn. 1990. Influence of various exposure periods on the biomass and chlorophyll of Cladophora glomerata (Chlorophyta). *Journal of Phycology* 26:244-249.

Ward, J.V. 1992. Aquatic insect ecology: 1. biology and habitat. John Wiley and Sons, New York.

Welch, E.B. and J.M. Jacoby. 2004. *Polluted Effects in Freshwater; Applied Limnology*. 3rd edition, Taylor and Francis, London.

Wetzel, R.G. 2001. *Limnology: Lake and River Ecosystems*. Academic Press, San Diego. 1006 pp.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

Appendix A. Periphyton HSI Annotated Bibliography

Annotated Bibliography

Angradi, T.R. and D.M. Kubly. 2006. Effects of atmospheric exposure on chlorophyll a, biomass and productivity of the epilithon of a tailwater river. Regulated Rivers: Research and Management 8(4): 345-358.

Field experiments were conducted to determine the effects of atmospheric exposure on the chlorophyll *a* content, biomass and gross primary productivity (GPP) of littoral epilithon in the Colorado River below Glen Canyon Dam, Arizona. The chlorophyll *a* content of the epilithon was much more sensitive to exposure than the biomass. The epilithon was rapidly bleached during summer daytime exposures, but algal filaments remained attached for several weeks after reinundation. Significant reductions in chlorophyll *a* content were detected for daytime exposures as short as six hours. The GPP of Cladophora epilithon from the permanently inundated channel was 10 times higher than the GPP of epilithon for the zone of daily water level fluctuation.

Benenati, P.L., and J.P. Shannon, D.W. Blinn. 1998. Desiccation and recolonization of phytobenthos in a regulated desert river: Colorado River at Lees Ferry, Arizona, USA. Regulated Rivers: Research and Management. 14(6): 519-532.

This study tested the recolonization of the phytobenthic community in the tailwaters of Glen Canyon Dam following long- and short-term experimentally induced desiccation. Diatom density on desiccated cobbles in the submerged and varial zones averaged 69 and 42 percent of that of the controls, respectively. Recovery and maintenance of benthic resources were found to be hindered by fluctuating flow regimes driven by electricity and irrigation requirements.

Biggs, B.J.F. 1988. Artificial substrate exposure times for periphyton biomass estimates in rivers. New Zealand Journal of Marine and Freshwater Research. 22:507-515.

This study investigated the time for periphyton biomass to accrue to approx. natural levels on a new artificial substrate sampler. In unenriched and enriched rivers, biomass on the artificial substrates approximated natural substrate communities after 4 weeks. In moderately enriched rivers results were highly variable and artificial substrate biomass gave only a fair representation of natural substrate levels after 8 weeks.

Biggs, B.J.F. 1996. Hydraulic habitat of plants in streams. Regulated Rivers: Research and Management. 12(2-3): 131-144.

The hydraulic stability among streams was reviewed to determine the effects on periphyton, bryophytes, and macrophytes. Periphyton and macrophyte colonization was determined to be enhanced by low velocities. However, for mature communities, the peak biomass of periphyton and macrophytes can be negatively correlated with velocity.

Biggs, B.J.F. and Gerbeaux, P. 1993. Periphyton development in relation to macro-scale (geology) and micro-scale (velocity) limiters in tow gravel-bed rivers, New Zealand. New Zealand Journal of Marine and Freshwater Research. 27:39-53.

Periphyton communities were sampled to distinguish the relative importance of large-scale catchment variables from small-scale local variables in determining the development of periphyton in rivers. It was determined that geology was more important in determining longer-term production, but velocity was more important in short-term temporal biomass dynamics.

Biggs, B.J.F. and S. Stokseth. 1996. Hydraulic habitat suitability for periphyton in rivers. Regulated Rivers: Research and Management. 12:251-261.

Relationships between periphyton biomass and water velocity were determined in two rivers for communities under various stages of accrual. No difference in periphyton biomass could be detected among low, medium, and high velocity habitats for the early stages of colonization. However, at the end of the colonization period there were differences with a gradient from highest biomass at low velocities (<0.3 m/s) to lowest biomass at highest velocities (>0.7 m/s). When the communities reached maturity (day 92) there was a unimodal distribution of biomass as a function of velocity with a peak in AFDM at 0.5 – 0.7 m/s.

Blinn, D.W., and J.P. Shannon, L.E. Stevens, J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. Journal of the North American Benthological Society. 14(2): 233-248.

The influence of fluctuations in river discharge on the structure and function of tailwaters benthos downstream from Glen Canyon Dam was tested. Periods of daily desiccation and freezing during river fluctuation significantly limited community biomass and energy. Discharge fluctuations during the summer and winter influenced the 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.

EPA. 1998. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. Available at http://www.epa.gov/owow/monitoring/tech/lakes.html.

EPA's protocol for lake bioassessment. Includes an overview of bioassessment and biocriteria, guidelines for reference condition selection, habitat measurements, index developments, and biocriteria implementation.

Falter, C.M. 2004. Lake Pend Oreille littoral periphyton community: an updated trophic status assessment, 2003. Final report submitted to the Tri-State Water Quality Council. Moscow, Idaho.

There is growing concern that nutrient enrichment and lake level management may cause a shift in periphyton distribution and composition in Lake Pend Oreille, Idaho. This study analyzing periphyton growth over multiple years shows 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.

Fillion, D.B. 1967. The abundance and distribution of benthic fauna of the three mountain reservoirs on the Kananaskis River in Alberta. Journal of Applied Ecology 4: 1-11.

Three artificially regulated reservoirs were investigated to assess the distribution of macroinvertebrate communities. While the greatest total number of species was recorded in the varial zone, the greatest number of individuals was recorded from below the drawdown limit.

Fisher, S.G. and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. Journal of the Fisheries Research Board of Canada 29: 1472-1476.

Water level fluctuations below a hydroelectric dam on the Connecticut River was shown to influence the benthic community. As the magnitude and frequency of water level fluctuations increase, the abundance and diversity of periphyton is reduced in the varial zone.

Furey, P.C., R.N. Nordin, and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. Journal of the North American Benthological Society 25(1): 19-31.

This study compared the benthic macroinvertebrate community in sediments of littoral areas in a reservoir with >30 years of seasonal drawdowns to a natural lake with little seasonal change in water levels. Densities and biomasses of macroinvertebrates were higher below the drawdown exposure zone than in the upper littoral area of the reservoir. Variable drawdown regimes could have significant impacts on benthic food webs and the transfer of energy and nutrients to the pelagic area.

Gislason, J.C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. North American Journal of Fisheries Management 5: 39-46.

In the Skagit River, Washington the aquatic insect abundance was examined after subject to diel flow fluctuation from hydroelectric power-peaking in 1976 and to a relatively stable flow pattern in 1977. Under fluctuating flow conditions, insect density increased from shallow to deep water and was negatively correlated with hours of dewatering. Under stable flow conditions, the abundance of benthic insects was greatly enhanced.

Horner, R.R. and Welch, E.B. 1981. Stream periphyton development in relation to current velocity and nutrients. Canadian Journal of Fisheries and Aquatic Sciences. 38: 449-457.

This study suggests 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.

Horner, R.R., and E.B. Welch, M.R. Seeley, J.M. Jacoby. 1990. Responses of periphyton to changes in current velocity, suspended sediment and phosphorus concentration. Freshwater Biology. 24(2): 215-232.

This study measured the responses of periphyton to changes in current velocity, suspended sediment, and a range of limiting nutrient (phosphorus) concentrations. Velocities of 60 cm/s significantly enhanced biomass accrual, but further increase resulted in substantial biomass reduction. Sudden increases in velocity raised instantaneous loss rates by an order of magnitude or more. An elevation in velocity above that to which algae were accustomed, led to increased loss rates however, recolonization was rapid. Uptake rates of P by algae increased above 35 cm/s.

Kaster, J.L. and Jacobi, G.Z. 1978. Benthic macroinvertebrates in a fluctuating reservoir. Freshwater Biology. 8(3): 283-290.

Benthic macroinvertebrates were observed in a fluctuating central Wisconsin reservoir. A substantial portion of the macroinvertebrates were stranded and subsequently decreased rapidly in drying and frozen substrates exposed to air. Macroinvertebrate numbers and biomass were greatest immediately below the drawdown limit.

Larson, G.L., C.D. McIntire & R.W. Jacobs, eds. 1993. Crater Lake Limnological Studies Final Report. Technical Report NPS/PNROWU-93/03. National Park Services, Pacific Northwest Region, Seattle, WA. 722 pp.

Limnological studies have been conducted at Crater Lake National Park for ten years in response to a decline in the lake's clarity. The results of the study found Crater Lake to be an oligotrophic lake. Secchi disk clarity was in the high 20-m to mid 30-m range. Depth of 1 percent incident surface light generally was between 80 and 100 m. The lake was relatively high in dissolved salts, total alkalinity, and conductivity. In the winter and spring maximum primary production occurred between 40 and 60 m and between 100 and 140 m in the summer and fall.

McLellan, J. G. 2001. 2000 WDFW Annual Report for the Project, Resident Fish Stock Status Above Chief Joseph and Grand Coulee Dams. Part I. Baseline Assessment of Boundary Reservoir, Pend Oreille River, and its Tributaries. Report to Bonneville Power Administration, Contract No. 00004619, Project No. 199700400.

A baseline fisheries assessment of Boundary reservoir and its tributaries was conducted in 2000. Water quality, primary and secondary production, fish species composition and relative densities in the reservoir, fish habitat, and species composition were measured. Limiting factors for the fishery in Boundary Reservoir were identified as high summer water temperatures for salmonids, short retention times limiting primary and secondary production and daily water level fluctuations reducing already limited littoral habitat.

Perry, S.A. and W.B. Perry. 1986. Effects of experimental flow regulation on invertebrate drift and stranding in the Flathead and Kootenai rivers, Montana, USA. Hydrobiologia. 134:171-182.

Studies were conducted to determine the effects of experimental manipulations of discharge on invertebrate drift in two regulated rivers in northwestern Montana. The study found an inverse relation between discharge and invertebrate drift densities. In the Kootenai River, density estimates were much lower when samples were collected during the fall when flows had been fluctuated more frequently and the rate of flow reduction was slower.

Reynolds, C.S. 1996. Algae. Pp 6-26 in Petts, G. and P. Calow, eds., River Biota: Diversity and Dynamics. Blackwell Science, Oxford, England.

This book provides a review of river biota as taken from a selection of chapters of The Rivers Handbook. The chapter on algae defines algae and its habitats, its controlling factors and ecological processes.

Stevenson, R.J. 1983. Effects of current and conditions simulating autogenically changing microhabitats on benthic diatom immigration. Ecology. 64: 1514-1524.

Diatom immigration rates were affected by changes in current patterns. Immigration rates in areas sheltered from a 27 cm/s current were greater than in areas exposed to the current. Diatom immigration rates also increased by a factor of six when microhabitat conditions were altered by interrupting currents near the substrate surface. Effects of current velocity and microhabitat conditions were also related to species size and growth habits.

Stevenson, R.J. 1990. Benthic algal community dynamics in a stream during and after a spate. Journal of the North American Benthological Society. 9:277-288.

Changes in benthic algal community were observed during and after a major storm. It was hypothesized that benthic diatoms are affected positively by all but sever storms. Increases in current or nutrient supply to periphyton may have stimulated growth of live cells and retarded sexual reproduction.

Tri-State Water Quality Council. 2004. Voluntary Nutrient Reduction Report. http://www.tristatecouncil.org/pages/vnrp3yr.htm.

This report reviews the progress made by the Clark Fork Voluntary Nutrient Reduction Program (VNRP), a voluntary effort to control nutrient pollution and nuisance algae. The VNRP is a collaborative effort among a group of municipalities, industries, state government and environmental groups. The VNRP participant organizations signed a formal agreement which committed them to specific measures each would take to reduce discharge of nitrogen and phosphorus to the river, and to monitoring the effects of their work on water quality in the river.

Troelstrup, Jr., N.H. and G.L. Hergenrader. 1990. Effects of hydropower peaking flow fluctuations on community structure and feeding guilds of invertebrates colonizing artificial substrates in a large impounded river. Hydrobiologia. 199: 217-228.

This study was performed to examine the community structure of invertebrates colonizing artificial substrates in an impounded, power peaking fluctuating river. Invertebrate communities on shallow samplers subjected to exposure from diel fluctuations in flow averaged 3 taxa per sampler and 91 organisms per square meter. In the absence of diel fluctuations, number of taxa per sampler increased to 12 and mean densities increased to 743 per square meter. Fluctuating discharges had no significant effect on numbers of taxa or densities on continually submerged artificial substrates.

Usher, H.D., and D.W. Blinn. 1990. Influence of various exposure periods on the biomass and chlorophyll a of Cladophora glomerata (Chlorophyta). Journal of Phycology 26:244-249.

A study of exposure periods of an algal species downstream of Glen Canyon Dam shows that biomass and chlorophyll *a* were significantly reduced when *Cladophora glomerata* was subjected to one time exposures of 12 daylight hours or more. Repeated exposures of 12/12 and 24/24 hours of exposure/submergence over a two-week period also showed a significant reduction in biomass. Continued exposure of the river bed may damage the holdfast and inhibit regeneration in the exposed zones.

Ward, J.V. 1992. Aquatic insect ecology: 1. biology and habitat. John Wiley and Sons, New York.

This book focuses on insect biology and habitats, it discusses evolutionary adaptation, aquatic insect trophic requirements and environmental needs in terms of water level and temperature.

Welch, E.B. and J.M. Jacoby. 2004. Polluted Effects in Freshwater; Applied Limnology. 3rd edition, Taylor and Francis, London.

This text provides an introduction to the ecological consequences of water pollution in aquatic ecosystems. This book reviews limnological and water pollution literature to describe how pollutants in wastewater affect populations of organisms in freshwater environments.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Academic Press, San Diego. 1006 pp.

This limnology text describes the structural and functional interrelationships of organisms of inland waters as they are affected by their dynamic physical, chemical, and biotic environments.

Wright, L.D. and A.T. Szluha. 1980. Impacts of water level fluctuations on biological characteristics of reservoirs. Pages 21-38 in Hildebrand, S. G. (editor). Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591.

The potential environmental impacts in reservoirs below dams that may be caused by water level fluctuations were identified. Potential impacts in reservoir biota include habitat destruction, partial or total loss of aquatic species, changes in habitat quality and shifts in species diversity. It was identified that 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 and the littoral areas are most susceptible to the effects of water level fluctuations.

Appendix 2. Periphyton Hard Substrate and Colonization Data

Table A.2-1. Periphyton hard substrate and colonization data.

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
5/29/2007	LV3-2A	Lower	Vertical	2	0*	--
5/29/2007	LV3-2B	Lower	Vertical	2	0*	--
5/29/2007	LV3-2C	Lower	Vertical	2	0*	--
5/29/2007	LV3-5A	Lower	Vertical	5	1.55	--
5/29/2007	LV3-5B	Lower	Vertical	5	2.46	--
5/29/2007	LV3-5C	Lower	Vertical	5	5.04	--
5/29/2007	LV3-10A	Lower	Vertical	10	4.50	--
5/29/2007	LV3-10B	Lower	Vertical	10	2.88	--
5/29/2007	LV3-10C	Lower	Vertical	10	2.46	--
5/29/2007	LV3-15A	Lower	Vertical	15	4.88	--
5/29/2007	LV3-15B	Lower	Vertical	15	1.98	--
5/29/2007	LV3-15C	Lower	Vertical	15	2.29	--
5/29/2007	LV3-25A	Lower	Vertical	25	2.90	--
5/29/2007	LV3-25B	Lower	Vertical	25	1.36	--
5/29/2007	LV3-25C	Lower	Vertical	25	1.91	--
5/29/2007	LV3-40A	Lower	Vertical	40	2.19	--
5/29/2007	LV3-40B	Lower	Vertical	40	0.95	--
5/29/2007	LV3-40C	Lower	Vertical	40	1.90	--
5/29/2007	LSA2-2A	Lower	Shoreline	2	0*	--
5/29/2007	LSA2-2B	Lower	Shoreline	2	0*	--
5/29/2007	LSA2-2C	Lower	Shoreline	2	0*	--
5/29/2007	LSA2-5A	Lower	Shoreline	5	0*	--
5/29/2007	LSA2-5B	Lower	Shoreline	5	0*	--
5/29/2007	LSA2-5C	Lower	Shoreline	5	0*	--
5/29/2007	LSA2-10A	Lower	Shoreline	10	2.42	--
5/29/2007	LSA2-10B	Lower	Shoreline	10	3.55	--
5/29/2007	LSA2-10C	Lower	Shoreline	10	2.71	--
5/29/2007	LSA2-15A	Lower	Shoreline	15	1.43	--
5/29/2007	LSA2-15B	Lower	Shoreline	15	0.32	--
5/29/2007	LSA2-15C	Lower	Shoreline	15	0.99	--
5/29/2007	LSA2-25A	Lower	Shoreline	25	1.58	--
5/29/2007	LSA2-25B	Lower	Shoreline	25	1.00	--
5/29/2007	LSA2-25C	Lower	Shoreline	25	0.10	--
5/29/2007	LSA2-40A	Lower	Shoreline	40	0.49	--
5/29/2007	LSA2-40B	Lower	Shoreline	40	0.77	--
5/29/2007	LSA2-40C	Lower	Shoreline	40	1.29	--
5/30/2007	USD-2A	Upper	Shoreline	2	0*	--
5/30/2007	USD-2B	Upper	Shoreline	2	0*	--
5/30/2007	USD-2C	Upper	Shoreline	2	0*	--
5/30/2007	USD-5A	Upper	Shoreline	5	1.27	--
5/30/2007	USD-5B	Upper	Shoreline	5	1.93	--
5/30/2007	USD-5C	Upper	Shoreline	5	1.89	--
5/30/2007	USD-10A	Upper	Shoreline	10	4.52	--
5/30/2007	USD-10B	Upper	Shoreline	10	4.95	--

Table A.2-1, continued...

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
5/30/2007	USD-10C	Upper	Shoreline	10	6.91	--
5/30/2007	USD-15A	Upper	Shoreline	15	5.01	--
5/30/2007	USD-15B	Upper	Shoreline	15	4.48	--
5/30/2007	USD-15C	Upper	Shoreline	15	3.30	--
5/30/2007	USD-25A	Upper	Shoreline	25	4.02	--
5/30/2007	USD-25B	Upper	Shoreline	25	2.23	--
5/30/2007	USD-25C	Upper	Shoreline	25	4.07	--
5/30/2007	USD-40A	Upper	Shoreline	40	0.85	--
5/30/2007	USD-40B	Upper	Shoreline	40	0.36	--
5/30/2007	USD-40C	Upper	Shoreline	40	0.83	--
5/31/2007	BCV1-2A	Box	Vertical	2	2.50	--
5/31/2007	BCV1-2B	Box	Vertical	2	3.91	--
5/31/2007	BCV1-2C	Box	Vertical	2	2.60	--
5/31/2007	BCV1-5A	Box	Vertical	5	1.85	--
5/31/2007	BCV1-5B	Box	Vertical	5	1.62	--
5/31/2007	BCV1-5C	Box	Vertical	5	1.40	--
5/31/2007	BCV1-10A	Box	Vertical	10	4.26	--
5/31/2007	BCV1-10B	Box	Vertical	10	3.20	--
5/31/2007	BCV1-10C	Box	Vertical	10	4.13	--
5/31/2007	BCV1-15A	Box	Vertical	15	2.86	--
5/31/2007	BCV1-15B	Box	Vertical	15	5.22	--
5/31/2007	BCV1-15C	Box	Vertical	15	2.31	--
5/31/2007	BCV1-20A	Box	Vertical	20	1.74	--
5/31/2007	BCV1-20B	Box	Vertical	20	2.48	--
5/31/2007	BCV1-20C	Box	Vertical	20	2.90	--
5/31/2007	BCV1-25A	Box	Vertical	25	1.16	--
5/31/2007	BCV1-25B	Box	Vertical	25	2.22	--
5/31/2007	BCV1-25C	Box	Vertical	25	0.94	--
5/31/2007	BCS1-2A	Box	Shoreline	2	1.07	--
5/31/2007	BCS1-2B	Box	Shoreline	2	2.95	--
5/31/2007	BCS1-2C	Box	Shoreline	2	1.63	--
5/31/2007	BCS1-5A	Box	Shoreline	5	1.90	--
5/31/2007	BCS1-5B	Box	Shoreline	5	1.36	--
5/31/2007	BCS1-5C	Box	Shoreline	5	1.04	--
5/31/2007	BCS1-10A	Box	Shoreline	10	4.95	--
5/31/2007	BCS1-10B	Box	Shoreline	10	1.73	--
5/31/2007	BCS1-10C	Box	Shoreline	10	4.28	--
5/31/2007	BCS1-15A	Box	Shoreline	15	5.04	--
5/31/2007	BCS1-15B	Box	Shoreline	15	2.13	--
5/31/2007	BCS1-15C	Box	Shoreline	15	2.55	--
5/31/2007	BCS1-25A	Box	Shoreline	25	1.96	--
5/31/2007	BCS1-25B	Box	Shoreline	25	0.93	--
5/31/2007	BCS1-25C	Box	Shoreline	25	0.93	--
5/31/2007	BCS1-40A	Box	Shoreline	40	0.78	--

Table A.2-1, continued...

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
5/31/2007	BCS1-40B	Box	Shoreline	40	1.36	--
5/31/2007	BCS1-40C	Box	Shoreline	40	0.70	--
8/30/2007	LV3-2A	Lower	Vertical	2	0.62	--
8/30/2007	LV3-2B	Lower	Vertical	2	0.71	--
8/30/2007	LV3-2C	Lower	Vertical	2	0.31	--
8/30/2007	LV3-5A	Lower	Vertical	5	27.70	--
8/30/2007	LV3-5B	Lower	Vertical	5	17.37	--
8/30/2007	LV3-5C	Lower	Vertical	5	23.47	--
8/30/2007	LV3-10A	Lower	Vertical	10	3.88	--
8/30/2007	LV3-10B	Lower	Vertical	10	2.56	--
8/30/2007	LV3-10C	Lower	Vertical	10	4.00	--
8/30/2007	LV3-15A	Lower	Vertical	15	13.29	--
8/30/2007	LV3-15B	Lower	Vertical	15	8.16	--
8/30/2007	LV3-15C	Lower	Vertical	15	10.64	--
8/30/2007	LV3-25A	Lower	Vertical	25	4.50	--
8/30/2007	LV3-25B	Lower	Vertical	25	1.57	--
8/30/2007	LV3-25C	Lower	Vertical	25	6.40	--
8/30/2007	LV3-40A	Lower	Vertical	40	1.24	--
8/30/2007	LV3-40B	Lower	Vertical	40	1.49	--
8/30/2007	LV3-40C	Lower	Vertical	40	0.83	--
8/30/2007	LSA2-2A	Lower	Shoreline	2	1.99	--
8/30/2007	LSA2-2B	Lower	Shoreline	2	1.76	--
8/30/2007	LSA2-2C	Lower	Shoreline	2	2.39	--
8/30/2007	LSA2-5A	Lower	Shoreline	5	9.03	--
8/30/2007	LSA2-5B	Lower	Shoreline	5	10.87	--
8/30/2007	LSA2-5C	Lower	Shoreline	5	11.92	--
8/30/2007	LSA2-10A	Lower	Shoreline	10	1.86	--
8/30/2007	LSA2-10B	Lower	Shoreline	10	3.17	--
8/30/2007	LSA2-10C	Lower	Shoreline	10	1.58	--
8/30/2007	LSA2-15A	Lower	Shoreline	15	0.76	--
8/30/2007	LSA2-15B	Lower	Shoreline	15	1.30	--
8/30/2007	LSA2-15C	Lower	Shoreline	15	1.26	--
8/30/2007	LSA2-25A	Lower	Shoreline	25	2.88	--
8/30/2007	LSA2-25B	Lower	Shoreline	25	2.24	--
8/30/2007	LSA2-25C	Lower	Shoreline	25	2.01	--
8/30/2007	LSA2-40A	Lower	Shoreline	40	1.30	--
8/30/2007	LSA2-40B	Lower	Shoreline	40	2.72	--
8/30/2007	LSA2-40C	Lower	Shoreline	40	1.11	--
8/30/2007	USD-2A	Upper	Shoreline	2	0.18*	--
8/30/2007	USD-2B	Upper	Shoreline	2	0.22*	--
8/30/2007	USD-2C	Upper	Shoreline	2	0.11*	--
8/30/2007	USD-5A	Upper	Shoreline	5	0.25*	--
8/30/2007	USD-5B	Upper	Shoreline	5	0.34*	--
8/30/2007	USD-5C	Upper	Shoreline	5	0.22*	--

Table A.2-1, continued...

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
8/30/2007	USD-10A	Upper	Shoreline	10	6.42	--
8/30/2007	USD-10B	Upper	Shoreline	10	2.20	--
8/30/2007	USD-10C	Upper	Shoreline	10	1.52	--
8/30/2007	USD-15A	Upper	Shoreline	15	3.08	--
8/30/2007	USD-15B	Upper	Shoreline	15	9.68	--
8/30/2007	USD-15C	Upper	Shoreline	15	20.70	--
8/30/2007	USD-25A	Upper	Shoreline	25	7.22	--
8/30/2007	USD-25B	Upper	Shoreline	25	4.60	--
8/30/2007	USD-25C	Upper	Shoreline	25	2.75	--
8/30/2007	USD-40A	Upper	Shoreline	40	10.06	--
8/30/2007	USD-40B	Upper	Shoreline	40	7.14	--
8/30/2007	USD-40C	Upper	Shoreline	40	2.50	--
9/1/2007	BCV1-2A	Box	Vertical	2	0.30*	--
9/1/2007	BCV1-2B	Box	Vertical	2	0.40*	--
9/1/2007	BCV1-2C	Box	Vertical	2	0.14*	--
9/1/2007	BCV1-5A	Box	Vertical	5	6.67	--
9/1/2007	BCV1-5B	Box	Vertical	5	7.65	--
9/1/2007	BCV1-5C	Box	Vertical	5	14.26	--
9/1/2007	BCV1-10A	Box	Vertical	10	2.75	--
9/1/2007	BCV1-10B	Box	Vertical	10	1.43	--
9/1/2007	BCV1-10C	Box	Vertical	10	4.98	--
9/1/2007	BCV1-15A	Box	Vertical	15	3.38	--
9/1/2007	BCV1-15B	Box	Vertical	15	3.74	--
9/1/2007	BCV1-15C	Box	Vertical	15	1.87	--
9/1/2007	BCV1-20A	Box	Vertical	20	2.43	--
9/1/2007	BCV1-20B	Box	Vertical	20	4.83	--
9/1/2007	BCV1-20C	Box	Vertical	20	6.87	--
9/1/2007	BCV1-25A	Box	Vertical	25	2.55	--
9/1/2007	BCV1-25B	Box	Vertical	25	1.57	--
9/1/2007	BCV1-25C	Box	Vertical	25	1.02	--
9/1/2007	BCS1-2A	Box	Shoreline	2	0.09*	--
9/1/2007	BCS1-2B	Box	Shoreline	2	0.31*	--
9/1/2007	BCS1-2C	Box	Shoreline	2	0.73*	--
9/1/2007	BCS1-5A	Box	Shoreline	5	15.21	--
9/1/2007	BCS1-5B	Box	Shoreline	5	9.41	--
9/1/2007	BCS1-5C	Box	Shoreline	5	13.83	--
9/1/2007	BCS1-10A	Box	Shoreline	10	5.55	--
9/1/2007	BCS1-10B	Box	Shoreline	10	6.76	--
9/1/2007	BCS1-10C	Box	Shoreline	10	1.81	--
9/1/2007	BCS1-15A	Box	Shoreline	15	10.24	--
9/1/2007	BCS1-15B	Box	Shoreline	15	5.19	--
9/1/2007	BCS1-15C	Box	Shoreline	15	6.00	--
9/1/2007	BCS1-25A	Box	Shoreline	25	3.38	--
9/1/2007	BCS1-25B	Box	Shoreline	25	2.01	--

Table A.2-1, continued...

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
9/1/2007	BCS1-25C	Box	Shoreline	25	2.48	--
9/1/2007	BCS1-40A	Box	Shoreline	40	0.72	--
9/1/2007	BCS1-40B	Box	Shoreline	40	1.10	--
9/1/2007	BCS1-40C	Box	Shoreline	40	0.62	--
8/31/2007	C0706-5A	Box	Colonization	5	17.76	0.32
8/31/2007	C0706-5B	Box	Colonization	5	17.85	0.32
8/31/2007	C0706-5C	Box	Colonization	5	12.54	0.22
8/31/2007	C0706-15A	Box	Colonization	15	20.28	0.36
8/31/2007	C0706-15B	Box	Colonization	15	1.22	0.02
8/31/2007	C0706-15C	Box	Colonization	15	9.92	0.18
8/31/2007	C0706-25A	Box	Colonization	25	2.91	0.05
8/31/2007	C0706-25B	Box	Colonization	25	18.44	0.33
8/31/2007	C0706-25C	Box	Colonization	25	11.73	0.21
8/31/2007	C0720-5A	Box	Colonization	5	16.05	0.38
8/31/2007	C0720-5B	Box	Colonization	5	12.18	0.29
8/31/2007	C0720-5C	Box	Colonization	5	22.83	0.54
8/31/2007	C0720-15A	Box	Colonization	15	5.64	0.13
8/31/2007	C0720-15B	Box	Colonization	15	4.16	0.10
8/31/2007	C0720-15C	Box	Colonization	15	5.27	0.13
8/31/2007	C0720-25A	Box	Colonization	25	2.04	0.05
8/31/2007	C0720-25B	Box	Colonization	25	5.59	0.13
8/31/2007	C0720-25C	Box	Colonization	25	2.85	0.07
8/31/2007	C0803-5A	Box	Colonization	5	8.18	0.29
8/31/2007	C0803-5B	Box	Colonization	5	8.08	0.29
8/31/2007	C0803-5C	Box	Colonization	5	9.74	0.35
8/31/2007	C0803-15A	Box	Colonization	15	2.96	0.11
8/31/2007	C0803-15B	Box	Colonization	15	3.02	0.11
8/31/2007	C0803-15C	Box	Colonization	15	3.64	0.13
8/31/2007	C0803-25A	Box	Colonization	25	0.90	0.03
8/31/2007	C0803-25B	Box	Colonization	25	1.08	0.04
8/31/2007	C0803-25C	Box	Colonization	25	1.75	0.06
8/31/2007	C0816-5A	Box	Colonization	5	8.41	0.56
8/31/2007	C0816-5B	Box	Colonization	5	7.41	0.49
8/31/2007	C0816-5C	Box	Colonization	5	8.98	0.60
8/31/2007	C0816-15A	Box	Colonization	15	5.94	0.40
8/31/2007	C0816-15B	Box	Colonization	15	2.47	0.16
8/31/2007	C0816-15C	Box	Colonization	15	7.38	0.49
8/31/2007	C0816-25A	Box	Colonization	25	2.96	0.20
8/31/2007	C0816-25B	Box	Colonization	25	3.03	0.20
8/31/2007	C0816-25C	Box	Colonization	25	3.81	0.25
8/31/2007	C0823-5A	Box	Colonization	5	3.91	0.49
8/31/2007	C0823-5B	Box	Colonization	5	3.14	0.39
8/31/2007	C0823-5C	Box	Colonization	5	5.13	0.64
8/31/2007	C0823-15A	Box	Colonization	15	3.71	0.46

Table A.2-1, continued...

Date	Site	Reservoir Location	Type of Site	Depth (ft)	Periphyton Biomass (mg/m^2)	Colonization Rate (mg/m^2-day)
8/31/2007	C0823-15B	Box	Colonization	15	2.10	0.26
8/31/2007	C0823-15C	Box	Colonization	15	1.39	0.17
8/31/2007	C0823-25A	Box	Colonization	25	1.74	0.22
8/31/2007	C0823-25B	Box	Colonization	25	2.01	0.25
8/31/2007	C0823-25C	Box	Colonization	25	2.38	0.30
8/31/2007	C0828-5A	Box	Colonization	5	0.98	0.33
8/31/2007	C0828-5B	Box	Colonization	5	0.76	0.25
8/31/2007	C0828-5C	Box	Colonization	5	0.43	0.14
8/31/2007	C0828-15A	Box	Colonization	15	0.94	0.31
8/31/2007	C0828-15B	Box	Colonization	15	0.96	0.32
8/31/2007	C0828-15C	Box	Colonization	15	0.66	0.22
8/31/2007	C0828-25A	Box	Colonization	25	0.96	0.32
8/31/2007	C0828-25B	Box	Colonization	25	0.96	0.32
8/31/2007	C0828-25C	Box	Colonization	25	0.48	0.16

* Samples retrieved dry.

Appendix 4. Study No. 7.4.3 – Benthic Macroinvertebrate HSI

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.3
Benthic Macroinvertebrate HSI
Interim Report

Prepared for
Seattle City Light

Prepared by
Tetra Tech

March 2008

TABLE OF CONTENTS

Appendices

List of Tables

List of Figures

Study No. 7.4.3: Benthic Macroinvertebrate HSI
Interim Report
Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 7.4.3, Benthic Macroinvertebrate Habitat Suitability Index (HSI), 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) 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 interim report for the 2007 study efforts of the Benthic Macroinvertebrate (BMI) HSI. This interim report is being submitted as part of the Initial Study Report.

Study 7.4.3 will support development of HSI curves for target metrics which will be used in Study 7, the Mainstem Aquatic Habitat Modeling Study. Information gathered in Study 7.4.3 will also be used in the Tributary Delta Habitat Modeling Study (Study 8) and in the Aquatic Productivity Study (Study 11) for a better understanding of biomass quantity and distribution that occurs in the Boundary Project area. The metrics evaluated for development of HSI curves include water depth, substrate, duration of inundation, duration of dewatering, and the biological response of periphyton and BMI based on colonization rates.

As part of Study 7.4.3, sampling of benthic macroinvertebrates and periphyton on hard substrate was conducted. This portion of the study was designed to measure a biological response to the range of elevations (with changing depths) and periods of inundation and exposure that are likely to occur for operations scenarios within Boundary Reservoir. Sampling baskets with artificial substrate were used to standardize the periphyton growth and macroinvertebrate colonization across sampling locations. The sampling baskets were placed at fixed locations and various elevation intervals, allowing a study of the response of macroinvertebrates and periphyton to pool water surface elevation fluctuations. Study 7.4.3 includes sampling in lower Boundary Reservoir, upper Boundary Reservoir, and in Box Canyon Reservoir. The sampling locations were chosen to represent conditions under large pool water surface elevation fluctuation (in the lower Boundary Reservoir), smaller pool surface elevation fluctuation (in the upper Boundary Reservoir), and an area that experiences very little pool surface elevation fluctuation (in the Box Canyon Reservoir).

2 STUDY OBJECTIVES

The primary objective of Study 7.4.3 was to develop a benthic macroinvertebrate HSI to help assess the effects of operations scenarios on aquatic productivity. The BMI HSI will be used in the Mainstem Aquatic Habitat Model, which integrates hydraulic modeling, reservoir bathymetry, and biological information on the distribution, timing, abundance, and suitability of habitat within Boundary Reservoir. Study 7.4.3 includes six primary elements necessary to develop accurate and comprehensive HSI.

2.1. Literature-Based Benthic HSC and HSI Curves

The objective for developing a BMI model for the Boundary Project is to evaluate how differences in depth, velocity, substrate and the frequency and duration of inundation and dewatering can influence BMI biomass (Appendix 1). The literature-based benthic HSI was developed for those commonly used benthic metrics based on available literature and applicable information. Details on methods and results for this task are found in the *Benthic Macroinvertebrate Literature-Based HSI Interim Report* (Appendix 1). The Boundary Project BMI evaluation process will use estimates of physical and hydraulic conditions for operations scenarios coupled with HSC and HSI information to provide a comparative index of BMI productivity.

2.2. Benthic Communities on Hard Substrate

Study 7.4.3 includes an assessment of benthic communities colonizing hard substrates along the reservoir bottom and on vertical surfaces during spring, summer, autumn, and winter. The objective of this portion of the study is to evaluate the response of BMI to a range of pool water surface elevation fluctuations in order to assess the effects of operations scenarios on BMI utilizing hard substrates within the reservoir. The site-specific information gathered during this study will be used in HSI curve development and applied as part of the Mainstem Aquatic Habitat Model.

2.3. Benthic Communities on Soft Substrate

Site specific-habitat suitability information was collected for BMI communities on soft substrates within the Boundary Reservoir and Box Canyon Reservoir to assess the effects of various pool water surface elevation fluctuations. The objective of this portion of Study 7.4.3 is to evaluate various operations scenarios on BMI utilizing soft substrates within the reservoir. The information gathered during this study will be used in HSI curve development and applied as part of the Mainstem Aquatic Habitat Model.

2.4. Benthic Colonization

Study 7.4.3 included an estimation of potential BMI colonization rates for different seasons within Boundary Reservoir. The objective of this study is to evaluate the depths and inundation durations that are optimal for benthic macroinvertebrate colonization on hard substrate. The site-specific information gathered during this portion of Study 7.4.3 will be used in HSI curve validation and applied as part of the Mainstem Aquatic Habitat Model.

2.5. Validation of Benthic HSI Curves

A histogram for each of the habitat parameters will be developed using the site-specific data collected at Boundary and Box Canyon Reservoirs. The histograms will be compared to the literature-based HSI curves in order to validate (and recalibrate, if necessary) the literature-based HSI curves used for aquatic habitat modeling.

2.6. Finalize Benthic HSI Information

The benthic HSI information collected during Study 7.4.3 will be discussed for each benthic metric through a roundtable discussion with relicensing participants and regional experts. The objective of this discussion is to review the literature-based benthic community information and site-specific data to develop a final set of HSI curves. The curves will be used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for each of the selected benthic metrics for operations scenarios.

3 STUDY AREA

The Boundary Hydroelectric 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 Study 7.4.3 encompasses lower Boundary Reservoir, upper Boundary Reservoir, and Box Canyon Reservoir. Hard and soft substrate sampling is conducted in all three areas, while the colonization study is limited to Box Canyon Reservoir. Box Canyon is utilized as a sample site for this study to represent low fluctuations in pool water surface elevation. The Box Canyon Project usually operates as a typical run-of-river project with incoming and outgoing flow levels approximately the same. In contrast, the Boundary Project operations result in daily fluctuations in pool elevations. In order to more fully validate the BMI HSI with site specific information, tests were needed under pool conditions with both high and low levels of water surface fluctuation.

3.1. Lower Boundary Reservoir

Lower Boundary Reservoir is located upstream of Boundary Dam and downstream of the hydrologic control of Metaline Falls (Figure 3.1-1). At the southern end of this portion of the reservoir is the town of Metaline Falls. The reservoir extends north, through Z Canyon, to the Boundary Dam. Just upstream of the dam is a campground and boat ramp facility, which is utilized to access the lower Boundary Reservoir. The sampling sites for the vertical hard substrate are upstream of Z Canyon on the east side of the reservoir at a vertical cliff face. The shoreline hard substrate sites are just downstream from the vertical sites, also on the east side of the reservoir. The soft substrate collection site is across the reservoir from the shoreline site, along the west side of the reservoir (Figure 3.1-1).

3.2. Upper Boundary Reservoir

Upper Boundary Reservoir is located upstream of Metaline Falls hydrologic control and downstream of Box Canyon Dam (Figure 3.1-1). Within the northern portion of the upper Boundary Reservoir is the town of Metaline. Metaline Park provides boat ramp facilities that allow access to the project sites located in upper Boundary Reservoir. The shoreline hard substrate site in upper Boundary Reservoir is shown in Figure 3.1-1, also on the east side of the reservoir. The soft substrate site is near the shoreline site, but on the west side of the reservoir.

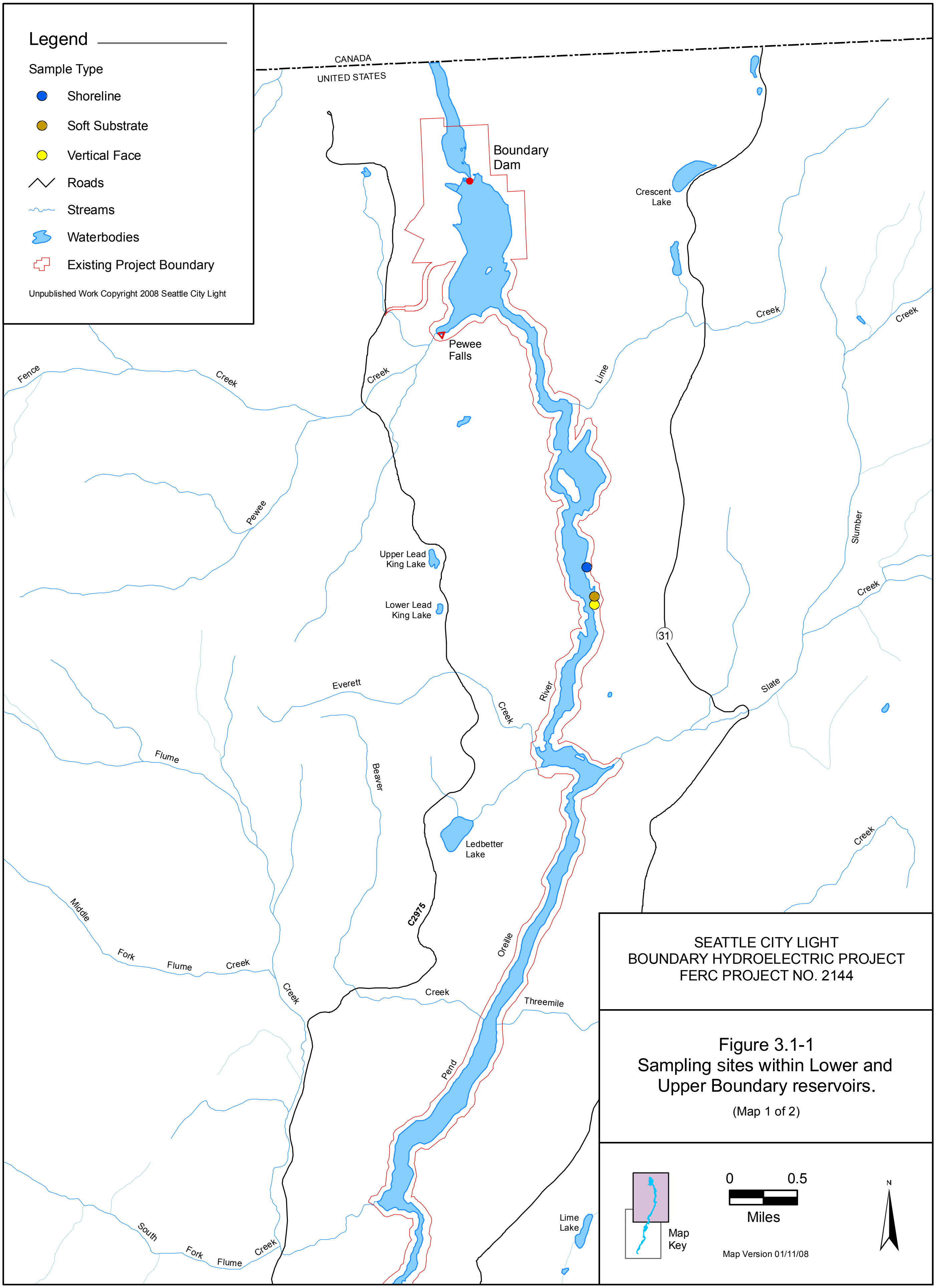


Figure 3.1-1
Sampling sites within Lower and Upper Boundary reservoirs.
(Map 1 of 2)

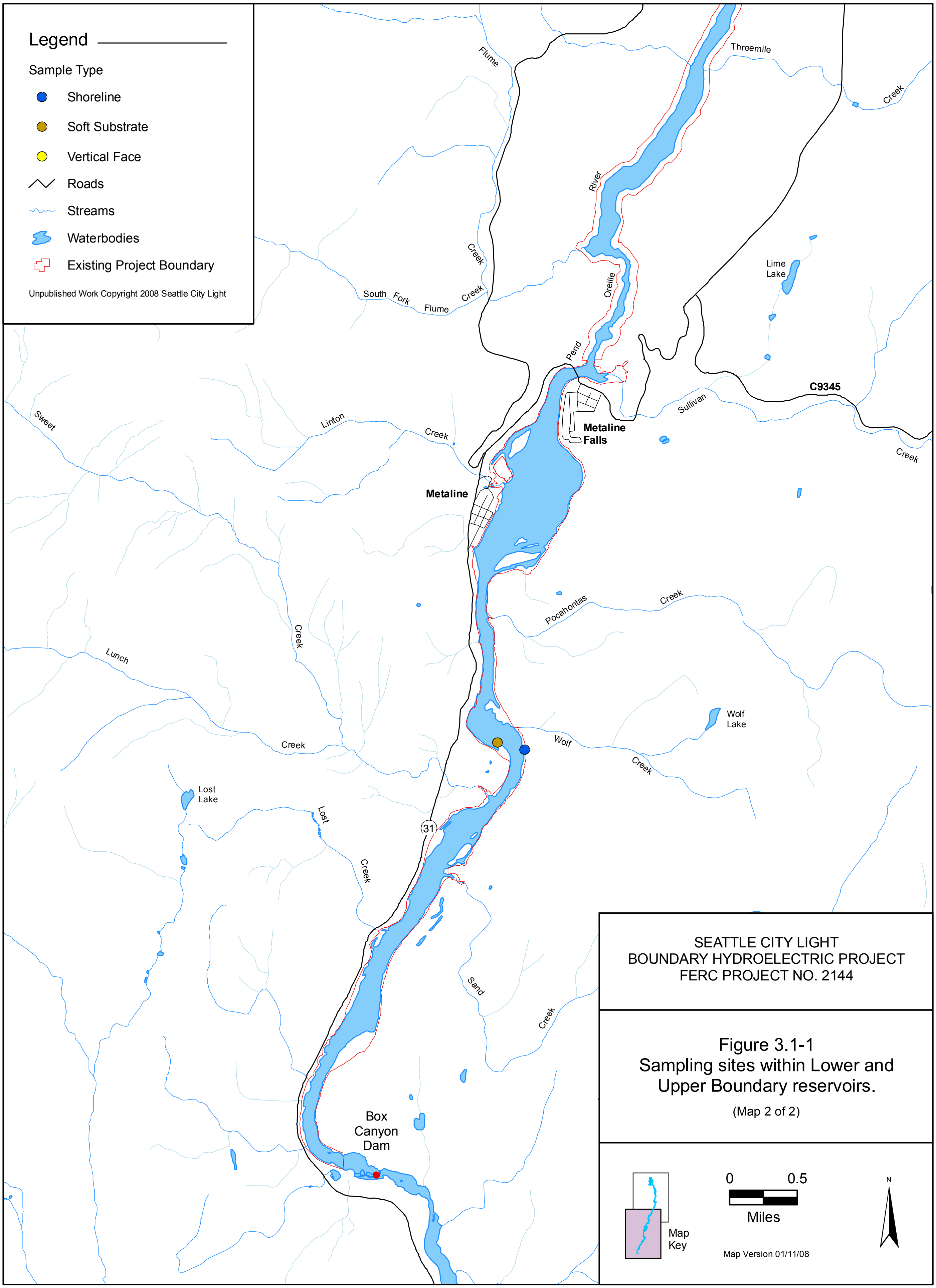


Figure 3.1-1
Sampling sites within Lower and Upper Boundary reservoirs.
(Map 2 of 2)

3.3. Box Canyon Reservoir

Box Canyon Reservoir is located upstream of Box Canyon Dam and extends approximately 55 miles up to Albeni Falls Dam (Figure 3.3-1). For the purpose of Study 7.4.3, efforts are focused in the area of the reservoir located between the town of Ione and the Box Canyon Dam. The town of Ione is located approximately 3 miles upstream from the dam. The survey locations within Box Canyon Reservoir are accessed by the boat ramp located at the public park in the town of Ione. The vertical hard substrate site is located on a vertical cliff near the Box Canyon Dam on the east side of the reservoir. The shoreline hard substrate site is located along a rocky shoreline on the west side of the reservoir. The soft substrate sampling site is also located on the west side of the reservoir (Figure 3.3-1). The colonization sampling site is located adjacent o the shoreline site on the west side of the reservoir.

3.4. GPS Coordinates for Sampling Locations

The geographic positioning system (GPS) coordinates for each location surveyed as part of Study 7.4.3 are listed in Table 3.4-1. These include sampling sites for hard substrate (vertical and shoreline), soft substrate, and colonization. All universal transverse mercator (UTM) coordinates are provided in NAD 1983, State-Plane Washington North, FIPS 4601 (US Survey Feet).

Table 3.4-1. GPS coordinates for sampling locations in Boundary and Box Canyon Reservoirs.

Sampling Site	GPS Coordinates (UTM)
Lower Boundary Reservoir vertical hard substrate site	727290.75 N, 2481869.72 E
Lower Boundary Reservoir shoreline hard substrate site	728748.92 N, 2481578.56 E
Lower Boundary Reservoir soft sediment site	727612.51 N, 2481878.68 E
Upper Boundary Reservoir shoreline hard substrate site	684375.43 N, 2471074.83 E
Upper Boundary Reservoir soft sediment site	684658.51 N, 2470010.98 E
Box Canyon vertical hard substrate site	664752.13 N, 2467826.05 E
Box Canyon shoreline shard substrate site	660108.69 N, 2465686.36 E
Box Canyon soft sediment site	660804.52 N, 2467584.10 E
Box Canyon colonization site	660170.31 N, 2465844.86 E

4 METHODS

Benthic macroinvertebrate site-specific monitoring consisted of three different components: 1) artificial substrate sampling on hard substrate surfaces; 2) sampling of soft substrates; and 2) 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.

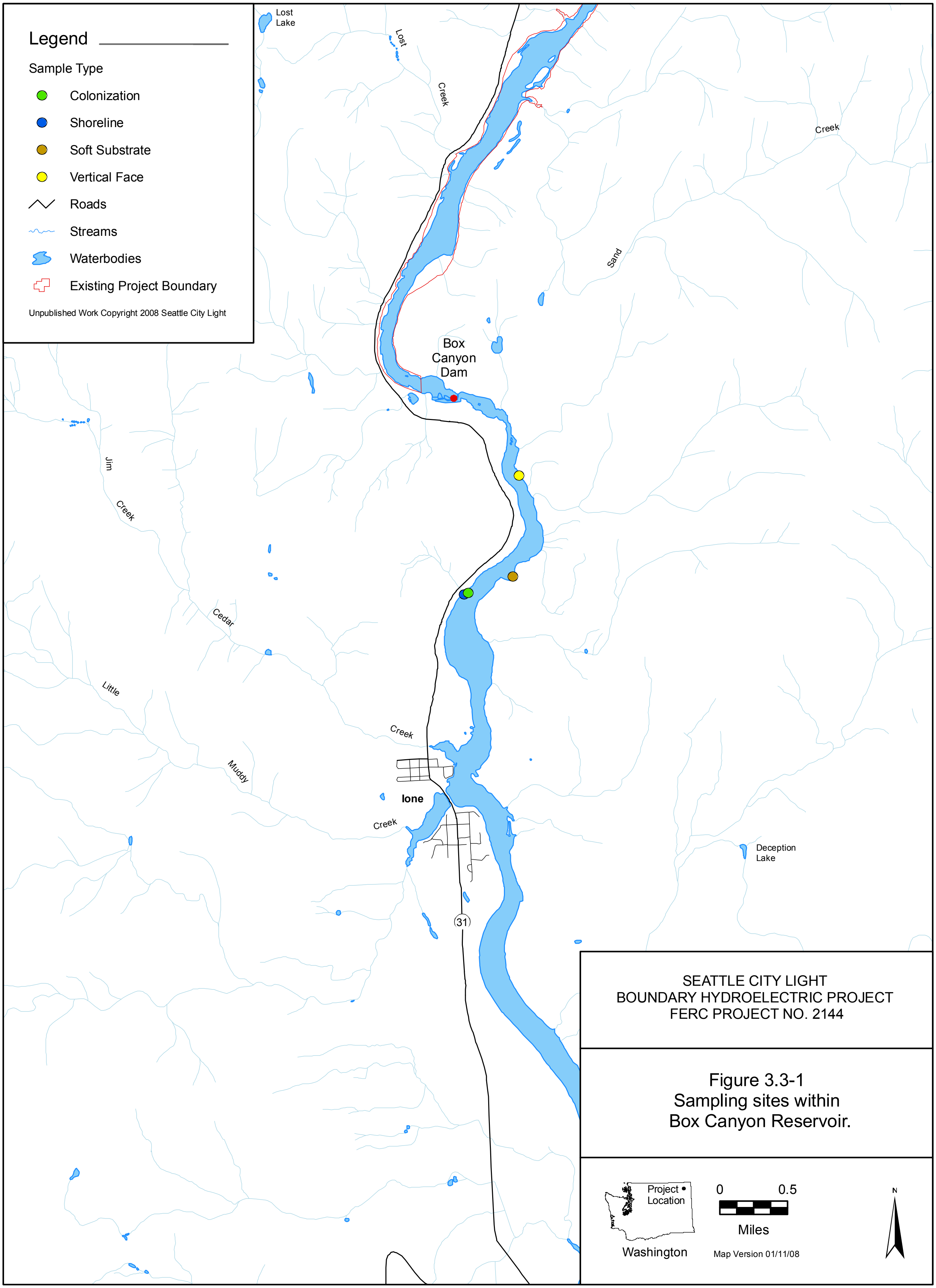


Figure 3.3-1
Sampling sites within
Box Canyon Reservoir.

In order to facilitate the sampling of BMI at predetermined elevations, a zero elevation level was established in the field. 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 date and time of the initial sampling basket deployments. During future deployments the vertical distance from the zero mark to the water surface was used 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 future deployments. The date and time information will be used in conjunction with water elevation records from Boundary Dam and Box Canyon Dam to determine the zero level elevation at the time of the initial deployment. The 2007 water elevation records from Box Canyon Dam have been obtained and will be adjusted to ensure that they are reported in the same datum as the records from Boundary Dam. Once this process is complete and the records have been reviewed for quality assurance/quality control (QA/QC), analysis will be conducted to determine depth and duration of inundation and exposure at sampling sites. It will be necessary to obtain additional water elevation records for samples collected in 2008. In this report, the samples will be identified by their off-set from the original zero mark (e.g., the sample set 2 feet below the original zero mark with be referred to at the 2-ft sample).

4.1. Hard Substrate Sampling

Sampling of artificial hard substrate was conducted at two types of sites, shoreline sites, in which the sampling units were placed at predetermined elevation intervals along the bottom of the reservoir, and vertical sites that allowed the units to be suspended at various predetermined elevation intervals mid-water column. The sampling elevation intervals specified for hard substrate sampling are 2 ft, 5 ft, 10 ft, 15 ft, 25 ft, and 40 ft. 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 low pool water surface elevation fluctuations in lower Boundary Reservoir, upper Boundary Reservoir, and Box Canyon reservoirs, respectively.

During 2007, a total of four hard substrate sampling unit deployments were conducted and three retrievals were completed. The 2007 sampling schedule is shown in Table 4.1-1. All hard substrate samples (shoreline and vertical sites) were retrieved 8 weeks following 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 270 hard substrate samples taken in the 2007 field season. Additional sampling events are scheduled for the first quarter of 2008.

At each vertical 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 sampling units. The ropes for each shoreline site were buried under the sediment and existing vegetation as much as possible to reduce visibility. Non-buoyant line was used to insure it remained on the bottom of the reservoir at the shoreline sites and did not float to the surface.

Table 4.1-1. Sampling schedule (2007) 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
Retrieval of hard substrate sampling units	May 29 – June 1
Deployment of hard substrate sampling units	July 5 – July 9
Retrieval of hard substrate sampling units	August 30 – September 1
Deployment of hard substrate sampling units	September 17 – September 19*
Retrieval of hard substrate sampling units	November 5 – November 8
Deployment of hard substrate sampling units	December 4 – December 7

* Details regarding sampling events after September 1, 2007 will be reported in 2008.

The sampling units used for hard substrate sampling consisted of 3 cylindrical wire mesh baskets, each containing a fixed volume of 1 to 3-inch diameter rocks, attached to a base frame. The volume of the rocks in each basket was 622 in^3 (16.4 cm^3). Each frame was then 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.

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 ft elevation intervals at this location. By placing a sampling unit at the 20 ft interval, rather than replicating one of the other elevations to obtain six sampling intervals, the results will better reflect the variability in BMI response to depth.

When hard substrate samples were retrieved, the following methods were used:

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. At the shoreline 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 to minimize disturbance of the sample.

b. When the sampling unit was near the surface, the zip ties were cut from the first basket 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. 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 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 were left on them. 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 packaged in coolers and shipped to the laboratory for analysis.

4.2. Soft Substrate Sampling

In addition to hard substrate, Study 7.4.3 evaluates benthic macroinvertebrate populations in soft substrate within Boundary Dam Reservoir and Box Canyon Reservoir. Soft substrate is not sampled for periphyton. Sediment samples were collected at predetermined elevation intervals within each of the reservoirs, including 2 ft, 5 ft, 10 ft, 15 ft, 25 ft, and 40 ft. The zero level for soft substrate collection was based on the same zero level established for hard substrate. 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. Unlike the hard substrate sites, no anchors or sampling units were left in place for soft substrate sampling so public interference was not a concern.

During 2007, a total of three soft sediment sampling events were completed (Table 4.2-1). Each sampling event included the collection of 54 soft sediment samples, for a total of 162 soft substrate samples taken during the 2007 field season. Additional sampling events are scheduled for the first quarter of 2008.

Table 4.2-1. Sampling schedule (2007) for benthic communities on soft substrate in Boundary and Box Canyon Reservoirs.

Sampling Event	Date
Collection of soft substrate samples	May 15 – May 18
Collection of soft substrate samples	August 28 – August 31
Collection of soft substrate samples	November 8 – November 10*

* Data from sampling events after September 2007 will be reported in 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 was lowered over the side of the boat on a davit and hydraulic winch. Once the Ponar 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.

4.3. Benthic Colonization Rates

Colonization samples utilized 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 ft. The sampling units were deployed on a specific schedule to evaluate the level of colonization that occurs 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 4.3-1 lists the deployment and retrieval dates for all sampling events occurring in 2007. The same deployment and retrieval procedures were used for the colonization samples as for the hard substrate shoreline samples.

Table 4.3-1. Sampling schedule (2007) for benthic colonization in Box Canyon Reservoir.

Sampling Event	Date	Duration (days)
Colonization deployment	July 6	56
Colonization deployment	July 20	42
Colonization deployment	August 3	28
Colonization deployment	August 16	14
Colonization deployment	August 23	7
Colonization deployment	August 28	3
Colonization retrieval	August 31	Retrieval of all samples

During 2007, eight colonization deployments and one retrieval event were conducted. Each retrieval event required the processing of 54 benthic macroinvertebrate and 54 periphyton colonization samples. Additional deployment and collection events are scheduled for December of 2007 and in 2008.

4.4. Sample Analysis

Following collection, all samples were shipped to Aquatic Biology Associates in Corvallis, Oregon for processing. Laboratory staff sorted the samples, separating benthic macroinvertebrates from organic matter, and identified all BMI to family level. The length of each specimen was measured and the life stage was determined.

Upon receiving sample data from the laboratory, the biomass was determined by entering the taxon length, and life stage information into an Access database containing length/mass coefficients for each taxon and life stage. The coefficients were used to determine the biomass for each taxon and life stage. The total biomass for each sample was then calculated by summing the biomass for each invertebrate in the sample. Biomass information can be used to estimate secondary production, or food to support fish populations within the reservoir.

4.5. Validation of Benthic HSI Curves

Following the literature review and development of literature-based habitat suitability curves, a histogram for each of the habitat parameters researched in Task 1 will be developed. The histograms will incorporate the site-specific field data collected in Tasks 2 through 4. Site-specific data for velocity will not be collected as part of Study 7.4.3. The histograms will then be compared with the literature-based HSI curves to validate the applicability of the literature-based HSI curve for aquatic habitat modeling.

4.6. Finalize Benthic HSI Information

The HSI curves for each benthic metric will be reviewed by a panel of relicensing participants and regional experts. Panel members will review the literature-based curves, along with the site-specific data in an effort to develop a final set of HSI curves. The panel may consist of relicensing participants and regional experts (agency, tribal, industry, and university researchers). Once the final benthic HSI curves are developed, they will be used in the aquatic habitat modeling study to define the needs of benthic macroinvertebrates, as they relate to selected benthic metrics, in relation to operations scenarios.

5 PRELIMINARY RESULTS

Study 7.4.3 is ongoing and data collection will continue into 2008. The first objective, involving the development of literature-based HSC and HSI curves, has been completed and the results are described in detail in the *Benthic Macroinvertebrate Literature-Based HSI Interim Report* (Appendix 1). Preliminary data from the first two phases of hard substrate sampling and soft sediment sampling, and the first phase of colonization sampling are presented below. The remaining data from sampling events conducted during the 2007 field season and the 2008 field season will be reported in 2008.

Upon reviewing the 2007 data, it was apparent that the taxonomic group *Hydra* sp. made up a large portion of the biomass in some samples. Although *Hydra* sp. was prevalent in the samples, it is unlikely that it serves to competitively exclude BMI by occupying space on the sampling substrate as BMI can colonize on top of a layer of *Hydra* sp., which are sessile organisms. Additionally, *Hydra* sp. colonized sampling apparatus as well as the rock substrate provided, hence artificially expanding their relative importance to the overall estimated biomass of invertebrates observed. There is likely little predatory interaction between *Hydra* sp. and the BMI collected at Boundary and Box Canyon reservoirs due to size differences, as the BMI that have been collected are larger (> 3mm in length) than the *Hydra* sp. that have been collected in the samples (1 to 3 mm in length). Hydra use a nematocyst and grappling tentacles to bring prey to their mouths (Barnes 1968) and are generally larger than their prey. In addition, animals with hard exoskeletons, like many BMI, are able to escape the effects of nematocysts (Slobodkin and

Bossert, 1991). As such, it is unlikely that the *Hydra* sp. are utilizing BMI as a food resource in this area, however, *Hydra* sp. may serve as a food source for omnivorous invertebrates (Slobodkin and Bossert, 1991). Benthic macroinvertebrates and *Hydra* sp. are of different trophic levels and are not comparable in terms of biological response. They demonstrate different tolerances to disturbance and pollution levels, have different life histories, and provide a different function in the ecosystem. While *Hydra* sp. may serve as food source for omnivorous invertebrates, they are not considered a food resource for fish of interest in Boundary Reservoir due to their sessile nature (Slobodkin and Bossert, 1991). Therefore, the biomass data are presented in this report both with *Hydra* sp. included, and without, for comparison purposes. Only biomass without *Hydra* sp. has been plotted, because the large portion of biomass represented by *Hydra* sp. in some samples masks the BMI response.

5.1. Hard Substrate Sampling

The Interim Report for Study 7.4.3 includes information and preliminary results for sampling events conducted up to September 1, 2007. This section generally describes the results of the hard substrate sampling. All data collected after September 1, 2007 will be described in the 2008 report. This section discusses preliminary variations observed, between the vertical samples and shoreline samples and production across elevation intervals for each reservoir section. It also identifies any apparent differences in biomass levels between lower Boundary Reservoir, upper Boundary Reservoir, and Box Canyon Reservoir.

5.1.1. Vertical Sampling

Specific results from May 2007 and September 2007 for the hard substrate sampling conducted in the vertical orientation in Boundary Reservoir and Box Canyon are shown in Figures 5.1-1 and 5.1-2. Numerical results can be found in Tables 5.1-1 and 5.1-2, and a taxonomic list can be found in Appendix 2. In Boundary Reservoir, the vertical cliff habitat is found in the lower reservoir and not in the upper reservoir, so vertical samples were only collected from the lower portion of Boundary Reservoir. In Box Canyon Reservoir, vertical cliff habitat was sampled as a comparison to the BMI production in lower Boundary Reservoir. However, in Box Canyon Reservoir, vertical cliff habitat is limited and it was not possible to find a location with a 40 ft vertical site. In lieu of the 40-ft elevation interval, a sampling unit was set at a 20-ft elevation interval in Box Canyon.

Table 5.1-1. Results from May 2007 vertical hard substrate sampling.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), without *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), with *Hydra* sp.
2	0.255	2.534	195.431	828.427
5	1.400	7.266	51.363	684.360
10	8.550	40.749	36.477	669.473
15	24.095	154.323	12.792	645.789
20*			6.388	593.176
25	11.529	207.040	6.071	586.233
40	9.210	114.330		

*A 40-ft sample was not collected at Box Canyon, so a sample was collected at 20 ft.

A review of the data shows that a single taxonomic group, *Hydra* sp., represented a large proportion of the sample biomass in the hard substrate samples in the vertical orientation. Despite the high numbers of *Hydra* sp. in the sample data, *Hydra* sp. are often microscopic and are generally transparent, so individual *Hydra* sp. were not observed on rock surfaces during field studies. *Hydra* sp. appeared as transparent film on rocks sampled. *Hydra* sp. are not considered available food resources for fish of interest in Boundary Reservoir due to their sessile nature (Slobodkin and Bossert, 1991); however, tabular data are displayed both without *Hydra* sp. to show the differences in biomass between the BMI species and BMI with *Hydra* sp.

Figure 5.1-1 shows BMI biomass (without *Hydra* sp.) for lower Boundary Reservoir and Box Canyon reservoirs for the May 2007 sampling event. The peak biomass in Box Canyon Reservoir is observed at the 2-ft elevation interval while the highest production in lower Boundary Reservoir is observed at the 15-ft elevation interval. At elevation intervals greater than 10 ft, lower Boundary Reservoir production appears to be similar to that of Box Canyon. During the May collection of vertical hard substrate samples, the 2-ft sampling unit in lower Boundary Reservoir was dry, which likely affected the biomass.

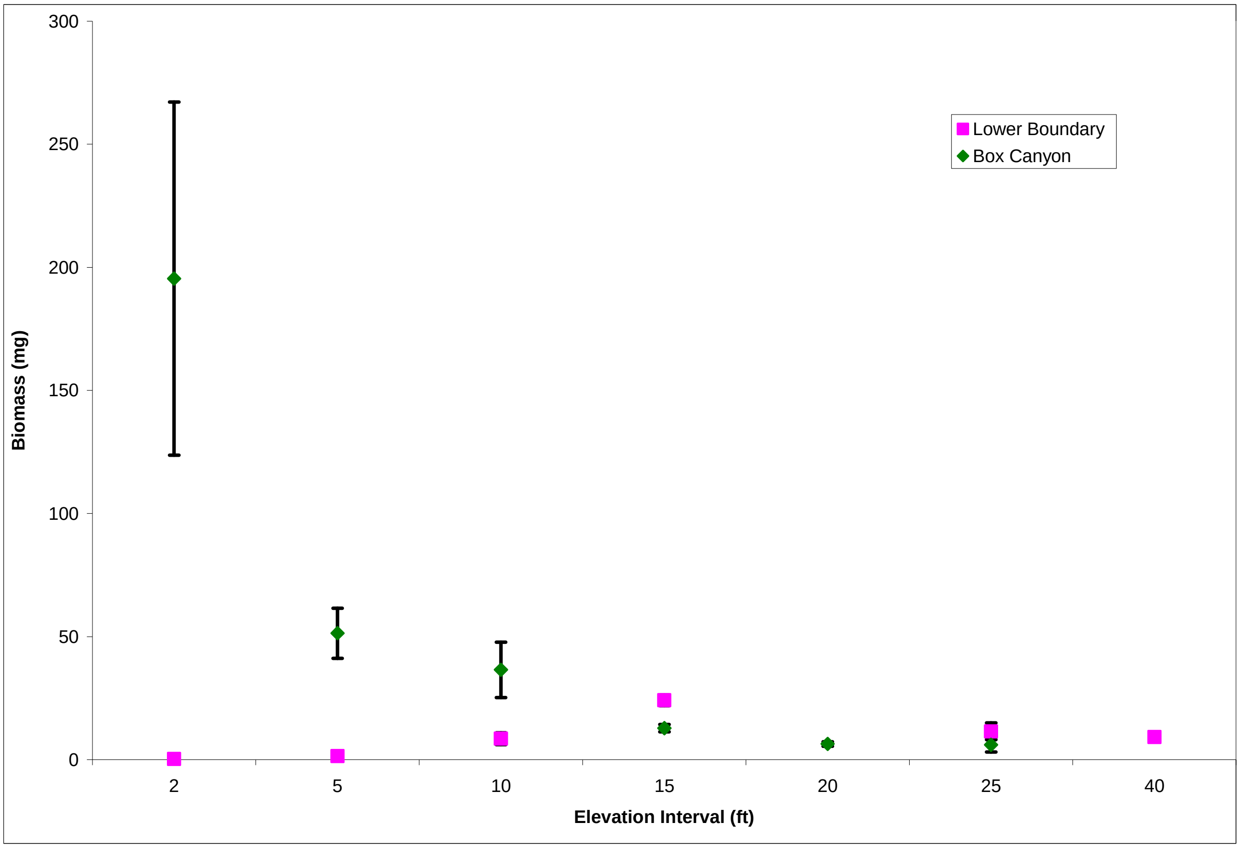


Figure 5.1-1. Hard substrate sampling in the vertical orientation, biomass without *Hydra* sp., May 2007.

In the May vertical samples, the most common taxa other than *Hydra* sp. were *Chironomidae* and *Ephemerella excrusians* in both Box Canyon and lower Boundary Reservoir. In lower Boundary Reservoir, *Ephemerella excrusians* was the most common taxon found at all elevation intervals, while it was most common the 5-ft, 10-ft, and 15-ft samples in Box Canyon. In the 2-ft sample in Box Canyon, *Lynmaea spp*. was the most common taxon and Chironomidae were prevalent in the 20-ft and 40-ft samples. The lower Boundary Reservoir vertical samples also showed high numbers of *Simulium* at all elevation intervals except for 2 ft. Other common taxa found in Box Canyon included *Cheumatopsyche*, *Oligochaeta*, and *Coenagrion/Enallagma*. Common names for these taxa can be found in Appendix 2.

The September samples show less of a difference in the biomass between just BMI, and BMI with *Hydra* sp. For just BMI biomass, Table 5.1-2 and Figure 5.1-2 show a peak biomass in Box Canyon Reservoir at the 5-ft interval, while the highest production in lower Boundary Reservoir is observed at the 15-ft interval (Table 5.1-2 and Figure 5.1-2). In general, biomass production in lower Boundary Reservoir appears to be lower than that of Box Canyon, in the shallow intervals, but equal to or higher than Box Canyon in the deeper intervals. During the September collection of vertical samples, all sampling units were wet except for the 2-ft baskets in Box Canyon, which may have affected biomass levels at that elevation interval. The September data suggest that as depth increases, biomass decreases, with the exception of the 20-ft elevation interval. This anomaly may be attributed to some environmental variation at that depth interval, which is not likely velocity or light. A similar observation was made in the September data collected in the periphyton study at this site.

Table 5.1-2. Results from September 2007 vertical hard substrate sampling.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), without *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), with *Hydra* sp.
2	4.986	5.011	0.815	0.857
5	3.442	3.831	142.820	183.742
10	9.452	10.256	101.832	104.648
15	101.767	102.221	38.026	39.279
20*			110.778	116.768
25	60.108	61.913	35.199	36.818
40	29.074	46.245		

*A 40-ft sample was not collected at Box Canyon, so an additional sample was collected at 20 ft.

The September vertical hard substrate samples collected in Box Canyon showed *Lymnaea* as the most common taxon at the 2-ft and 5-ft intervals, while *Polycentropus* was the most common taxon encountered at elevation intervals greater than 5 ft. Also commonly found in Box Canyon were *Chironomidae*, *Cheumatopsyche*, and *Helisoma anceps*. In lower Boundary Reservoir, *Cladocera* was the most common taxon at all intervals except for 2 ft, where *Porifera* dominated *Polycentropus*, *Chironomidae*. *Hyalella*, *Gammarus*, and *Lymnaea* were also found to be among the most common taxa. Common names for these taxa can be found in Appendix 2.

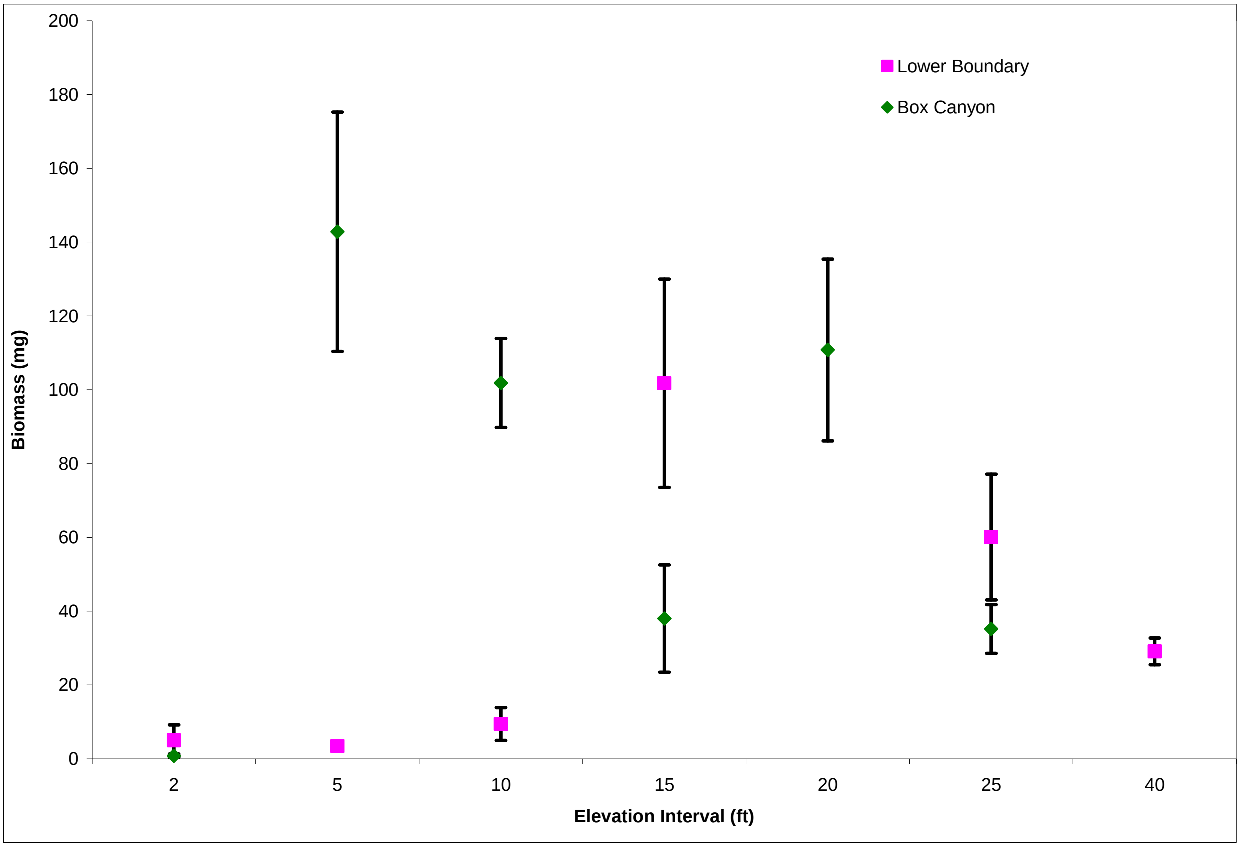


Figure 5.1-2. Hard substrate sampling in the vertical orientation, biomass without *Hydra* sp., September 2007.

5.1.2. Shoreline

The specific results from May 2007 and September 2007 for the shoreline hard substrate sampling conducted in both lower and upper Boundary Reservoir and Box Canyon Reservoir are shown in Figures 5.1-3 and 5.1-4. Tables 5.1-3 and 5.1-4 contain the numerical results for this sampling effort.

In the May samples, the patterns observed in each section of each reservoir are unique. In lower Boundary Reservoir, the greatest biomass for the shoreline samples is found at the 40 ft interval (Table 5.1-3 and Figure 5.1-3). The biomass in lower Boundary Reservoir is again generally lower that that in either upper Boundary Reservoir or Box Canyon. In upper Boundary Reservoir, biomass increases sharply as the elevation interval increases to 15 ft, and then biomass tapers off at the 25 ft and 40 ft intervals. At the 15 and 25 ft intervals, the biomass in upper Boundary Reservoir is higher than that in Box Canyon, and, in general, the production levels in upper Boundary Reservoir and Box Canyon are more similar than those in lower Boundary Reservoir. In Box Canyon, there is a biomass peak in the 2-ft sample and another peak at the 15-ft sample with a drop in biomass at the 5-ft sample and the 25-ft and 40-ft samples (Table 5.1-3 and Figure 5.1-3). During the May collection of shoreline hard substrate samples, the 2-ft and 5-ft sampling units in both lower and upper Boundary Reservoirs were dry, which likely affected the biomass.

Table 5.1-3. Results from May 2007 shoreline hard substrate sampling.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), without *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), with *Hydra* sp.
2	0.000	0.000	0.026	0.111	222.002	908.592
5	0.321	0.363	61.695	106.173	52.136	702.097
10	1.125	3.404	298.244	931.241	135.250	219.311
15	26.268	33.906	437.347	1070.344	142.871	900.357
25	27.033	36.528	316.893	1001.373	52.130	195.145
40	76.026	103.920	240.412	751.283	31.227	231.591

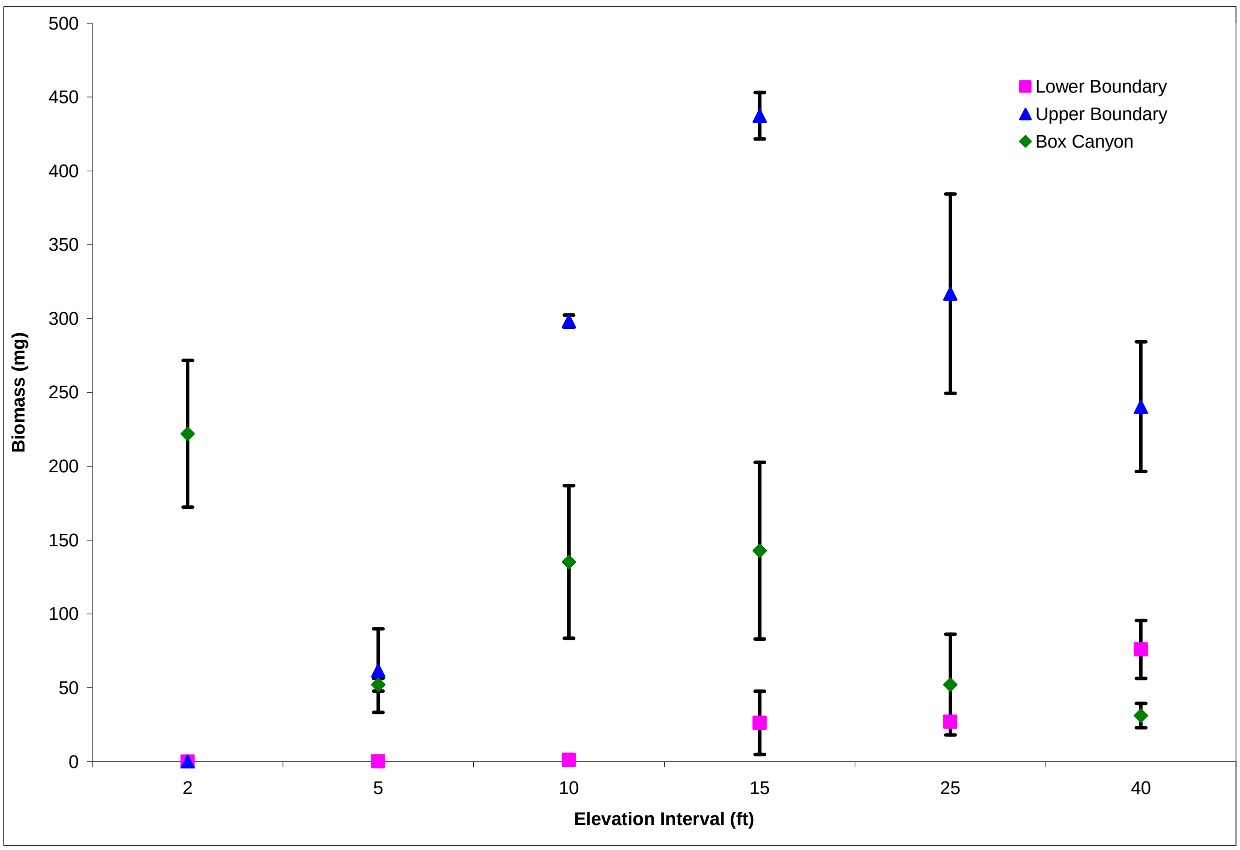


Figure 5.1-3. Hard substrate sampling along the shoreline, biomass without *Hydra* sp., May 2007.

In the May shoreline samples from lower Boundary Reservoir, no benthic macroinvertebrates were detected in the 2-ft 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*. In Box Canyon, *Ephemerella excrusian* was the most common taxon found at most elevation intervals, with the exception of the 10-ft and 25-ft samples. At the 10-ft interval, *Caecidotea* was most abundant, while *Ophiogomphus occidentis* was most common at the 25-ft interval. Other than *Hydra*, *Cheumatopsyche* was the most common taxon encountered in the upper Boundary Reservoir shoreline samples in May. Common names for these taxa can be found in Appendix 2.

For the shoreline samples, in September 2007, the *Hydra* sp. biomass was much lower than in May 2007 (Tables 5.1-3 and 5.1-4). For just the BMI biomass, the results of the September samples show a somewhat different response than the May samples in Box Canyon, but similar patterns in both lower and upper Boundary Reservoir (Table 5.1-4 and Figure 5.1-4). Biomass in lower Boundary Reservoir was greatest at the 15-ft sample and the 40-ft sample, and was lower overall than upper Boundary Reservoir and Box Canyon. Biomass in upper Boundary Reservoir again increased sharply to the 15-ft interval, and then decreased as the elevation interval increased. Biomass in upper Boundary Reservoir from the September 2007 samples was generally greater than that in Box Canyon. Biomass in Box Canyon was greatest at the 25 ft interval. During the September collection of shoreline samples, the 2-ft and 5-ft baskets in upper Boundary Reservoir were dry, as well as the 2-ft unit in Box Canyon. This exposure may have affected the biomass of the samples.

The September shoreline samples showed differences in taxa from the May samples. In lower Boundary Reservoir, *Physa* and *Polycentropus* were most common in the deeper samples. At shallower intervals, *Cladocera*, *Hyalella*, and *Helisoma anceps* were more common. In upper Boundary Reservoir, *Cheumatopsyche* was very abundant at the 40-ft interval, with *Ophiogomphus occidentis* and *Physa* also being common at intervals of 15 ft or greater. At shallower intervals, *Cladocera*, *Lymnaea*, *Gammarus*, *Polycentropus*, *Chironomidae* were the most commonly encountered taxa. Also found to be abundant in upper Boundary Reservoir were *Cheumatopsyche* and *Hydropsyche*. The samples collected in Box Canyon showed *Polycentropus* as the most abundance taxon in the 2-ft to 15-ft samples, while *Cheumatopsyche* was most common in the 25-ft and 40-ft samples. Also commonly found in the Box Canyon shoreline samples were *Chironomidae*, *Macromia magnifica*, *Porifera*, *Caecidotea*, and *Ophiogomphus occidentis*. Common names for these taxa can be found in Appendix 2.

Table 5.1-4. Results from September 2007 shoreline hard substrate sampling.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), without *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), with *Hydra* sp.
2	1.130	1.451	0.069	0.069	0.392	0.392
5	3.113	3.113	1.233	1.233	103.422	103.777
10	21.007	21.049	30.872	31.074	24.979	25.164
15	46.468	47.312	118.590	121.936	83.205	83.289
25	40.671	41.801	183.435	201.387	217.651	233.815
40	44.391	44.931	464.927	509.504	124.618	141.919

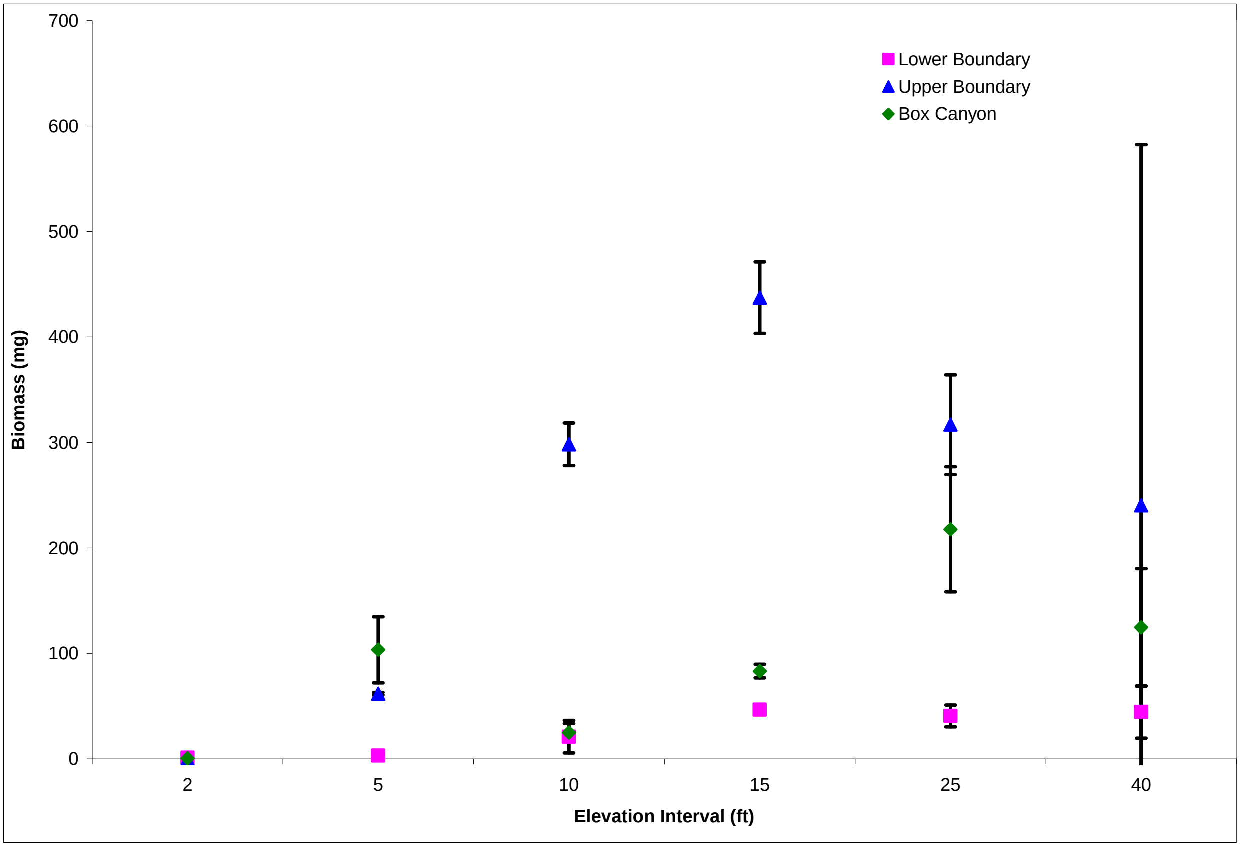


Figure 5.1-4. Hard substrate sampling along the shoreline, Biomass without *Hydra* sp., September 2007.

5.2. Soft Substrate Sampling

The results of the May 2007 and September 2007 soft substrate sampling for lower and upper Boundary Reservoir and Box Canyon Reservoir are shown in Figures 5.2-1 and 5.2-2. Table 5.2-1 and 5.2-2 contain numerical results for these samples. In the soft substrate samples, there was no difference between total biomass and biomass without *Hydra* sp., so only total biomass is reported.

Table 5.2-1. Results from May 2007 soft substrate sampling. Only total biomass is provided because *Hydra* were rarely present in soft substrate samples.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), without *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), without *Hydra* sp.
2	0.000	161.200	52.036
5	0.880	8.860	79.120
10	2.817	24.218	16.797
15	24.596	20.086	77.929
25	79.722	0.153	41.949
40	25.290	1.745	2.790

Biomass data in lower Boundary Reservoir from the May 2007 samples reflect an increase up to the 25-ft elevation interval and then a decrease. In upper Boundary Reservoir, biomass is greatest at the 2-ft interval. In Box Canyon, peak biomass occurs at the 5-ft interval and the 15-ft interval (Table 5.2-2 and Figure 5.2-2). Except for the peak at the 2-ft interval in upper Boundary Reservoir, soft sediment biomass levels are fairly similar across the three areas. During the May collection of soft substrate, some of the sampling locations were dry due to water surface elevation fluctuations, which likely affected biomass. In lower Boundary Reservoir, the 2-ft, 5-ft, and 10-ft elevation intervals were dry at the time of collection. In upper Boundary Reservoir, the 2-ft interval was dry. All samples collected in Box Canyon were wet at the time of collection.

The May soft substrate samples taken in lower Boundary Reservoir showed *Oligochaeta*, *Chironomidae*, and *Lumbriculidae* as the most common taxa at all elevations, with the exception of the 2-ft sample. No benthic macroinvertebrates were found in the 2-ft sediment sample. Other common taxa in lower Boundary Reservoir included *Pisidium* and *Nematoda*. In upper Boundary Reservoir, May samples showed *Oligochaeta* as one of the three most common taxa at all elevation intervals except for the 5 ft interval, 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 Box Canyon, *Chironomidae* was among the most common taxon at all elevation intervals except for the 2-ft and 5-ft intervals. At the 2-ft interval, *Oligochaeta* was most common, while *Lymnaea auricularia* was most prevalent at the 5-ft interval. Other common taxa in the Box Canyon May soft substrate samples included *Hyalella*, *Lumbriculidae, Ephemerella excrusians*, *Caecidotea*, and *Gammarus* at shallower elevation intervals and *Nectophsyche*, and *Nematoda* in the deeper samples. Common names for these taxa can be found in Appendix 2.

The results of the September samples show similar biomass levels across the three sampling areas at all elevations except for the 10-ft sample (Table 5.2-2 and Figure 5.2-2). Biomass from the 10-ft sample was greatest in upper Boundary Reservoir, then in Box Canyon, and lowest in lower Boundary Reservoir. Biomass in lower Boundary Reservoir was greatest at the 25-ft interval. As with the May samples, some of the samples collected in September were dry at the time of collection, which may have affected the biomass. The 2-ft sampling unit and a portion of the 5-ft unit in upper Boundary Reservoir were exposed, as well as the 2-ft baskets in Box Canyon. Due to high velocities, it was not possible to collect the sample from the 40-ft interval in upper Boundary Reservoir during this sampling period.

The September soft substrate samples showed *Oligochaeta* as one of the top three most abundant taxa in all three reservoirs at all elevations. The only exception to this was the 2-ft sample in Box Canyon, which only had one taxon present, which was *Dolichopodidae.* In lower Boundary Reservoir, *Chironomidae* was also found to be common at all elevation intervals, except for in the 40-ft sample. *Cladocera*, *Lymnaea*, *Nematoda*, *Erpobdellidae*, *Hyalella*, and *Sialis* were also abundant in the September lower Boundary Reservoir samples. In upper Boundary Reservoir, no benthic macroinvertebrates were found in the 2-ft or 5-ft samples. The 10-ft, 15-ft, and 25-ft samples showed *Chironomidae*, *Dubiraphia*, and *Hyalella* as common taxa, in addition to *Oligochaeta*. The Box Canyon samples showed the same common taxa as lower and upper

Boundary Reservoir, but also included *Harpacticoida*, *Physa*, and *Caecidotea*. Common names for these taxa can be found in Appendix 2.

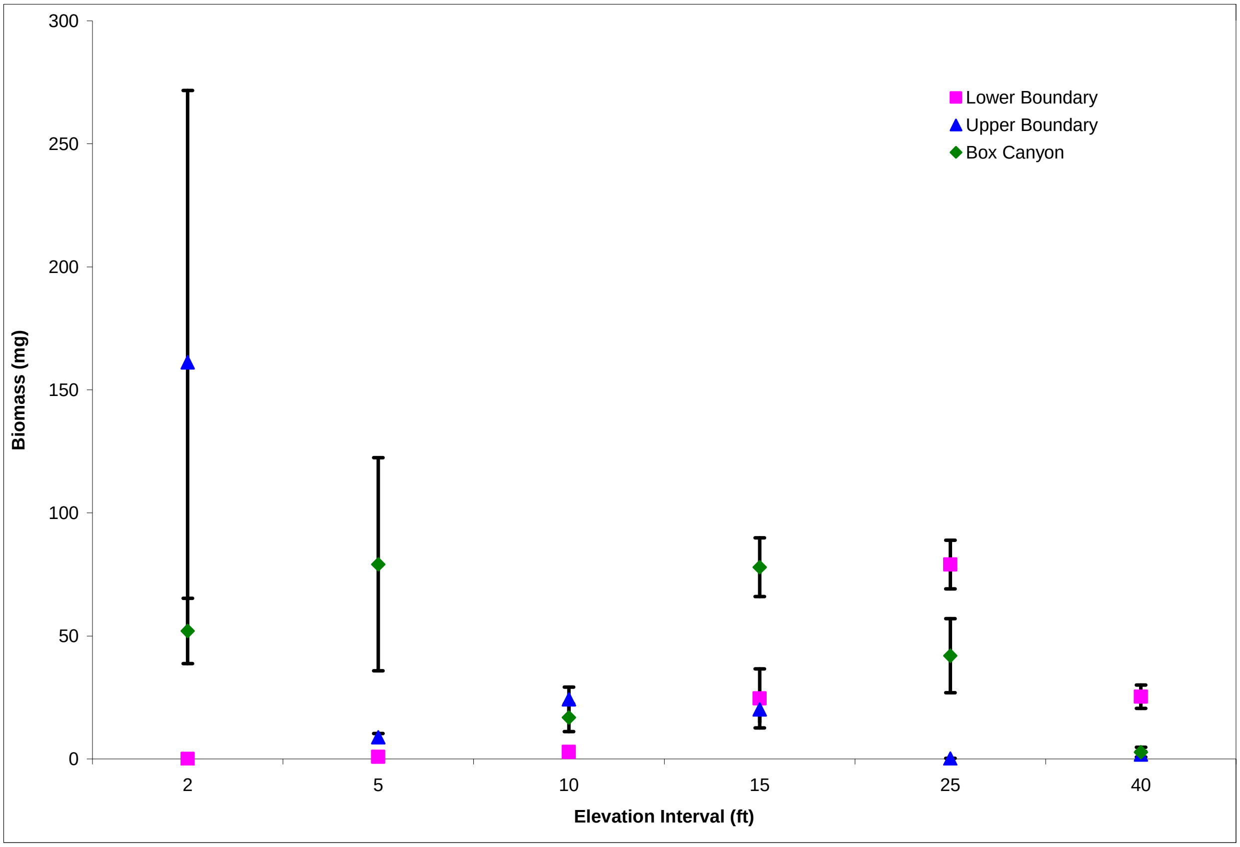


Figure 5.2-1. Soft substrate sampling, biomass without hydra, May 2007.

Table 5.2-2. Results from September 2007 soft substrate sampling. Only total biomass is provided because *Hydra* were rarely present in soft substrate samples.

Elevation Interval	Lower Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Upper Boundary Reservoir Mean Biomass (mg), with *Hydra* sp.	Box Canyon Reservoir Mean Biomass (mg), with *Hydra* sp.
2	0.441	0.000	0.059
5	1.731	0.000	1.244
10	3.686	58.587	25.545
15	9.515	13.787	8.399
25	13.781	13.278	7.099
40	9.219	N/A	11.661

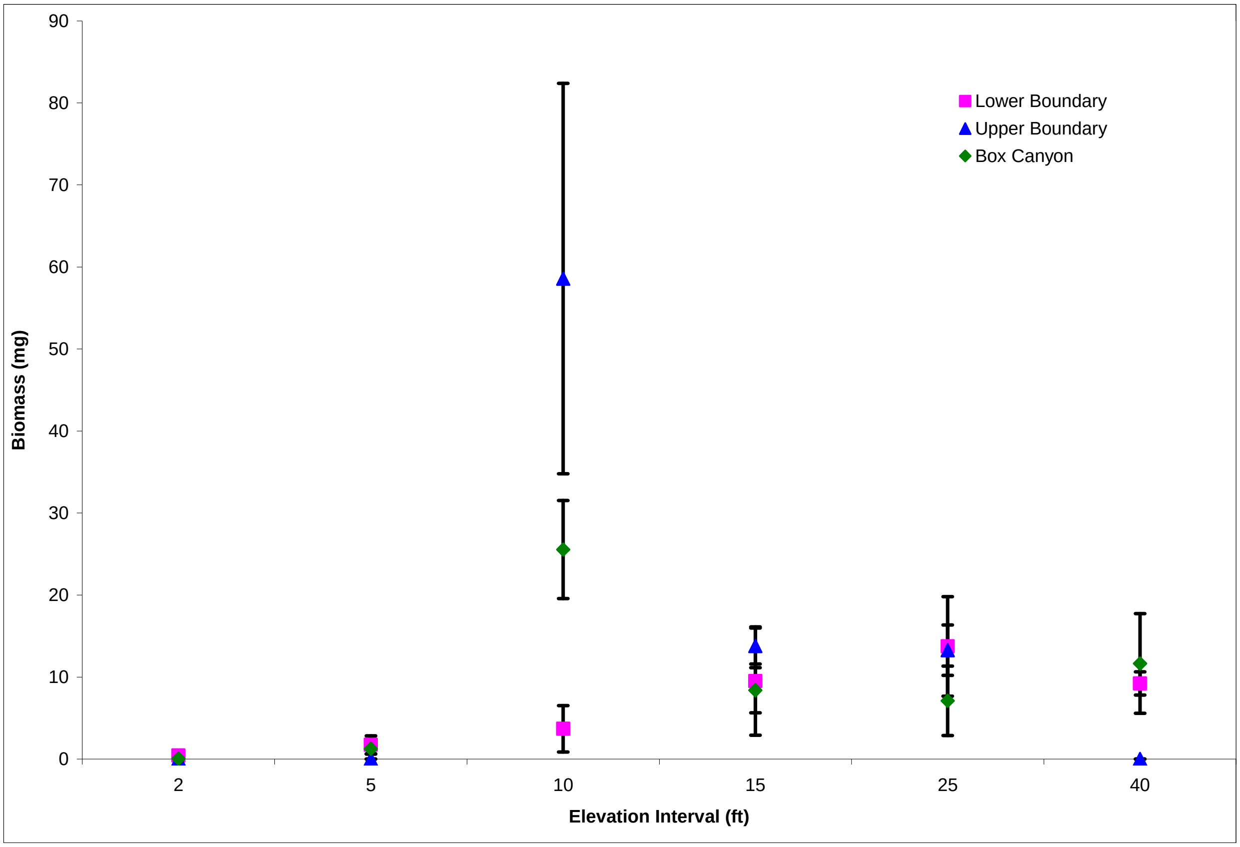


Figure 5.2-2. Soft substrate sampling, Biomass without hydra, September 2007.

5.3. Benthic Colonization Sampling

This section of the report will describe the results of benthic colonization sampling conducted in Box Canyon Reservoir. Sample collection was conducted in September 2007 and the results are discussed below and illustrated in Figure 5.3-1. Table 5.3-1 contains numerical results. Colonization sampling will be conducted again in February 2008 and those results will be reported in the 2008 Report.

The 2007 colonization samples reflect that at the 5 ft interval, biomass generally increases with inundation time up to 28 days. After 28 days, biomass appears to decrease and then level off. At the 15 ft interval, biomass initially increases in the first 7 days, and then slightly decreases with inundation between 7 and 14 days. With greater than 14 days of inundation, total biomass continually rises, with the greatest increase between 42 and 56 days of inundation. The 25-ft samples show an increasing trend at all inundation periods, with the most marked increases in the first 7 days and the period from 42 to 56 days (Table 5.3-1 and Figure 5.3-1).

Table 5.3-1. Results from 2007 colonization sampling in Box Canyon Reservoir.

Length of Inundation Time (days)	Average Biomass (mg)					
	5 Feet, without *Hydra* sp.	**5 Feet, with *Hydra* sp.**	**15 Feet, without *Hydra* sp.**	**15 Feet, with *Hydra* sp.**	**25 Feet, without *Hydra* sp.**	**25 Feet, with *Hydra* sp.**
56	131.407	132.427	585.306	731.777	678.441	702.858
42	118.079	120.039	167.578	143.220	214.118	247.490
28	234.645	236.018	129.481	131.430	190.032	193.685
14	103.767	103.901	93.073	93.537	120.447	120.514
7	111.986	112.011	119.106	119.562	96.771	96.923
3	2.918	3.053	1.049	1.049	8.797	8.797

Common taxa encountered in the colonization samples varied by elevation and duration of inundation. At the 5-ft interval, *Cladocera*, *Hyalella*, *Turbellaria*, and *Oligochaeta* were most commonly found in samples that were exposed for less than 14 days. As inundation period increased, *Polycentropus*, *Chironomidae*, *Macromia magnifica*, *Cheumatopsyche*, *Cladocera*, and *Oligochaeta* became the more prevalent taxa. Samples placed at the 15-ft interval showed *Cladocera* as the dominant taxa in samples exposed for up to 14 days. As inundation 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 at 3 days of exposure, but not in any of the other samples. Other common taxa found in samples inundated for greater than three days included *Helisoma anceps*, *Maccaffertium*, *Polycentropus*, and *Ophiogomphus occidentis*. Similar to the 15-ft samples, the 25-ft samples showed *Cladocera* as the most common taxa found during inundation periods of up to 14 days and *Cheumatopsyche* as the most prevalent taxa in samples inundated 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-ft interval were similar to those found at the 15-ft interval, including *Hydropsyche*, *Ophiogomphus occidentis*, *Maccaffertium*, *Helisoma anceps*, and *Chironomidae*.

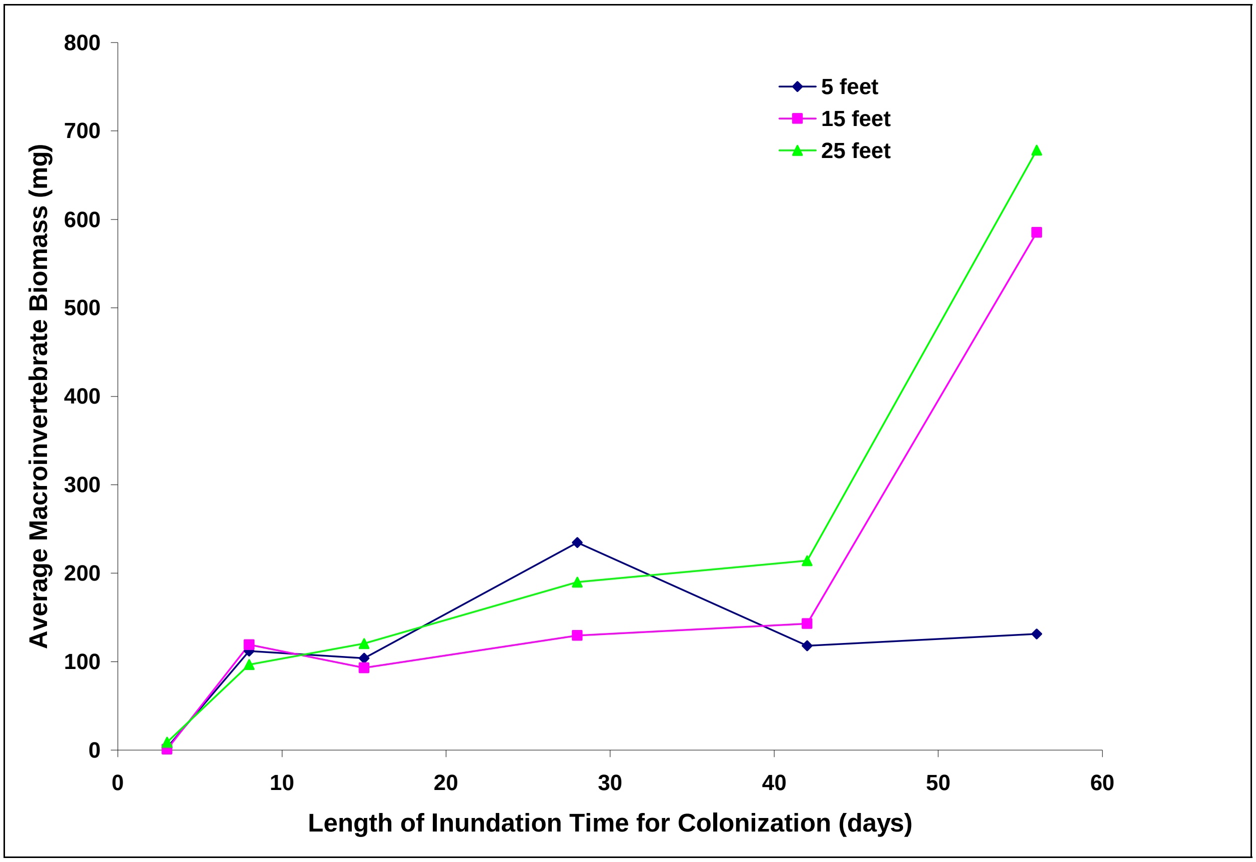


Figure 5.3-1. Colonization sampling, biomass without *Hydra* sp., May 2007.

5.4. Sample Analysis

Figures presenting water surface elevations at each Boundary Reservoir sampling site during the sampling period will be included in the final report once the data become available in 2008. Hourly water surface elevations in Box Canyon Reservoir during sampling periods will also be presented in graphical form once the data are obtained. These data will not be obtained until field data collection efforts are completed in February 2008. The hydraulic model, which is currently being developed, will provide information on site-specific water surface elevations in Boundary Reservoir. Water surface elevations in Box Canyon Reservoir were requested from the staff at the Box Canyon Dam from their control room data. The 2007 gauge data for Box Canyon has been obtained and may need to be adjusted to reflect the same datum as the Boundary Dam water elevation data. This need is currently being assessed. Analysis will be conducted once this process and QA/QC is conducted. Additional gauge data will be required for any sampling events conducted in 2008. One model will be used to incorporate the data from Box Canyon Reservoir and from Boundary Reservoir to determine the effects of inundation on BMI. This model has not been completed at this point. Once the model is completed, the water surface elevations at each sampling site over the course of each deployment will be used to calculate the depth of water at each sample over time. This information will then be used in the BMI HSI validation. Site-specific water surface elevations will also be used to help better understand benthic macroinvertebrate responses to fluctuating water surface elevations (i.e., duration of inundation and dewatering). Output from the model will also include estimates of velocity at the samples and the duration of inundation and dewatering for each sample during the sampling period. These data will be compared with the BMI data and the HSI model as described in Section 5.5.

Due to the high biomass of *Hydra* sp. in the samples and periphyton biomass pattern observed in Study 7.4.3 Periphyton HSI, Appendix 3 in the Study 7 report, two variables are proposed to be tested to define and provide potential correction factors if needed for BMI field bias. One is the relative effect of the artificial sampling platform on providing additional colonization area and hence subsequent bias for high biomass of *Hydra* sp. Second is the relative impact of the artificial sampling platform potentially providing decreased exposure velocities that result in a more stable colonization environment and more primary production for BMI to forage upon. Both of these potential biases can be defined numerically and thus a correction factor derived by conducting a side by side artificial substrate and natural substrate exposures at 5, 10, and 15 feet during the spring growth period. This study will be conducted in concert with additional periphyton study (see Appendix 3).

This additional study in 2008 will compare the invertebrate production in the artificial substrate samplers with production on natural hard substrate at shoreline sites in Box Canyon Reservoir, upper Boundary Reservoir, and lower Boundary Reservoir. The study will evaluate any differences in BMI community structure and biomass that may result from altered conditions caused by the sampling baskets. Specifically, impacts of potential reduced velocity within the samplers resulting in greater potential food availability and differentiation between *Hydra* sp. abundance and colonization due to influences of the artificial basket environment versus existing Project operations. Differences in relative abundance of *Hydra* sp. from artificial substrate and natural substrate will lead to the calculation of a potential correction factor(s) for *Hydra* sp. biomass. Relative differences in BMI biomass between artificial and natural substrate will be used to develop adjustment factors if needed in BMI biomass.

5.5. Validation of BMI HSI Curves

Once all BMI monitoring data are collected and corrected for any identified bias as discussed in section 5.4, corrected field data will be used to validate HSI curves for depth, velocity, substrate, and frequency of inundation/dewatering. A histogram will be developed for each of the habitat parameters using site-specific benthic macroinvertebrate field data and then compared to the literature-based HSI curve to validate applicability of the literature-based HSI curve for aquatic habitat modeling. Validated HSI curves will be presented in the final report.

5.6. Finalize Benthic HSI Information

A panel of relicensing participants and regional experts (agency, tribal, industry and university researchers) will convene to review the benthic HSI curves that were validated with site-specific data. A roundtable discussion format is proposed, where the panel members will review literature-based BMI community information and site-specific data to develop a final set of HSI curves. These curves will then be used in the aquatic habitat modeling study to define the relationship between habitat quantity and quality for operations scenarios.

6 SUMMARY

A review of available literature has provided general information regarding the habitat suitability of benthic macroinvertebrates related to depth, velocity, substrate type, duration of exposure, and rate of colonization (Appendix 1). Provisional suitability curves in Appendix 1 have been developed based on this information. Field studies are currently underway to gather data specific to benthic macroinvertebrate communities in the Boundary Reservoir, which will be used to calibrate and revise the provisional suitability curves. An additional study is recommended in 2008 to compare the invertebrate production in the artificial substrate samplers with production on natural hard substrate at shoreline sites in all three reservoir locations. The study will evaluate any differences in BMI community structure and biomass that may result from altered conditions caused by the sampling baskets. Differences in relative abundance of *Hydra* sp. from artificial substrate and natural substrate will lead to the calculation of a potential correction factor(s) for *Hydra* sp. biomass using measurement of bias as a refinement factor. Relative differences in BMI biomass between artificial and natural substrate will be used to develop adjustment factors, if needed, in BMI biomass.

Once the suitability curves for benthic macroinvertebrates at the Boundary Reservoir have been finalized, they will be incorporated into the larger HSI model, along with the periphyton, macrophyte, and fish data, to gain a broader understanding of the biotic response to operations at the Boundary Dam. This information will enable Seattle City Light and other relicensing participants to evaluate the effects of operations scenarios to support relicensing decisions.

This page is intentionally left blank.

Appendix 1. Benthic Macroinvertebrate Boundary HSI Interim Methods Report

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.4.3
Periphyton and Benthic Macroinvertebrate HSI
Subtask 1 (Part): Benthic Macroinvertebrate Boundary HSI
Interim Methods Report

Prepared for
Seattle City Light

Prepared by
Tetra Tech

March 2008

TABLE OF CONTENTS

Appendices

List of Tables

List of Figures

Study No. 7.4.3: Periphyton and Benthic Macroinvertebrate HSI
Subtask 1 (Part): Benthic Macroinvertebrate Boundary HSI Interim Methods Report
Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Benthic macroinvertebrates (BMI) are included in the mainstem aquatic habitat model in the form of Habitat Suitability Curves (HSC) and Habitat Suitability Indices (HSI) to estimate BMI productivity for operations scenarios. This report describes provisional literature-based HSC and HSI that will describe the response of BMI to water depth, velocity, and substrate, and inundation and dewatering. These literature-based HSC and HSI will be supplemented by site-specific information developed through field studies described in the Methods Outline for Study 7.4.3. Project operations may affect flows and reservoir pool water surface elevations, and the frequency and duration of inundation and dewatering of shoreline areas. BMI are secondary producers inhabiting those shoreline areas and provide food resources to fish and other animals that inhabit the Boundary Reservoir (Seattle City Light 2007). The response of BMI to operations scenarios will be evaluated as part of Fish and Aquatic Study 11: Productivity Assessment to provide information on the effects of Project operations on primary and secondary productivity.

The abbreviation HSI is used in this document to refer to either HSI models or a combination of HSI and HSC, depending on the context. HSI models provide a quantitative relationship between 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, under 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 under various flow regimes (Bovee et al. 1998). HSC describes the instream suitability of habitat variables related only to stream hydraulics and channel structure (i.e., depth, velocity, and substrate). Both HSC and HSI models are scaled to produce an index between 0 (unsuitable habitat) and 1 (optimal habitat). Both HSI and HSC are hypotheses of species-habitat relationships and are intended to provide indicators of habitat change. For the Boundary Project aquatic habitat studies, HSC (i.e., depth, velocity, and substrate) and HSI (i.e., duration of inundation and dewatering) models will be integrated to analyze the effects of operations scenarios on benthic macroinvertebrates.

Benthic macroinvertebrates utilize a variety of habitat types within the Boundary Reservoir. Habitat suitability information for BMI taxa have been documented in Merritt and Cummins (1984), including HSCs for depth, velocity, and substrate. Conditions in the littoral zone of the Boundary Reservoir (where most BMI are found) are potentially affected by flow and water surface elevation fluctuations that occur in response to Project operations, flow releases from upstream water control projects, and natural flow fluctuations. The response of BMI to varying combinations of depth and substrate will be refined using site-specific field data. Water velocity will be included as a modeling parameter; however, it is expected to be of minor importance in defining potential BMI productivity. Water velocities experienced by BMI within the boundary layer above the substrate are expected to be different from the mean water column velocity estimated by the mainstem aquatic habitat model. Velocity is included in this HSC/HSI model but will be used to indicate general presence or absence of BMI using literature-based values.

The combined depth, velocity, and substrate HSC will be used to identify optimal BMI habitats for production. HSI describing the rate of BMI colonization and effects of dewatering will then be used to estimate the effects of operations scenarios on BMI productivity.

Data provided in this report are provisional estimates of suitability curves that can be used to estimate BMI productivity for operations scenarios. Once field data from the Boundary and Box Canyon reservoirs have been collected and analyzed, the HSC/HSI will be adjusted, if needed, to accommodate this information.

2 STUDY OBJECTIVES

The objective for the development of a Boundary BMI model is to help assess the effect of operations scenarios on aquatic productivity. Developing a BMI model for the Boundary Project will help in evaluating how differences in depth, velocity, and substrate and the frequency, duration, and magnitude of inundation and dewatering can influence BMI biomass. The Boundary BMI evaluation process will use estimates of physical and hydraulic conditions for operations scenarios coupled with HSC and HSI information to provide a comparative index of BMI productivity.

3. STUDY METHODS

The Boundary Project benthic macroinvertebrate 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 3.0-1). 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 3.0-1. Boundary Project benthic macroinvertebrate (BMI) model

Benthic Macroinvertebrate Composite Suitability Index	$CSI_{BMI} = HSC_i * HSI_i$
Benthic Macroinvertebrate HSC	$HSC_i = Di * Vo_i * S_i$
Benthic Macroinvertebrate HSI	$HSI_i = f (DI_i , DD_i)$ [1]
BMI Variables	D_i = Depth Vo_i = Velocity S_i = Substrate DI_i = Duration of Inundation DD_i = Duration of Dewatering

[1] 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 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 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 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 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 BMI biomass than cells that are newly inundated. Cells that have been dewatered for even a period of hours will have a lower BMI biomass than cells that have not been dewatered. Frequent cycles of dewatering and inundation will affect 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 will be tracked using hourly time steps. As the duration of continuous inundation increases, the BMI biomass is assumed to increase up to a maximum suitability of 1.0. The rate of BMI increase is determined from a Duration of Inundation (DI) HSI. While BMI biomass in a cell increases as the duration of continuous inundation increases, dewatering of the cell will reduce BMI biomass through emigration or mortality. The rate of BMI 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.

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 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 meeting materials] 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 BMI production 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.

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. However, these studies primarily documented BMI HSC for lotic environments, with no appropriate suitability curves that would directly apply to the conditions in the Boundary Reservoir. Existing work on BMI suitability curves has focused on specific invertebrate taxa. The focus of this BMI model is to determine the response of aquatic macroinvertebrates as a whole. 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 and professional experience and judgment (see Appendix 1: Published Suitability Curves). 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 (see Appendix 2: Suitability Curve Data Produced from Published Suitability Curves). Section 4 includes a summary of the information from literature sources and the provisional suitability curves.

4 HSI MODEL VARIABLES

4.1. 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 ft (1 and 2 m) in lentic environments, with the exception of a few Dipterans that have been found at depths exceeding 700 ft (213 m).

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 describes the littoral zone (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 arise 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 are likely to be one of the most abundant aquatic insect taxa in the Boundary Reservoir based on data from McLellan (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 ft (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 ft

(2.5 m) decreasing in very shallow water (less than 2.72 ft [0.83 m]), but remaining moderately abundant at a depth of 14.76 ft (4.5 m) (Appendix 1: Published Suitability Curves, Figure 1) (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 ft (0.5 m) (Appendix 1: Published Suitability Curves, Figures 2 and 3). At depths greater than 2.3 ft (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 ft (0 m) in any of the three studies. In a large Canadian lake, Ephemeroptera and Trichoptera were collected at depths of 39 and 49 ft (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 (Appendix 1: Published Suitability Curves, Figures 3 and 4). Jowett and Davey (2007) found the Trichoptera taxa *Aoteapsyche* had peak suitability of 1.0 from about 0.0 to 1.6 ft (0.0 to 0.5 m), falling to a suitability of approximately 0.2 at depths greater than 4.3 ft (1.3 m) (Appendix 1: Published Suitability Curves, Figure 4). Gore et al. (2001) presents results for Trichoptera illustrating a 0.0 suitability at 0.0 ft (0.0 m) and a peak suitability of 1.0 between 1.3 and 3.1 ft (0.4 to 0.95 m) (Appendix 1: Published Suitability Curves, Figure 3). 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 ft (0 and 0.1 m), a peak suitability of 1.0 at depths between 1.3 and 2.5 ft (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 ft (0.85 and 0.95 m) (Appendix 1: Published Suitability Curves, Figure 3). In Lake Tahoe, Nevada, adults of the Plecopteran *Capnia tahoensis* have been found on submerged plants at depths between 197 and 263 ft (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 ft (0.6 m), and minimum suitability at both 0.0 and 4.3 ft (0.0 and 1.3 m) deep (Appendix 1: Published Suitability Curves, Figure 6).

As described in Section 3 of this report, the data from existing BMI suitability curves (see Appendix 2: Suitability Curve Data Produced from Literature, Figure 1), an extensive literature review, and professional judgment were used to develop depth ranges and provisional suitability values (Table 4.1-1 and Figure 4.1-1). BMI biomass below 50 feet is insignificant relative to the biomass that occurs in the varial zone above 50 feet within the reservoir. Therefore, the HSI is assigned a zero value as measurement of BMI. Further calibration of the provisional values will be supported with data collected in the field evaluating the differences in BMI biomass at varying water depths.

Table 4.1-1. Depth ranges and provisional suitability values for BMI.

Depth in feet (meters)	Provisional Suitability Values
0 ft (0 m)	0.0
0.3 ft (0.09 m)	0.2
0.5 ft (0.15 m)	0.4
3.0 ft (0.91 m)	0.7
10 ft (3.05 m)	1.0
15 ft (4.6 m)	1.0
20 ft (6.10 m)	0.6
40 ft (12.19 m)	0.3
>50 ft (15.24 m)	0

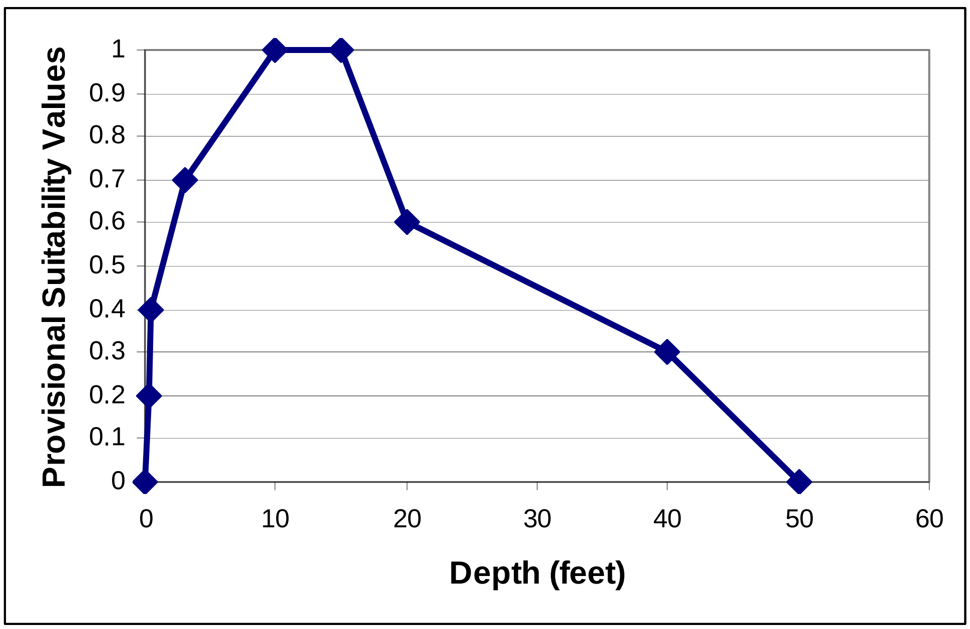


Figure 4.1-1. Provisional depth suitability curve for benthic macroinvertebrates (BMI). Maximum depth for presence of BMI exceeds 60 ft.

4.2. 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 [ft/s] (0.75 and 1.25 meters per second [m/s]) at depths between 0.66 and 1.31 ft (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 ft/s (1.0 to 1.5 m/s) (Appendix 1: Published Suitability Curves, Figure 7). In addition, the suitability index was greater than 0.3 for all velocities between 0 and 5.25 ft/s (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 ft/s (0.1 to 0.3 m/s) (Appendix 1: Published Suitability Curves, Figure 8), with the suitability index ranging from 0.5 at 0 ft/s (0 m/s) to 0.0 at 2.95 ft/s (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 ft/s (0 m/s) (Appendix 1: Published Suitability Curves, Figures 8 and 9). However, Jowett and Davey (2007) determined peak suitability for the Trichoptera genus *Aoteapsyche* to be at velocities greater than 4.92 ft/s (1.5 m/s), while Gore et al. (2001) found a suitability of 0.0 for velocities at 2.95 ft/s (0.9 m/s).

Evaluating velocity suitability for total macroinvertebrates in the Sacramento River, California, Gard (2006) found a peak suitability at 2.2 ft/s (0.67 m/s) and minimum suitability at 0.0 and 5.0 ft/s (0.0 and 1.52 m/s) (Appendix 1: Published Suitability Curves, Figure 10).

As described in Section 3 of this report, an extensive literature review (see Appendix 2: Suitability Curve Data Produced from Literature, Figure 2), and professional judgment were used to develop velocity ranges and provisional suitability values (Table 4.2-1 and Figure 4.2-1).

Table 4.2-1. Velocity ranges and provisional suitability values for benthic macroinvertebrates (BMI).

Velocity in feet per second (meters per second)	Provisional Suitability Values
0 ft/s (0 m/s)	0.6
0.12 ft/s (0.04 m/s)	0.8
1.4 ft/s (0.43 m/s)	1.0
2.6 ft/s (0.79 m/s)	1.0
3.8 ft/s (1.16 m/s)	0.6
5 ft/s (1.52 m/s)	0.3
8 ft/s (2.44 m/s)	0.1
20 ft/s (6.10 m/s)	0.0

4.3. 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

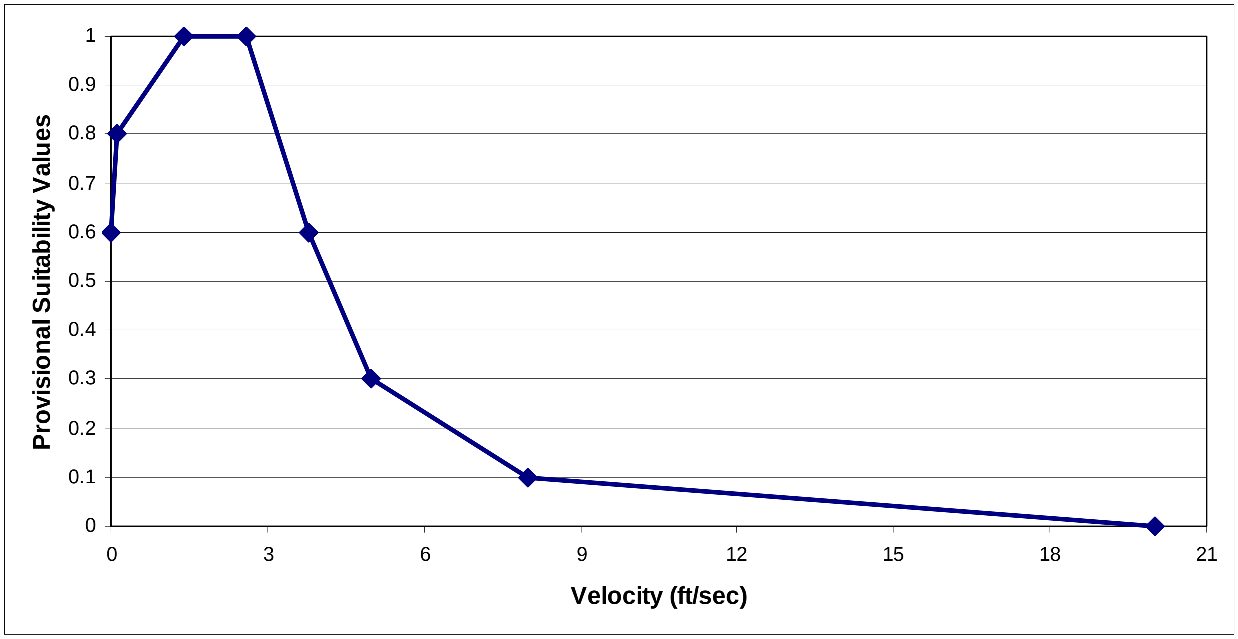


Figure 4.2-1. Provisional velocity suitability curve for benthic macroinvertebrates (BMI).

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 (Appendix 1: Published Suitability Curves, Figure 5). 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 (Appendix 1: Published Suitability Curves, Figure 11) (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. (Appendix 1: Published Suitability Curves, Figure 12). These results were confirmed in two studies of rivers in New Zealand (Jowett et al. 1991, Jowett and Davey 2007) (Appendix 1: Published Suitability Curves, Figure 13). 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 (Appendix 1: Published Suitability Curves, Figure 14). 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 (Appendix 1: Published Suitability Curves, Figures 12 and 15). 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 (Appendix 1: Published Suitability Curves, Figure 12). Oligochaete abundance was also found to correlate inversely with substrate size, with the finest substrate (sand) having the highest abundance and gravel the lowest (Appendix 1: Published Suitability Curves, Figure 16) (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]) (Appendix 1: Published Suitability Curves, Figure 17) in relation to a depth preference of 1 ft (0.30 m), and a velocity preference of 2 ft/s (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).

As described in Section 3, the data from BMI suitability curves (see Appendix 2: Suitability Curve Data Produced from Literature, Figure 3), an extensive literature search, and professional judgment were used to develop substrate types and provisional suitability values (Table 4.3-1 and Figure 4.3-1). Further calibration of the provisional values will be supported with data collected in the field evaluating the differences in BMI biomass on artificial substrates.

Table 4.3-1. 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

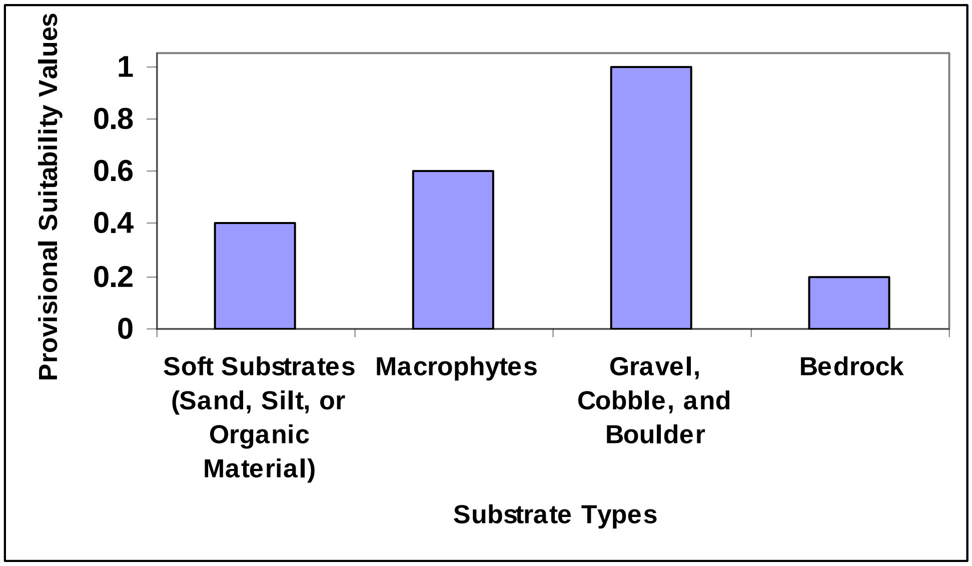


Figure 4.3-1. Provisional substrate suitability curve for BMI.

4.4. 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 ft (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 – 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 – 48 hours. When temperatures were cool, survival was relatively high for Lepidoptera, Trichoptera, and Diptera at 24 – 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 – 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 4.4-1 and Figure 4.4-1.

Table 4.4-1. Duration of dewatering provisional suitability values for BMI.

Duration of Dewatering (time)	Provisional Suitability Values
No dewatering (0 hours)	1.0
6 hours (0.25 day)	0.6
12 hours (0.5 day)	0.4
24 hours (1.0 day)	0.2
48 hours (2 days)	0.1
96 hours (4 days)	0.05
720 hours (30 days)	0.0

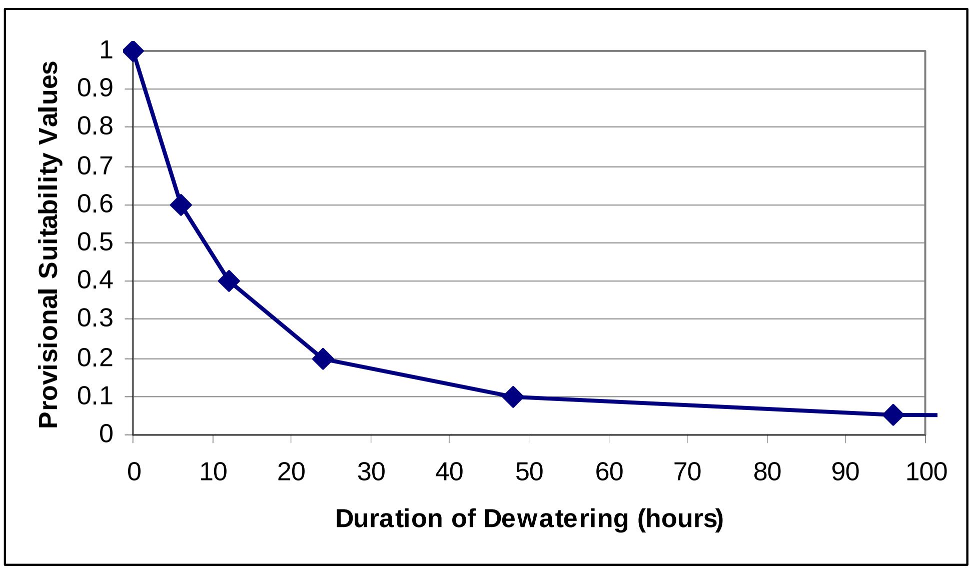


Figure 4.4-1. Provisional duration of dewatering suitability curve for benthic macroinvertebrates (BMI), curve goes to zero after 30 days.

4.5. 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 4.5-1 and Figure 4.5-1 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 4.5-1. Duration of inundation provisional suitability values for BMI.

Duration of inundation (time)	Provisional Suitability Values
No inundation (0 hours)	0.0
1 day (24 hours)	0.1
4 day (96 hours)	0.4
7 days (168 hours)	0.6
15 days (360 hours)	0.8
45 days (1,080 hours)	1.0
365 days (8,760 hours)	1.0

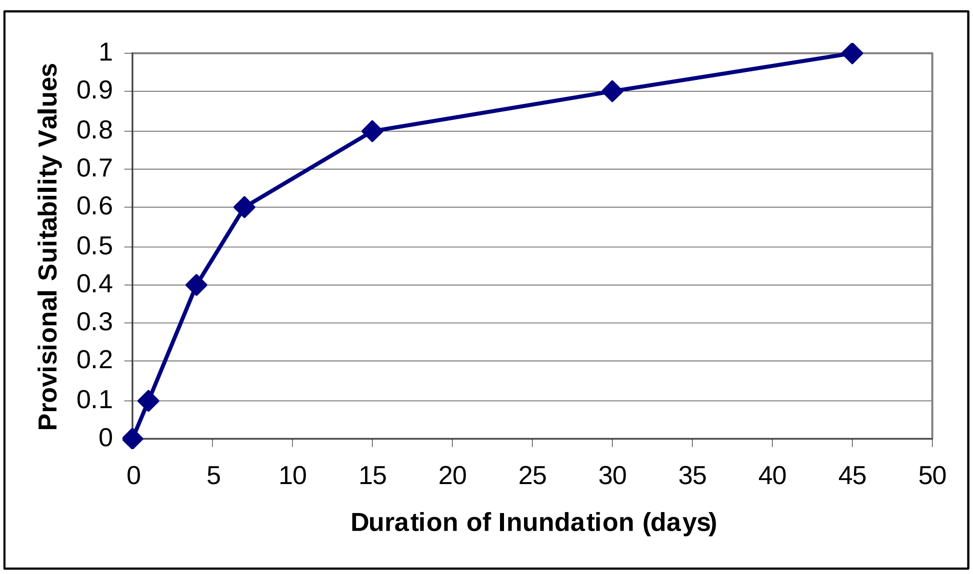


Figure 4.5-1. Provisional duration of inundation suitability curve for benthic macroinvertebrates (BMI).

5 CONCLUSION

A review of available literature has provided general information regarding the habitat preferences of benthic macroinvertebrates related to depth, velocity, substrate type, duration of exposure, and rate of colonization. Provisional suitability curves have been developed based on this information. Field studies are currently underway to gather data specific to benthic macroinvertebrate communities in the Boundary Reservoir, which will be used to calibrate and revise the provisional suitability curves. Once the suitability curves for benthic macroinvertebrates at the Boundary Reservoir have been finalized, they will be incorporated into the larger HSI model, along with the periphyton, macrophyte, and fish data, to gain a broader understanding of the biotic response to operations scenarios at the Boundary Dam. This information will enable Seattle City Light and other stakeholders to evaluate the effects of operations scenarios to support relicensing decisions.

6 REFERENCES

Adamstone, F.B. 1924. The distribution and economic importance of the bottom fauna of Lake Nipigon with an appendix on the bottom fauna of Lake Ontario. Univ. Toronto Studies Biology, Publ. Ontario Fish. Res. Lab. 24: 35-100. As cited in Ward, J.V. 1992. *Aquatic Insect Ecology*. John Wiley and Sons, Inc. New York. 438 pp.

Anderson, N.H., and J.B. Wallace. 1984. Habitat, life history, and behavioral adaptations of aquatic insects. In: R.W. Merritt and K. W. Cummins (eds.). *An Introduction to the Aquatic Insects of North America*. Kendall/Hunt Publishing Company: Dubuque, Iowa. 721 pp.

Ashe, B.L., and A.T. Scholz. 1992. Assessment of the fishery improvement opportunities on the Pend Oreille River: recommendations for fisheries enhancement. Final Report. Upper Columbia United Tribes Fisheries Center, Department of Biology, Eastern Washington University, Cheney, Washington. Prepared for U.S. Department of Energy, Bonneville Power Administration. Project No. 99-66, Contract No. DE-179-88BP39339.

Barnes, R. D. 1968. *Invertebrate Zoology*. W.B. Saunders Company: Philadelphia, Pennsylvania. 734 p.

Blinn, D.W., J.P. Shannon, L.E. Stevens, and J.P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. *Journal of the North American Benthological Society* 14 (2): 233-248.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the Instream Flow Incremental Methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii+131 pp. (http://www.fort.usgs.gov/products/pubs/3910/3910.asp).

Brusven, M.A. 1984. The distribution and abundance of benthic insects subjected to reservoir-release flows in the Clearwater River, Idaho, U.S.A. Page 167 in A. Lillehammer and S.J. Saltveit, editors. *Regulated Rivers*. Universitetsforlaget AS, Norwa.

Brusven, M.A., C. MacPhee, and R. Biggam. 1974. Chapter 5 Benthic Insects (Effects of Water Fluctuation on Benthic Insects). University of Idaho: Moscow, Idaho.

Ciborowski, J.J.H., and H.F. Clifford. 1984. Short-term colonization patterns of lotic macroinvertebrates. *Canadian Journal of Fisheries and Aquatic Sciences* 41: 1626-1633.

Collier, K.L., and J.M. Quinn. 2003. Land-use influences macroinvertebrate community responses following a pulse disturbance. *Freshwater Biology* 48:1462-1481.

Diggins, M.R., and J.H. Thorp. 1985. Winter-spring depth distribution of Chironomidae in a Southeastern reservoir. *Freshwater Invertebr. Biol.* 4(1): 8-21.

Fisher, S.G., and A. LaVoy. 1972. Differences in Littoral Fauna Due to Fluctuating Water Levels Below a Hydroelectric Dam. Journal Fisheries Research Board of Canada. Vol. 29, No. 10, 1972: 1472-1476.

Furey, P.C., R.N. Nordin, and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. *Journal of the North American Benthological Society* (2006) 25(1): 19-31.

Gard, M. 2006. Flow-habitat relationships for macroinvertebrates in the Sacramento river between Keswick dam and Battle Creek. Energy and Planning and Instream Flow Branch, USFWS, Sacramento, CA. 44 Pp.

Gersich F.M., and M.A. Brusven. 1981. Insect colonization rates in near-shore regions subjected to hydroelectric power peaking flows. *Journal of Freshwater Ecology* 1(2): 231-236.

Gore, J.A. 1982. Benthic invertebrate colonization: Source distance effects on community composition. *Hydrobiologia* 94:183-193.

Gore, J.A. 1978. A technique for predicting in-stream flow requirements of benthic macroinvertebrates. *Freshwater Biology* 8 (2), 141–151.

Gore, J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: A role in stream management and restoration. *Regul. Rivers: Res. Mgnt*. 17: 527 – 542.

Grimas, U. 1962. The effect of increased water level fluctuation upon the bottom fauna in Lake Blasjon, northern Sweden. Institute of Zoology, Entomological Department, Uppsala. Pages 14-41.

Hauer, F.R., and J.A. Stanford. 1997. Long-term influence of Libby Dam operation on the ecology of macrozoobenthos of the Kootenai River, Montana and Idaho. Unpublished report to the Montana Department of Fish, Wildlife and Parks, Helena, MT. 63 pp.

Holomuzki, J.R., and B.J.F. Biggs. 1999. Distributional responses to flow disturbance by a stream-dwelling snail. OIKOS 87: 36-47.

Jewett, S.G. Jr. 1963. A stonefly aquatic in the adult stage. *Science* 139: 484-485. As cited in Williams, D.D., and B.W. Feltmate. 1992. *Aquatic Insects*. C.A.B. International. Wallingford, UK, 358 pp.

Jowett, I.G., J. Richardson, B.J.F. Biggs, C.W. Hickey, and J.M. Quinn. 1991. Microhabitat preferences of benthic invertebrates and the development of generalized *Deleatidium* spp. habitat suitability curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* 25: 187-199.

Jowett, I.G., and A.J.H. Davey. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence – habitat availability. *Trans. Amer. Fish. Soc.* 136: 428-444.

Kaster, J.L., and G.Z. Jacobi. 1978. Benthic macroinvertebrates of a fluctuating reservoir. *Freshwater Biology* (1978) 8, 283-290.

Keup, L. E. 1988. Invertebrate fish food resources of lotic environments. Instream Flow Information Paper No. 24. United States Fish and Wildlife Service Biological Report 88(13). 96 p.

McCabe, D.J. and N.J. Gotelli. 2000. Effects of disturbance frequency, intensity, and area on assemblages of stream macroinvertebrates. *Oecologia* 124: 270-279.

McLellan, J.G. 2001. 2000 WDFW Annual Report for the Project, Resident Fish Stock Status Above Chief Joseph and Grand Coulee Dams. Part I. Baseline Assessment of Boundary Reservoir, Pend Oreille River, and its Tributaries. Report to Bonneville Power Administration, Contract No. 00004619, Project No. 199700400.

Merritt, R.W., and K.W. Cummins. 1984. An introduction to aquatic Insects of North America. 2nd Edition. Kendal/Hunter Publishing Company, Dubuque, Iowa. 772 pp.

Milhous, R.T. 1990. The physical habitat versus streamflow relationships for the Salmon River, Oswego County, New York. National Ecology Research Center. U.S. Fish Wildl. Serv., Fort Collins, CO.

Miller, A.M., and S.W. Gollady. 1996. Effects of spates and drying on macroinvertebrate assemblages of an intermittent and a perennial prairie stream. *Journal of North American Benthological Society.* 15(4):670 -689.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. In: V.H. Resh and D.M. Rosenberg (eds.), The Ecology of Aquatic Insects. Praeger, New York. Pp. 358-400.

Niemi, G.J., P. DeVore, N. Detenbeck, D. Taylor, A. Lima, J. Pastor, J.D. Yount, and R.J. Naiman. 1990. Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management* 14:571-587.

Negishi, J.N. and J.S. Richardson. 2006. An experimental test of the effects of food resources and hydraulic refuge on patch colonization by stream macroinvertebrates during spates. *Journal of Animal Ecology* 75(1): 118-129.

Ploskey, G.R. 1986. Effects of Water-Level Changes on Reservoir Ecosystems, with Implications for Fisheries Management. Reservoir Fisheries Management: Strategies for the 80's. Pp. 86-97.

R.L.&L. Environmental Services, Ltd. 2000. Brilliant Expansion Project: Prediction and assessment of project related flow variations on the aquatic environment. Report prepared for the Columbia Power Corporation, Castlegar, B.C. R.L. & L. Report No. 837F: 95 pp. + 6 app.

Rosenberg, D.M., and V.H. Resh. 1982. The use of artificial substrates in the study of freshwater benthic macroinvertebrates. In: J. Cairns Jr. (ed). *Artificial Substrates*. Ann Arbor Science Publishers, Inc. Pp. 175-274.

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.

Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. *Environmental Management* 14:711-724.

Slobodkin, L. B. and P. E. Bossert. 1991. The Freshwater Cnidaria – or Coelenterates. In: J.H. Thorp and A. P. Covich, eds. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press. p. 132-133.

Smock, L.A. 1996. Macroinvertebrate movements: Drift, Colonization, and Emergence. In: F.R. Hauer and G.A. Lamberti (eds.) *Methods in Stream Ecology*. Academic Press, San Diego, CA.

Stark, E.J., and D.H. Bennett, PhD. 2001. Effects of Water Level Fluctuations on Benthic Macroinvertebrates in the Hanford Reach, Columbia River, A Thesis.

Thorp, J.H., and A.P. Covich. 2001. An overview of freshwater habitats. In: J.H. Thorp and A.P. Covich, editors. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press, San Diego, California. Pp. 19-41.

Townsend, C.R., and A.G. Hildrew. 1976. Field experiments on the drifting, colonization, and continuous redistribution of stream benthos. *J. Amin. Ecol*. 45: 759-772.

Turner, R.R. 1980. Impacts of water level fluctuation on physical and chemical characteristics of reservoir. In: Hildebrand, S.G. (editor). *Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development, III: Water Level Fluctuation*. U.S. Department of Energy, Environmental Sciences Division Publication No. 1591. Pp. 3-14.

USFWS (U.S. Fish and Wildlife Service). 1980. Habitat evaluation procedures (HEP). ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C. March 31, 1980.

Ward, J.V. 1992. *Aquatic Insect Ecology*. John Wiley and Sons, Inc. New York. 438 pp.

Weatherhead, M.A., and M.R. James. 2001. Distribution of macroinvertebrates in relation to physical and biological variables in the littoral zone of nine New Zealand lakes. *Hydrobiologia* 462: 115-129.

Wetzel, R.G. 2001. *Limnology – Lake and River Ecosystems.* Third Edition. Academic Press. San Diego and London. 1006 pp.

Williams, D.D., and B.W. Feltmate. 1992. *Aquatic Insects*. C.A.B. International. Wallingford, UK. 358 pp.

Wise, D. H. and M. C. Molles. 1979. Colonization of artificial substrata by stream insects: Influence of substratum size and diversity. *Hydrobiologia* 65: 69-74.

Appendix 1: Published Suitability Curves

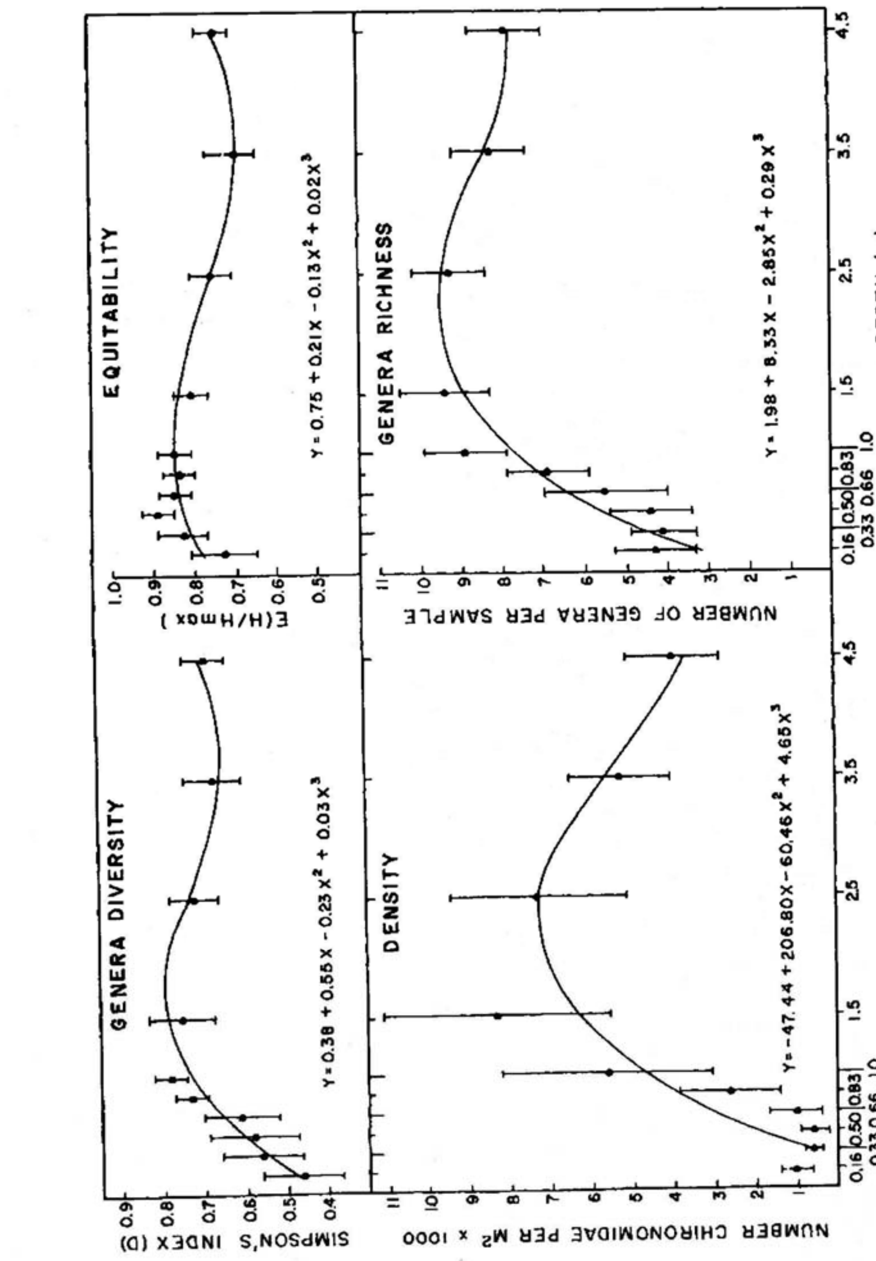


Figure 1. Chironomidae data obtained from Diggins and Thorp (1985) for relation of water depth to density, genera richness, Simpson's index of diversity, and equitability of the chironomid assemblage. Note: Study occurred in Par Pond, an 1100 ha cooling reservoir for the Savannah River Plant in South Carolina.

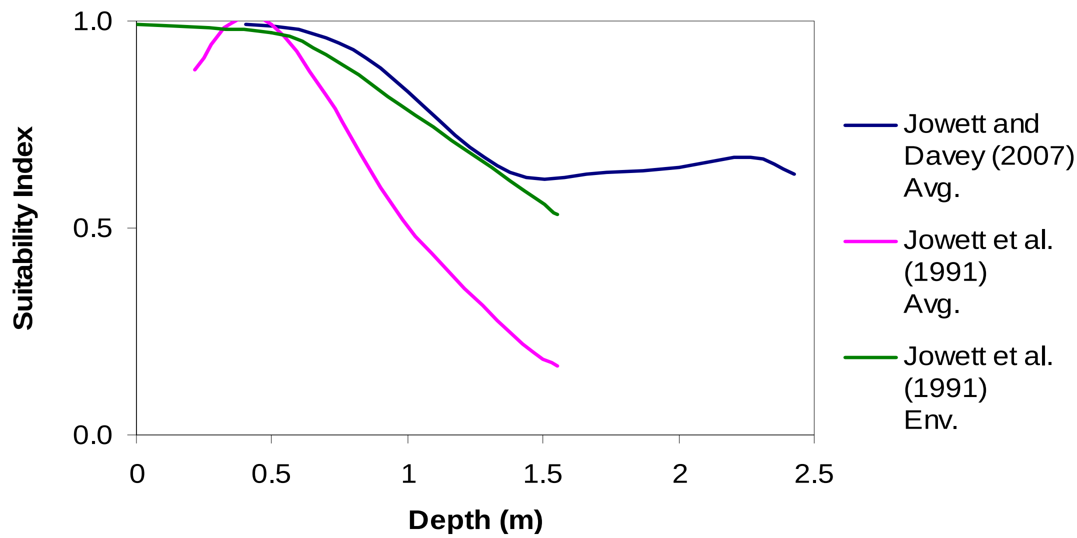


Figure 2. Habitat suitability curve of depth for Ephemeroptera - mayflies: Leptophlebiidae: *Deleatidium* spp.; reproduced from Jowett and Davey (2007) and Jowett et al. (1991).
Note: Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand. Curves from Jowett et al. (1991) are the average (Avg.) and enveloped (Env.) curves developed from four rivers in New Zealand. Enveloped curve was developed from smoothed data from each of the rivers.

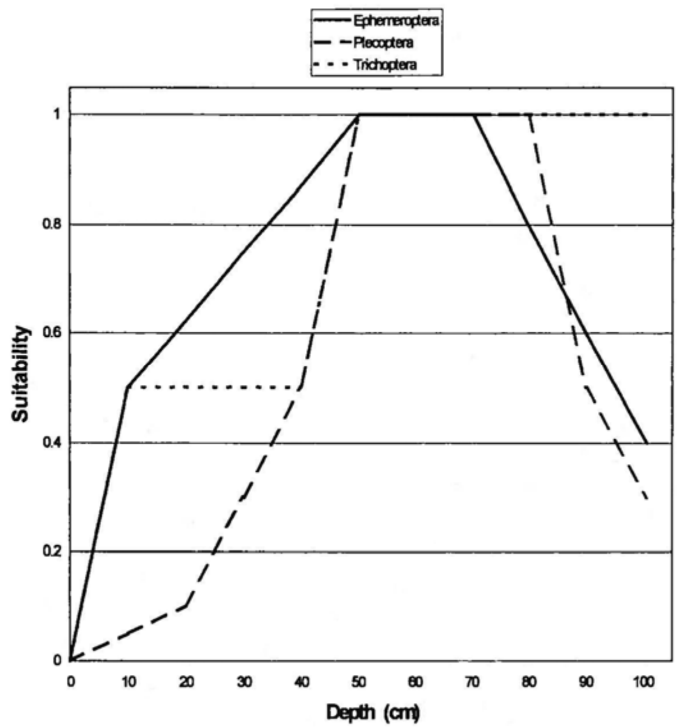


Figure 3. Ephemeroptera, Plecoptera, and Trichoptera depth suitability curves from Gore et al. (2001).
Note: Curves were developed from a series of benthic samples (approximately 1200 samples with a minimum of 50 samples per location) taken over 10 year s across a range of streams and rivers from the southeastern United States.

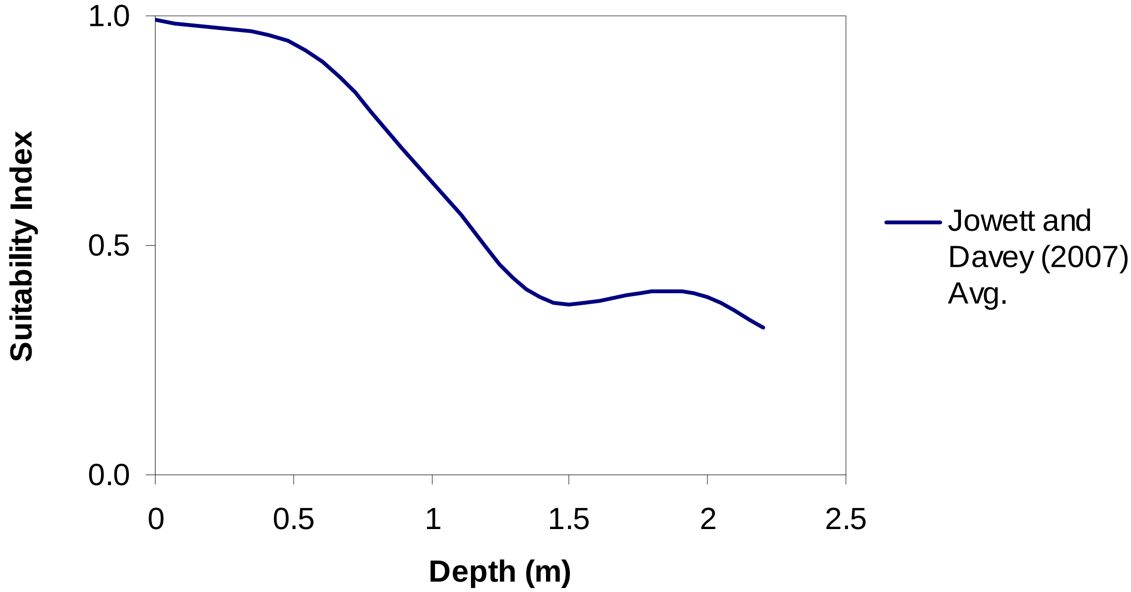


Figure 4. Habitat suitability curve of depth for Trichoptera - caddisflies: Hydropsychidae: *Aoteapsyche* spp.; reproduced from Jowett and Davey (2007).
Note: Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand.

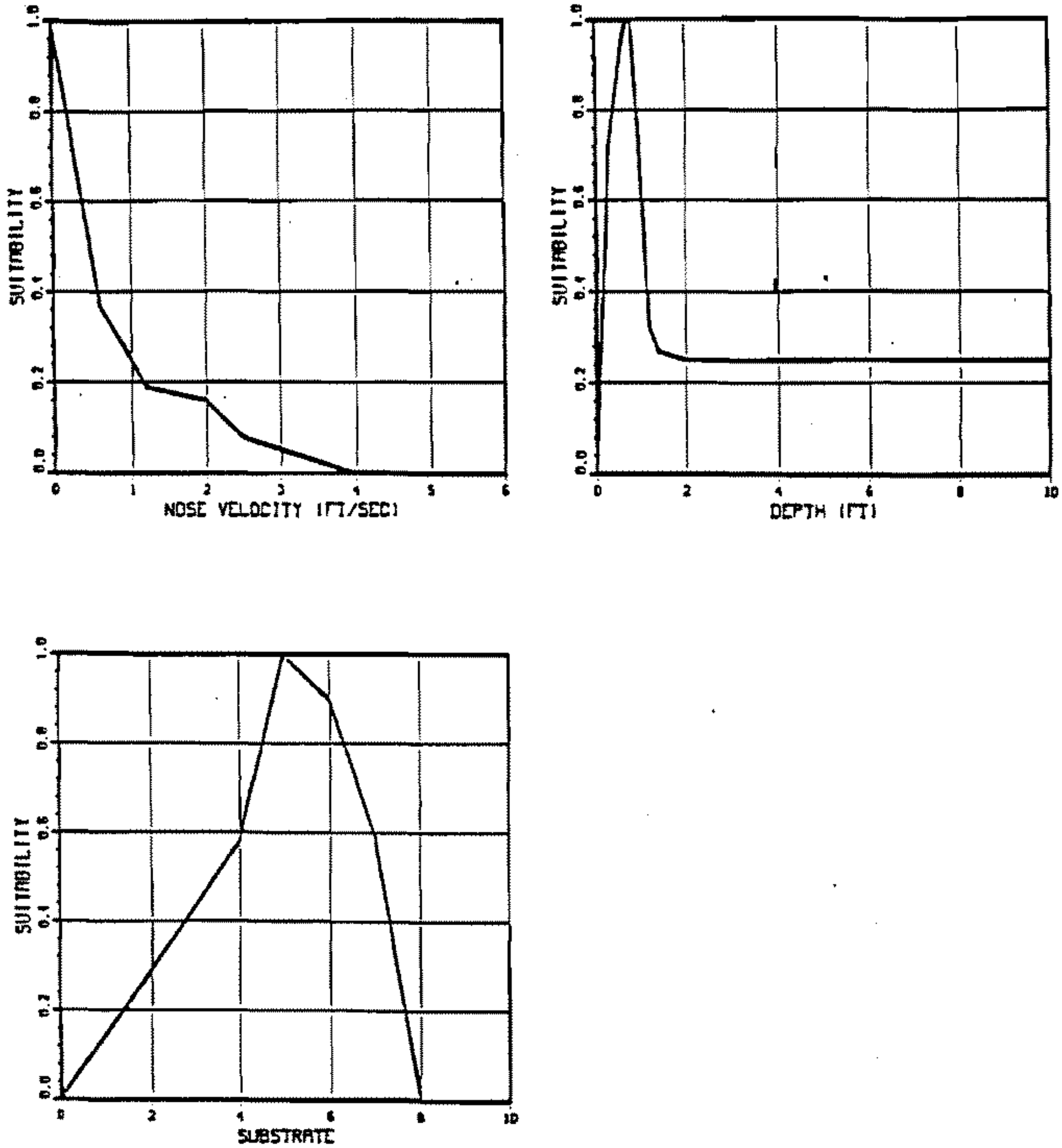


Figure 5. Velocity, depth and substrate suitability curves for benthic biomass – chironomid, developed for the Salmon River, New York by Milhous (1990).

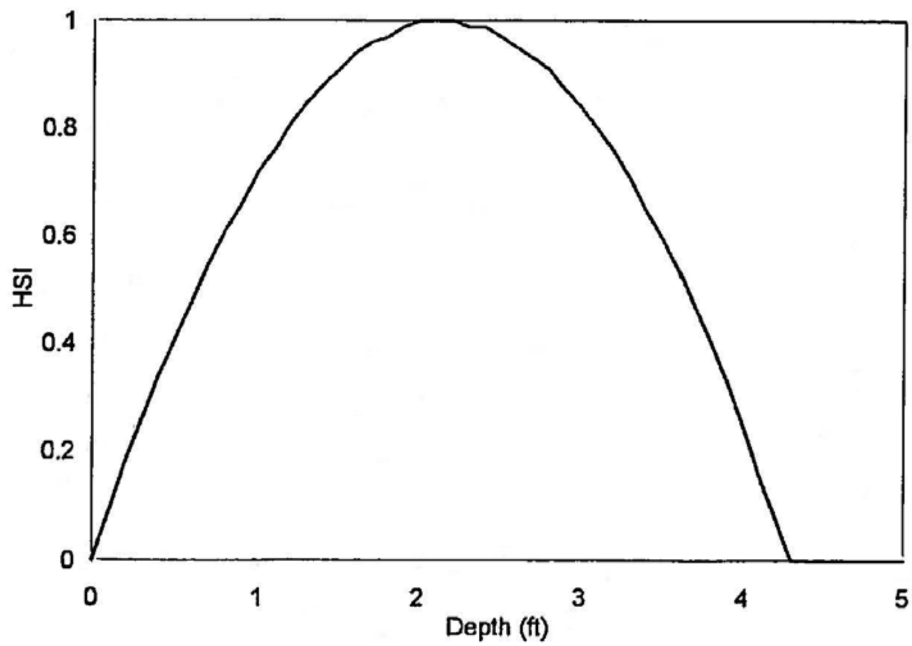


Figure 6. Total macroinvertebrate ash free dry weight for depth suitability in the Sacramento River, California developed by Gard (2006).
Note: The study is based on 75 samples taken in a stratified manner (depth, velocity, substrate, season).

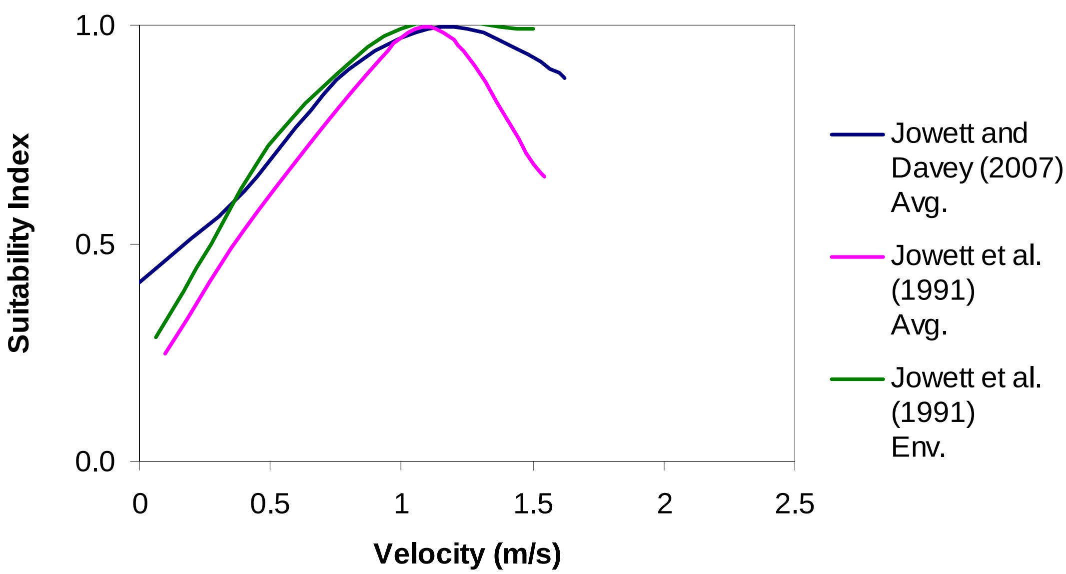


Figure 7. Habitat suitability curve of velocity for Ephemeroptera - mayflies: Leptophlebiidae: *Deleatidium* spp.; reproduced from Jowett and Davey (2007) and Jowett et al. (1991).
Note: Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand. Curves from Jowett et al. (1991) are the average (Avg.) and enveloped (Env.) curves developed from four rivers in New Zealand. Enveloped curve was developed from smoothed data from each of the rivers.

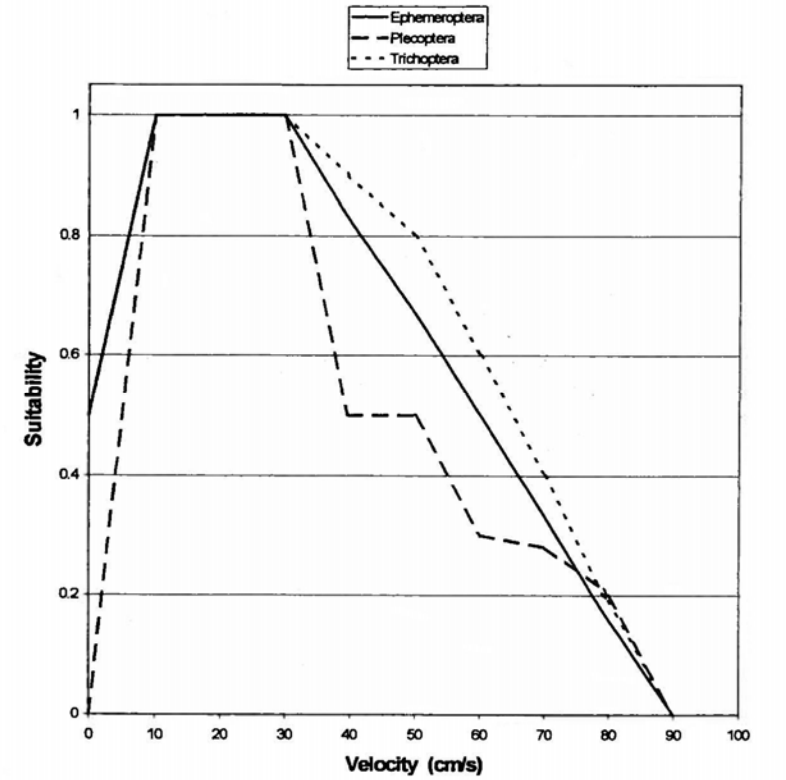


Figure 8. Ephemeroptera, Plecoptera, and Trichoptera velocity suitably curves from Gore et al. (2001).
Note: Curves were developed from a series of benthic samples (approximately 1200 samples with a minimum of 50 samples per location) taken over 10 years across a range of streams and rivers from the southeastern United States.

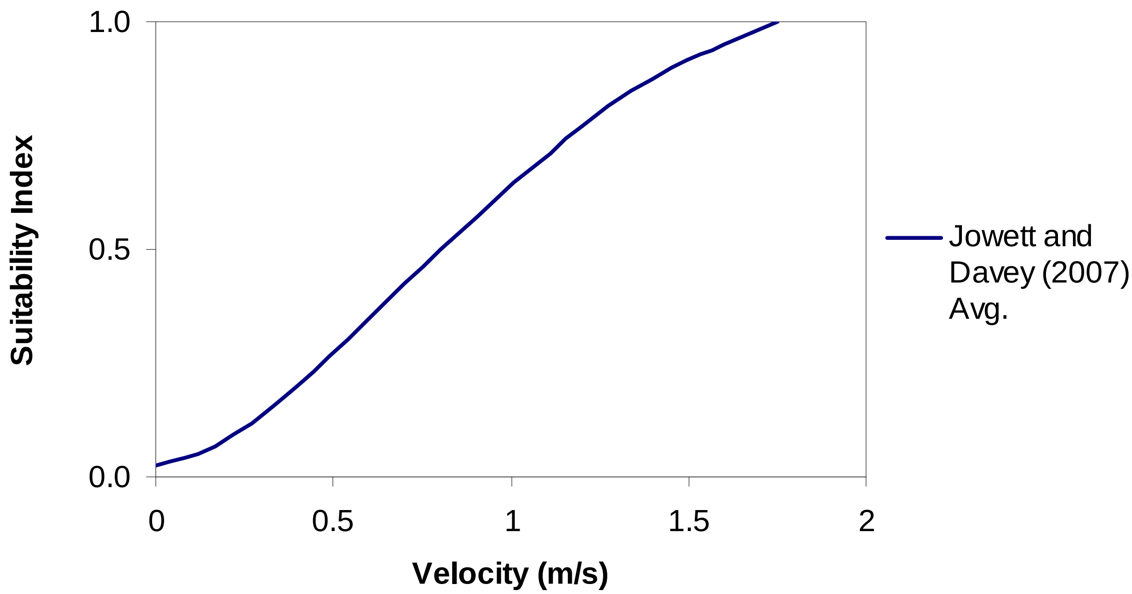


Figure 9. Habitat suitability curve of velocity for Trichoptera - caddisflies: Hydropsychidae: *Aoteapsyche* spp.; reproduced from Jowett and Davey (2007).
Note: Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand.

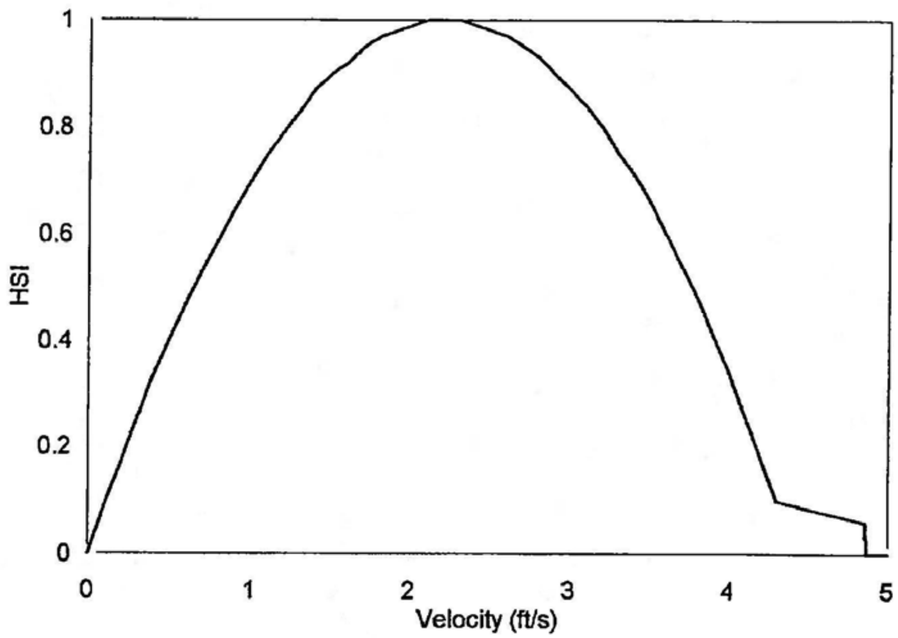


Figure 10. Total macroinvertebrate ash free dry weight for velocity suitability in the Sacramento River, California developed by Gard (2006).

Note: The study is based on 75 samples taken in a stratified manner (depth, velocity, substrate, season)

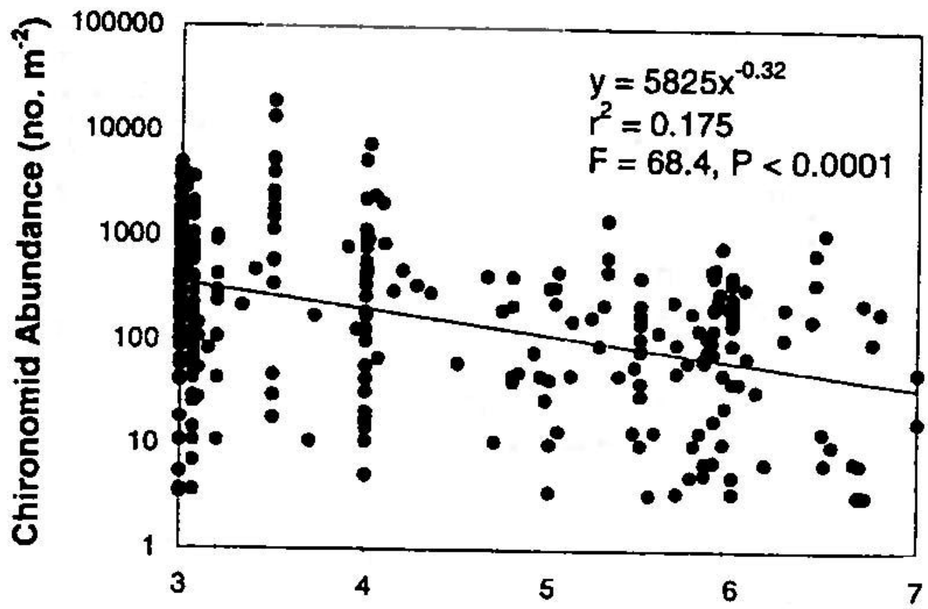


Figure 11. Relationship between substrate index and chironomid density from Weatherhead and James (2001).

Note: Data were collected in the littoral zone of nine New Zealand lakes. Substrate index code: 3 – Mud/silt , 4 – Sand, 5 – Gravel, 6– Cobble, 7 – Boulder.

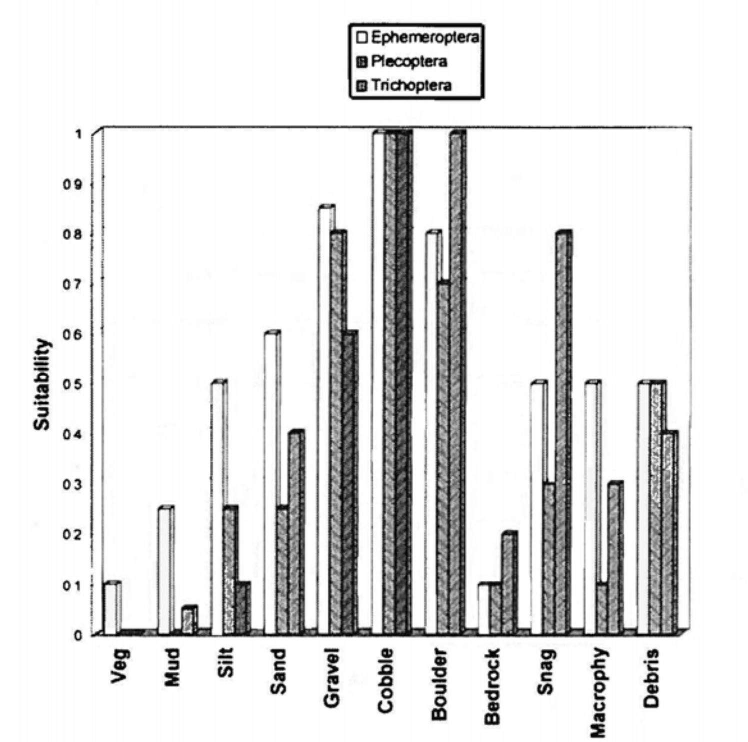


Figure 12. Ephemeroptera, Plecoptera, and Trichoptera substrate suitability curves from Gore et al. (2001).

Note: Curves were developed from a series of benthic samples (approximately 1200 samples with a minimum of 50 samples per location) taken over 10 years across a range of streams and rivers from the southeastern United States.

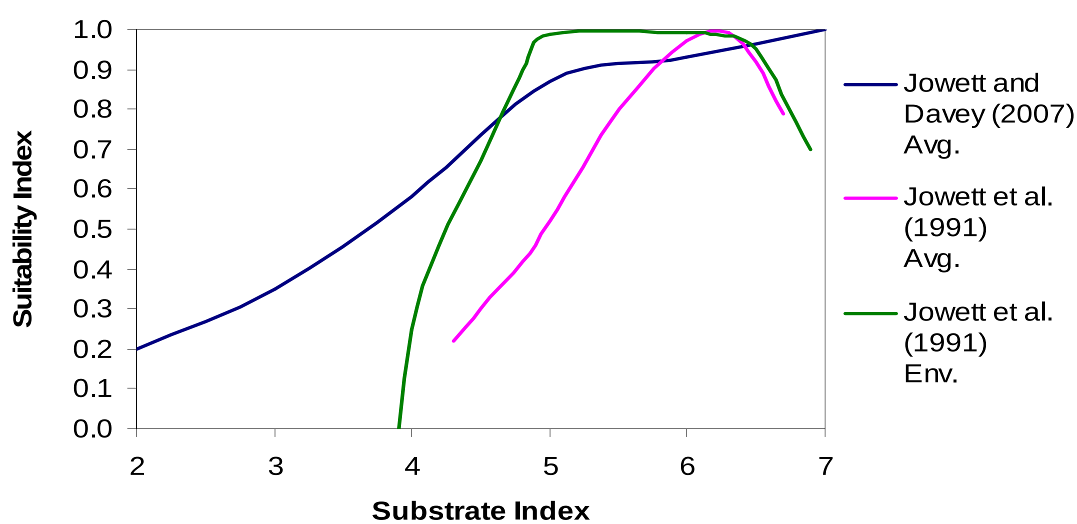


Figure 13. Habitat suitability curve of substrate for Ephemeroptera - mayflies: leptophlebiidae: *Deleatidium* spp.; reproduced from Jowett and Davey (2007) and Jowett et al. (1991).

Note: Substrate index code: 2 – Mud/silt, 3 – Sand, 4 – Fine gravel, 5 - Coarse gravel, 6 – Cobble, 7 – Boulder. Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand. Curves from Jowett et al. (1991) are the average (Avg.) and enveloped (Env.) curves developed from four rivers in New Zealand. Enveloped curve was developed from smoothed data from each of the rivers.

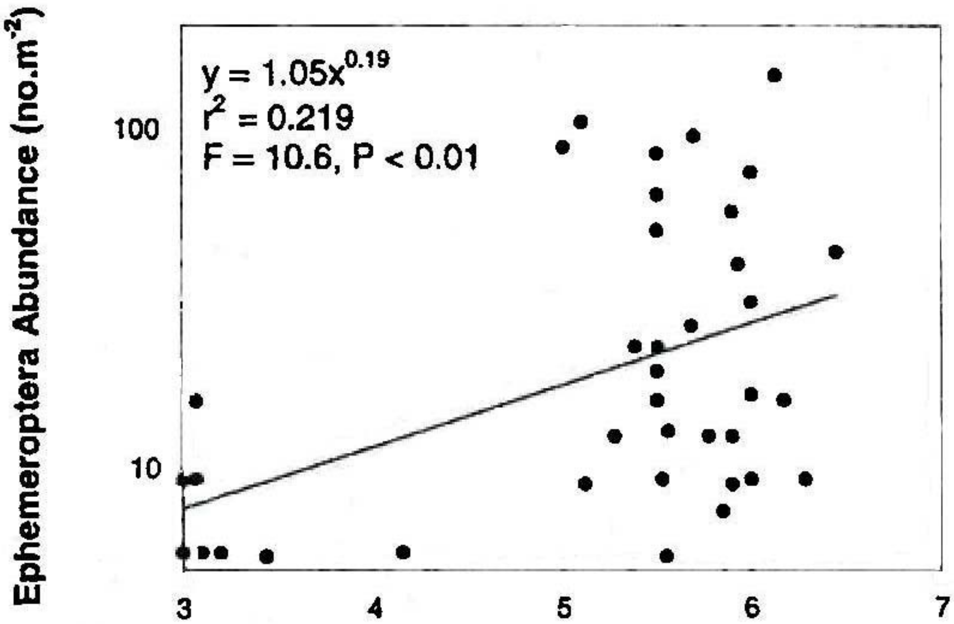


Figure 14. Relationship between substrate index and Ephemeroptera density from Weatherhead and James (2001).
Note: Data were collected in the littoral zone of nine New Zealand lakes. Substrate index code: 3 – Mud/silt , 4 – Sand, 5 – Gravel, 6– Cobble, 7 – Boulder.

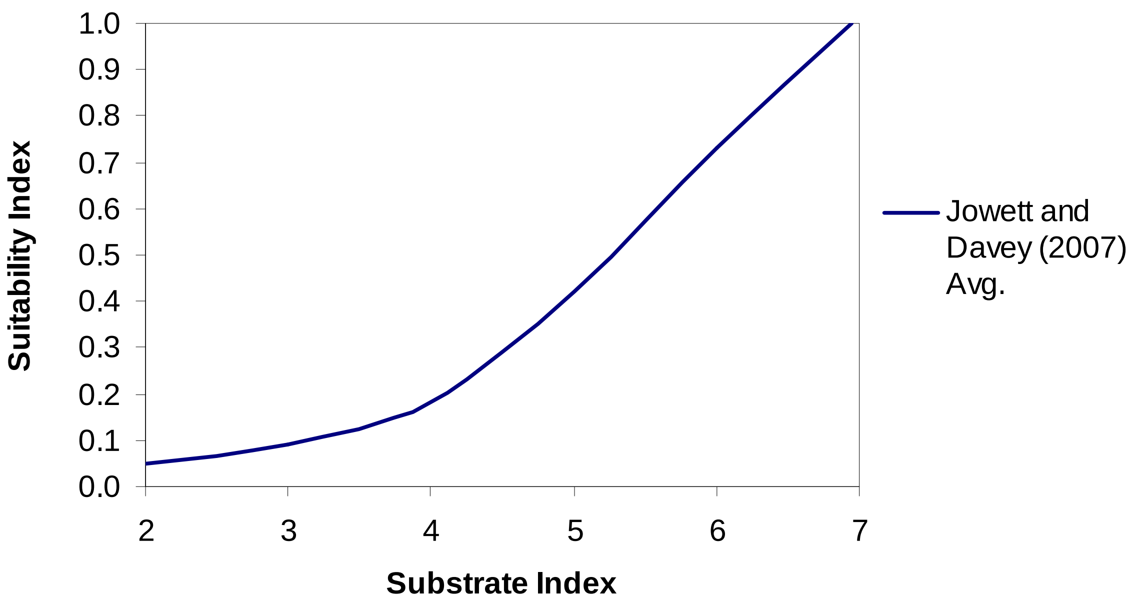


Figure 15. Habitat suitability curve of substrate for Trichoptera - caddisflies: Hydropsychidae: *Aoteapsyche* spp.; reproduced from Jowett and Davey (2007).
Note: Curve from Jowett and Davey (2007) is the average (Avg.) curve developed from five rivers in New Zealand. Substrate index code: 2 – Mud/silt, 3 – Sand, 4 – Fine gravel, 5 - Coarse gravel, 6 – Cobble, 7 – Boulder.

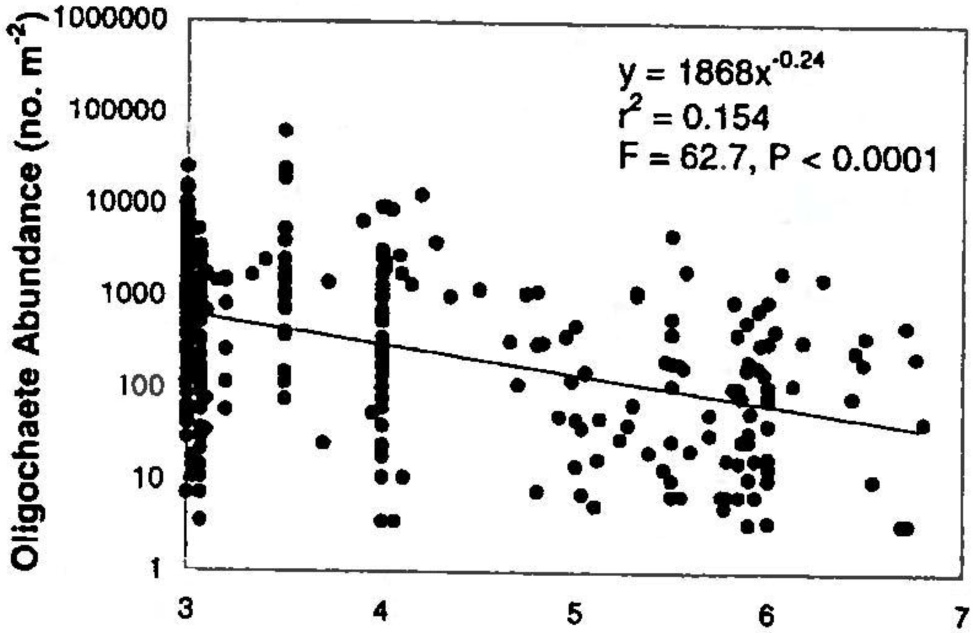


Figure 16. Relationship between substrate index and oligochaete density from Weatherhead and James (2001).

Note: Data were collected in the littoral zone of nine New Zealand lakes. Substrate index code: 3 – Mud/silt , 4 – Sand, 5 – Gravel, 6– Cobble, 7 – Boulder

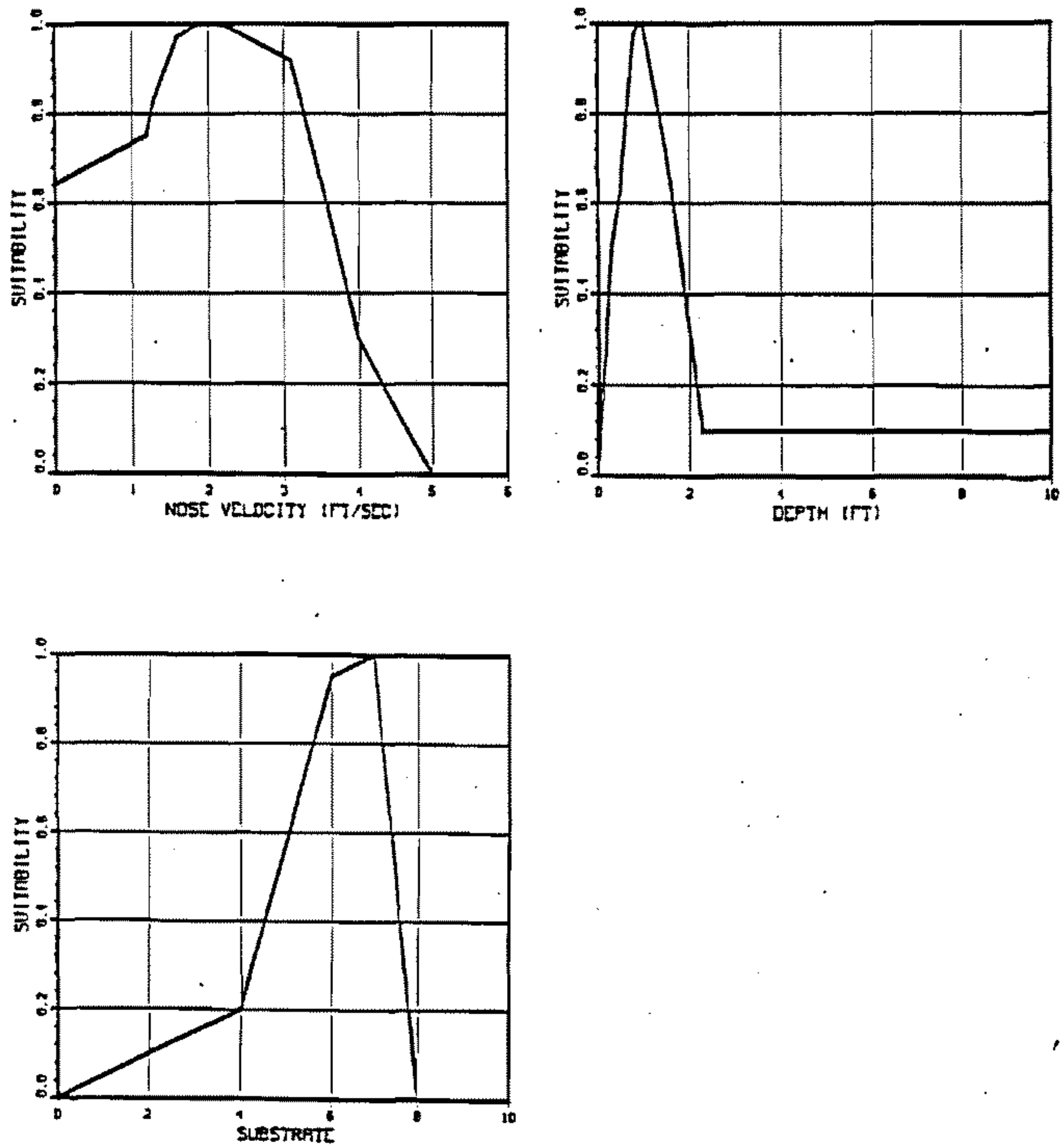


Figure 17. Velocity, depth and substrate suitability curves for benthic biomass – total, developed for the Salmon River, New York by Milhous (1990).

This page is intentionally left blank.

Appendix 2: Suitability Curve Data Produced from Published Suitability Curves

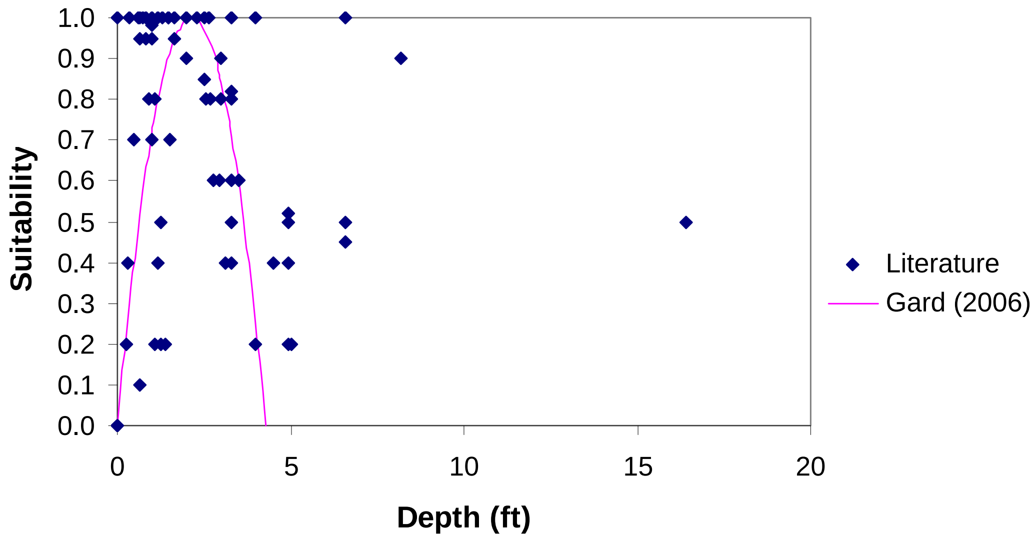


Figure 1. Habitat suitability curve data of depth for total BMI produced from suitability curves developed by Gore and Judy (1981), Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007). Gard (2006) suitability curve was developed directly from data provided in report.

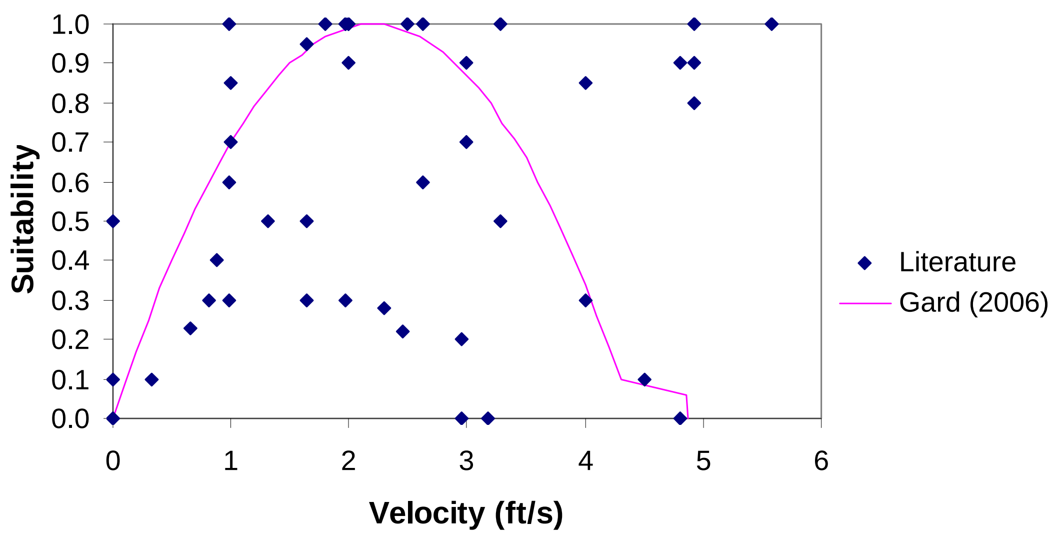


Figure 2. Habitat suitability curve data of velocity for total BMI produced from suitability curves developed by Gore and Judy (1981), Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007). Gard (2006) suitability curve was developed directly from data provided in report.

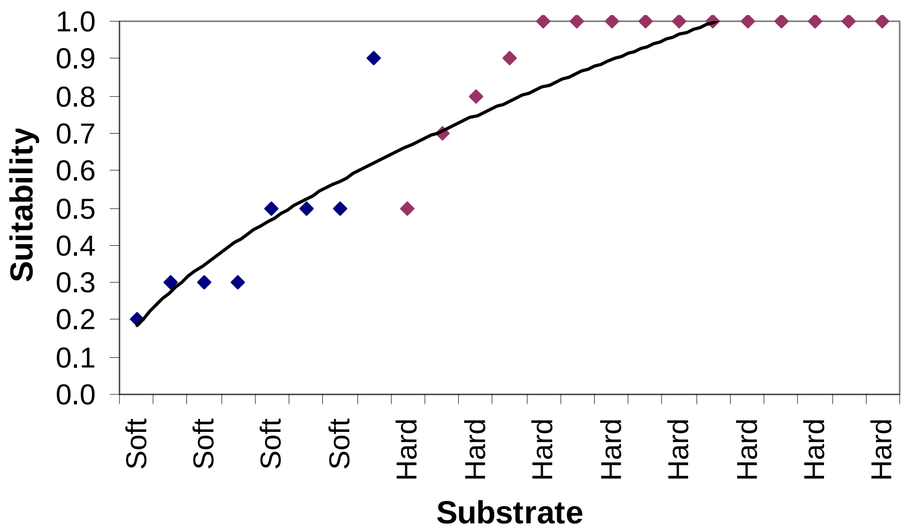


Figure 3. Habitat suitability curve data of substrate for total BMI produced from suitability curves developed by Gore and Judy (1981), Diggins and Thorp (1985), Keup (1988), Milhous (1990), Jowett et al. (1991), Gore et al. (2001), Weatherhead and James (2001), Gard (2006), and Jowett and Davey (2007).

Appendix 3: Contacts for Input on Suitability Curve Development

Boris Kondratieff
Phone: 970-491-7314
Fax: 970-491-0564
Email: bkondrat@ceres.agsci.colostate.edu
Status: Need to contact

Travis S. Schmidt
Research Ecologist
Mendenhall Fellow
U.S. Geological Survey
Mineral Resources Program
P.O. Box 25046, MS 973
Denver, CO 80225
Phone: 970-214-0358
Fax: 303-236-3200
Email: tschmidt@usgs.gov
Status: Contacted and he provided information and references. Great source of information for macroinvertebrates.

Robert E. Zuellig
Ecologist
U.S. Geological Survey
Colorado Water Science Center
Denver, CO 80225
Phone: 970-226-9419
Email: rzuellig@usgs.gov
Status: Provided information in email discussion. Has a lot of information and input on this subject.

Brian S. Cade
U. S. Geological Survey
Fort Collins Science Center
2150 Centre Ave., Bldg. C
Fort Collins, CO 80526-8818
Phone: 970-226-9326
Email: brian_cade@usgs.gov
Status: Provided information in email discussion from the USGS.

Lance Everette
U.S. Geological Survey
Fort Collins Science Center
2150 Centre Ave Bldg C
Fort Collins, CO 80526
Phone: 970-226-9225
Email: lance_everette@usgs.gov
Status: Provided information in email discussion from the USGS.

Bob Milhous
Email: milhousb@usgs.gov
Status: Provided information in email discussion from the USGS. Has curves he uses, said he would contact me, have not heard back from him.

Mark Gard Ph.D.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
2800 Cottage Way, Suite W-2605
Sacramento, CA 95825
Phone: 916-414-6589
Fax: 916-414-6712
Email: Mark_Gard@fws.gov
Status: Provided paper on studies and work he has done in developing curves. He will review our reference list to make sure that we have all that he knows about.

Hal Beecher
Email: BEECHHAB@DFW.WA.GOV
Status: WDFW leading expert on in-stream flows. Hal provided suggestions on who to contact, which provided numerous sources of information.

Dr. E. George Robison
Instream Flow Specialist
Water Quantity/Quality Program, Fish Division
Oregon Department of Fish and Wildlife
3406 Cherry Ave NE
Salem OR 97303
Phone: 503-947-6093
Fax: 503-947-6070
Email: george.robison@state.or.us
Status: Has provided useful information and discussion. Has been doing some related work and has very useful input.

Dr. Robert L. Vadas, Jr. (Bob)
Washington Department of Fish and Wildlife
Habitat Program
600 Capitol Way N.

Olympia, WA 98501-1091
Phone: 360-902-2594
Fax: 360-902-2946
Email: vadasrlv@dfw.wa.gov
Status: Provided information in an email discussion.

Dr. Jim Gore
River Ecology and Water Resources Management
Professor and Chair, Ph.D., University of Montana, 1981
Phone: 727-553-4825 (O), or 727-553-4831 (Lab)
Email: Dr. Jim Gore
Status: Main contact in terms of who has developed curves for macroinvertebrates. Very informative and has published many papers. Will follow up with him again. He is working on Chironomidae curves.

This page is intentionally left blank.

Appendix 2. Taxonomic List of Macroinvertebrates Sampled

Taxon (as appears in data)	Common name	Lower Boundary			Upper Boundary		Box Canyon		
		Vertical	Shoreline	Soft Substrate	Shoreline	Soft Substrate	Vertical	Shoreline	Soft Substrate
Acari	mites	Found	Found	Found	Found	Found	Found	Found	Found
Agraylea	caddisflies								Found
Argia	damselflies						Found		
Caecidotea	aquatic sow bugs		Found	Found		Found		Found	Found
Caenis	mayflies		Found	Found	Found	Found	Found	Found	Found
Calanoida	microcrustaceans	Found	Found	Found	Found	Found	Found	Found	Found
Ceraclea	caddisflies	Found	Found		Found		Found	Found	Found
Ceratopogoninae	no-see-um midges			Found		Found	Found	Found	Found
Cheumatopsyche	caddisflies				Found		Found	Found	
Chironomidae	midges	Found	Found	Found	Found	Found	Found	Found	Found
Chydoridae	water fleas: microcrustcaens						Found	Found	Found
Cladocera	water fleas: microcrustcaens	Found	Found	Found	Found	Found	Found	Found	Found
Climacia	spongillaflies						Found		
Coenagrion/Enallagma	damselflies	Found	Found		Found	Found	Found	Found	Found
Copepoda	microcrustaceans						Found	Found	
Crangonyx	scuds				Found			Found	
Dasyhelea	no-see-um midges					Found			
Dolichopodidae	Long Legged Fly								Found
Dubiraphia	riffle beetles					Found		Found	Found
Ephemerella excrusians	mayflies						Found	Found	Found
Epitheca spinigera	dragonflies			Found		Found	Found	Found	Found
Erpobdellidae	leeches			Found					Found
Ferrissia	freshwater limpets				Found				
Forcipomyiinae	no-see-um midges								
Gammarus	scuds	Found	Found		Found		Found	Found	Found
Glossiphoniidae	leeches			Found				Found	Found
Gyraulus	snails		Found	Found	Found	Found	Found	Found	Found
Harpacticoida	microcrustaceans			Found		Found			Found
Helisoma anceps	snails		Found		Found		Found	Found	
Helobdella	leeches					Found		Found	Found
Hemerodromia	dance flies								
Hyalella	scuds	Found	Found	Found		Found	Found	Found	Found
Hydra	hydroids	Found	Found	Found	Found		Found	Found	Found
Hydropsyche	caddisflies				Found		Found		
Hydroptila	caddisflies		Found		Found		Found	Found	Found
Leptophlebiidae	mayflies								
Lumbriculidae	segmented worms-earthworm type					Found			Found
Lymnaea	snails	Found	Found	Found	Found	Found	Found	Found	
Lymnaea auricularia	snails						Found		Found
Maccaffertium	mayflies	Found	Found		Found		Found	Found	
Macromia magnifica	dragonflies							Found	
Mystacides	caddisflies								
Nectopsyche	caddisflies	Found			Found	Found	Found	Found	Found
Nematoda	round worms		Found	Found	Found	Found	Found	Found	Found
Neureclipsis bimaculata	caddisflies								
Oecetis	caddisflies	Found	Found	Found	Found		Found	Found	Found
Oligochaeta	segmented worms	Found	Found	Found	Found	Found	Found	Found	Found
Ophiogomphus occidentis	dragonflies				Found		Found	Found	
Optioservus	riffle beetles								Found
Orthotrichia	caddisflies		Found						
Ostracoda	seed shrimps: microcrustaceans			Found		Found			Found
Oxyethira	caddisflies						Found	Found	
Petrophila	aquatic moths								
Physa	snails	Found	Found	Found	Found		Found	Found	Found
Piscicolidae	leeches			Found					
Pisidium	pea clams			Found		Found		Found	Found
Polycentropus	caddisflies	Found	Found		Found		Found	Found	Found
Porifera	sponges	Found	Found	Found	Found	Found	Found	Found	Found
Sialis	alderflies			Found					
Simulium	black flies						Found	Found	Found
Sphaerium	fingernail clams			Found		Found			
Tipulidae	crane flies					Found			
Triaenodes	caddisflies					Found		Found	Found
Turbellaria	flatworms	Found	Found		Found	Found	Found	Found	Found
Valvata	Snails								
Valvata sincera	snails				Found	Found			
Valvata tricarinata	snails			Found				Found	Found

This page is intentionally left blank.

Appendix 5. Cross Section Location Figures and Model Calibration Result Graphs for Study 7.2 (Hydraulic Routing Model)

Boundary Hydroelectric Project (FERC No. 2144)

Study No. 7.2
Hydraulic Routing Model

Interim Report

Prepared for
Seattle City Light

Prepared by
Bill Fullerton, Jay Smith and Adam Baines
Tetra Tech

March 2008

TABLE OF CONTENTS

Appendices

List of Tables

List of Figures

This page is intentionally left blank.

Study No. 7.2: Hydraulic Routing Model
Interim Report
Boundary Hydroelectric Project (FERC No. 2144)

1 INTRODUCTION

Study No. 7, Mainstem Aquatic Habitat Modeling, 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 (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.

The Mainstem Aquatic Habitat Modeling Study (Study 7) represents the integration of efforts being conducted to assess the changes in aquatic habitat of the Pend Oreille River resulting from existing Project operations and from operations scenarios. The Hydraulic Routing Model (Study 7.2) is a component study effort within the larger Mainstem Aquatic Habitat Modeling Study.

This report is an interim report for the 2007 study efforts of the Hydraulic Routing Model component of the Mainstem Aquatic Habitat Modeling Study.

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 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.

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 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 water 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, which slows the translation and attenuates the peak of the floodwave as it travels upstream into the Upper Reservoir Reach.

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 can travel upstream to the Boundary Dam tailrace. Consequently, the effects of existing Project operations on aquatic habitats below Boundary Dam are influenced by existing Seven Mile Project operations. At low Seven Mile forebay elevations, riverine habitat is present in the Boundary Dam tailwater, but at high Seven Mile forebay elevations, the riverine habitat becomes reservoir habitat.

1.2. Study Description

The Hydraulic Routing Model (Study 7.2) is being used to translate output from the Scenario Tool model (described in Section 4.4) 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. A one-dimensional unsteady flow hydraulic routing software is being 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. The results of 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.

The application of the 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, and flow fluctuations originating in the tailrace of the Project travel downstream to as far as just above the confluence with the Salmo River. A one-dimensional unsteady flow Hydraulic Routing Model is being used to analyze the translation and attenuation of these waves and to quantify the spatial variability in the flow rate upstream and downstream of the Project.

Descriptions of the methods for conducting the hydraulic routing modeling are presented in Section 4.2. Hydraulic routing modeling results to date are presented in Section 5.2. Section 6.2 summarizes the current status of the hydraulic routing modeling effort with any variances and recommendations presented in Section 7.2

2 STUDY OBJECTIVES

The overall goal of the Mainstem Aquatic Habitat Modeling Study and its component study efforts is 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 Hydraulic Routing Model component is to develop a hydraulic routing model that estimates water surface elevations, discharges, and cross section average water velocity along modeled transects on an hourly basis for existing Project operations and operations scenarios.

The hydraulic routing model will be used within the context of the larger Mainstem Aquatic Habitat Modeling Study (Study 7) 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 include (but are not necessarily limited to):

- Water surface elevation and flow rates at selected reservoir locations

- Characterization of the varial zone
- 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

Output from the hydraulic routing model will also be used in conjunction with output from the Mainstem Aquatic Habitat Model to conduct a variety of post-processing comparative analyses to identify the effects of operations scenarios. These include (but are not necessarily limited to):

- Downramping rates
- Juvenile fish stranding and trapping

3 STUDY AREA

Two levels of study areas are defined for the Mainstem Aquatic Habitat Modeling effort. There is a detailed study area for which the potential effects of operations scenarios on biological indices will be evaluated. There is also the larger study area required to conduct the hydraulic routing modeling effort in order 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 – 19.4)
- Forebay Reach — Downstream end of Z-Canyon to Boundary Dam (PRM 19.4 – 17.0)
- Tailrace Reach — Boundary Dam downstream to Red Bird Creek confluence with the Pend Oreille River, British Columbia (PRM 17.0 – 13.1)

The effects of existing Project operations on aquatic habitats below Boundary Dam are influenced by Seven Mile Project operations. At low Seven Mile Dam forebay water surface elevations, riverine habitat is present in the Pend Oreille River downstream to the confluence with Red Bird Creek. At high Seven Mile Dam forebay water surface elevations, the riverine habitat above the Red Bird Creek confluence becomes reservoir habitat. The mainstem aquatic habitat modeling effort includes collecting data on up to 3.9 miles of the Pend Oreille River channel exposed for low Seven Mile Dam forebay elevations and performing modeling the Tailrace Reach similar to the three reaches above Boundary Dam.

The hydraulic routing model will extend an additional 7.1 miles downstream of the detailed study area to Seven Mile Dam at PRM 6.0. This is 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 13.1. The hydraulic routing model will be used to determine hourly water surface elevations and flow conditions in the Tailrace Reach based on Seven Mile forebay elevations and outflows from the Boundary Project.

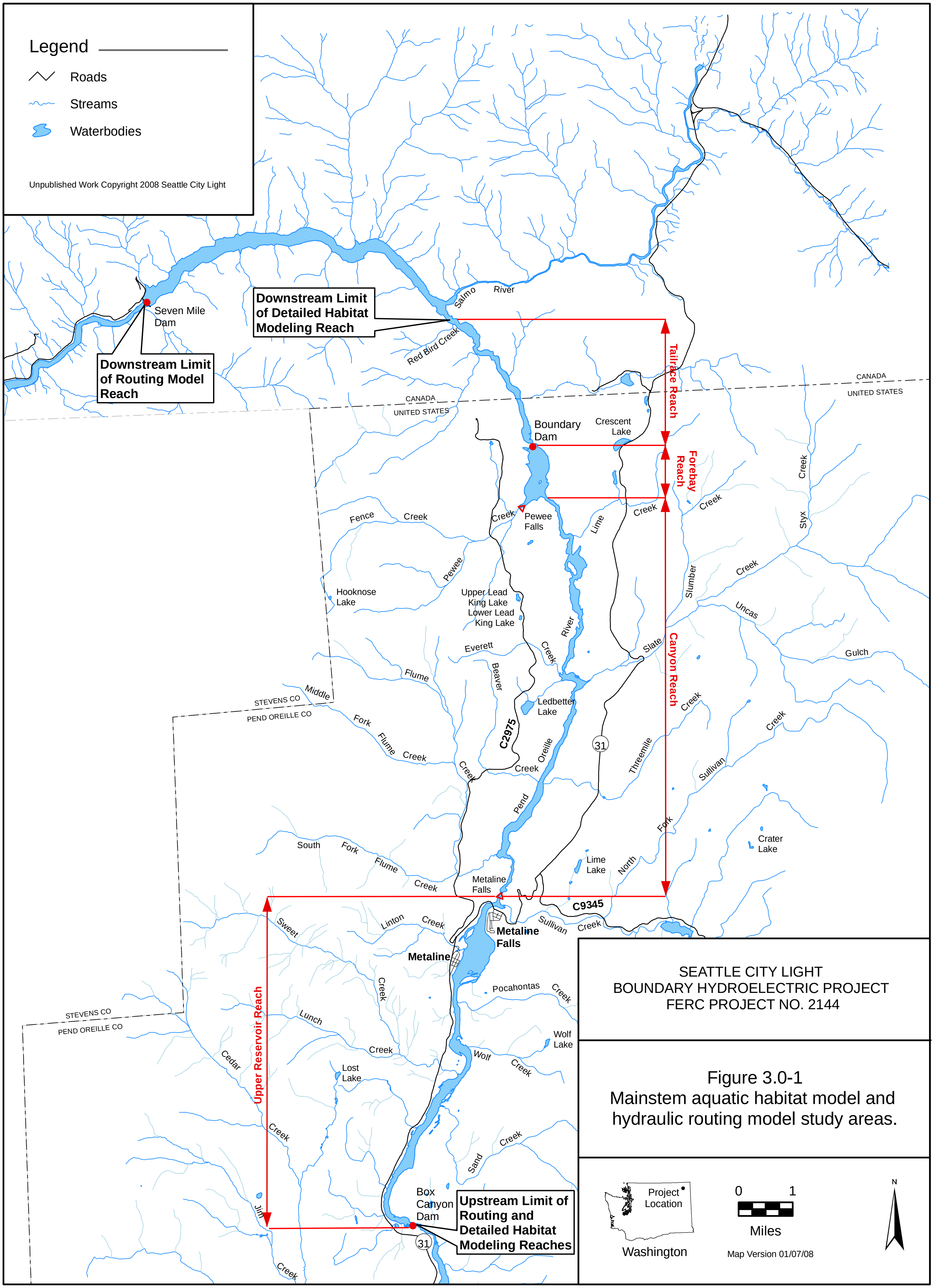


Figure 3.0-1
Mainstem aquatic habitat model and hydraulic routing model study areas.

4 METHODS

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 Dam and in the reach downstream of Boundary Dam between Boundary Dam and Seven Mile Dam. The results of the hydraulic model will be used to support the analysis of potential impacts of operations scenarios on aquatic habitats in the Pend Oreille River between Box Canyon and Seven Mile Dam.

The need for an unsteady flow hydraulic model is necessitated by the 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 Boundary forebay travel upstream through the Pend Oreille River to as far upstream as Box Canyon Dam, and flow fluctuations originating in the Boundary tailrace travel downstream to as far as just south of the confluence with the Salmo River. A one-dimensional unsteady flow hydraulic routing model is being used to analyze the translation and attenuation of these waves and to quantify the spatial variability in the flow rate upstream and downstream of the Boundary Dam.

Section 4.1 describes the methods used to construct the hydraulic model and Section 4.2 presents the approach used for model calibration. The method used to evaluate the need for separate seasonal models is described in Section 4.3. The model documentation and executable model are 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 24th meeting, the presentation included the data requirements for the hydraulic routing model, the proposed calibration method, the cross section locations, and the relationship of the hydraulic routing model to the other studies such as the Peak Flow Study (Study 2, SCL 2008a), the Aquatic Habitat Model (Study 7) and the Tributary Habitat Model (Study 8, SCL 2008b). At the October 17th 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 (Beta) 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 2006).

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 comprises a series of cross sections spaced at intervals along the channel along with definitions of the upstream and downstream boundary conditions.

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. Version 4.1.1 of the HEC-GeoRAS is compatible with ArcGIS Version 9.1.

Two separate hydraulic routing models will be required for this study. A hydraulic model of the reach upstream of Boundary Dam (upstream routing model) will be 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 (downstream routing model) will be used to analyze the translation and attenuation of flood waves 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, is due to the presence of Boundary Dam. The HEC-RAS modeling software is a purely hydraulic modeling tool that does not have the capabilities to model dam operations. Therefore, a separate model or software is needed to provide the link between the upstream and downstream hydraulic models. The Scenario Tool is designed specifically to simulate operations scenarios, and will therefore function as the link between the two hydraulic models by providing boundary condition information to each hydraulic model.

The upstream hydraulic model was developed in 2007; however, the downstream hydraulic model has not yet been developed. Development of the downstream hydraulic model was delayed until 2008 due to the unavailability of the final bathymetric data downstream of Boundary Dam, which was completed in December 2007.

4.1.1. Upstream Routing Model

The basic data and information necessary for the development of the hydraulic routing model are 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 system. The boundary condition data were used to define the hydraulic conditions at the open boundaries of the hydraulic model. Boundary condition data are in the form of flow rates or water surface elevations. Since the hydraulic routing model is an unsteady flow model, the boundary condition data are in the form of a time series of flow rate or water surface elevation.

The data and information that were used to specifically construct the upstream hydraulic routing model included the following:

- Current bathymetric data of the reservoir between Box Canyon Dam and Boundary Dam
- Recent Light Detection and Ranging (LIDAR)-based data of the upper banks of the reservoir between Box Canyon Dam and Boundary Dam
- Continuously recorded water surface elevation data (at 15-minute time intervals) obtained from recently deployed pressure transducers specific to this project.

- Continuously recorded water surface elevation data (at 15-minute time intervals) obtained from USGS gaging stations
- Flow rate data (at 15-minute time intervals) obtained from USGS gaging stations

Current topographic and bathymetric data were used as the basis for the cross section geometry of reservoir system. The bathymetric and LIDAR data were distinct products that were subsequently merged together to form a continuous digital terrain model (DTM) in the form of a triangulated irregular network (TIN).The bathymetric data were used to develop the below water portion of the cross section geometry. The process used to collect the bathymetric data is described in the Study 25 Report, Boundary Dam/Seven Mile Dam Bathymetry Survey (SCL 2008c). The LIDAR-based data were used to develop the above water portion of the cross section geometry. The LIDAR-based data set was derived from aerial flights conducted in August 2005 by Terrapoint (Terrapoint 2005).

Cross sections of the reservoir system were cut through the DTM at specific locations along the profile of the reservoir using the HEC-GeoRAS software. The cross sections were defined by a set of station (X) and elevation (Y) coordinate pairs. The cross sections were then imported into the HEC-RAS software.

Continuously recorded 15-minute water surface elevation data and flow rate data were used to define the boundary conditions for the hydraulic routing model. Recorded water surface elevation data were obtained from pressure transducers deployed in September 2006 at seven locations along the Pend Oreille River. Five pressure transducer installations were deployed between Box Canyon Dam and Boundary Dam and two pressure transducer installations were deployed downstream of Boundary Dam. Each installation comprised a set of two Solinst Levelogger Gold units (model M10/F30) to provide redundancy in the event one of the transducers malfunctions. Table 4.1-1 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 4.1-1. 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

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

Each pressure transducer provided continuous recording of water depth above the transducer at 15-minute time intervals. The raw data collected by the pressure transducers were downloaded in approximately 3-month intervals and were post-processed in Microsoft Excel®. The post-processing converted each recorded depth value to a water surface elevation value. The Boundary forebay (BND_LK) pressure transducer data were used to represent the downstream boundary condition for the upstream hydraulic model.

USGS flow data are available at one currently operating gaging station in the Project area as summarized in Table 4.1-2 and Figure 4.1-1. Raw 15-minute flow data from USGS Gage 12396500 was used to define the upstream boundary condition of the upstream hydraulic model. USGS gaging station 12398600 is a total dissolved gas (TDG) monitoring station and does not provide direct measurement of flow rate.

Table 4.1-2. USGS gaging stations in Project area.

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.

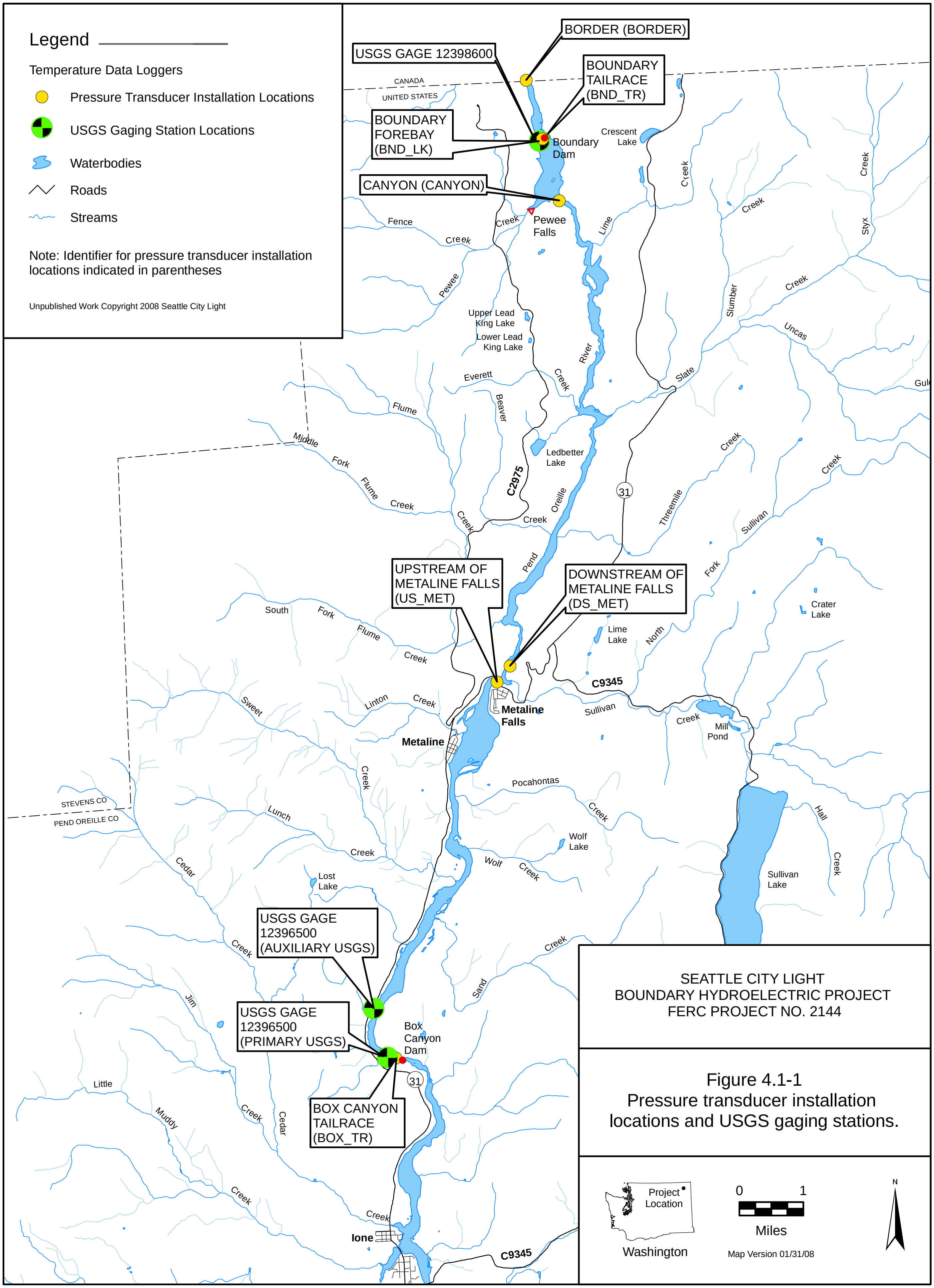
Development of the hydraulic routing model will continue in 2008 as new data and new information becomes available. Additional data that are expected include the following:

- Cross section surveys of each habitat transect
- Continuous pressure transducer data collected subsequent to September 2007
- Continuous USGS gage data collected subsequent to September 2007

Between April and September 2007, Thomas R. Payne and Associates (TRPA) conducted detailed cross section surveys at the location of each habitat transect upstream of Boundary Dam. Fifty cross section surveys were conducted (5 in the Forebay Reach, 20 in the Canyon Reach, and 24 in the Upper Reservoir Reach). The hydraulic model currently includes a cross section at the location of each habitat transect; however, the cross sections are based on the DTM. Once the actual habitat transect cross sections are finalized, they will replace the DTM derived cross sections throughout the model.

The current plan is to have the pressure transducers in place through December 2008; therefore, continuous 15-minute depth data will be collected for an additional 15 months. It has been proposed, although not approved, to maintain the pressure transducers only through July 2008. Regardless, the additional data collected subsequent to September 2007 will be used to extend the data record for the downstream boundary condition.

Gage data collected at the USGS gage 12396500 subsequent to September 2007 will be used to extend the data record for the upstream boundary condition. The period of record for the USGS gage data will be consistent with the data record for the pressure transducer data collection.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 4.1-1
Pressure transducer installation locations and USGS gaging stations.

4.1.2. Downstream Routing Model

A hydraulic routing model of the reach downstream of Boundary Dam (between Boundary Dam and Seven Mile Dam) will be developed. Data and information that will be used to construct the hydraulic routing model in this tailrace reach will include the following:

- Current bathymetric 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
- Continuously recorded Boundary Dam outflow data (15-minute time intervals)
- Continuously recorded water surface elevation data (at 1-hour time intervals) in the Seven Mile Dam forebay, obtained from BC Hydro

Current topographic and bathymetric data will be used to define the geometry of the cross sections representative of the reservoir system. The bathymetric and LIDAR data were distinct products that were subsequently merged together to form a continuous DTM in the form of a TIN. The bathymetric data will be used to develop the below water portion of the cross section geometry. The process used to collect the bathymetric data is described in the Study 25 Report, Boundary Dam/Seven Mile Dam Bathymetry Survey (SCL 2008c). The LIDAR based data will be used to develop the above water portion of the cross section geometry. The LIDAR based data set was derived from aerial flights conducted in August 2005 by Terrapoint (Terrapoint 2005). Cross sections of the river system will be cut through the DTM at specific locations along the profile of the reservoir using the HEC-GeoRAS software. The cross sections will be defined by a set of X, Y coordinate pairs and will be imported into the HEC-RAS software.

Continuously recorded water surface elevation data from the forebay of BC-Hydro's Seven Mile Dam (1-hour time intervals) will be obtained and used to represent the downstream boundary condition of the downstream hydraulic routing model. The raw data provided by BC Hydro will be in CGVD 28 datum and will be corrected to NAVD 88 datum using a 4.03 foot correction factor.

Continuously recorded Boundary outflow data are available from SCL System Control Center (SCC) in 15-minute time intervals. These data will be used to define the upstream boundary condition for the downstream hydraulic model.

4.2. Hydraulic Routing Model Calibration

Calibration of the upstream hydraulic routing model (Box Canyon Dam to Boundary Dam) 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 for the 13-month period between September 2006 and September 2007. Streamflow data from USGS Gage 12396500 and Boundary Dam outflow data from the same 13-month period 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 or converted to

NAVD 88 vertical datum. Water surface elevation data surveyed at each of the habitat transects will be incorporated into the model calibration process in 2008.

The calibration of the downstream hydraulic model (Boundary Dam to Seven Mile Dam) will use the post processed water surface elevation data from the two pressure transducer sites downstream of Boundary Dam for the 13-month period between September 2006 and September 2007. Seven Mile Dam outflow data from the same 13-month period will be used to support the calibration effort. The pressure transducer data will be available in 15-minute resolution and will be converted to PST. The calibration of the downstream hydraulic model will also use water surface elevation data surveyed at each of the habitat transects.

The calibration of the upstream hydraulic routing model was conducted in three phases as summarized below. The calibration of the downstream hydraulic model will be conducted using the same phased approach.

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

The objective of the model calibration is 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 or conditions other than those used for calibration to verify validity of the calibration. The broad scale verification process provides further validity of the model calibration for the entire data collection period.

Phase One included identification of the primary model parameters that will be used as variables during calibration, initial selection of the magnitudes of the parameters, selection of the historical time periods for the calibration, determination of an acceptable error range for the calibration, and finally execution of the calibration.

Phase Two included selection of the historical time periods for the verification, determination of an acceptable error range for the verification, and then execution of the verification. The second phase also included refinement of the calibration, using the verification time periods, in the event that the verification was outside of the acceptable error range.

Phase Three included an execution of the verified model for the 13-month data collection period and a reporting of the error range for the 13-month data collection period.

4.2.1. Upstream Hydraulic Routing Model 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.

Prior to starting the calibration, it was necessary to develop initial estimates of the magnitudes of each parameter listed above. Estimates of the 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. Manning's roughness coefficient values published in Barnes (1967) and Arcement and Schneider (1989) were 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 2006).

For the upstream hydraulic model calibration, a sufficient portion of the 13-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 the 13-month record. A matrix comprising six specific portions of the 13-month record was developed using unique combinations of the following forebay conditions and Box Canyon outflow conditions:

- High Pool Conditions—conditions where 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 where 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 where outflow from Box Canyon Dam was greater than 40,000 cfs as recorded at USGS Gage 12396500.
- Moderate Flow Conditions—conditions where outflow from Box Canyon Dam was approximately 20,000 cfs.
- Low Flow Conditions—conditions where outflow from Box Canyon Dam was less than 10,000 cfs.

Table 4.2-1 presents the matrix and summarizes the identified time periods that were used for the calibration of the upstream hydraulic model. 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 13-month record. Figure 4.2-1 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 Appendix 1.

Table 4.2-1. Calibration periods for upstream hydraulic routing model.

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

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

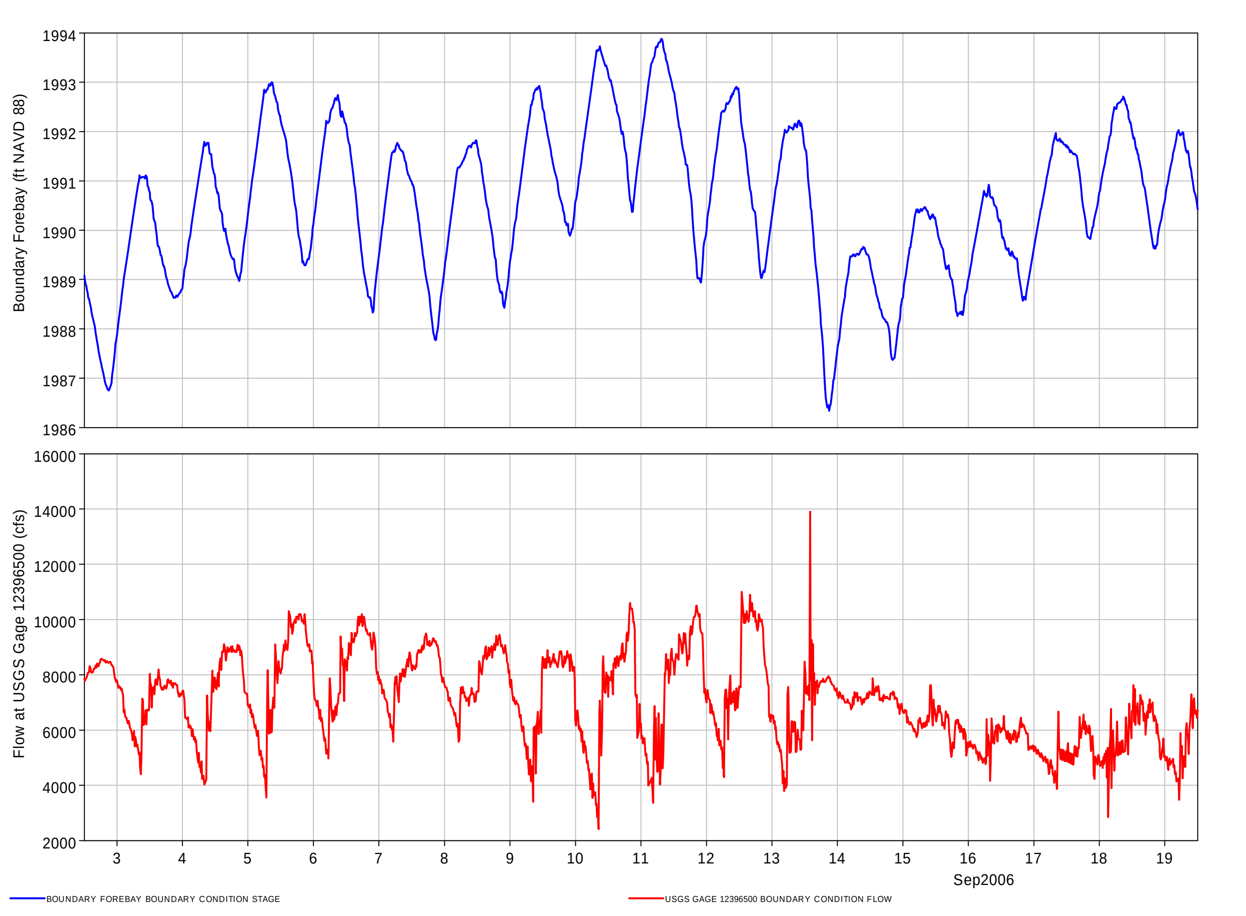


Figure 4.2-1. Stage and flow boundary condition hydrographs for Hi_Lo calibration period for upstream hydraulic model.

Calibration of the upstream hydraulic model used 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 upstream hydraulic routing model.

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
34.3	101003	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.

During the iterative calibration process, 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. 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, 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

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 pre-defined acceptable error range. The pre-defined error range for absolute error was specified at a nominal value of 0.75 foot. The pre-defined error range for RMSE for a single calibration location within a single calibration period was specified as 0.50 foot.

Calibration of the upstream hydraulic model will continue as additional data are made available. Additional calibration periods may be derived with the additional data and the model calibration will be updated as appropriate. The additional data includes the following:

- Water surface elevations surveyed by TRPA at the habitat transect locations during May, July and August 2007 (see Section 4.3.4 of the main Study 7 report)
- Additional raw pressure transducer data (that will be converted to water surface elevation) recorded at the four pressure transducer stations for the period following September 2007.

4.2.2. Upstream Hydraulic Routing Model Calibration – Phases Two and Three

An independent verification of the model calibration was conducted using a separate set of time periods from the 13-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 13-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. 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 Appendix 1.

Table 4.2-3. Verification periods for upstream hydraulic routing model.

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 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.

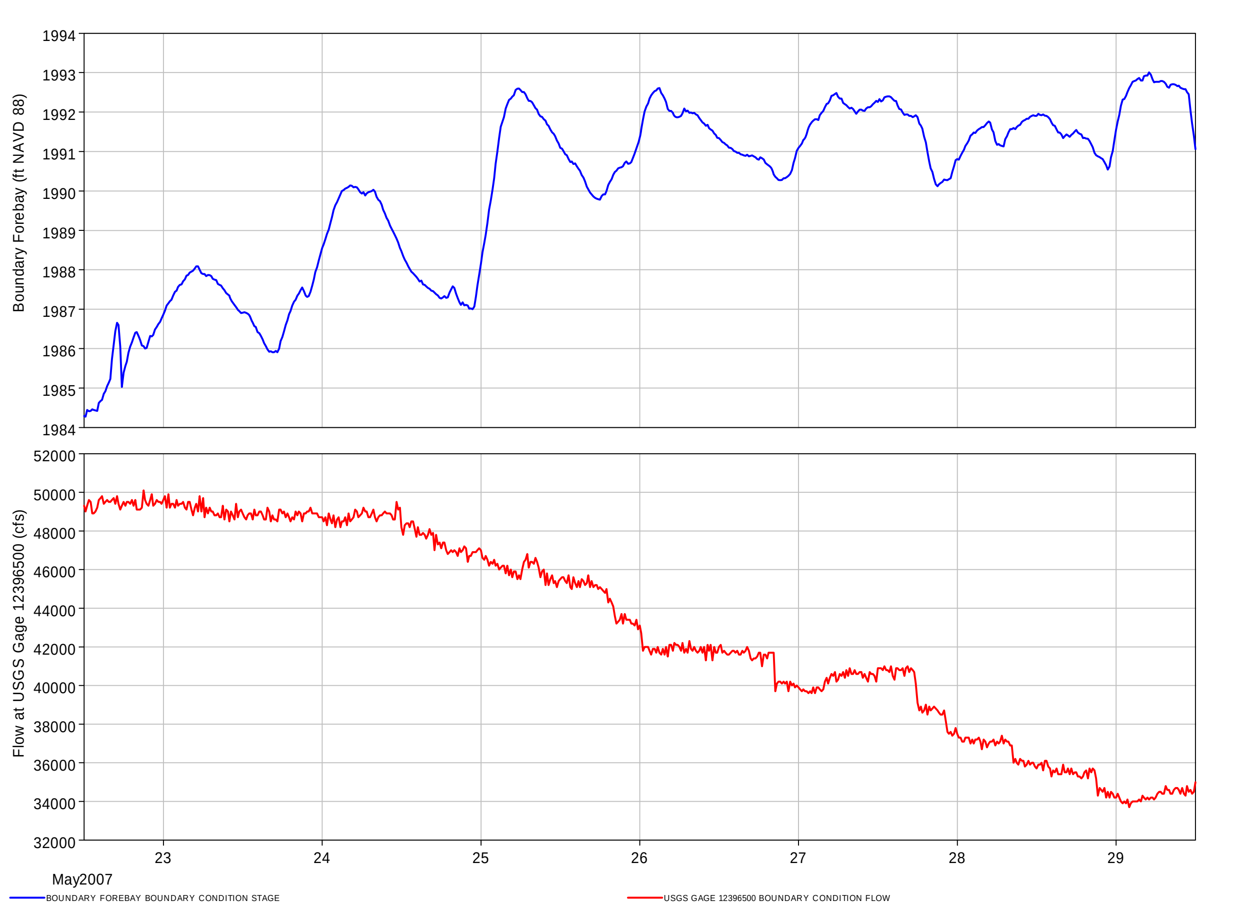


Figure 4.2-2. Stage and flow boundary condition hydrographs for Hi_Hi verification period for upstream hydraulic model.

At this time, the habitat transect water surface elevation data are not available for use in the calibration. Once these data are available, then they will be incorporated into Phase Two. The use of these data will allow for verification of the hydraulic model at multiple locations between the six calibration locations.

The final step in the calibration process (Phase Three) was to execute the verified model for the entire 13-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. Downstream Hydraulic Routing Model Calibration and Verification

Calibration and verification of the downstream hydraulic model will follow the same three phase methodology as was used to calibrate the upstream hydraulic model. The calibration and verification periods will be defined to ensure that the entire range of operations conditions and hydrologic conditions recorded during the time period starting in September 2006 is represented. The downstream hydraulic model will be calibrated using observed water surface elevation hydrographs at two internal locations within the reach downstream of Boundary Dam. Water surface elevation hydrographs will be derived from data measured at the pressure transducer installations. The two locations are summarized in Table 4.2-4. Refer to Figure 4.1-1 for spatial illustration of these locations. The downstream model calibration will also use water surface elevation data surveyed by TRPA during the acoustic doppler current profiler (ADCP) velocity measurement field work. This is data specific to a point in time, as opposed to continuous hydrograph data, but will be very important since it will be the only information available between the international border and Seven Mile Dam.

Table 4.2-4. Calibration locations for downstream hydraulic routing model.

Approximate Project River Mile[1]	HEC-RAS Cross Section ID	Source of Stage Hydrograph Data	Notes
17.0	TBD[2]	BND_TR Pressure Transducer	Data from pressure transducer installed in Boundary Dam tailrace
16.0	TBD	BORDER Pressure Transducer	Data from pressure transducer installed at the international border

Notes:
1 Calibration locations are listed from upstream to downstream.
2 TBD = cross section ID will be determined once hydraulic model is developed.

4.3. Evaluate Need for Separate Seasonal Models

The presence of macrophyte beds in the Upper Reservoir Reach may contribute to the need to develop a separate seasonal hydraulic model. During the period of most robust growth of macrophytes, June through September, the density of the growth has the potential to sufficiently 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 period.

The specific time periods used to calibrate and validate the hydraulic routing model were selected to include time periods when macrophyte growth is most robust. 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, one outside of the macrophyte growth period and one during the macrophyte growth period, during equivalent flow conditions. The intent of the review was to determine if there was a consistent trend that the calibration parameters determined for the entire 13-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.

Final determination of the need for a separate seasonal hydraulic model will be made once all of the habitat transect sections have been incorporated into the model. Once the habitat transects are incorporated into the model this will also enable incorporation of the water surface elevations surveyed at each transect location into the calibration process. This will allow for comparison of model predicted water surface elevations within and outside of the macrophyte growth period at numerous locations between Metaline Falls and Box Canyon Dam, not just at the upstream end of the reach.

If determination is made that separate seasonal models are required, then the “Seasonal Roughness Change Factor” in HEC-RAS will be employed. The appropriate factors will 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 hydraulic routing model will be used integrally with several other models in the evaluation of various operations scenarios. Figure 4.2-3 is a conceptual schematic illustration of the relationship between the models that will be used in support of the study.

The Scenario Tool 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 simulate optimization of Boundary Project, under specific operations constraints, using three hydrologic periods corresponding to an average year, a wet year, and a dry year. The calendar year 2000 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 Scenario Tool 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.

The hourly Boundary forebay elevation time series from the Scenario Tool will be used as the downstream boundary condition in the upstream hydraulic routing model. The hydraulic routing model will route the flood 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.

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.

Output from the hydraulic routing models will also be used in several of the other studies in assessing changes in aquatic habitat for operations scenarios. Section 6.3.2 of the main Study 7 report outlines the other studies that will be using output from the hydraulic routing model.

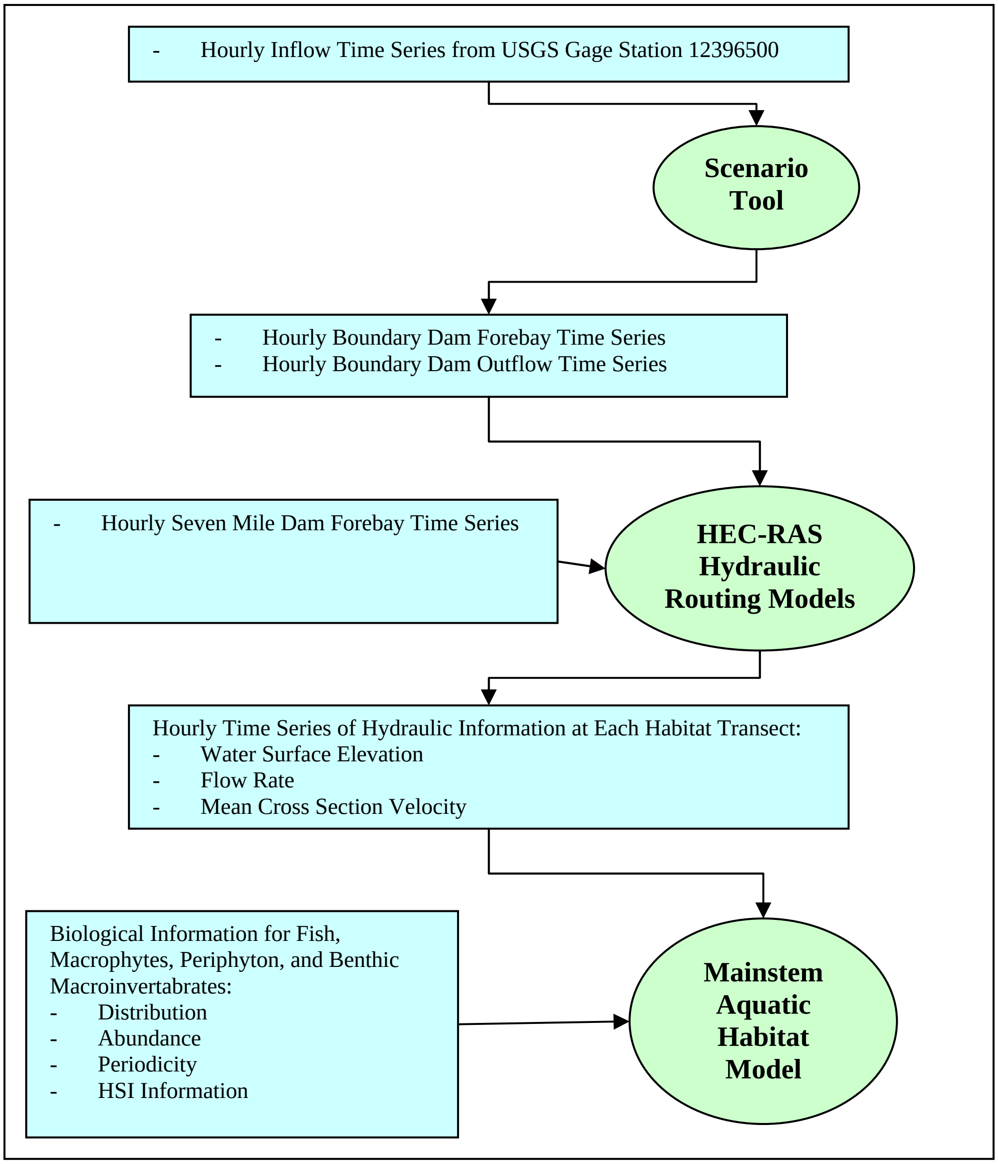


Figure 4.2-3. Conceptual model framework for Study 7.

5 RESULTS

Fluctuations in water surface elevation in the Boundary forebay occur in response to in-flow fluctuations at Box Canyon Dam and the existing Project operations. Existing Project operations therefore contribute to the fluctuating water surface elevations in Boundary forebay and the fluctuating flow releases to Boundary tailrace. Slow moving waves originating in the forebay travel upstream through the Pend Oreille River to as far as Box Canyon Dam, and flow fluctuations originating in the tailrace of Boundary Project travel downstream to as far as just south of the confluence with the Salmo River. These slow moving waves impact the aquatic habitat of the Pend Oreille River both upstream and downstream of Boundary Dam.

A one-dimensional, unsteady flow hydraulic model was used to analyze the translation and attenuation of water surface elevation and flow fluctuations upstream and downstream from Boundary Dam. The hydraulic routing model was calibrated to data collected on the Pend Oreille River between September 2006 and September 2007, inclusive. The results of the calibrated hydraulic routing model will then be used to support the analysis of potential impacts of operations scenarios on aquatic habitats in the Pend Oreille River between Box Canyon Dam and the confluence of Red Bird Creek.

This section includes presentation of the results of the model development and the results of the primary calibration of the upstream hydraulic model (Boundary Dam to Box Canyon Dam). The development of the upstream hydraulic model is nearly complete, with the only remaining task to replace the DTM derived cross section geometry with the ADCP-derived transect geometry at each of the habitat transect locations. The primary calibration effort for the upstream hydraulic model is complete, meaning that all data available through December 2007 have been incorporated into the calibration of the model. As additional data are collected and post-processed in 2008, the primary calibration will be updated to incorporate this additional data.

The downstream hydraulic model (Boundary Dam to Seven Mile Dam) has not been developed nor calibrated at this time and as such is not discussed in detail in this section.

5.1. Description of System and Need for Hydraulic Routing Model

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, because backwater effects from Boundary Dam are minimized 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 between Boundary Dam and Box Canyon Dam represented by the upstream hydraulic routing model.

Water surface elevation fluctuations originating from the forebay of the Boundary Project are translated the 17.5 mile long distance to Box Canyon Dam. However, the wave characteristics dampen, or attenuate, as the wave travels upstream. Variability in the channel morphology of the Pend Oreille River upstream of Boundary Dam affects the wave travel time and the magnitude of the wave attenuation. The most dominant example of this is Metaline Falls. The constriction and sharp change in channel gradient results in hydraulic conditions that can greatly reduce the water

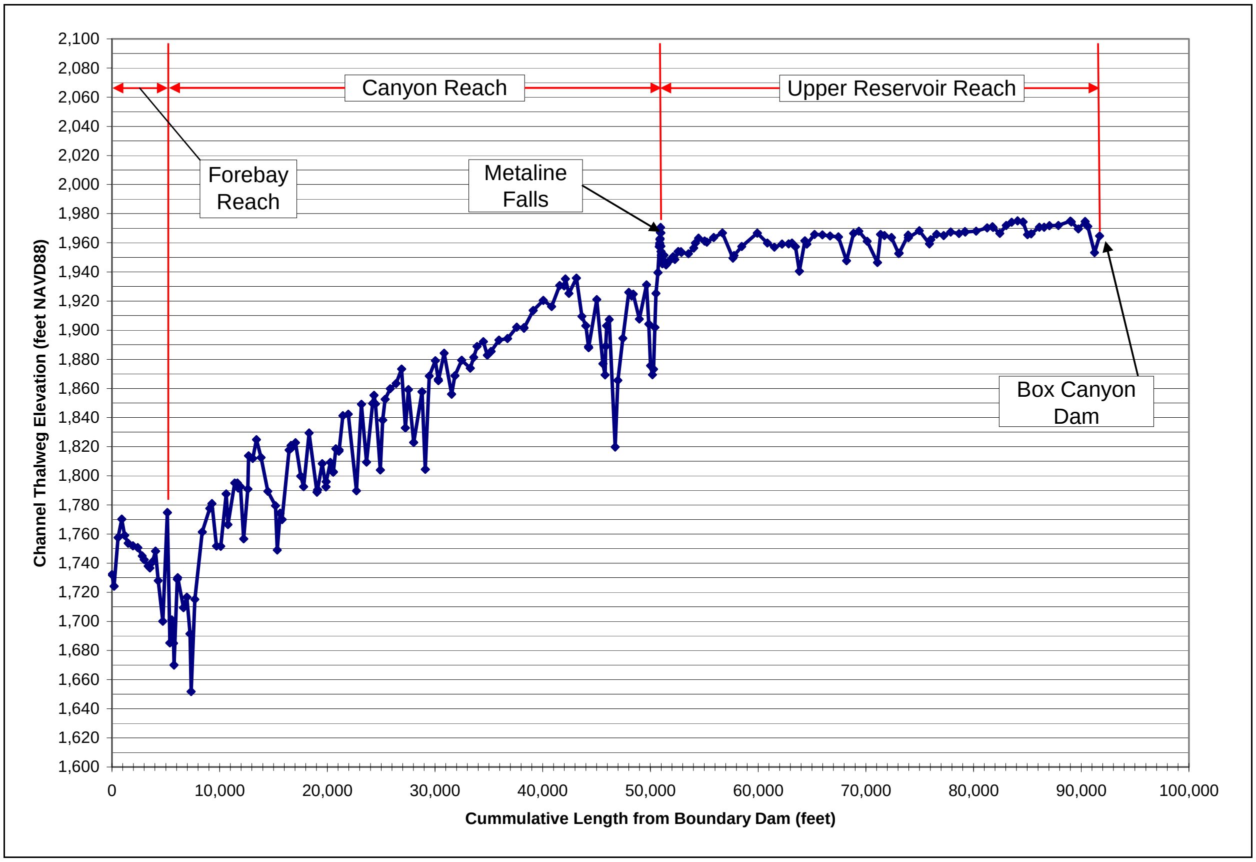


Figure 5.1-1. Thalweg profile of upstream hydraulic routing model.

surface elevation fluctuations in the Upper Reservoir Reach. During conditions when the forebay elevation of Boundary Project fluctuates below a threshold value, the fluctuations in water surface elevation observed at the Boundary forebay are greatly reduced upstream of Metaline Falls.

The calibrated upstream hydraulic model will provide specific information regarding wave travel time and wave attenuation throughout the 17.5 mile reach. This information will be directly used to evaluate the effects of operations scenarios on aquatic habitats in the Pend Oreille River between Box Canyon Dam and Boundary Dam.

5.2. Data Used to Construct and Calibrate the Hydraulic Routing Model

This section will present various aspects of the upstream hydraulic model development, including:

- Bathymetry and topography used to develop the upstream hydraulic model
- Cross section location and development
- Boundary conditions for the upstream hydraulic model
- Data and information specifically used to calibrate the upstream hydraulic model

5.2.1. Bathymetry and Topography

A multibeam sonar bathymetric survey was conducted within the Boundary Dam Reservoir by Global Remote Sensing, LLC (GRS) in 2006. The data from this survey were supplemented and checked, in selected areas, with a high resolution multibeam bathymetry and scanning laser shoreline survey, collected by Tetra Tech EC, Inc. (TtEC) in June/July 2007. GRS partially resurveyed the reservoir with a high resolution multibeam bathymetry system in October 2007. TtEC conducted a concurrent shoreline scanning laser survey to provide full coverage of the shoreline below Metaline Falls. More detail regarding the methods and results of this data collection effort are summarized in the Study 25 (Bathymetric Survey) report (SCL 2008c).

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).

Pacific Geomatic Services (PGS) provided 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 LIDAR data were merged together to form a continuous DTM in the form of a TIN. The DTM is a digital representation of the ground surface topography. Figure 5.2-1 shows an example portion of the terrain model through Metaline Falls.

5.2.2. Cross Sections

The first step in the development of the upstream hydraulic routing model 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 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) and were located at the periphyton sampling locations (for Study 7.4.3). Cross sections were also located at all habitat transect locations.

For the upstream hydraulic routing model, 231 cross sections were ultimately included in the model. The average spacing between the cross sections is approximately 400 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 20 feet.

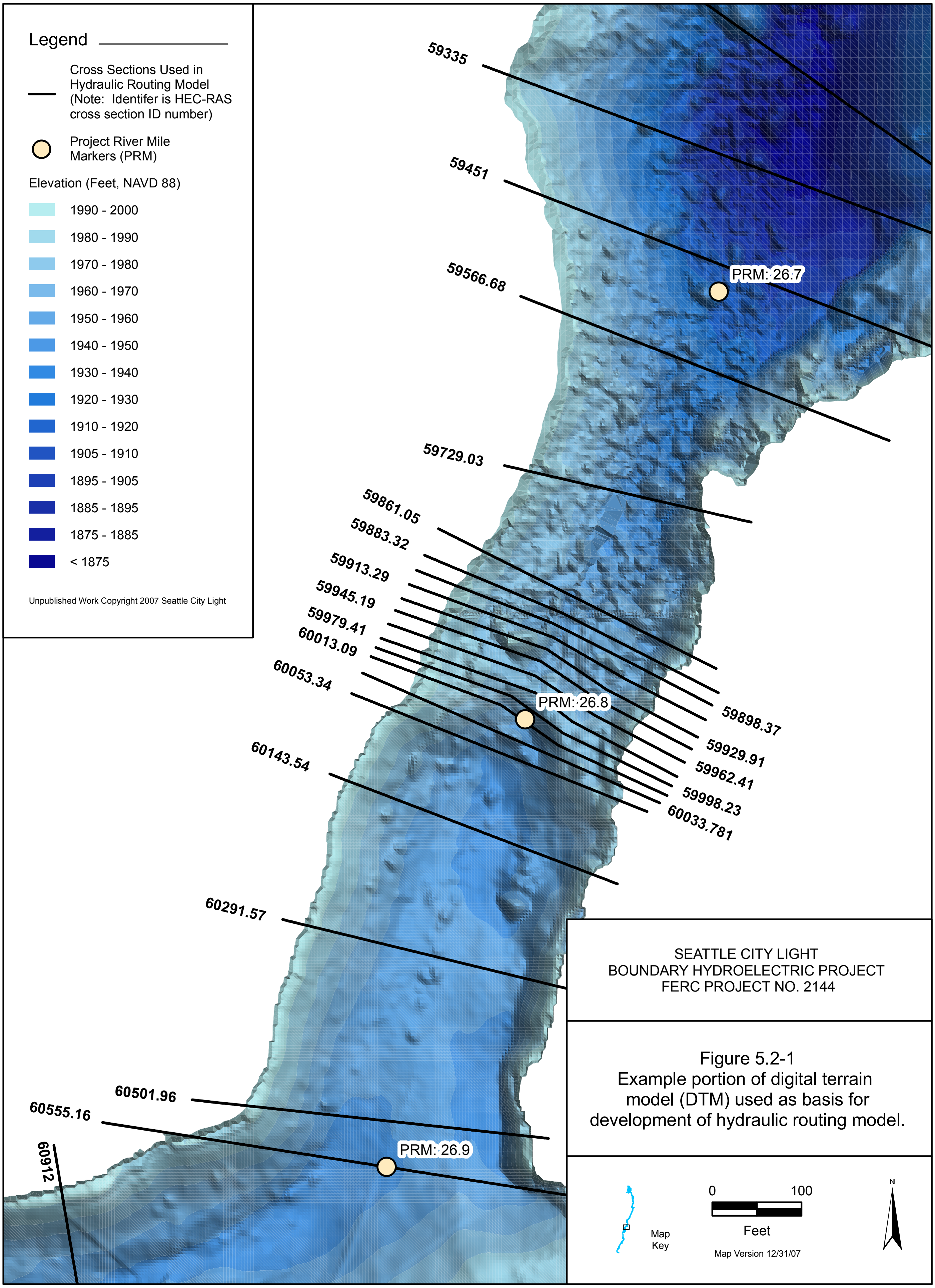


Figure 5.2-1
Example portion of digital terrain model (DTM) used as basis for development of hydraulic routing model.

Figure 5.2-2 is an example figure showing the cross section locations in the most upstream portion of the reach above Boundary Dam. A complete set of figures showing all cross section locations for the upstream hydraulic model is included in Appendix 1.

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 surface with a downstream orientation (i.e., how the cross sections would look to an observer standing upstream looking downstream). Figures 5.2-3 and 5.2-4 are examples of the cross section geometry input into the hydraulic model at two specific locations. Figure 5.2-3 shows the cross section at the location of habitat transect U-16, which corresponds with HEC-RAS cross section 86100. Figure 5.2-4 shows the cross section at the location of habitat transect C-4, which corresponds with HEC-RAS cross section 18399.

All cross sections currently included in the upstream hydraulic model were derived from the DTM. Once the habitat transect cross section geometry is available, each cross section in the hydraulic model that is located at a habitat transect will be replaced with the field surveyed habitat transect geometry.

The selection of the magnitude of the computational time step is a function of the spacing of the cross sections. The HEC-RAS Users Manual (HEC-USACE 2006) provides guidance in selecting the time step that would result the greatest 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:

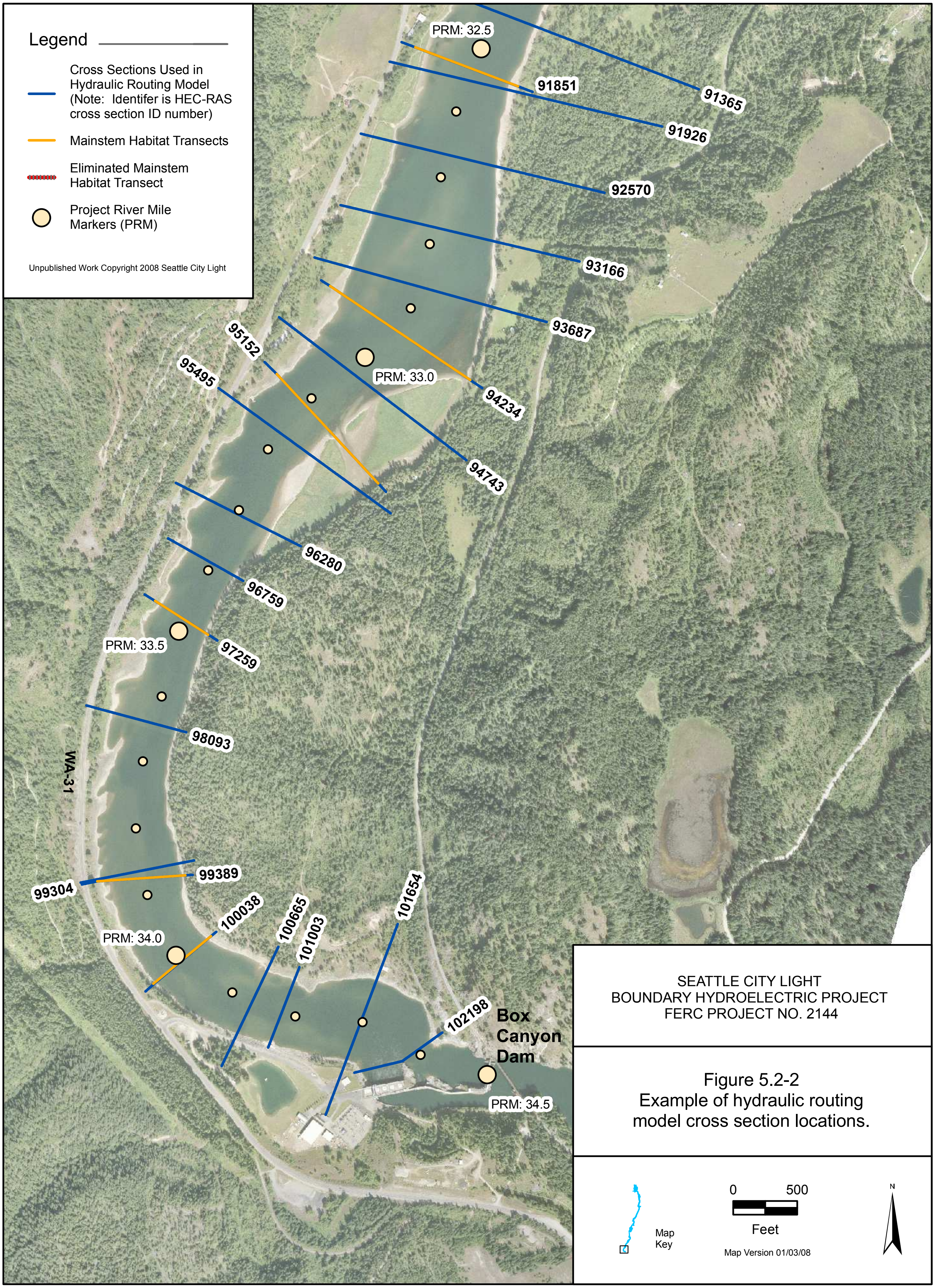
t = computational time step, hours

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.

5.2.3. Boundary Conditions

The boundary conditions for the calibration of the upstream hydraulic model included a time series of Boundary Project forebay elevations (downstream boundary condition) and a time series of flow rates as measured at the USGS Gaging Station 12396500 (upstream boundary condition). The data were continuously recorded and were available at a 15-minute time interval.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure 5.2-2
Example of hydraulic routing model cross section locations.

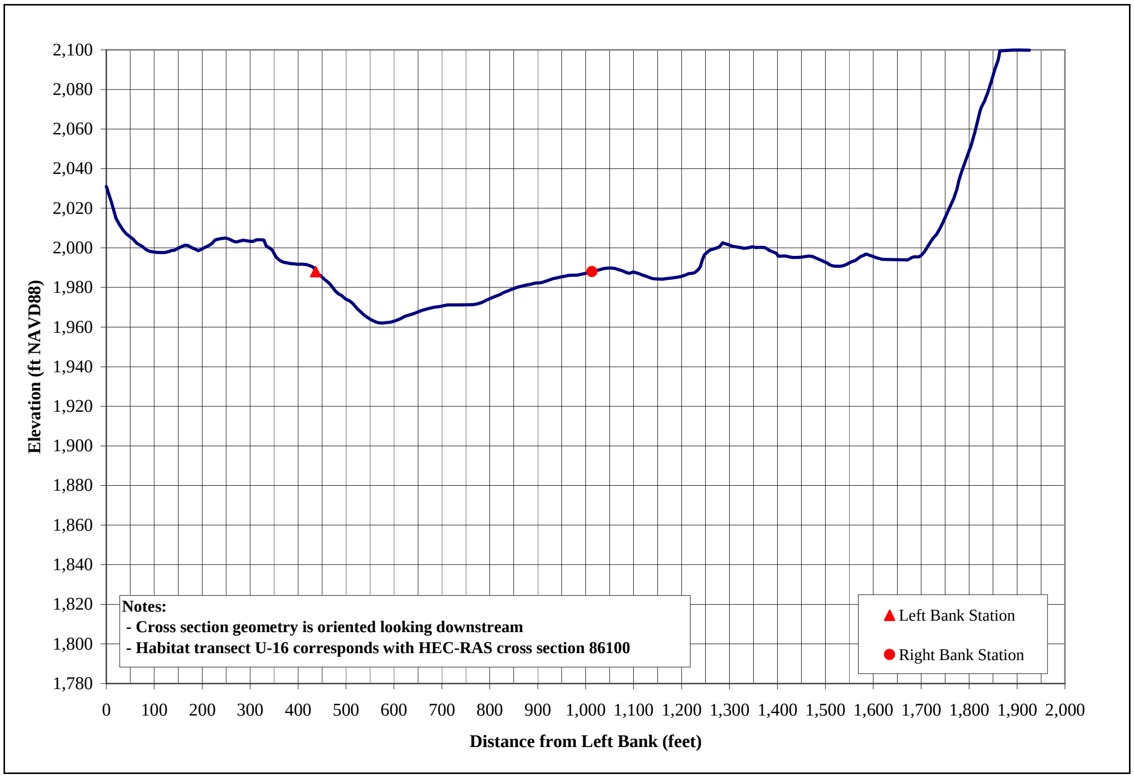


Figure 5.2-3. Example of typical cross section in hydraulic routing model (DTM-derived cross section at Habitat Transect U-16).

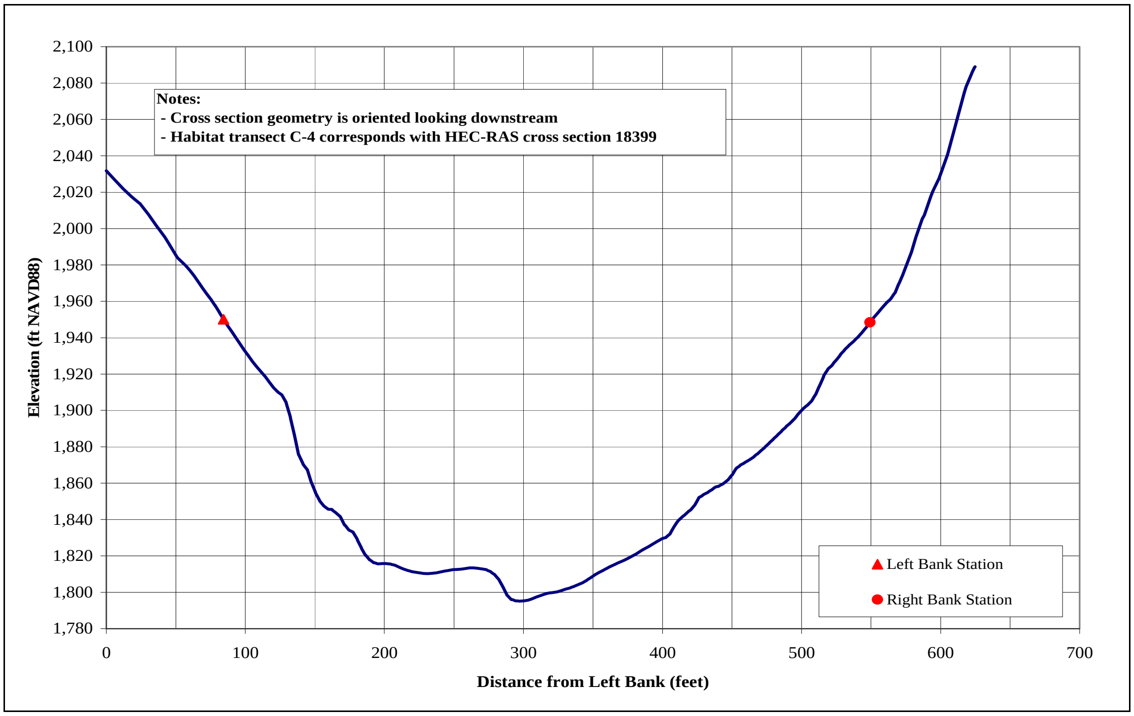


Figure 5.2-4. Example of typical cross section in hydraulic routing model (DTM-derived cross section at Habitat Transect C-4).

The boundary conditions that will be used to calibrate the downstream hydraulic routing model will include a time series of Seven Mile Project forebay elevations (downstream boundary condition) and a time series of Boundary Project outflow data as provided by SCL. The Seven Mile forebay data will be supplied in 1-hour time intervals and the Boundary Project outflow data are available in 15-minute time intervals. Therefore, in the execution of the hydraulic model, HEC-RAS will interpolate the 1-hour stage data to resolve the data into a shorter time interval.

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 upstream hydraulic routing model 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 Scenario Tool. The source of this data is the USGS Gage Station 12396500 for the calendar years 1997, 2000, and 2001.

The downstream hydraulic routing model 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 Scenario Tool optimization.

5.2.4. Information for Calibration

The period of record that the upstream (and downstream) hydraulic routing models will ultimately be calibrated to include the months of September 2006 through December 2008. It has been proposed, although not approved, to maintain the pressure transducer installations only through July 2008. The model has currently been calibrated to data collected through September 2007, therefore representing a 13-month period of continuously collected data.

Available data used for the calibration of the upstream hydraulic model (including verification) include the following:

- USGS water surface elevation data at USGS Gage Station 12396500
- Water depth data collected at five pressure transducer installations between Boundary Dam and Box Canyon Dam
- Boundary Dam outflow data provided by SCL

Data that are not yet available but that will be used for model calibration include the water surface elevation data collected at each habitat transect during specific flow conditions in 2007. Table 5.2-1 summarizes the periods when these data are available. Each one of these periods is included in one of the model verification periods described previously in Section 4.2.2. The data have been collected and are currently being post-processed. The data will provide 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 will supplement the continuously collected data from USGS and the pressure transducers.

Table 5.2-1. Available periods for transect water surface elevation data.

Dates	General Pool Condition	General Flow Condition	Reaches Included in Survey
May 26 – 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
Early Spring 2008[1]	High	High	Canadian Portion of Tailrace
Early Spring 2008[1]	Low	High	Tailrace
Early Spring 2008[1]	Low	Moderate	Tailrace
Early Spring 2008[1]	Low	Low	Tailrace

Notes:
1 The exact dates for this field work have not yet been determined

The raw 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 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 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 5.2-2, thus providing additional confidence in the data. Based on this review, erroneous data were eliminated. 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.

Boundary Dam outflow data were provided by SCL at 15-minute time increments. The upstream hydraulic routing model 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.

Table 5.2-2. Number of instances where differential in pressure transducer readings exceeded nominal value of 0.5 foot.

Time Period	BOX_TR	US_MET[2]	DS_MET[3]	CANYON	BND_LK	BND_TR	BORDER
Sept 06 – Dec 06	1	0	0	0	N/A	1	3
Dec 06 – Mar 07	1	0	0	0	N/A	6098[1]	82
Mar 07 – June 07	23	0	6	0	1	99	2
June 07 – Sept 07	2	1	1	0	47[1]	0	0

Notes:
N/A = not applicable due to the fact that only one pressure transducer was installed at this location for this time period.
1 Due to failure 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.

5.3. Model 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.

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 and guidance presented in USACE-HEC (2006), 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 upstream hydraulic routing model.

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	100038	34.39	34.01	0.045	0.040	0.045	0.1	0.3
100038	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	27.59	26.90	0.035	0.030	0.035	0.1	0.3
60555	60143	26.90	26.83	0.028	0.028	0.028	0.1	0.3
60143	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 Appendix 1 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.

Observations of main channel substrate in the Upper Reservoir Reach (upstream of Metaline Falls) indicated predominantly cobble material with gravel deposits and localized areas of sand deposits. 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. Estimates of the main channel Manning’s Roughness coefficient through the 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 1985 NAVD 88.

Estimates of the contraction and expansion loss coefficients were based on guidance presented in the HEC-RAS Users Manual (USACE-HEC 2006) and observations of site conditions. According to USACE-HEC (2006), 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. Primary Calibration and Verification of Hydraulic Model

Calibration of the upstream hydraulic model 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). 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 error ranges as established in Section 4.2. The calibration process also included defining ineffective flow areas within each cross section 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 cross sections immediately upstream and downstream of the controlling cross section. 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 stage conditions.

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.

Table 5.3-2. Final estimates of model calibration parameters for upstream hydraulic routing model.

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	98093	34.39	33.64	0.060	0.037	0.050	0.1	0.3
98093	94743	33.64	33.03	0.060	0.036	0.050	0.1	0.3
94743	90344	33.03	32.24	0.050	0.032	0.050	0.1	0.3
90344	83995	32.24	31.08	0.040	0.028	0.040	0.1	0.3
83995	81030	31.08	30.54	0.050	0.032	0.050	0.1	0.3
81030	76404	30.54	29.75	0.050	0.032	0.075	0.1	0.3
76404	72815	29.75	29.08	0.050	0.032	0.050	0.1	0.3
72815	60555	29.08	26.90	0.050	0.032	0.050	0.3	0.5
60555	60143	26.90	26.83	0.089	0.089	0.089	0.5	0.7
60143	59729	26.83	26.75	0.123	0.123	0.123	0.5	0.7
59729	59451	26.75	26.69	0.123	0.123	0.123	0.9	0.9
59451	57424	26.69	26.31	0.089	0.089	0.089	0.9	0.9
57424	12044	26.31	17.99	0.089	0.089	0.089	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 Appendix 1 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.

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 5.3-3. Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the calibration periods.

Cumulative Range	Calibration Location					
	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
< 0.2 feet	59.40 %	62.21 %	48.04 %	75.71 %	80.92 %	99.76 %
< 0.4 feet	92.30 %	95.04 %	80.39 %	95.25 %	93.65 %	99.99 %
< 0.6 feet	99.95 %	98.59 %	95.65 %	98.50 %	99.57 %	100.00 %
< 0.75 feet	99.97 %	99.99 %	99.89 %	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.

Table 5.3-4. Summary of maximum model error at each calibration location for the calibration periods.

		BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
Calibration Period		**102198[1]**	**101003[1]**	**96759[1]**	**61170[1]**	**59451[1]**	**12445[1]**
Hi_Lo	Maximum Positive	+ 0.9 (+ 0.5)[2]	+ 0.3	+ 0.3	+ 0.3	+ 0.3	+ 0.2
	Maximum Negative	- 1.0 (- 0.5)[2]	- 0.6	- 0.6	- 0.2	N/A	N/A
Hi_Mod	Maximum Positive	+ 0.5	+ 0.3	+ 0.4	+ 0.4	+ 0.2	+ 0.2
	Maximum Negative	- 0.3	- 0.5	- 0.5	- 0.2	- 0.2	N/A
Hi_Hi	Maximum Positive	+ 0.5	N/A	N/A	+ 0.2	N/A	+ 0.2
	Maximum Negative	- 0.7	- 0.4	- 0.7	- 0.2	- 0.4	N/A
Lo_Lo	Maximum Positive	+ 0.4	+ 0.2	+ 0.8	+ 0.3	+ 0.5	+ 0.4
	Maximum Negative	- 0.6	- 0.7	- 0.3	- 0.7	- 0.1	N/A
Lo_Mod	Maximum Positive	+ 1.2 (+ 0.5)[2]	+ 0.8 (+ 0.4)[2]	+ 0.8 (+ 0.5)[2]	+ 0.5	+ 0.4	+ 0.2
	Maximum Negative	- 0.2	- 0.3	- 0.3	- 0.5	- 0.2	N/A
Lo_Hi	Maximum Positive	+ 0.5	+ 0.2	N/A	+ 0.5	N/A	+ 0.2
	Maximum Negative	- 0.5	- 0.5	- 0.7	- 0.6	- 0.7	N/A

Notes:
N/A indicates that the computed error at the location was either entirely positive or entirely negative for the entire simulation.
Error computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where the maximum error was greater than the initial goal of 0.75 foot.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.
2 Value in parentheses is the computed value of the error if the outliers are excluded.

Table 5.3-5. Summary of root mean square error (RMSE) at each calibration location for the calibration periods.

	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
Calibration Period	**102198[1]**	**101003[1]**	**96759[1]**	**61170[1]**	**59451[1]**	**12445[1]**
Hi_Lo	0.18	0.18	0.15	0.07	0.13	0.08
Hi_Mod	0.21	0.19	0.23	0.16	0.05	0.09
Hi_Hi	0.19	0.22	0.40	0.09	0.18	0.15
Lo_Lo	0.23	0.33	0.47	0.33	0.15	0.09
Lo_Mod	0.31	0.21	0.26	0.17	0.10	0.09
Lo_Hi	0.17	0.14	0.29	0.22	0.41	0.07

Notes:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.

The first table, Table 5.3-3, shows that for 96 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 5.3-3 also shows that with the exception of the Auxiliary USGS location, the model-predicted water surface elevations were within 0.4 feet of the observed water surface elevations more than 93 percent of the time. As described previously in Section 4.2, an initial goal of a maximum absolute error of 0.75 foot was established at the onset of the model calibration process. Table 5.3-3 shows that this goal was attained at three of the calibration locations, including the two transducer locations upstream and downstream of Metaline Falls. The instances where the maximum absolute error was greater than 0.75 foot were not necessarily attributed to an unsuccessful model calibration, as illustrated in Table 5.3-4.

Table 5.3-4 summarizes the maximum positive and maximum negative error at each calibration location for 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. Five of the six shaded boxes are attributed to unique instances where outflow from Box Canyon Dam was 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. 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. As seen in Table 5.3-4, if these instantaneous outliers are excluded in the error computations, then the computed error is within the previously stated 0.75 foot error bound, as indicated by the values in parentheses. Figure 5.3-1 illustrates this phenomenon for the instance where it occurred during the Hi_Lo calibration period. As seen in this figure, the calibrated model replicated the magnitude of the water surface fluctuation, but not the exact timing.

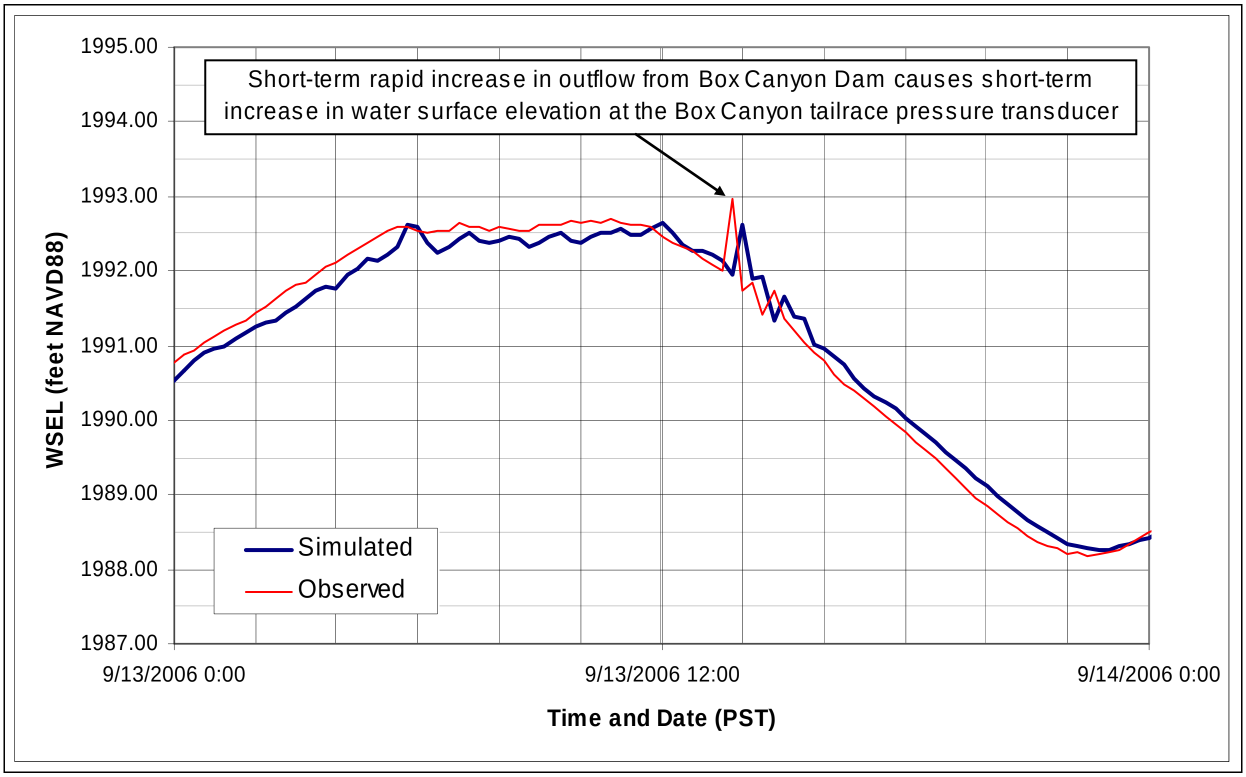


Figure 5.3-1. Example of timing associated with rapid short-term change in Box Canyon Dam outflow

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 Hi_Lo calibration period within an average error of less than 0.20 foot at each of the calibration locations.

Verification of the calibrated hydraulic model was conducted by executing the calibrated model for five time periods (verification periods) that were not originally included in the model calibration effort. No changes to the model input parameters were made. Based on the same evaluators that were used to quantify the success of the model calibration, it was found that the model predicted results for the verification periods equaled or exceeded the success associated with the calibration periods. The results of the verification model runs provided an independent substantiation to the model calibration, and it was therefore determined that adjustments to the model input parameters were not warranted or necessary.

Tables 5.3-6, 5.3-7, and 5.3-8 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. 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 time that model results were within specified range of observed conditions at each calibration location for the verification periods.

Cumulative Range	Calibration Location					
	BOX_TR	**Primary USGS**	**Auxiliary USGS**	**US_MET**	**DS_MET**	**CANYON**
< 0.2 feet	61.38 %	68.62 %	44.11 %	83.10 %	88.54 %	99.98 %
< 0.4 feet	91.41 %	96.55 %	80.91 %	99.12 %	99.69 %	100.00 %
< 0.6 feet	99.88 %	99.96 %	96.31 %	99.96 %	100.00 %	100.00 %
< 0.75 feet	99.92 %	99.98 %	99.90 %	99.96 %	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 5.3-7. Summary of maximum model error at each calibration location for the verification periods.

		BOX_TR	**Primary USGS**	**Auxiliary USGS**	**US_MET**	**DS_MET**	**CANYON**
Verification Period		**102198[1]**	**101003[1]**	**96759[1]**	**61170[1]**	**59451[1]**	**12445[1]**
Hi_Hi	Max Positive	+ 0.3	N/A	N/A	+ 0.3	N/A	+ 0.2
	Max Negative	- 0.4	- 0.3	- 0.5	- 0.2	- 0.5	N/A
Var_Var	Max Positive	+ 1.2 (+ 0.6)[2]	+ 0.5	+ 0.6	+ 0.6	+ 0.4	+ 0.3
	Max Negative	- 0.3	- 0.6	- 0.6	- 0.2	- 0.2	- 0.1
Lo_Lo	Max Positive	+ 0.5	+ 0.1	+ 0.9	+ 0.2	+ 0.3	+ 0.1
	Max Negative	- 0.4	- 0.5	- 0.4	- 0.2	N/A	N/A
Lo_Mod	Max Positive	+ 0.5	+ 0.4	+ 0.5	+ 0.4	+ 0.4	+ 0.1
	Max Negative	- 0.1	- 0.2	- 0.2	- 0.3	- 0.1	- 0.1
Lo_Hi	Max Positive	+ 1.5 (+ 0.3)[2]	+ 0.8 (+ 0.3)[2]	+ 0.9 (+ 0.3)[2]	+ 0.8 (+ 0.4)[2]	+ 0.2	+ 0.2
	Max Negative	- 0.3	- 0.3	- 0.5	- 0.4	- 0.4	N/A

Notes:
N/A indicates that the computed error at the location was either entirely positive or entirely negative for the entire simulation.
Error computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where the maximum error was greater than the initial goal of 0.75 foot.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.
2 Value in parentheses is the computed value of the error if the outliers are excluded.

Table 5.3-8. Summary of root mean square error (RMSE) at each calibration location for the verification periods.

	BOX_TR	**Primary USGS**	**Auxiliary USGS**	**US_MET**	**DS_MET**	**CANYON**
Verification Period	**102198[1]**	**101003[1]**	**96759[1]**	**61170[1]**	**59451[1]**	**12445[1]**
Hi_Hi	0.12	0.16	0.32	0.09	0.23	0.10
Var_Var	0.28	0.19	0.27	0.19	0.06	0.10
Lo_Lo	0.15	0.25	0.41	0.09	0.12	0.09
Lo_Mod	0.22	0.18	0.28	0.12	0.09	0.05
Lo_Hi	0.16	0.14	0.20	0.15	0.18	0.08

Notes:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration locations.

The first table, Table 5.3-6, shows that for 96 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 5.3-6 also shows that with the exception of the Auxiliary USGS location, the model-predicted water surface elevations were within 0.4 feet of the observed water surface elevations more than 91 percent of the time. As described previously in Section 4.2, an initial goal of a maximum absolute error of 0.75 foot was established at the onset of the model calibration process. Table 5.3-6 shows that this goal was attained at the pressure transducers located downstream of Metaline Falls. As was described previously in the calibration discussion, those instances where the maximum absolute error was greater than 0.75 foot were not necessarily attributed to an unsuccessful model calibration, as illustrated in Table 5.3-7.

Table 5.3-7 summarizes the maximum positive and maximum negative error at each calibration location for each verification period. 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. Similar to the calibration period results, five of the six shaded boxes are attributed to unique instances where outflow from Box Canyon Dam was 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. 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. As seen in Table 5.3-7, if these instantaneous outliers are excluded in the error computations, then the computed error is within the previously stated 0.75 foot error bound, as indicated by the values in parentheses.

Finally, Table 5.3-8 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 0.30 foot at each of the calibration locations.

The final step of the calibration process was to execute the calibrated model for the entire 13-month period of available pressure transducer data, which was inclusive of the previously run calibration and verification periods. The time period for this model run was September 2006 through September 2007. This step is considered a broad verification of the calibrated model in that it provides verification of the model calibration using all pressure transducer data collected to date. Tables 5.3-9, 5.3-10, and 5.3-11 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. Because the broad verification period includes nearly 13 months of continuously collected data, there were a total of nearly 38,000 time ordinate comparisons made at each of the calibration locations.

Table 5.3-9. Cumulative percent of time that model results were within specified range of observed conditions at each calibration location for the broad verification period.

Cumulative Range	Calibration Location					
	BOX_TR	Primary USGS	Auxiliary USGS	US_MET	DS_MET	CANYON
< 0.2 feet	62.24 %	73.88 %	56.23 %	82.47 %	87.39 %	99.75 %
< 0.4 feet	94.20 %	98.11 %	88.59 %	98.64 %	97.93 %	99.99 %
< 0.6 feet	99.96 %	99.65 %	98.13 %	99.65 %	99.90 %	100.00 %
< 0.75 feet	99.98 %	99.99 %	99.96 %	99.99 %	100.00 %	100.00 %

Notes:
1 There were a total of 13 months represented in the broad verification period.
2 Broad verification period includes entire 13-month period of data collection used for the primary model calibration.
3 Model output and observed data were compared at 15-minute time intervals.

Table 5.3-10. Summary of maximum model error at each calibration location for the broad verification period.

Month		BOX_TR 102198[1]	Primary USGS 101003[1]	Auxiliary USGS 96759[1]	US_MET 61170[1]	DS_MET 59451[1]	CANYON 12445[1]
September 2006	Max Positive	+ 0.9 (+ 0.5)[2]	+ 0.3	+ 0.7	+ 0.3	+ 0.3	+ 0.2
	Max Negative	- 1.0 (- 0.5)[2]	- 0.6	- 0.6	- 0.2	N/A	N/A
October 2006	Max Positive	+ 1.2 (+ 0.5)[2]	+ 0.8 (+ 0.4)[2]	+ 0.8 (+ 0.5)[2]	+ 0.5	+ 0.4	+ 0.4
	Max Negative	- 0.3	- 0.4	- 0.3	- 0.5	- 0.2	N/A
November 2006	Max Positive	+ 0.6	+ 0.4	+ 0.5	+ 0.3	+ 0.4	+ 0.2
	Max Negative	- 0.1	- 0.3	- 0.4	- 0.1	- 0.2	N/A
December 2006	Max Positive	+ 0.6	+ 0.4	+ 0.6	+ 0.5	+ 0.3	+ 0.2
	Max Negative	- 0.5	- 0.8	- 0.6	- 0.5	- 0.2	- 0.1
January 2007	Max Positive	+ 0.5	+ 0.3	+ 0.5	+ 0.4	+ 0.4	+ 0.3
	Max Negative	- 0.3	- 0.5	- 0.5	- 0.2	- 0.2	N/A
February 2007	Max Positive	+ 1.2 (+ 0.7)[2]	+ 0.5	+ 0.6	+ 0.6	+ 0.4	+ 0.3
	Max Negative	- 0.3	- 0.6	- 0.6	- 0.1	- 0.2	- 0.1
March 2007	Max Positive	+ 0.6	+ 0.4	+ 0.5	+ 0.4	+ 0.4	+ 0.4
	Max Negative	- 0.7	- 0.5	- 0.7	- 0.2	- 0.4	- 0.1
April 2007	Max Positive	+ 0.6	+ 0.3	+ 0.2	+ 0.3	+ 0.2	+ 0.2
	Max Negative	- 0.3	- 0.5	- 0.6	- 0.2	- 0.4	N/A
May 2007	Max Positive	+ 0.5	+ 0.3	+ 0.2	+ 0.5	+ 0.2	+ 0.2
	Max Negative	- 0.5	- 0.5	- 0.7	- 0.4	- 0.7	N/A
June 2007	Max Positive	+ 1.5 (+ 0.8)[2]	+ 0.8 (+ 0.5)[2]	+ 0.9 (+ 0.4)[2]	+ 0.8 (+ 0.5)[2]	+ 0.3	+ 0.2
	Max Negative	- 0.5	- 0.4	- 0.6	- 0.4	- 0.5	- 0.1
July 2007	Max Positive	+ 0.5	+ 0.4	+ 0.5	+ 0.4	+ 0.4	+ 0.2
	Max Negative	- 0.5	- 0.3	- 0.3	- 0.2	- 0.2	- 0.1
August 2007	Max Positive	+ 0.5	+ 0.2	+ 0.9	+ 0.4	+ 0.3	+ 0.2
	Max Negative	- 0.4	- 0.5	- 0.4	- 0.2	N/A	N/A
September 2007	Max Positive	+ 0.4	+ 0.2	+ 0.8	+ 0.3	+ 0.5	+ 0.4
	Max Negative	- 0.6	- 0.7	- 0.3	- 0.7	- 0.1	N/A

Notes:
N/A indicates the computed error at the location was either entirely positive or entirely negative for the entire simulation.
Error computed as simulated value minus observed value.
Shaded boxes indicate a calibration location where the maximum error was greater than the initial goal of 0.75 foot.
1 Table includes identifiers for HEC-RAS model cross sections associated with each calibration location.
2 Value in parentheses is the computed value of the error if the outliers are excluded.

Table 5.3-11. Summary of root mean square error (RMSE) at each calibration location for the broad verification period.

Month	BOX_TR 102198[1]	Primary USGS 101003[1]	Auxiliary USGS 96759[1]	US_MET 61170[1]	DS_MET 59451[1]	CANYON 12445[1]
September 2006	0.17	0.17	0.21	0.09	0.14	0.08
October 2006	0.28	0.19	0.22	0.14	0.09	0.09
November 2006	0.24	0.14	0.19	0.12	0.08	0.09
December 2006	0.29	0.17	0.26	0.18	0.07	0.07
January 2007	0.21	0.18	0.23	0.15	0.06	0.09
February 2007	0.28	0.19	0.27	0.18	0.06	0.10
March 2007	0.22	0.19	0.28	0.15	0.12	0.12
April 2007	0.19	0.15	0.25	0.15	0.15	0.12
May 2007	0.15	0.15	0.29	0.17	0.33	0.09
June 2007	0.15	0.13	0.24	0.15	0.20	0.09
July 2007	0.19	0.15	0.20	0.11	0.09	0.07
August 2007	0.15	0.20	0.25	0.09	0.11	0.09
September 2007	0.20	0.24	0.34	0.23	0.13	0.09

Notes:
1 Table includes identifiers for HEC-RAS model cross sections at each calibration location.

5.4. Primary Calibration Results

This section presents the primary calibration results in the form of graphical output of the calibrated model to provide illustration of the adequacy of the model calibration. Using the calibrated model as a tool, this section then proceeds to present discussion illustrating the Pend Oreille River system’s hydraulic characteristics, such as the point-in-time variability of the flow rate through the length of Boundary Reservoir and the attenuation and translation of the floodwaves 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. Finally, this section presents the conclusions regarding the need for separate seasonal models, based on the data available to this point and the primary model calibration results.

Figures 5.4-1 and 5.4-2 are time series plots that compare the water surface elevation predicted by the calibrated hydraulic model to the observed water surface elevation. Both figures are at the pressure transducer location located immediately upstream of Metaline Falls (US_MET). Figure 5.4-1 is for the Hi_Hi calibration period (High Pool and High Flow) and Figure 5.4-2 is for the Lo_Mod calibration period (Low Pool and Moderate Flow). Appendix 1 contains identical plots for each of the six calibration locations during each of the six calibration periods. Appendix 1 also contains these same types of plots for each of the six calibration locations during each of the five verification periods.

In addition to illustrating the success of the model calibration on the rising and falling limbs of the floodwaves, it is seen in these time series plots that the calibrated model resulted in very good replication of the timing of the peaks. In the case of the Lo_Mod calibration period shown in Figure 5.4-2, these peaks are the by-product of existing Project operations. Quantitative analysis of

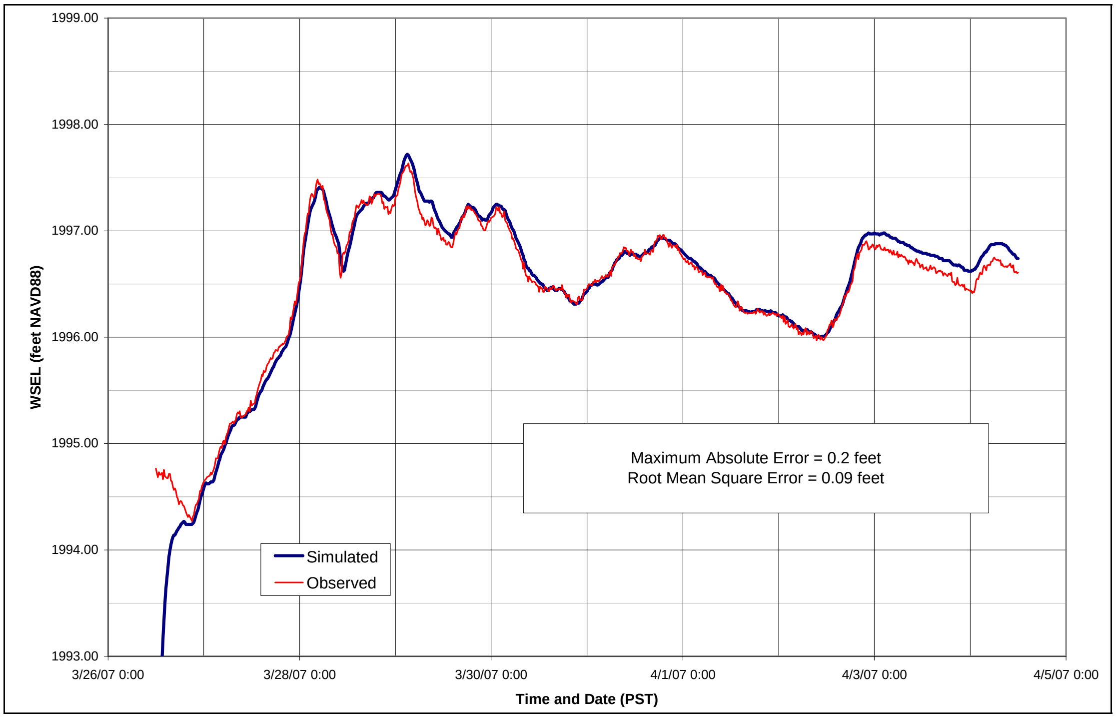


Figure 5.4-1. Model calibration results for Hi_Hi Calibration Period at US_MET Pressure Transducer Location.

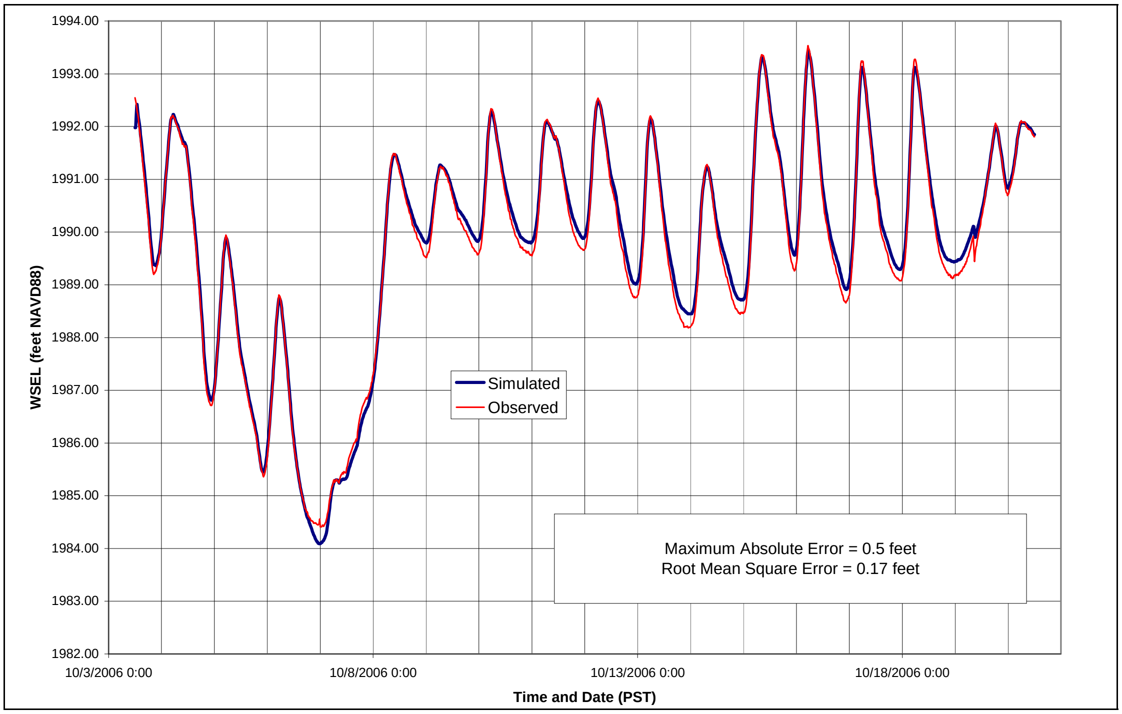


Figure 5.4-2. Model calibration results for Lo_Mod Calibration Period at US_MET Pressure Transducer Location.

the accuracy of the model 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 floodwave, throughout the reach upstream of the Project.

Based on the tables presented in Section 5.3.2 and the comparative time series plots presented in Appendix 1, it is concluded that the primary calibration of the upstream hydraulic routing model was successfully completed. The model calibration was conducted for inflow rates ranging between 2,400 cfs and 55,400 cfs and for Boundary forebay elevations ranging between 1,964.62 and 1,995.08 feet NAVD 88 (1,960.59 and 1,991.05 feet NGVD 29). The most deviation from observed conditions was for low pool-low flow (Lo_Lo) conditions, such as those experienced in August and September 2007. However, for all other conditions, the model-predicted water surface elevations were within 0.75 foot of the observed conditions at all calibration locations for the 13-month calibration period.

The calibrated hydraulic model 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 5.4-3 illustrates the attenuation and translation of the floodwave using a 36-hour portion of the Lo_Mod calibration period. During this period, the outflow from Box Canyon was fairly consistent 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 floodwave translation, showing a nearly 2-hour travel time from Boundary Dam to Box Canyon Dam for the peak occurrence on October 13. The figure also shows the broadening, or attenuating, of the floodwave as it travels upstream. As seen in this figure, Metaline Falls plays an important factor in both the translation time and shape of the floodwave. This figure illustrates that when the Project is operating at reservoir water surface elevations lower than the hydraulic control at Metaline Falls, fluctuations in water surface elevations are greatly reduced upstream of Metaline Falls. In Figure 5.4-3, it is seen that there is nearly 16 feet of water surface fluctuation in Boundary forebay; however, upstream of Metaline Falls, it is seen that 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 5.4-4 illustrates this point-in-time variability. The flow rate profile 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, outflow from Box Canyon has increased from 18,200 cfs to 22,800 cfs, generation at Boundary Dam has been reduced, and the reservoir upstream of Boundary Dam is actively being filled. The flow rate profile at this later point-in-time shows significantly greater flow variability on account of these changed conditions.

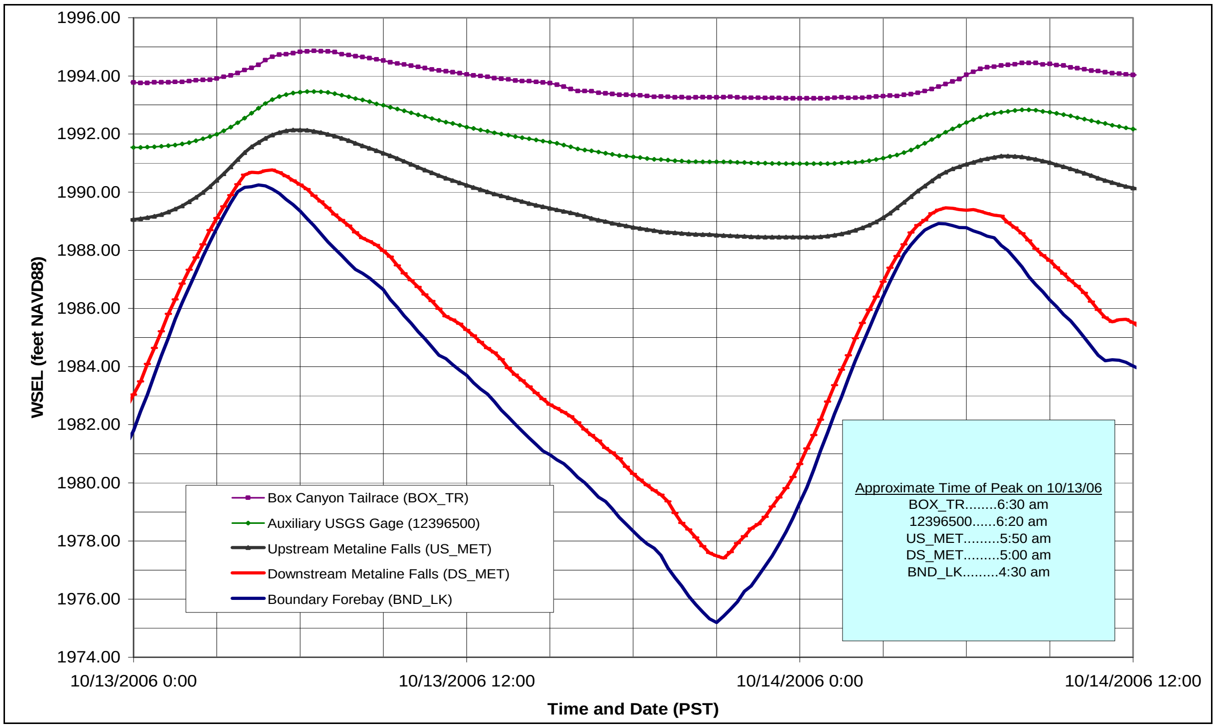


Figure 5.4-3. Illustration of flood wave attenuation upstream of Boundary Dam during low pool and moderate flow conditions using output from calibrated hydraulic model.

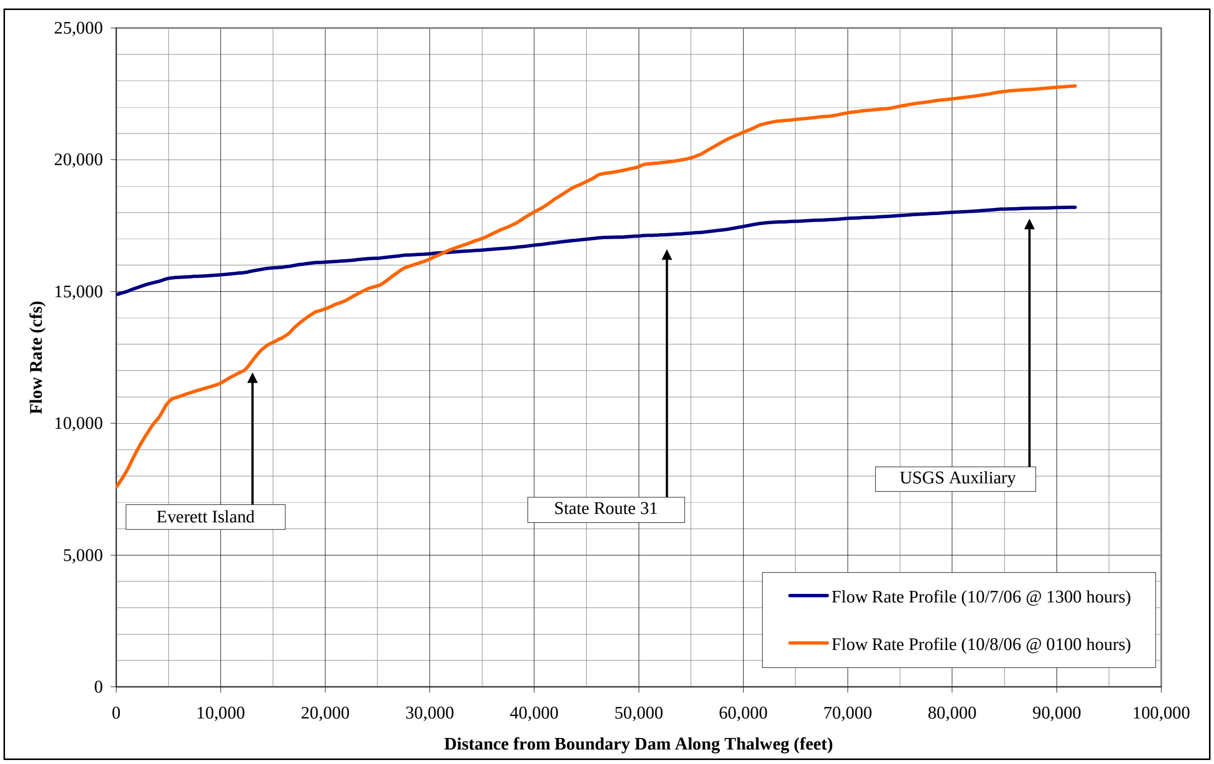


Figure 5.4-4. Illustration of point-in-time variability in the magnitude of flow rate using output from calibrated hydraulic model.

5.4.1. Assessment of the Need for Separate Seasonal Models

Successful model calibration and verification was attained for the 13-month data collection period without the need for using seasonal correction factors to account for the potential 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 model were reviewed to determine if the calibrated 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 5.4-1 summarizes the periods that were selected for each hydrologic condition.

Table 5.4-1. 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	Flow Rate Range (cfs)	Boundary forebay Elevation Range (feet NAVD 88)
High Flow	11/9/06 1200 hrs – 11/9/06 1800 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

For each period, the error range of the calibrated model 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 is 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. This conclusion will be reevaluated when water surface elevation data are available from the summer of 2008.

6 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 a hydraulic routing model of the Boundary Reservoir between Box Canyon Dam and Boundary Dam. This model is referred to as the upstream hydraulic routing model so as to differentiate it from the downstream hydraulic routing model (Boundary Dam to Seven Mile Dam) that will be developed and calibrated in 2008. Recently collected topographic data and bathymetric data, in the form of a single DTM, were used to define the geometry of the cross sections used to represent the Boundary Reservoir. A total of 231 cross sections were used to define the hydraulic characteristics of the 17.5 mile reach between Boundary Dam and Box Canyon Dam. The upstream hydraulic model currently includes a cross section at the location of each habitat transect. Once the habitat transect cross section surveys are finalized, they will replace the DTM-derived cross sections throughout the model.

The upstream hydraulic routing model 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 was continuously recorded at 15-minute time increments. The primary model calibration effort, which was described in this report, used the continuously collected data from September 2006 through September 2007.

The upstream boundary condition for the model was defined using flow rate data from the USGS gaging station 12396500. The downstream boundary condition was defined using data collected with a pressure transducer installed in the Boundary forebay.

Successful calibration of the model was attained using specific portions of the 13-month record. Six distinct periods of the 13-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 13-month period. The calibration of the model was successfully verified, using five additional periods of the 13-month record, encompassing a total of 54 days. The calibrated model was then executed for the entire 13-month period.

The last step of the primary calibration effort will be to incorporate the water surface elevation data surveyed at each of the habitat transects. Incorporation of this data will be completed in February 2008.

7 REFERENCES

Arcement George J and Verne Schneider. 1989. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. United States Geological Survey Water-Supply Paper 2339. United States Government Printing Office, Washington.

Barnes, Harry H. Jr. 1967. Roughness of Characteristics of Natural Channels. United States Geological Survey Water-Supply Paper 1849. United States Government Printing Office, Washington.

CddHoward Consulting Inc. 2006. BOPT Technical Documentation (Rev.8 for BOPT June 1st Version).

SCL. 2007a. 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. 2008a. Study 2 – Analysis of Peak Flood Flow Conditions above Metaline Falls Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Terrapin, Golder Associates Ltd., and Tetra Tech. March 2008.

SCL. 2008b. Study 8 – Sediment Transport and Boundary Reservoir Tributary Delta Habitats Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech and Thomas R. Payne and Associates, Fisheries Consultants. March 2008.

SCL. 2008c. Study 25 – Bathymetry Survey – Boundary Reservoir and Tailwater to Seven Mile Dam Interim Report for the Boundary Hydroelectric Project (FERC No. 2144). Prepared by Tetra Tech. March 2008.

Terrapoint. 2005. Project Report, Metaline Falls (Contract #2354-H). Report presented to DeGross Aerial Mapping Inc.

U.S Army Corps of Engineers – Hydrologic Engineering Center (USACE-HEC). 2006. HEC-RAS, River Analysis System User's Manual. Version 4.0 Beta.

Appendix 1: Boundary Condition Hydrographs for Calibration and Verification Periods
Cross Section Location Figures
Model Calibration Results Graphs

List of Figures

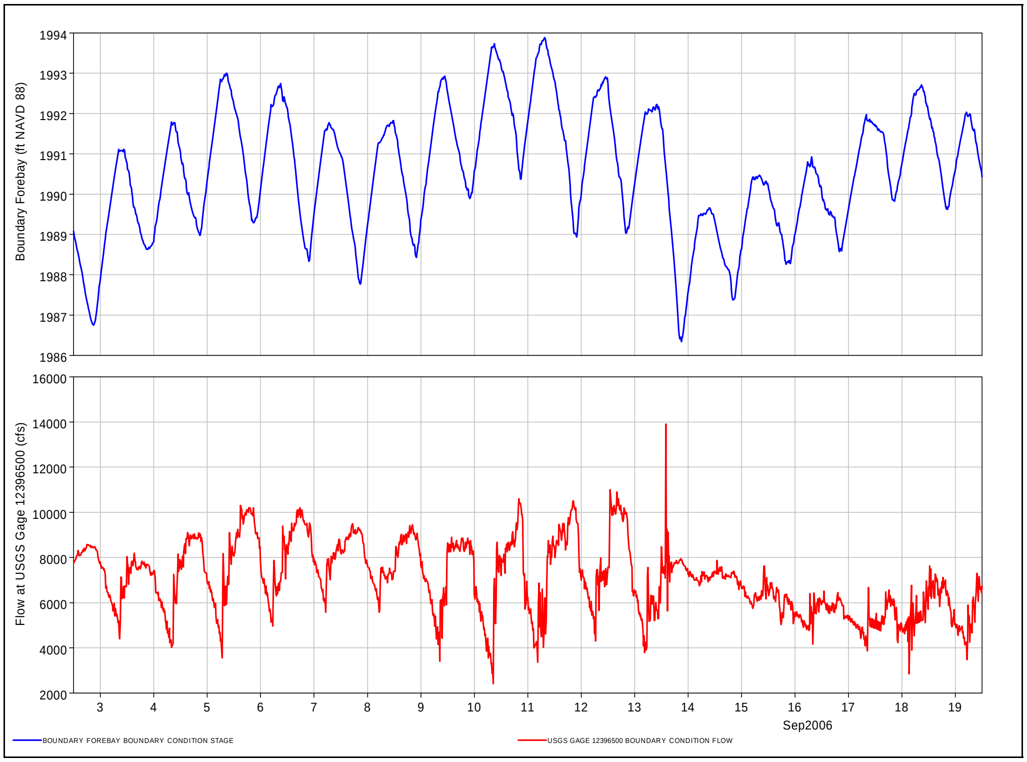


Figure A.1-1. Stage and flow boundary condition hydrographs for Hi_Lo calibration period for upstream hydraulic model.

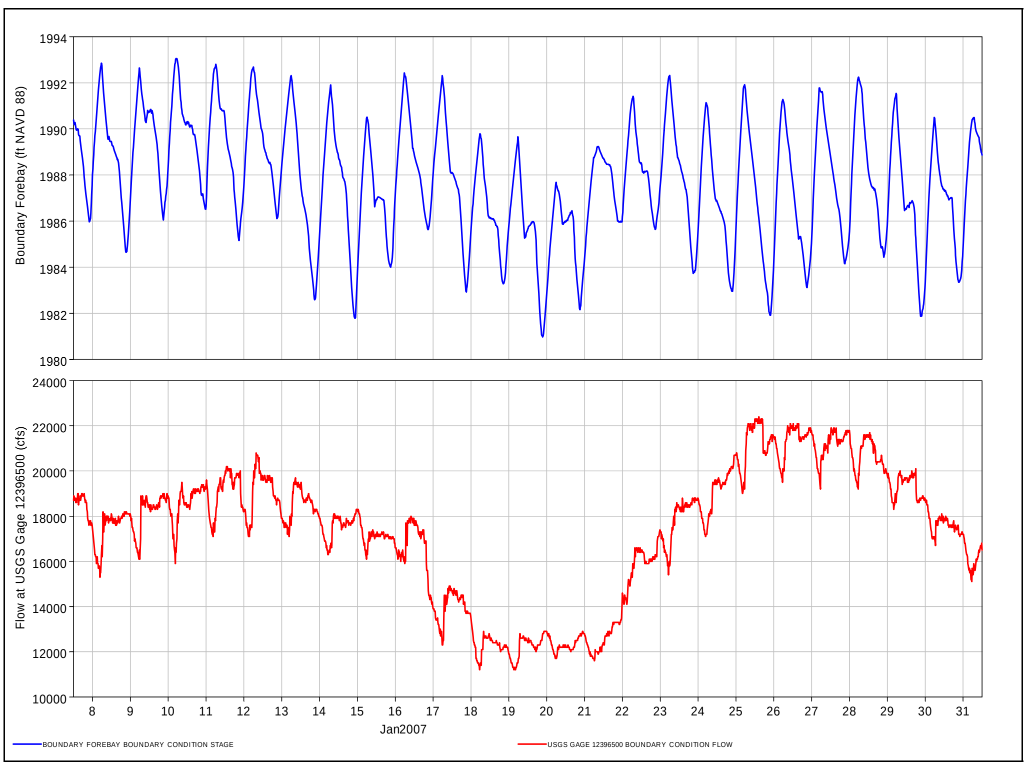


Figure A.1-2. Stage and flow boundary condition hydrographs for Hi_Mod calibration period for upstream hydraulic model.

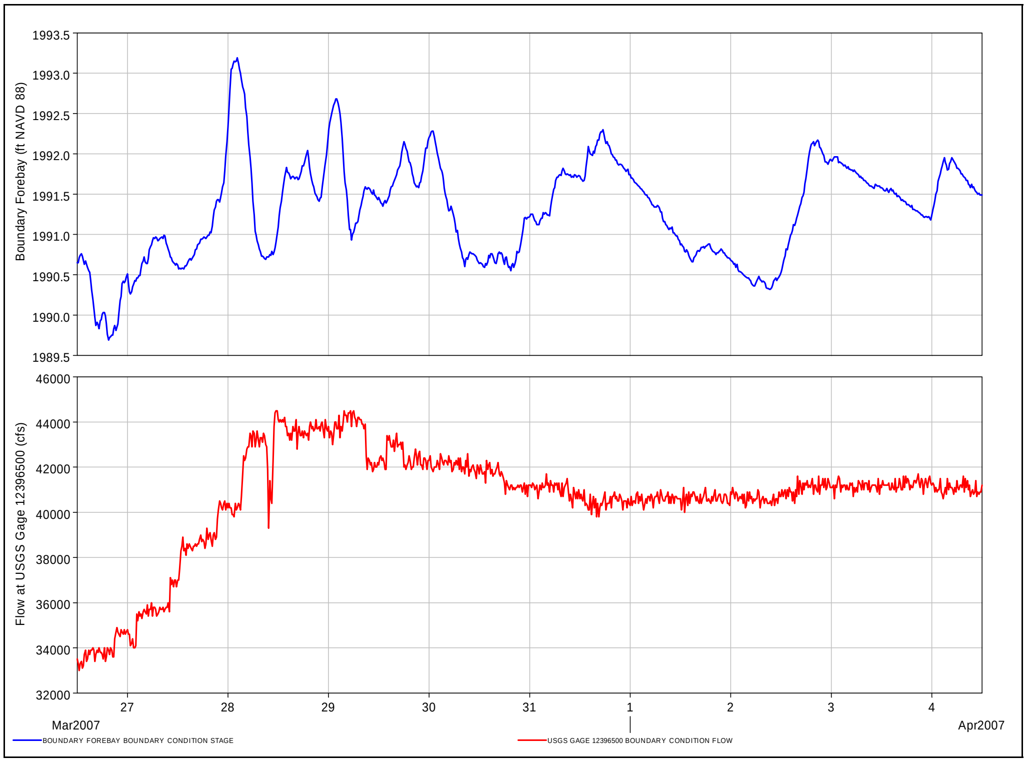


Figure A.1-3. Stage and flow boundary condition hydrographs for Hi_Hi calibration period for upstream hydraulic model.

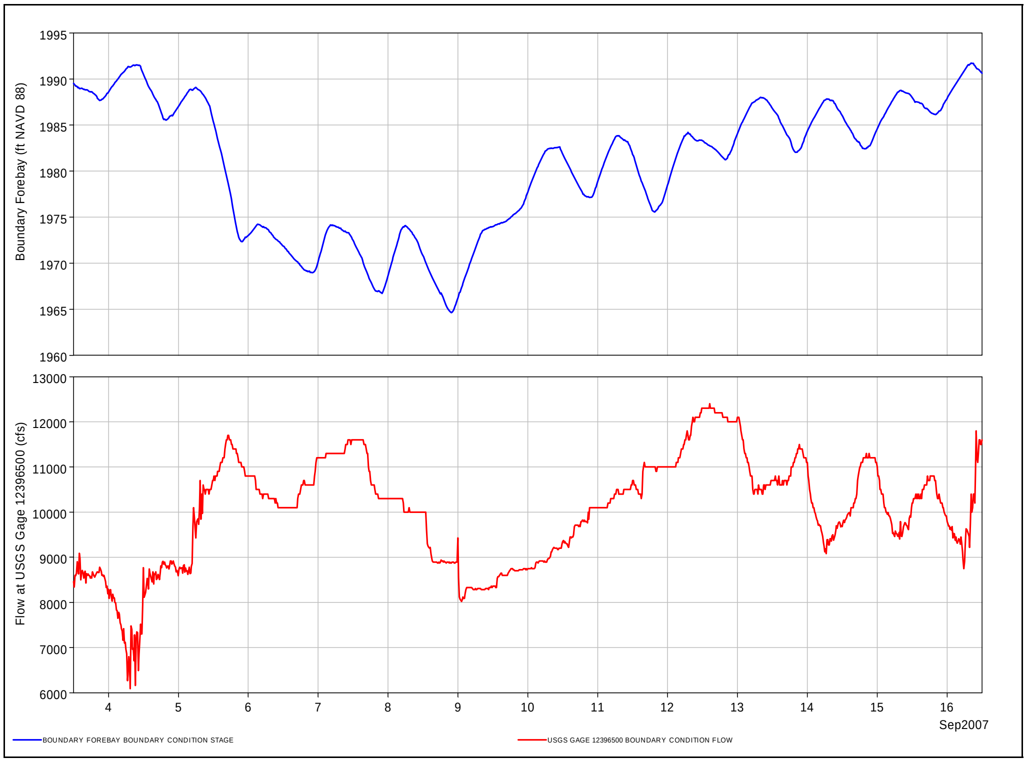


Figure A.1-4. Stage and flow boundary condition hydrographs for Lo_Lo calibration period for upstream hydraulic model.

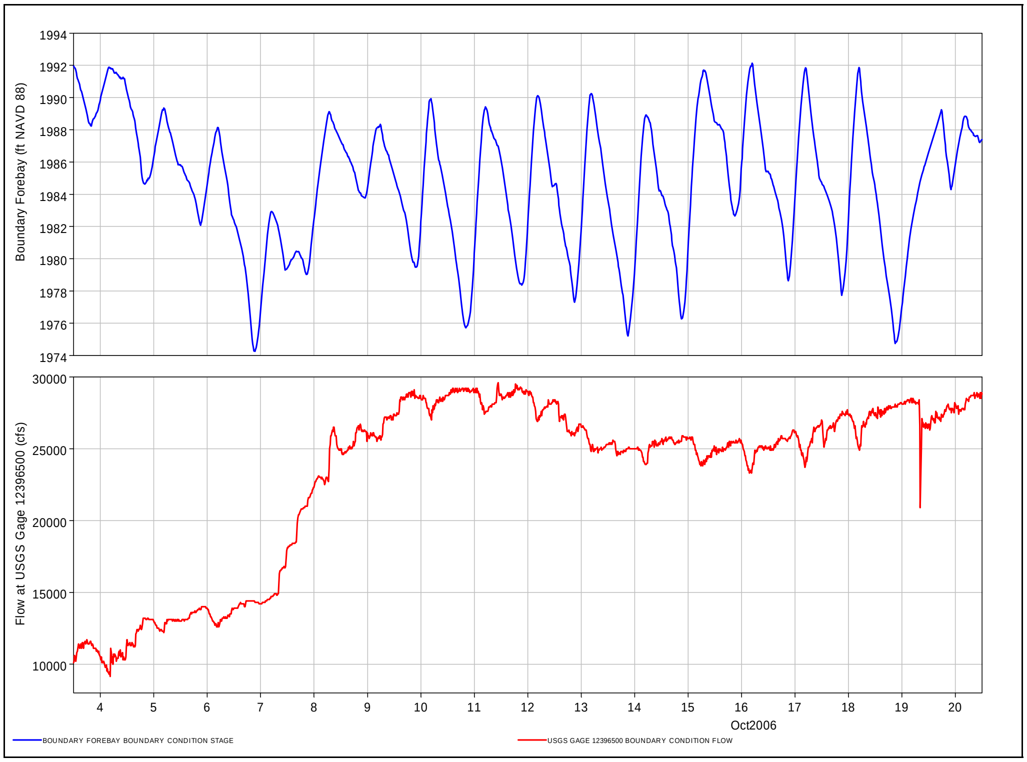


Figure A.1-5. Stage and flow boundary condition hydrographs for Lo_Mod calibration period for upstream hydraulic model.

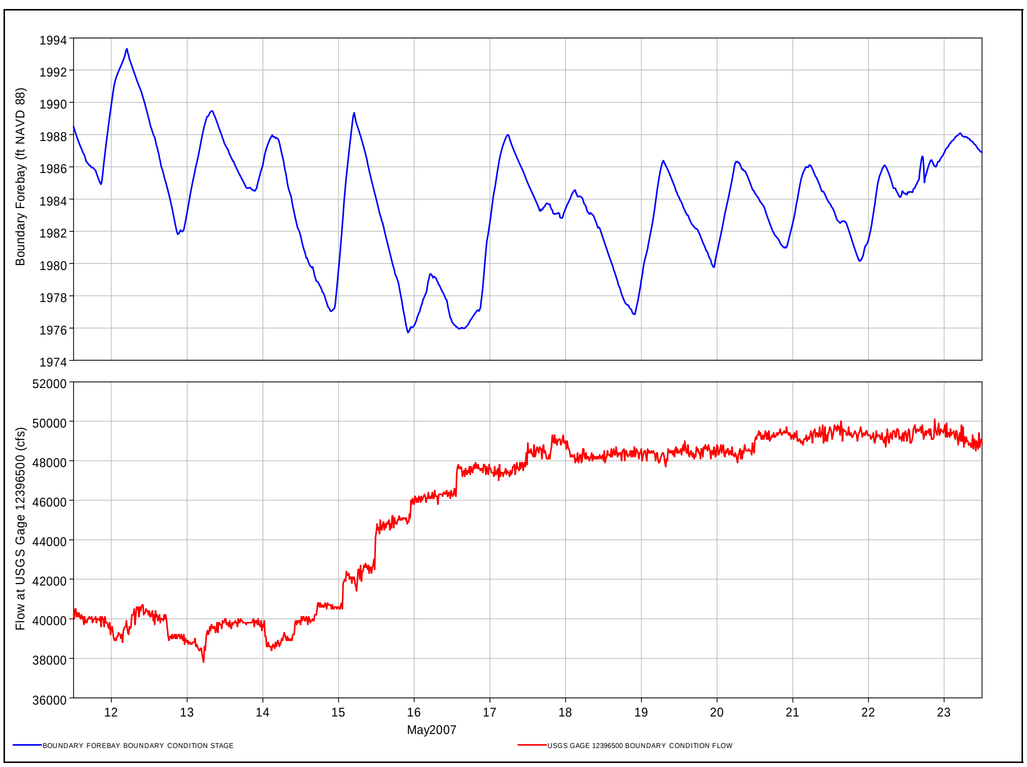


Figure A.1-6. Stage and flow boundary condition hydrographs for Lo_Hi calibration period for upstream hydraulic model.

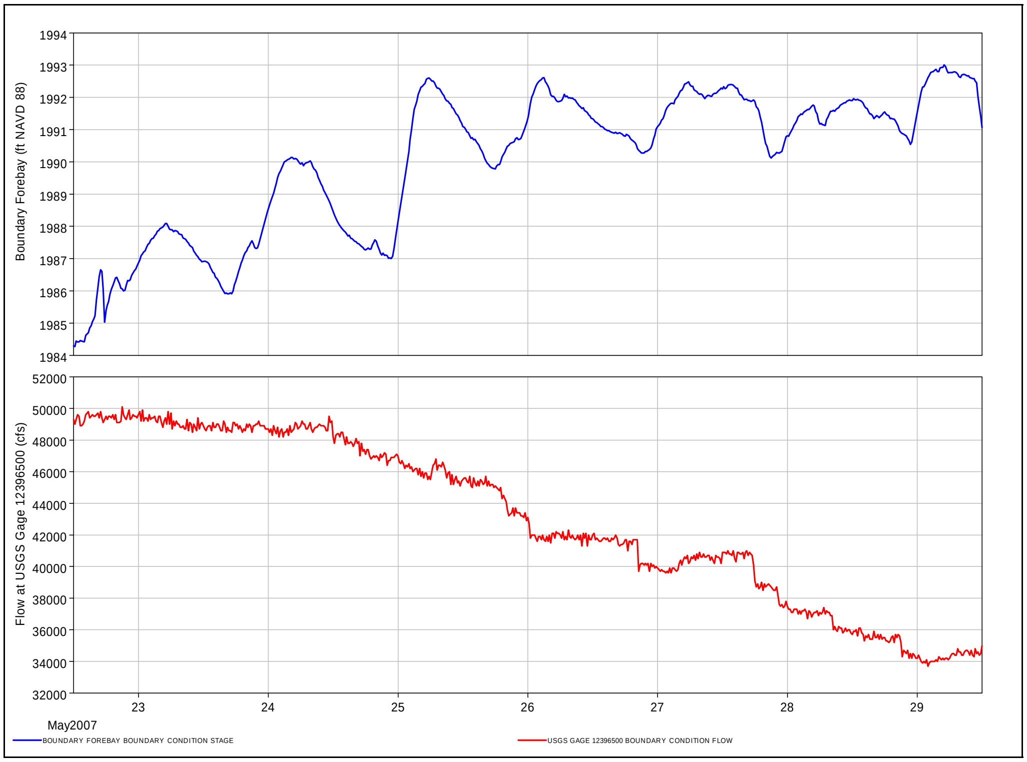


Figure A.1-7. Stage and flow boundary condition hydrographs for Hi_Hi verification period for upstream hydraulic model.

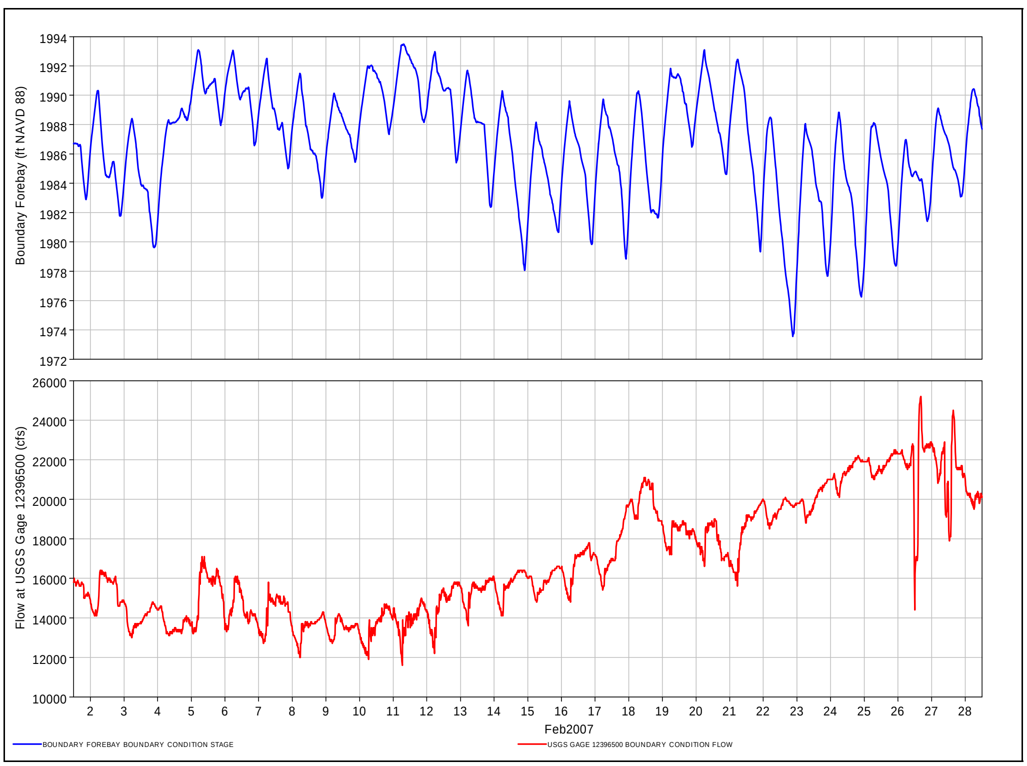


Figure A.1-8. Stage and flow boundary condition hydrographs for Var_Var verification period for upstream hydraulic model.

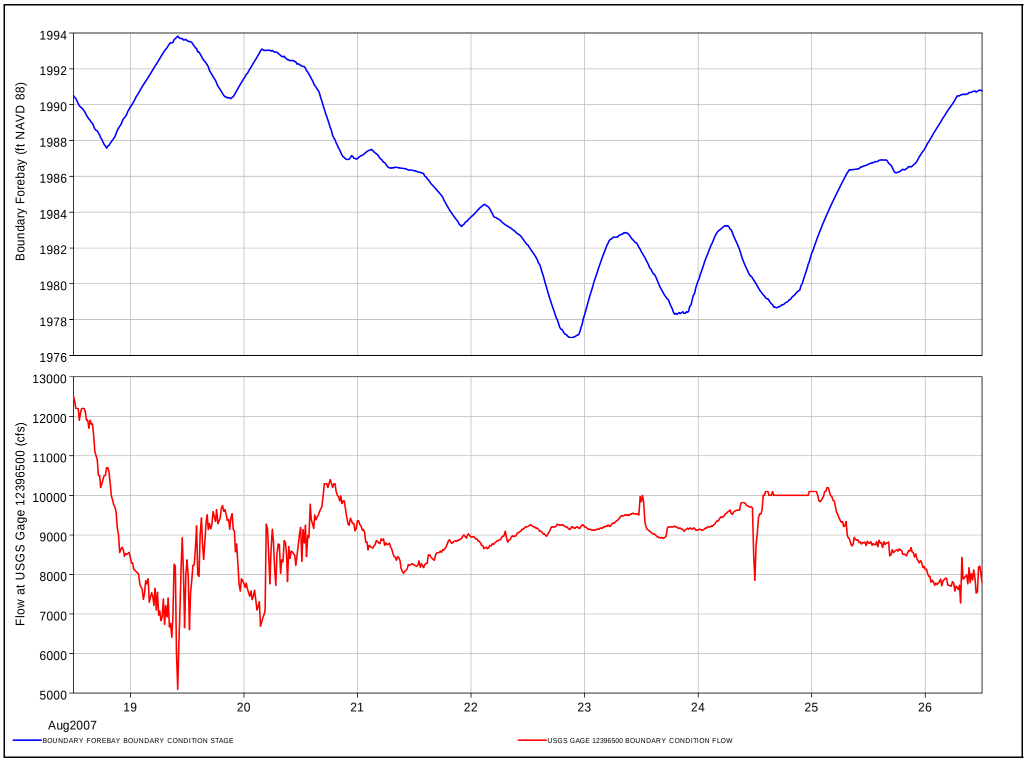


Figure A.1-9. Stage and flow boundary condition hydrographs for Lo_Lo verification period for upstream hydraulic model.

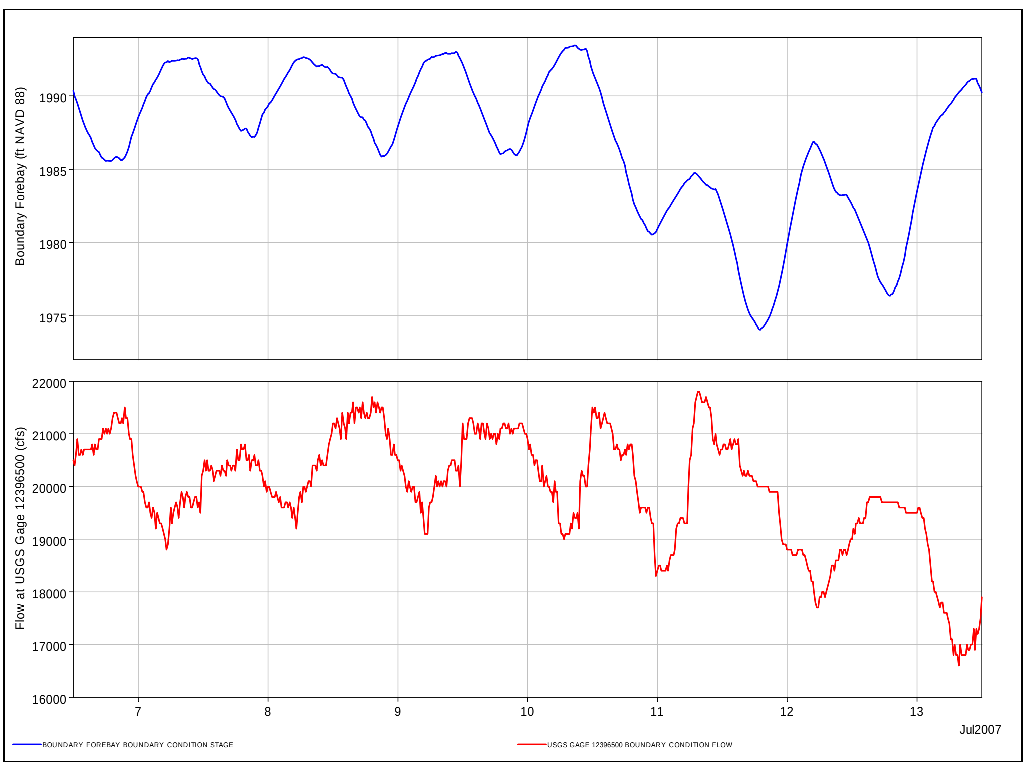


Figure A.1-10. Stage and flow boundary condition hydrographs for Lo_Mod verification period for upstream hydraulic model.

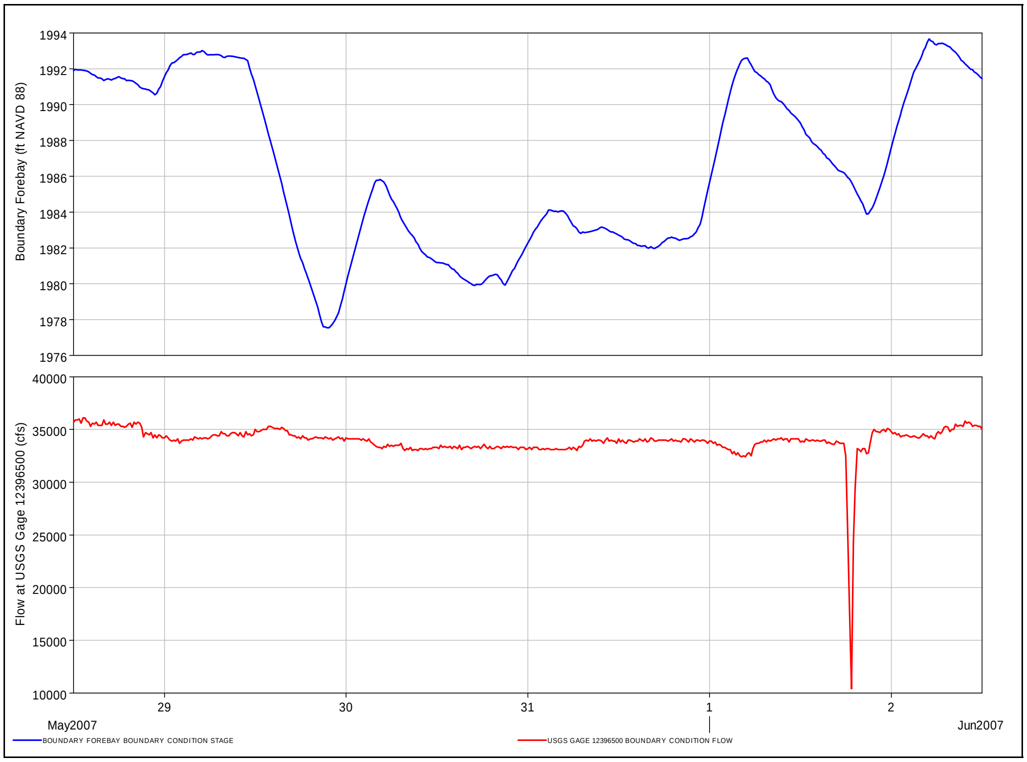
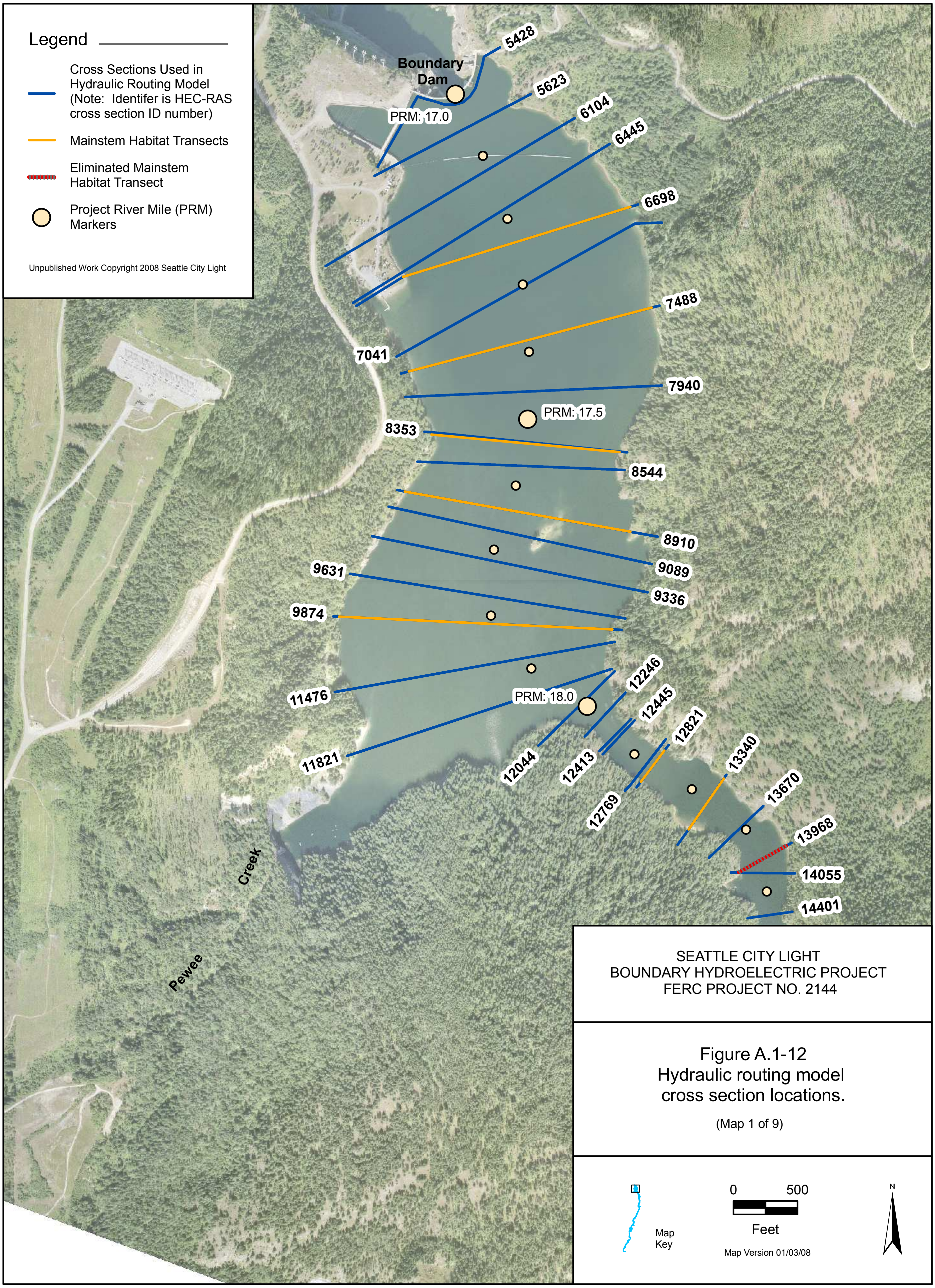


Figure A.1-11. Stage and flow boundary condition hydrographs for Lo_Hi verification period for upstream hydraulic model.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model cross section locations.

(Map 1 of 9)

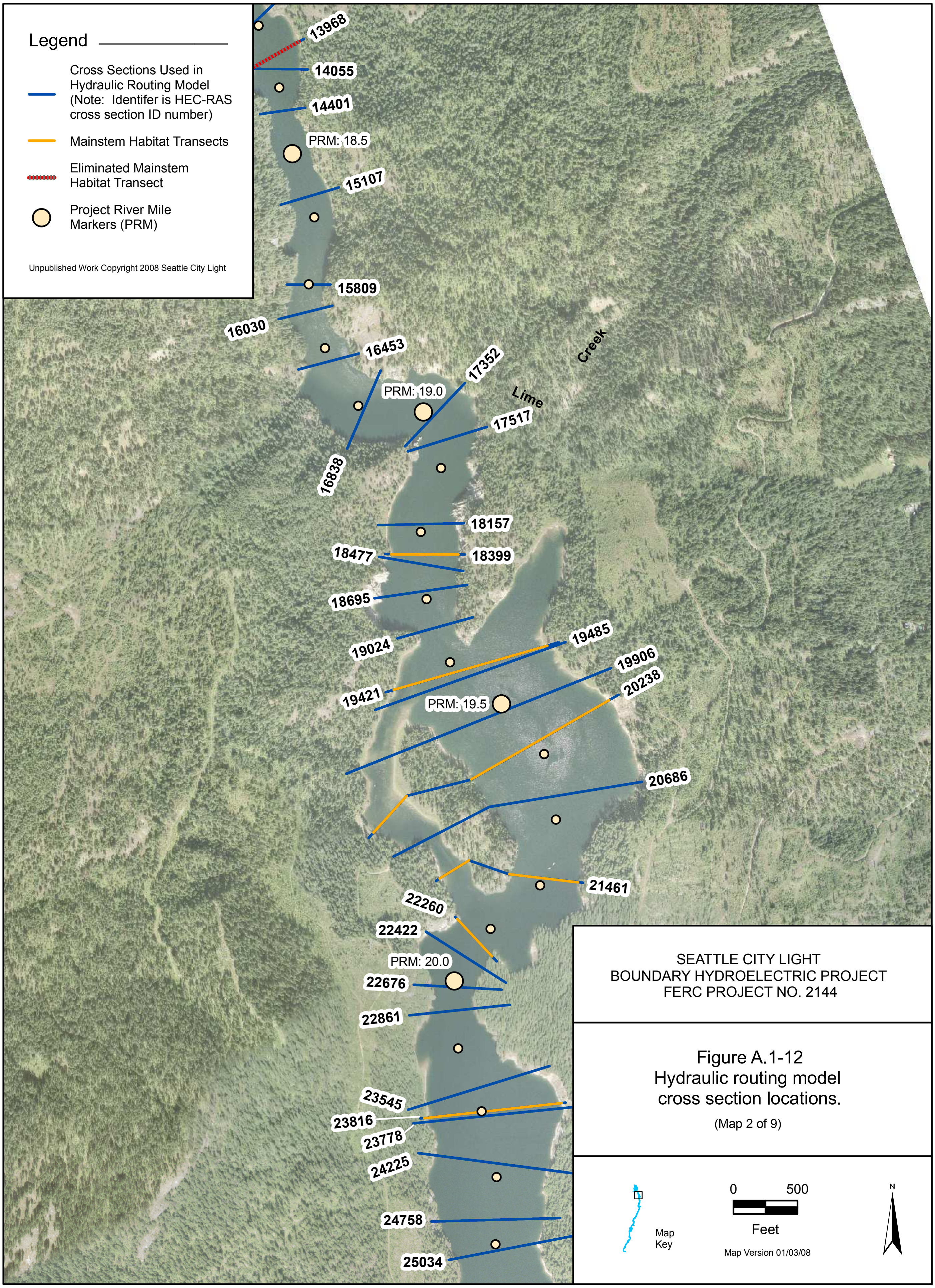
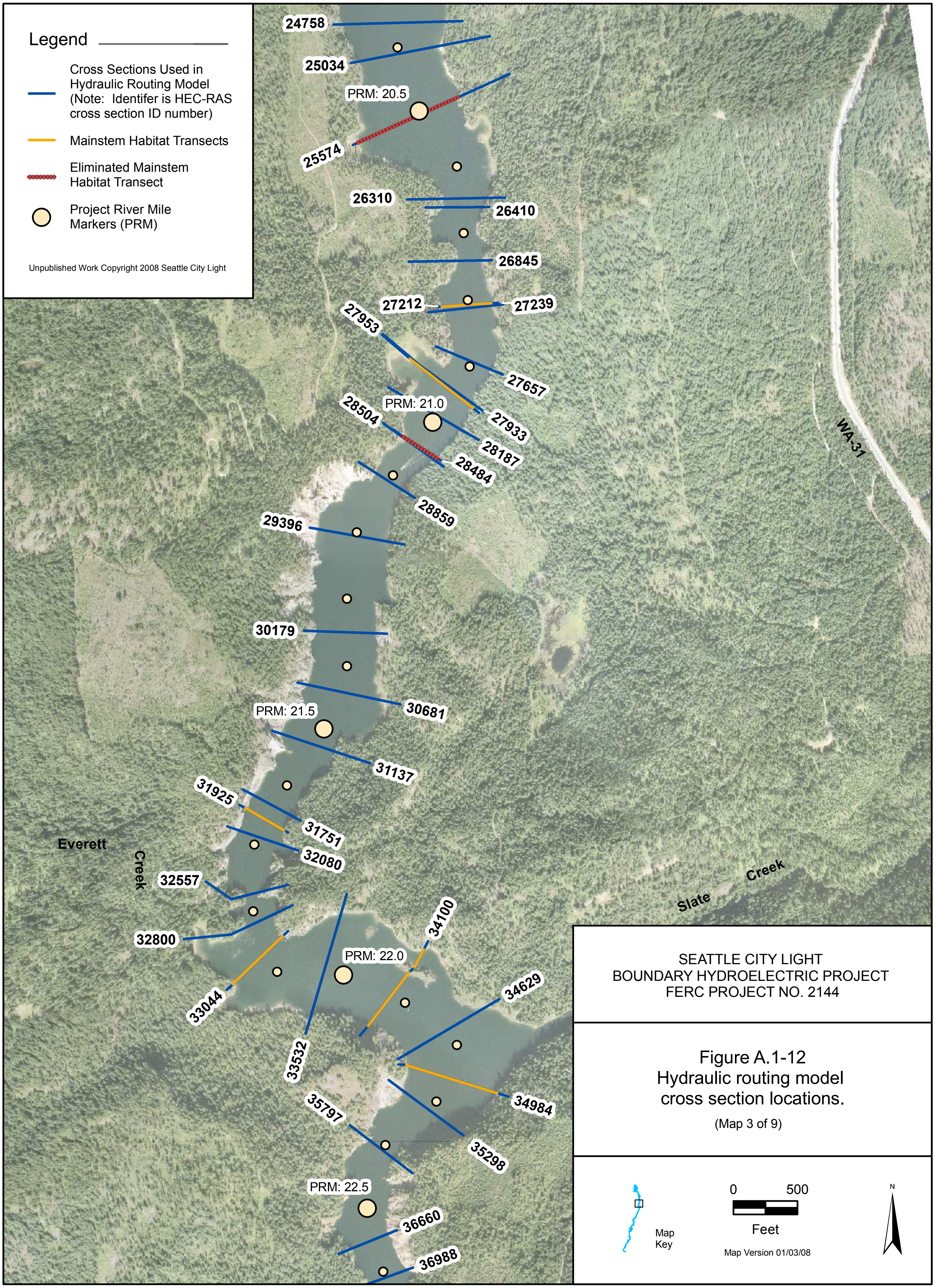
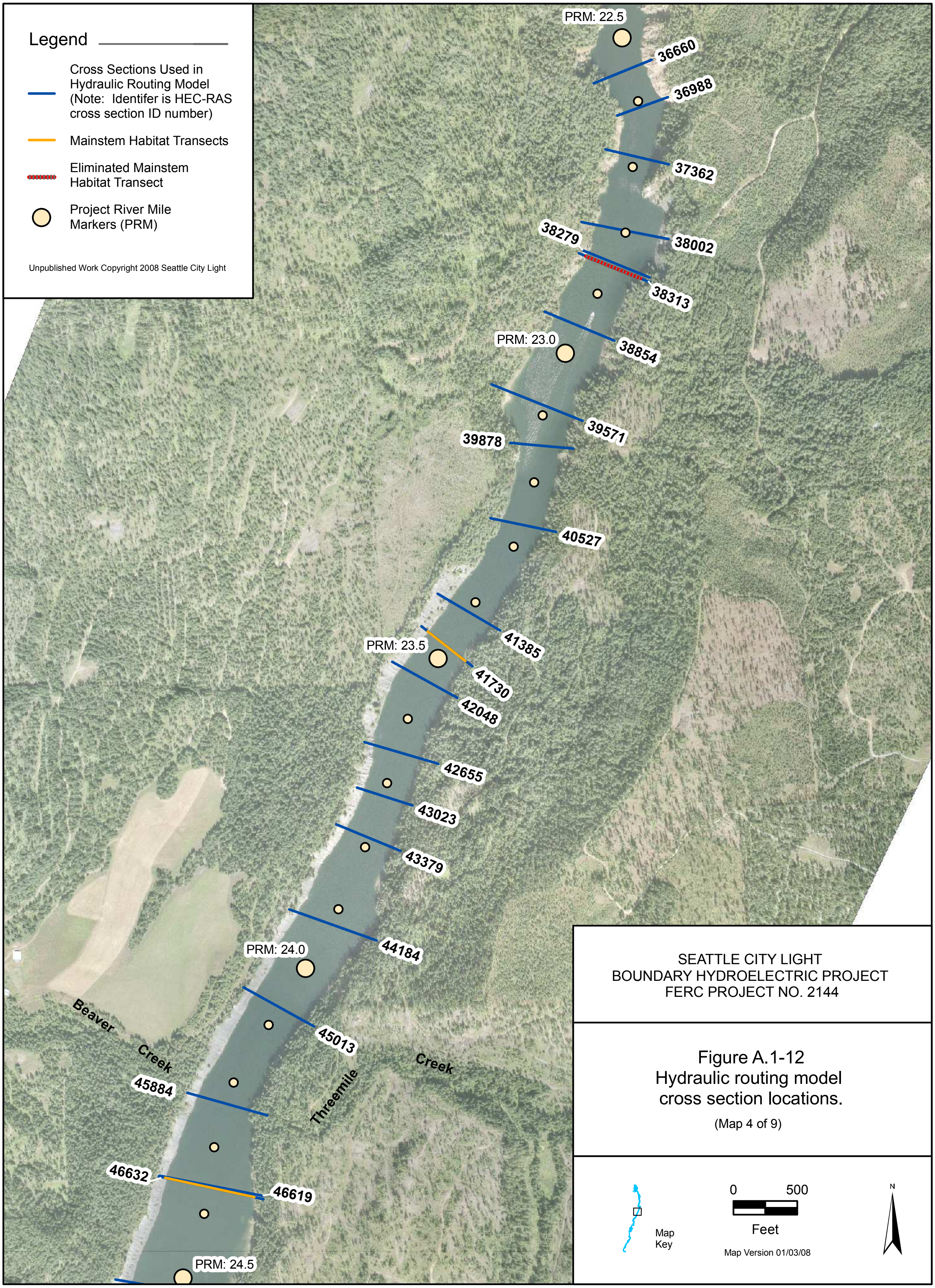


Figure A.1-12
Hydraulic routing model cross section locations.
(Map 2 of 9)



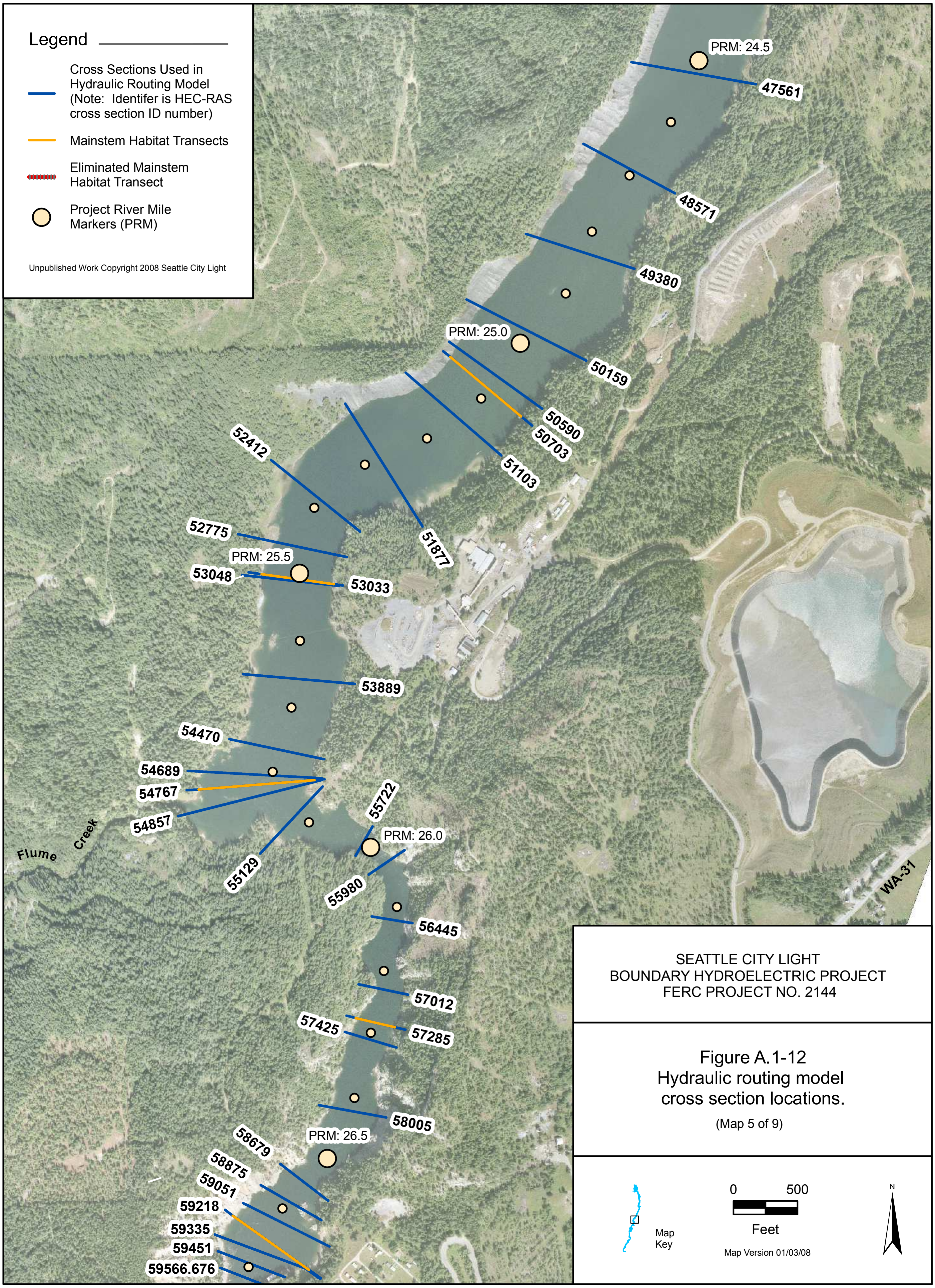
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model cross section locations.
(Map 3 of 9)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model cross section locations.
(Map 4 of 9)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model
cross section locations.
(Map 5 of 9)

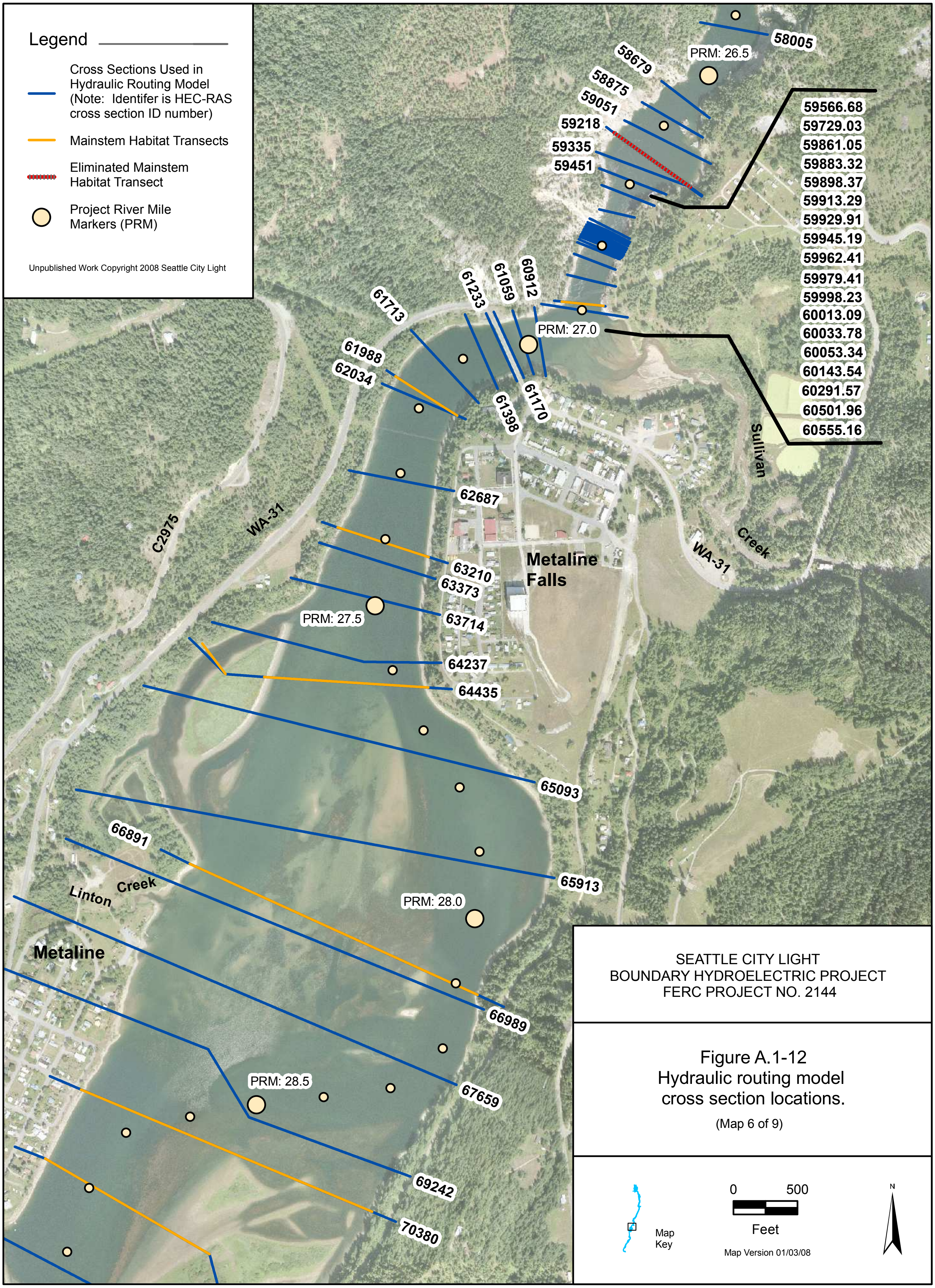
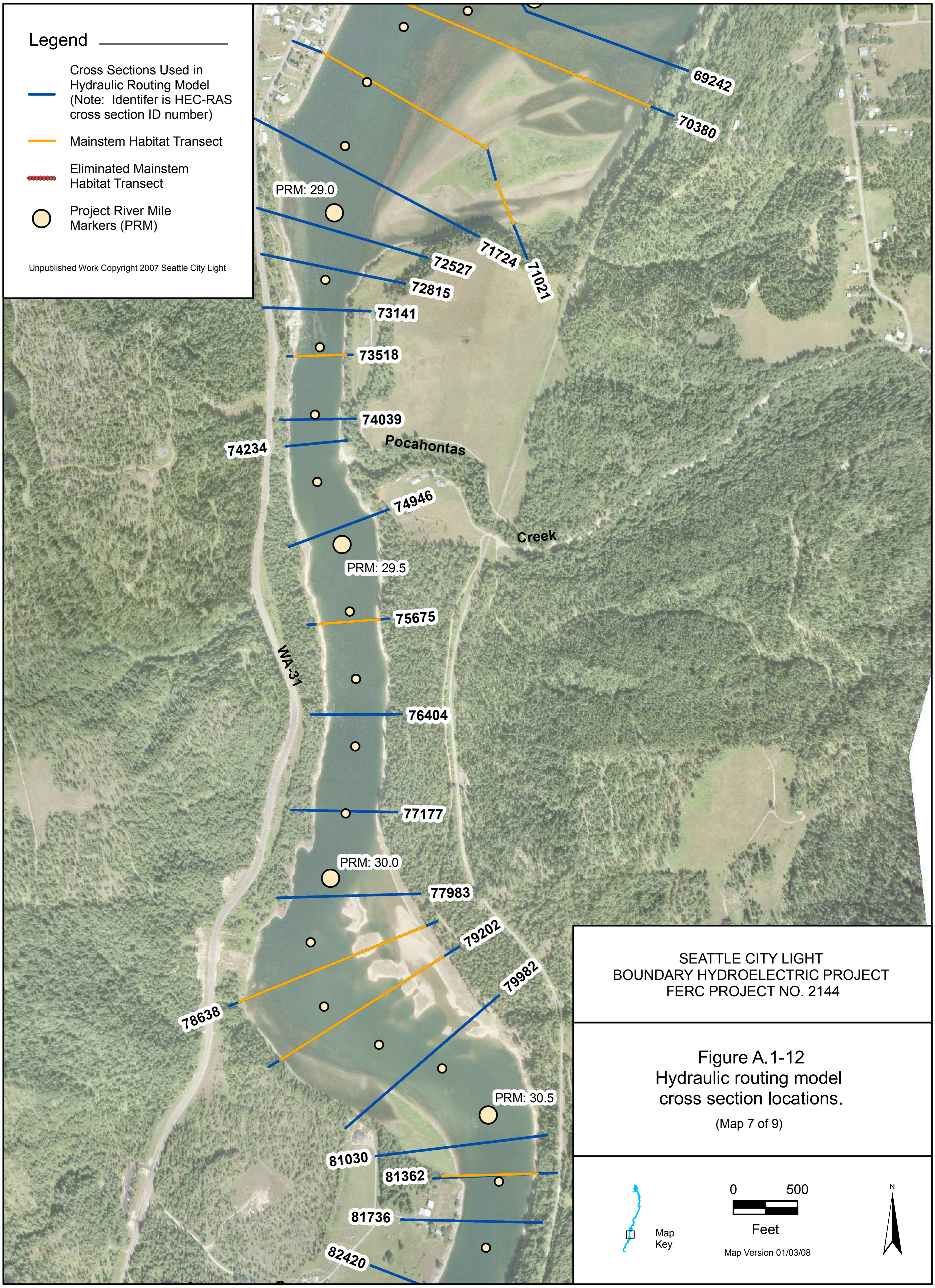
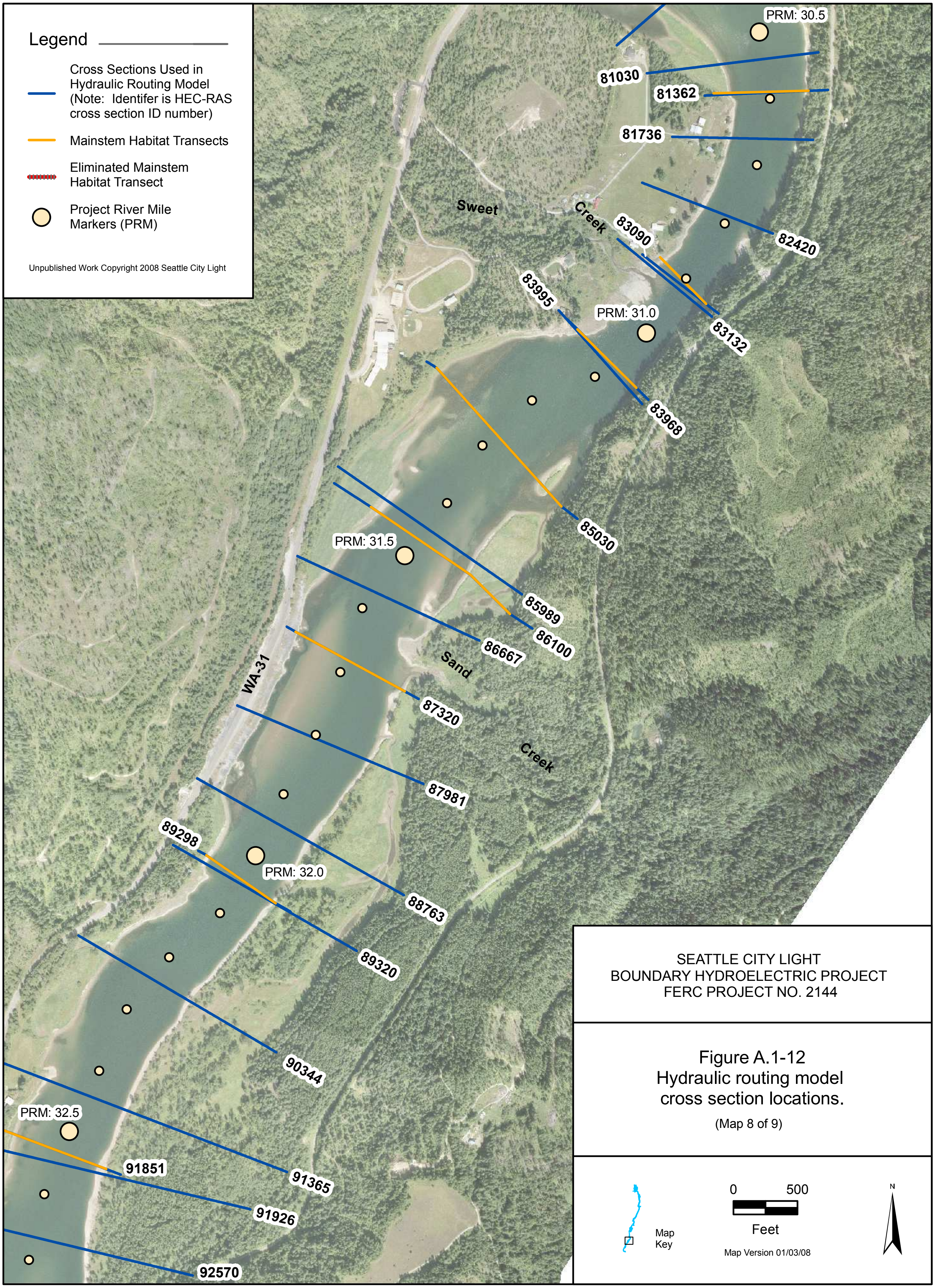


Figure A.1-12
Hydraulic routing model cross section locations.
(Map 6 of 9)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model cross section locations.
(Map 7 of 9)



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.1-12
Hydraulic routing model cross section locations.
(Map 8 of 9)

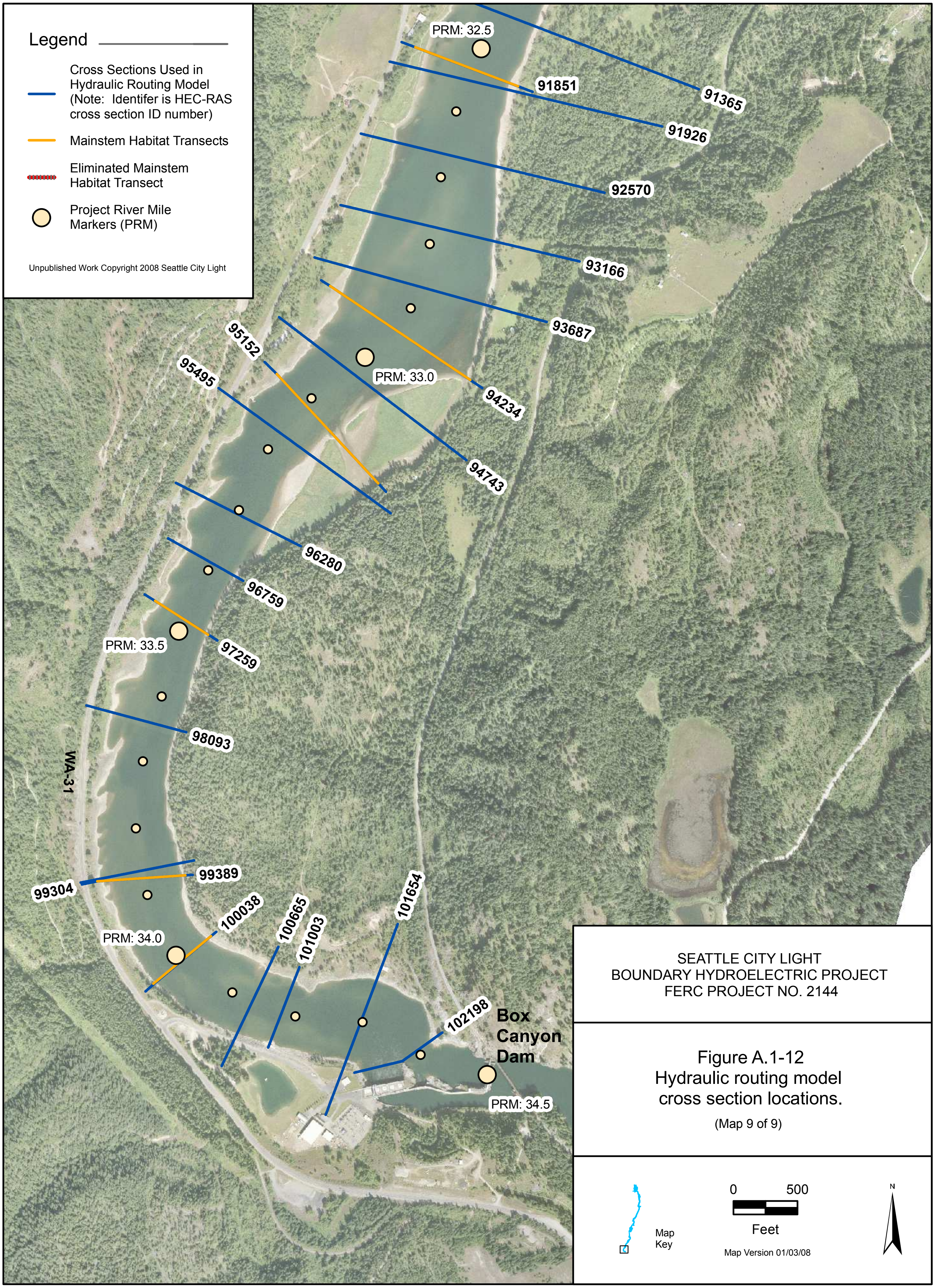


Figure A.1-12
Hydraulic routing model cross section locations.
(Map 9 of 9)

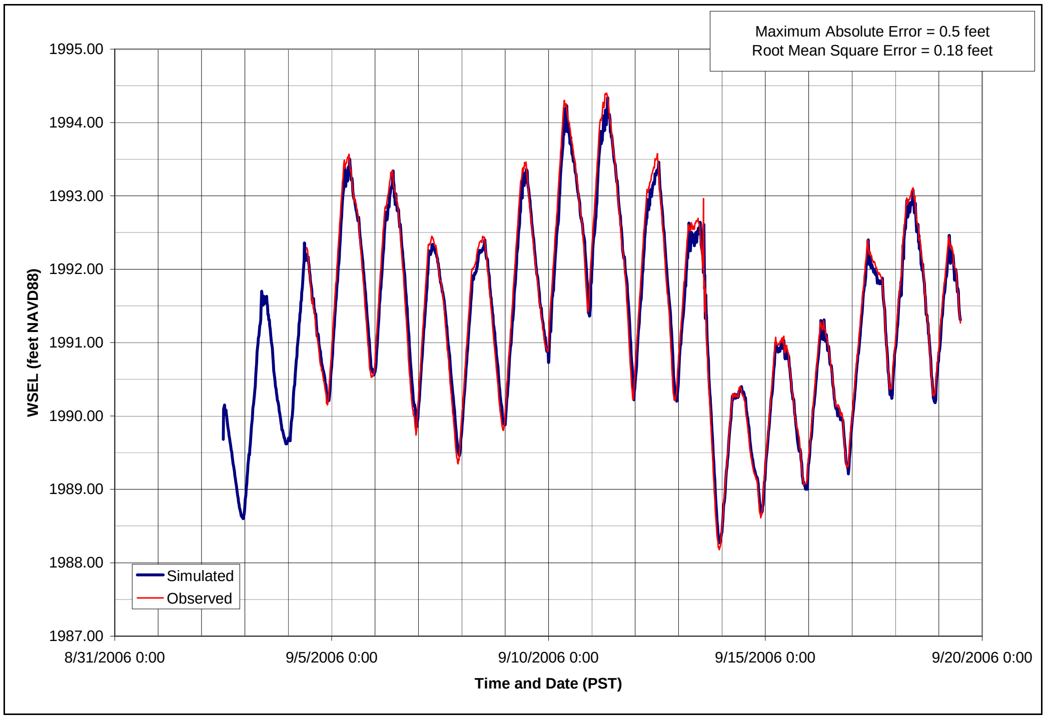


Figure A.1-13. Model calibration results for Hi_Lo Calibration Period at BOX_TR Pressure Transducer Location.

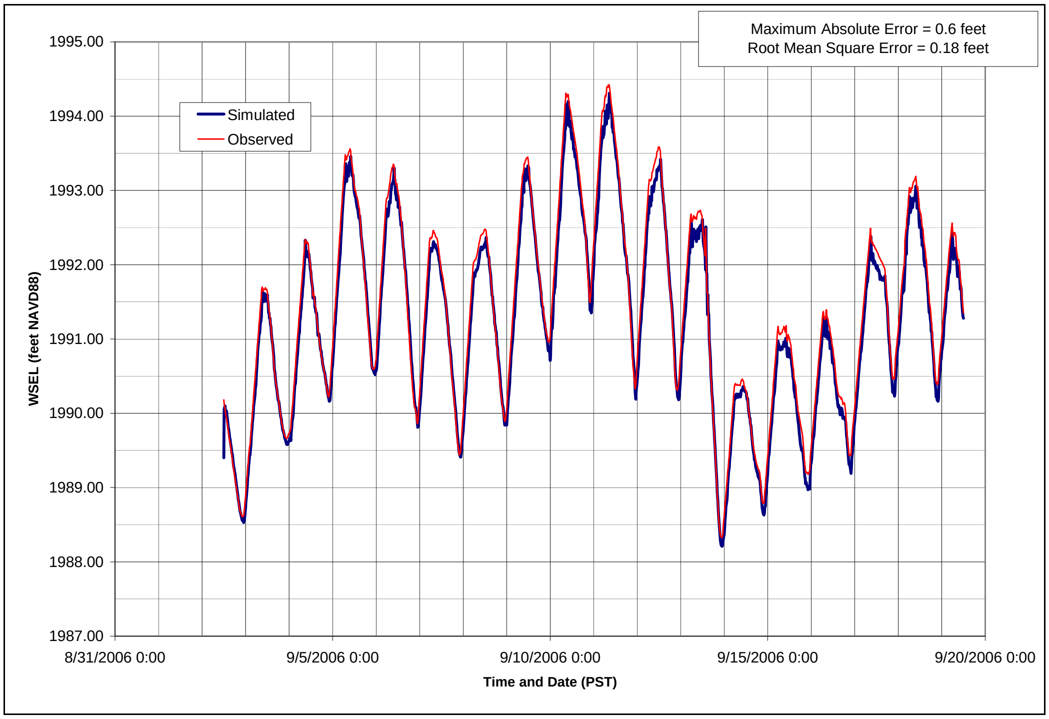


Figure A.1-14. Model calibration results for Hi_Lo Calibration Period at USGS Station 12396500 (Primary) Location.

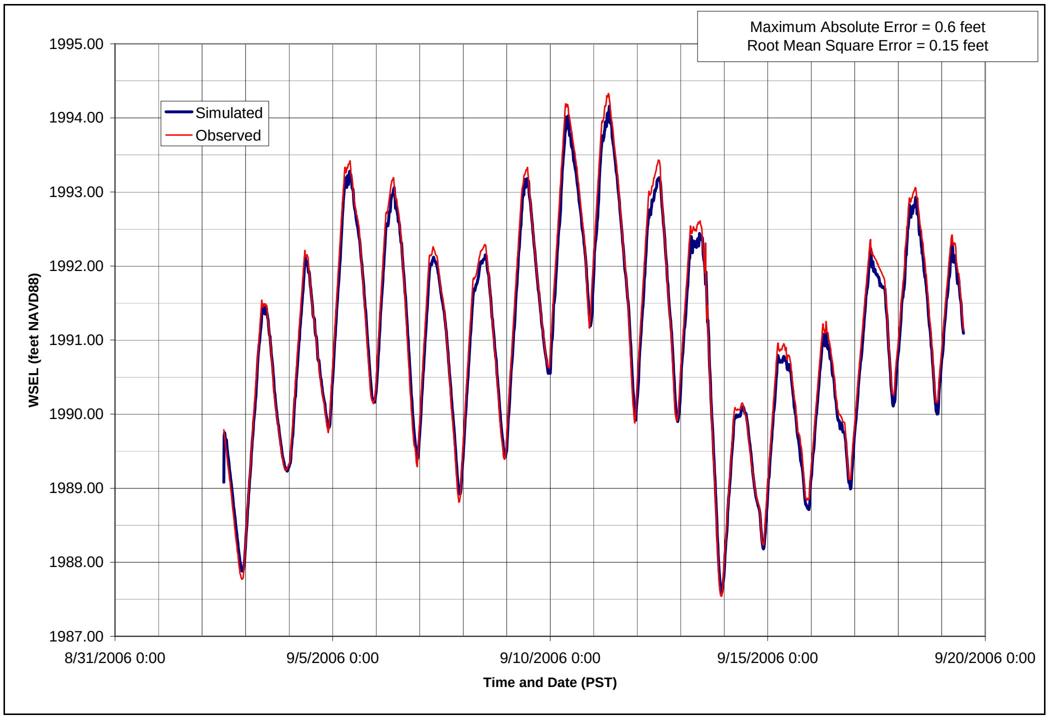


Figure A.1-15. Model calibration results for Hi_Lo Calibration Period at USGS Station 12396500 (Auxiliary) Location.

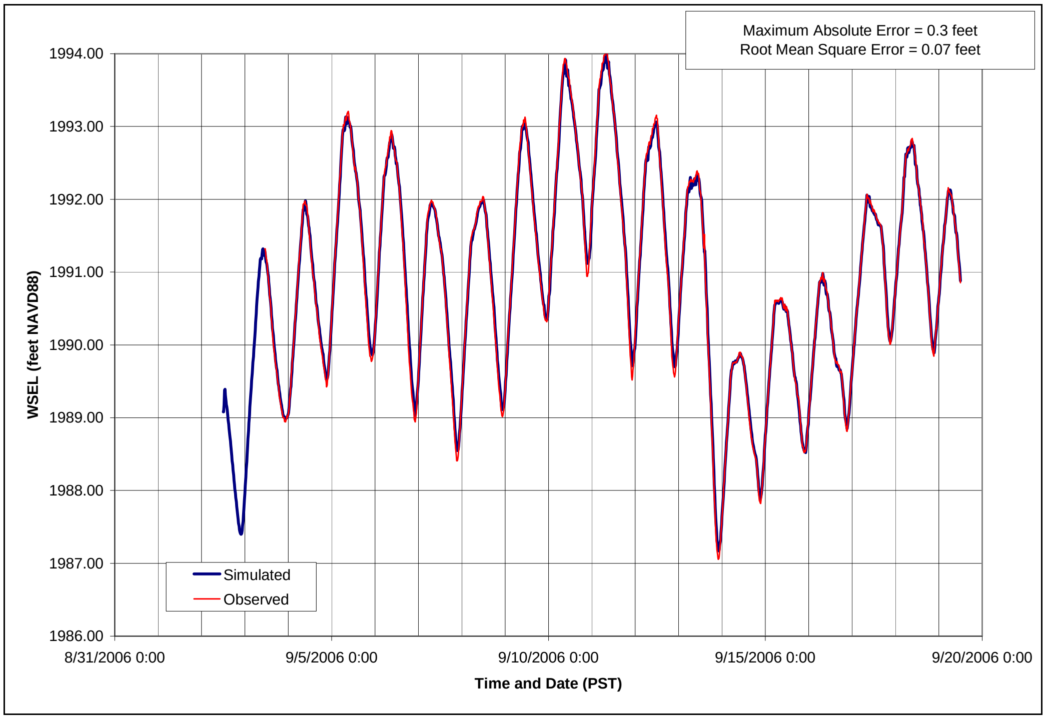


Figure A.1-16. Model calibration results for Hi_Lo Calibration Period at US_MET Pressure Transducer Location.

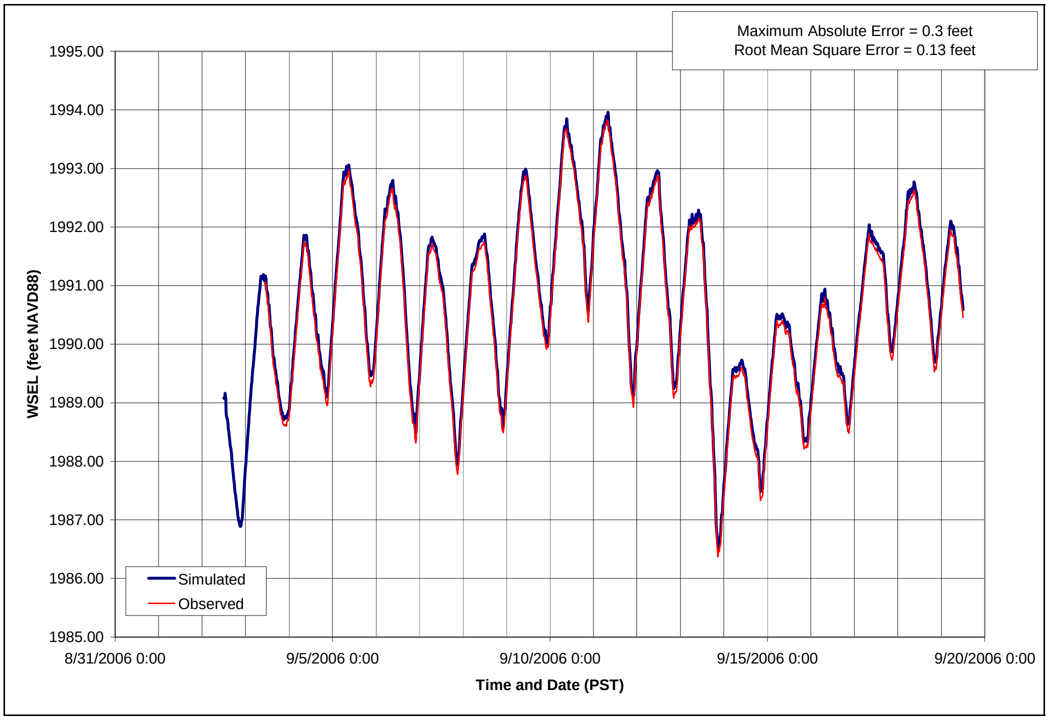


Figure A.1-17. Model calibration results for Hi_Lo Calibration Period at DS_MET Pressure Transducer Location.

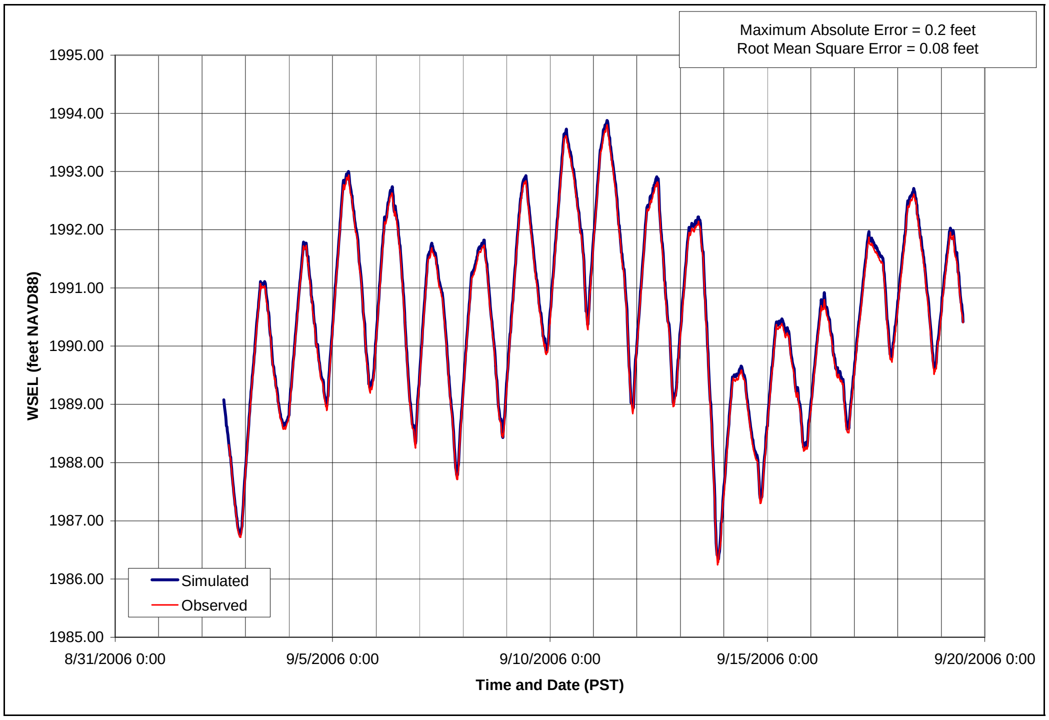


Figure A.1-18. Model calibration results for Hi_Lo Calibration Period at CANYON Pressure Transducer Location.

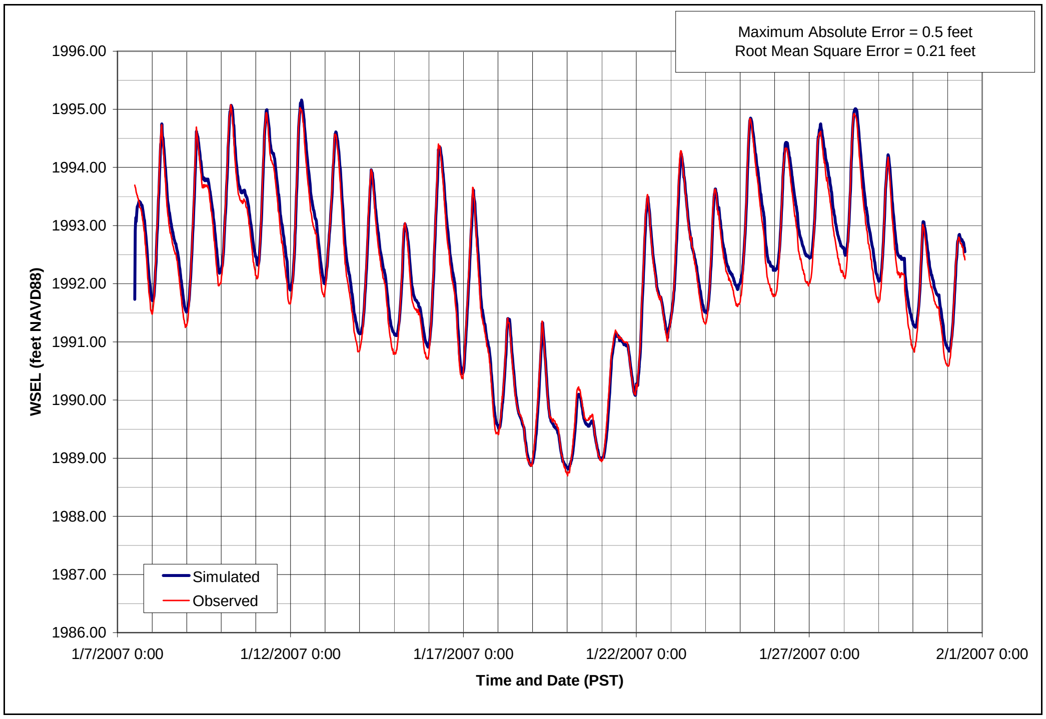


Figure A.1-19. Model calibration results for Hi_Mod Calibration Period at BOX_TR Pressure Transducer Location.

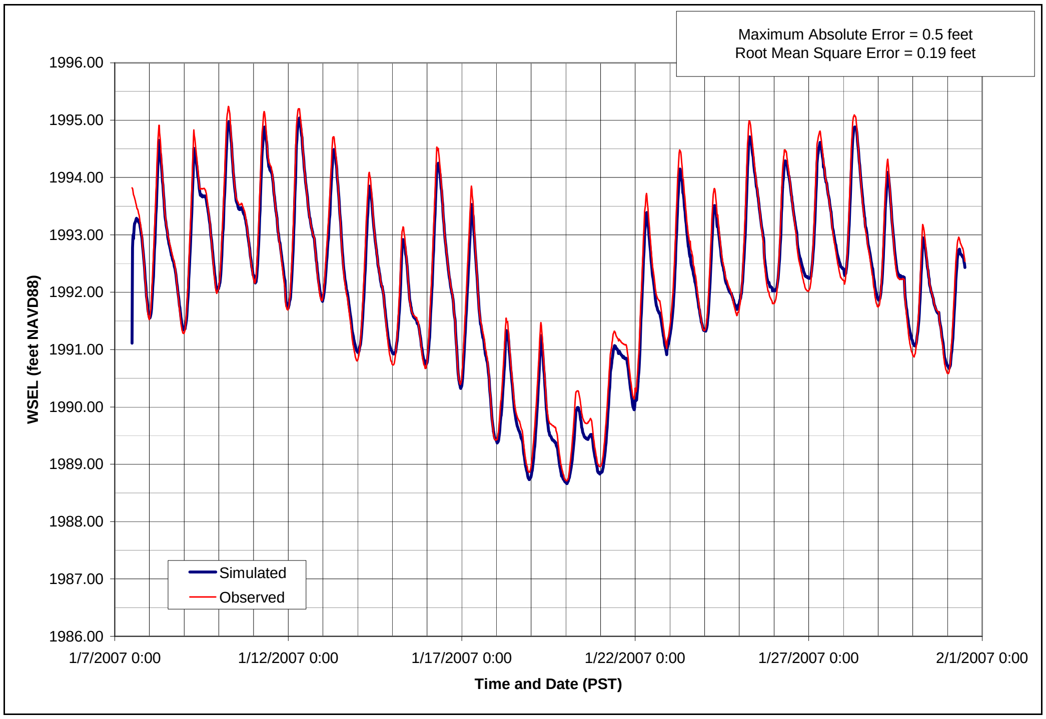


Figure A.1-20. Model calibration results for Hi_Mod Calibration Period at USGS Station 12396500 (Primary) Location.

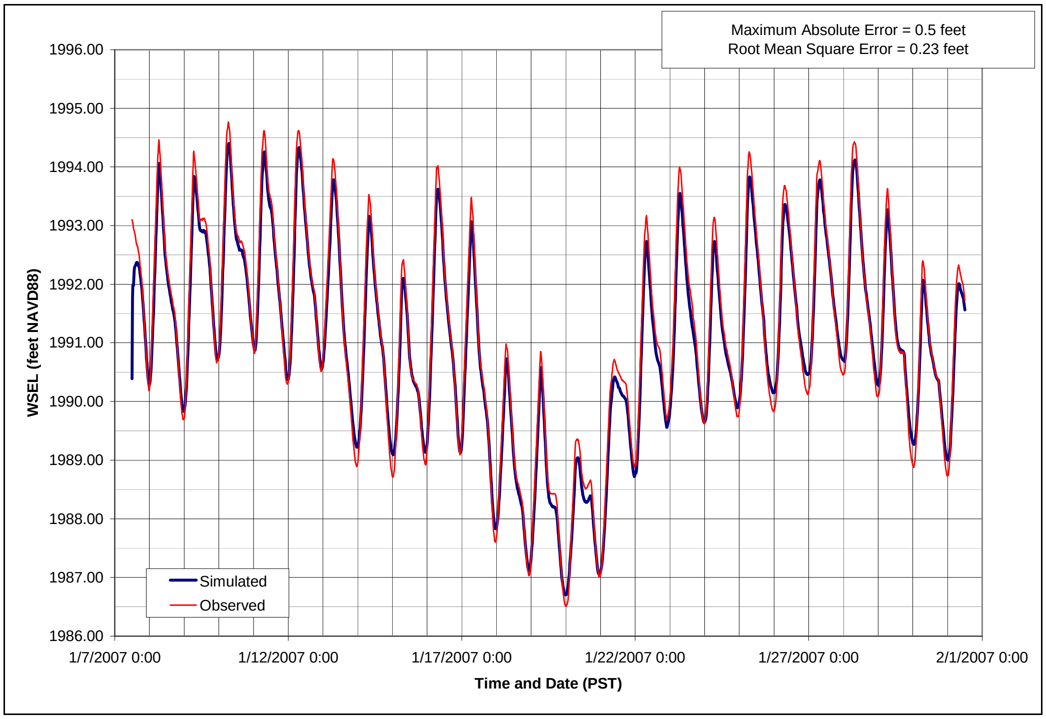


Figure A.1-21. Model calibration results for Hi_Mod Calibration Period at USGS Station 12396500 (Auxiliary) Location.

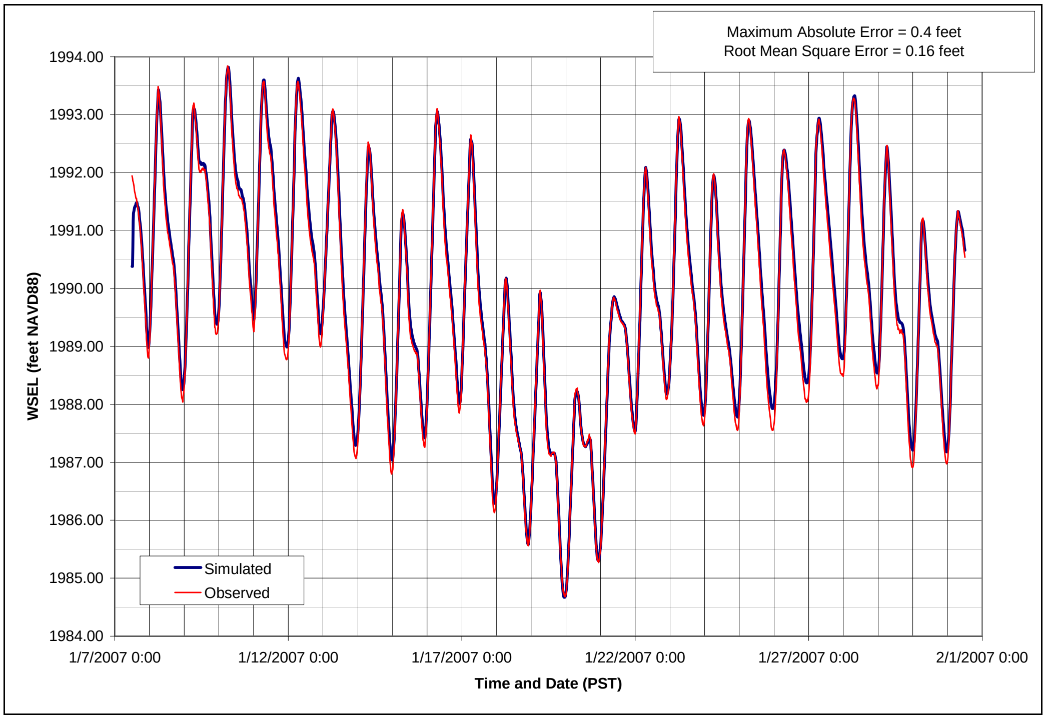


Figure A.1-22. Model calibration results for Hi_Mod Calibration Period at US_MET Pressure Transducer Location.

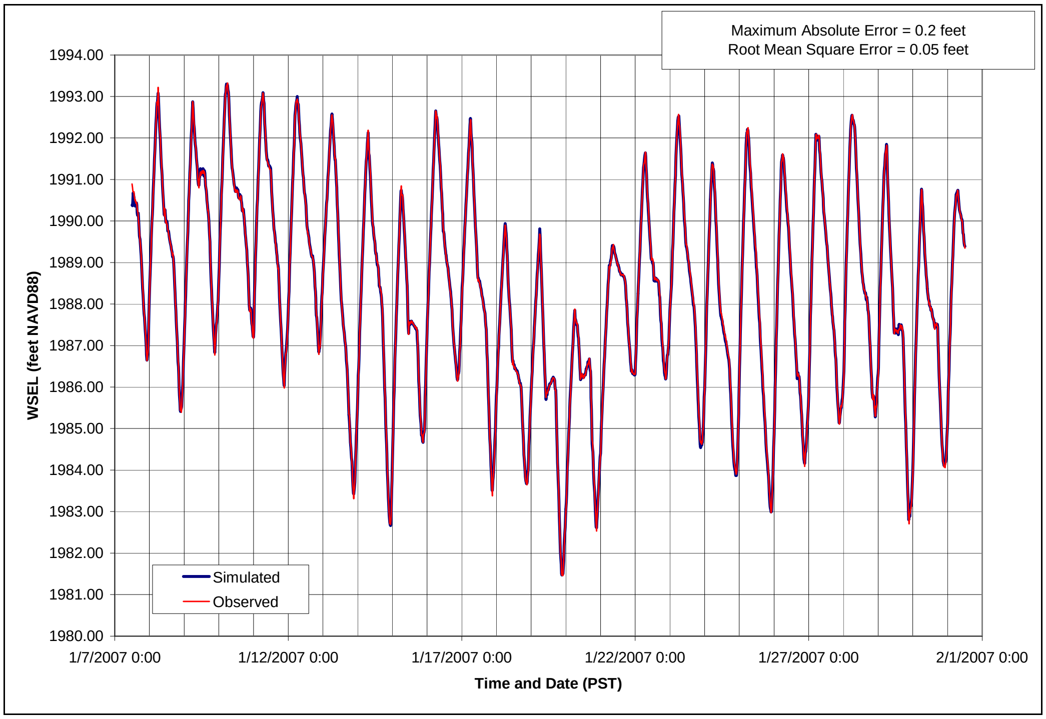


Figure A.1-23. Model calibration results for Hi_Mod Calibration Period at DS_MET Pressure Transducer Location.

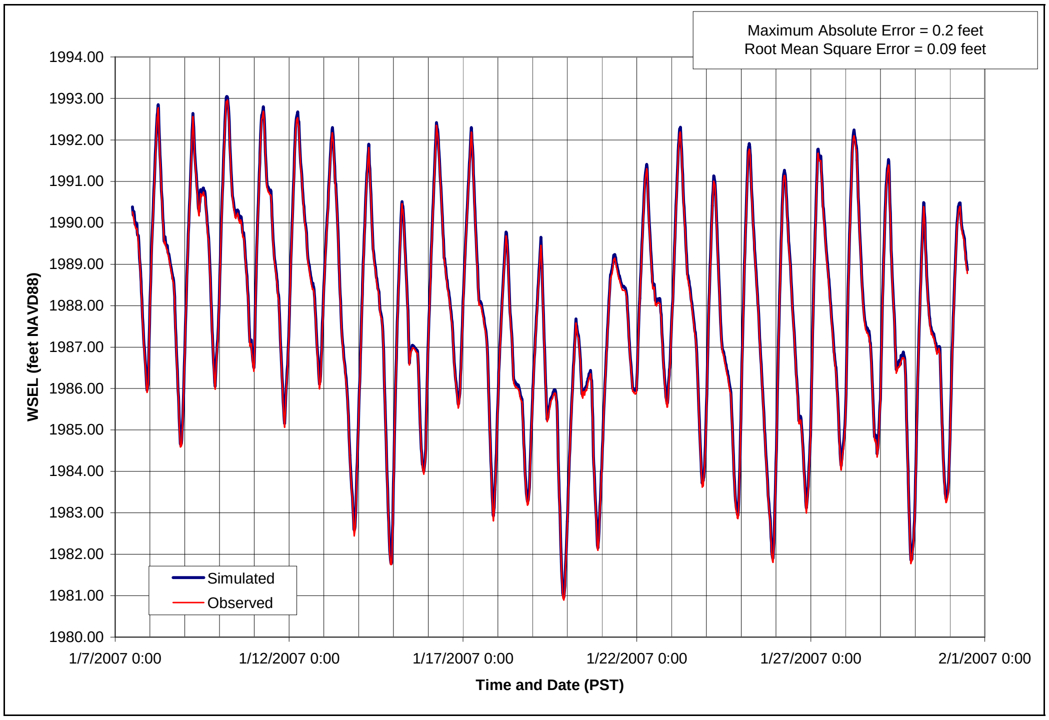


Figure A.1-24. Model calibration results for Hi_Mod Calibration Period at CANYON Pressure Transducer Location.

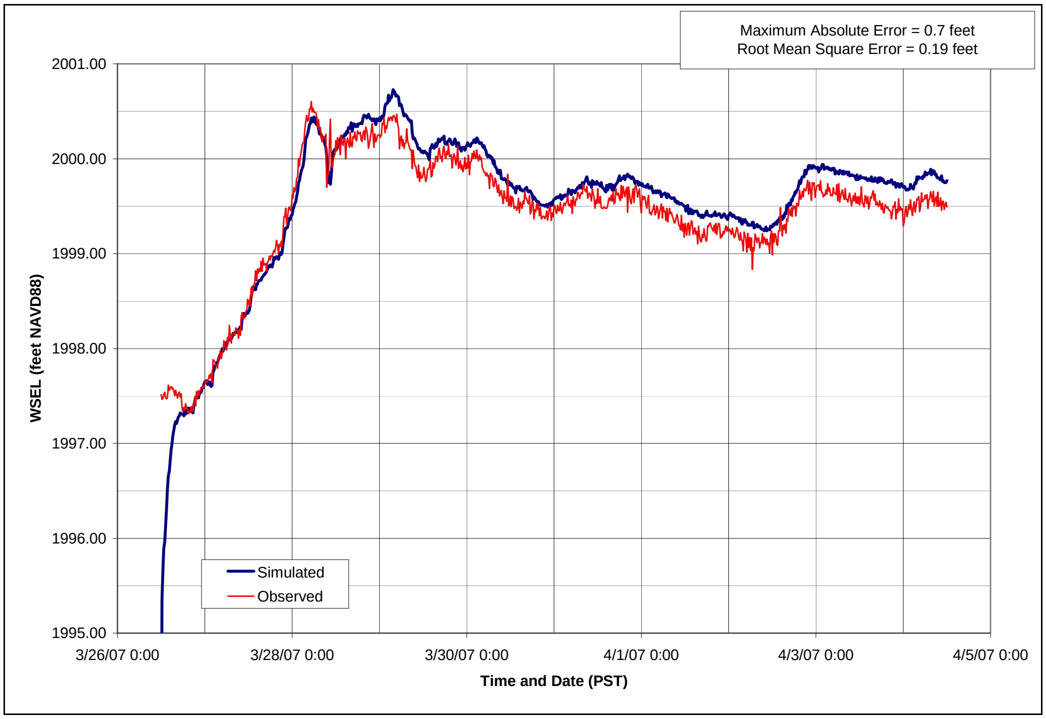


Figure A.1-25. Model calibration results for Hi_Hi Calibration Period at BOX_TR Pressure Transducer Location.

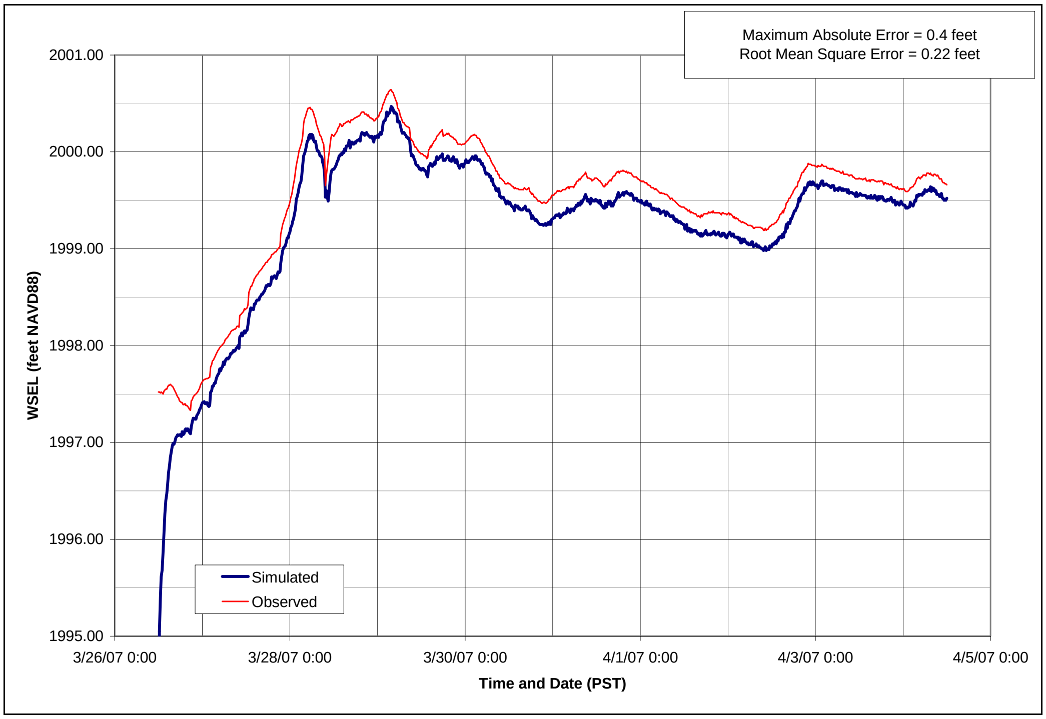


Figure A.1-26. Model calibration results for Hi_Hi Calibration Period at USGS Station 12396500 (Primary) Location.

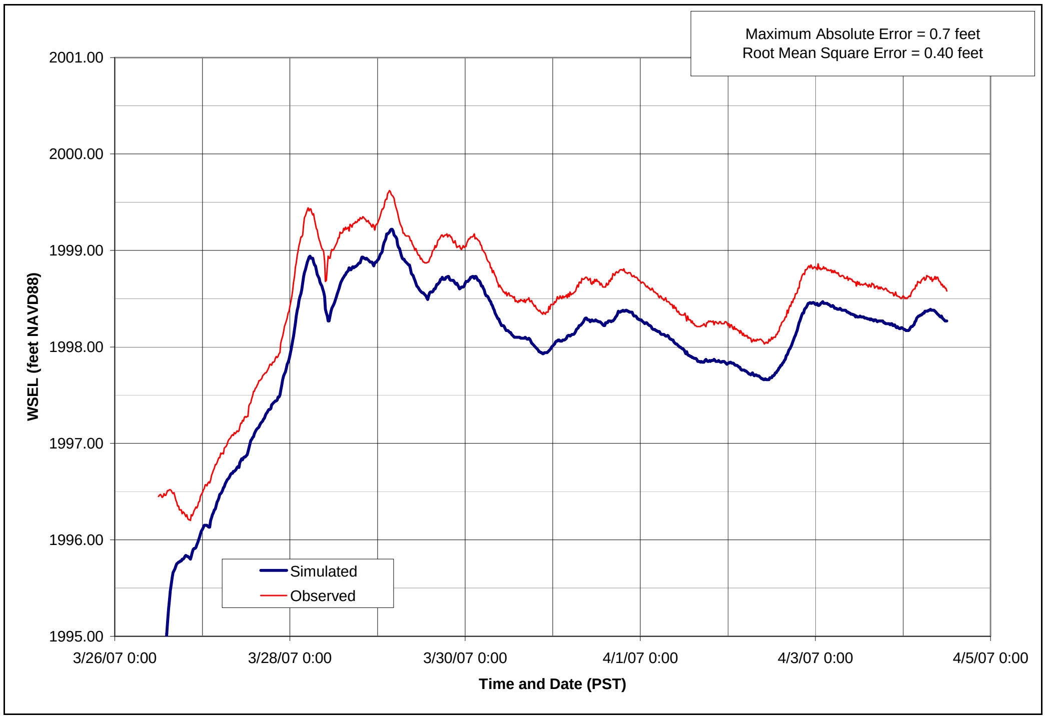


Figure A.1-27. Model calibration results for Hi_Hi Calibration Period at USGS Station 12396500 (Auxiliary) Location.

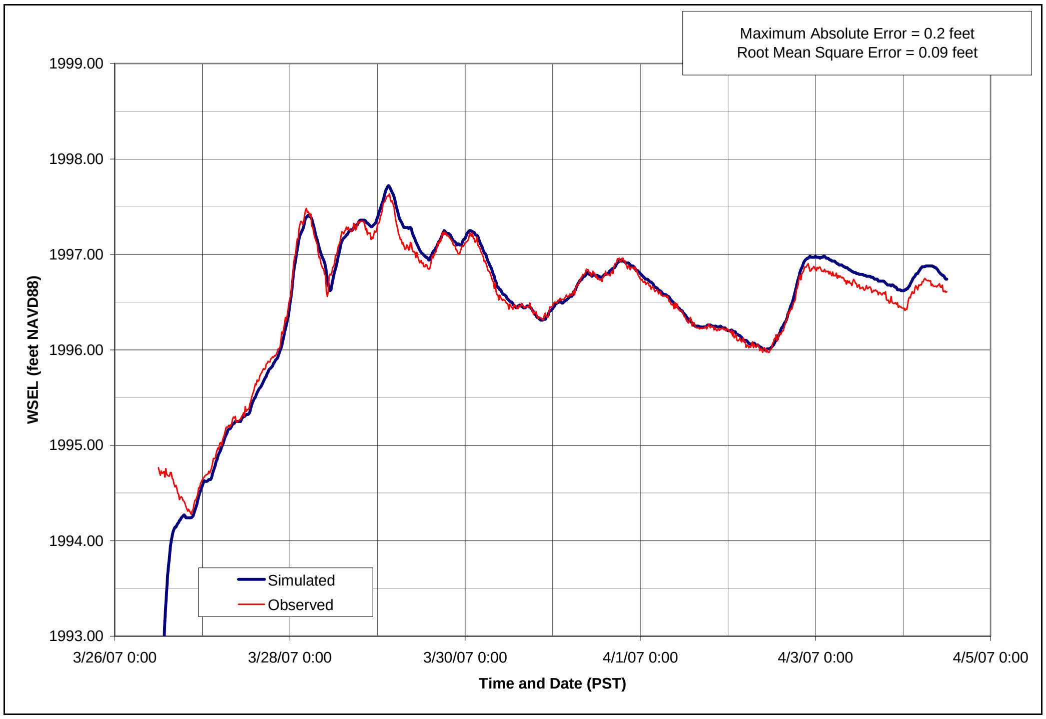


Figure A.1-28. Model calibration results for Hi_Hi Calibration Period at US_MET Pressure Transducer Location.

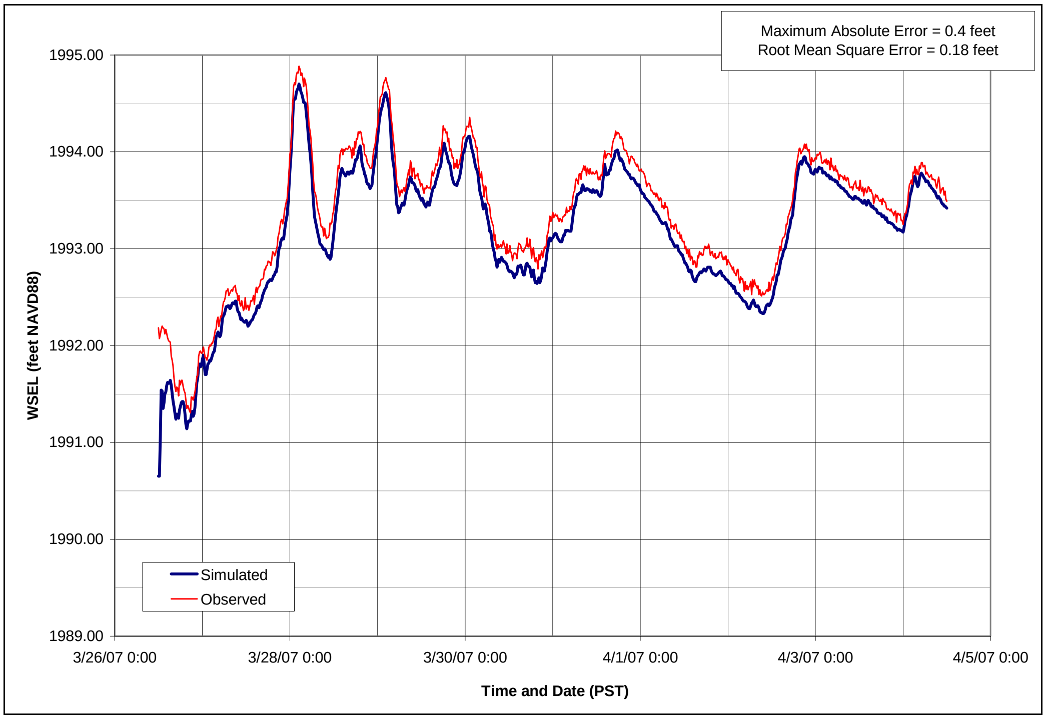


Figure A.1-29. Model calibration results for Hi_Hi Calibration Period at DS_MET Pressure Transducer Location.

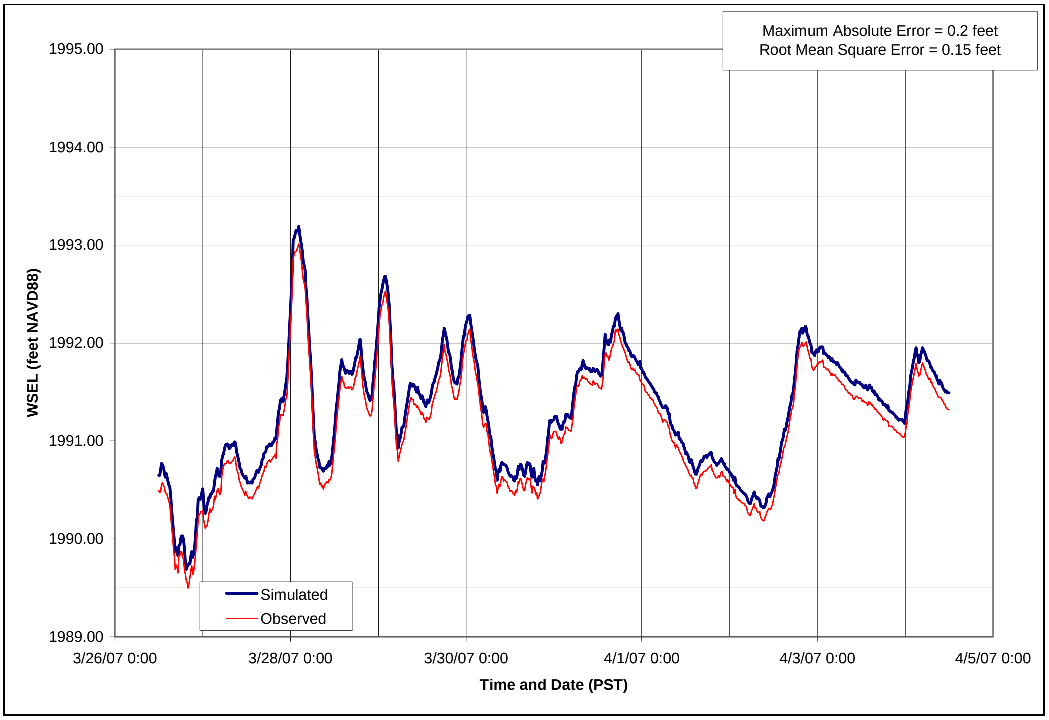


Figure A.1-30. Model calibration results for Hi_HI Calibration Period at CANYON Pressure Transducer Location.

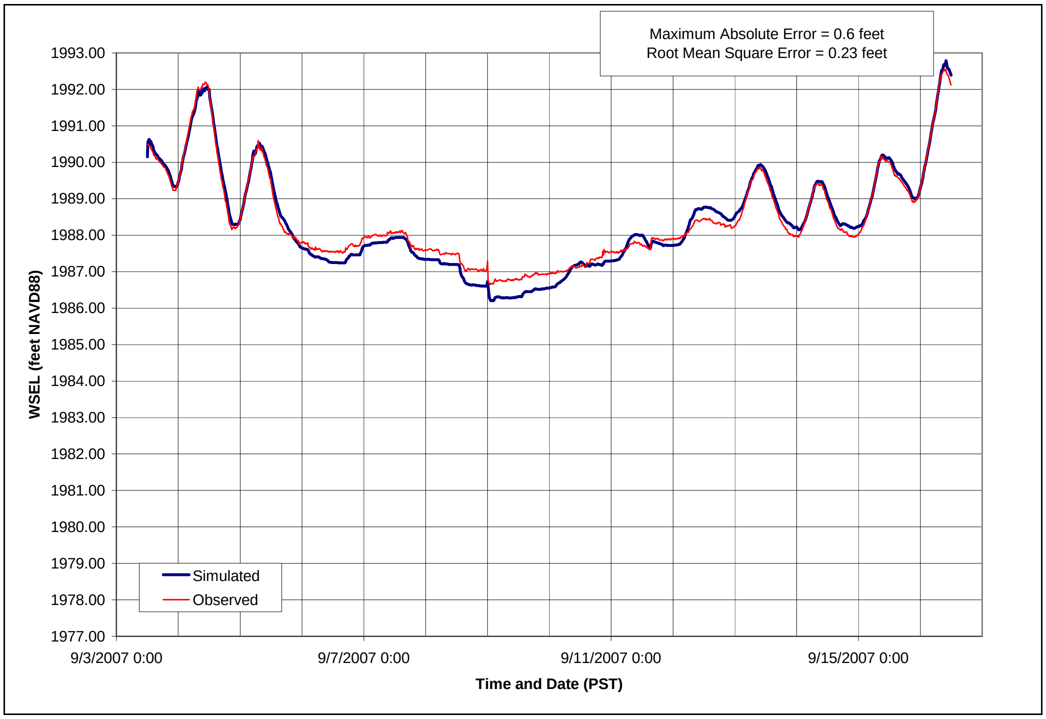


Figure A.1-31. Model calibration results for Lo_Lo Calibration Period at BOX_TR Pressure Transducer Location.

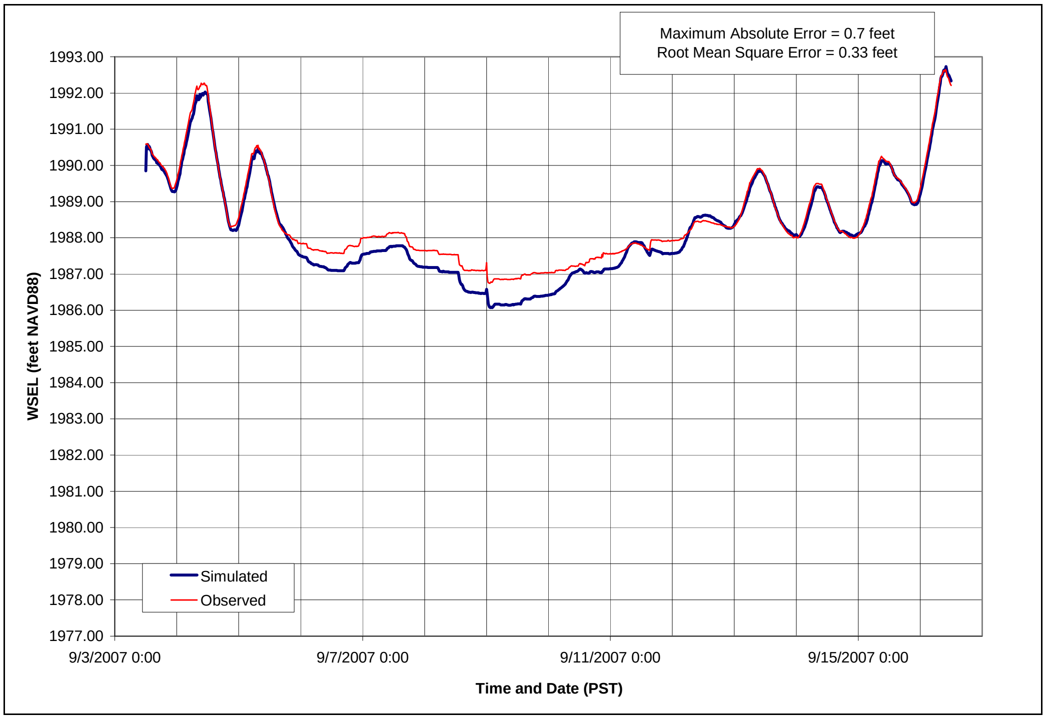


Figure A.1-32. Model calibration results for Lo_Lo Calibration Period at USGS Station 12396500 (Primary) Location.

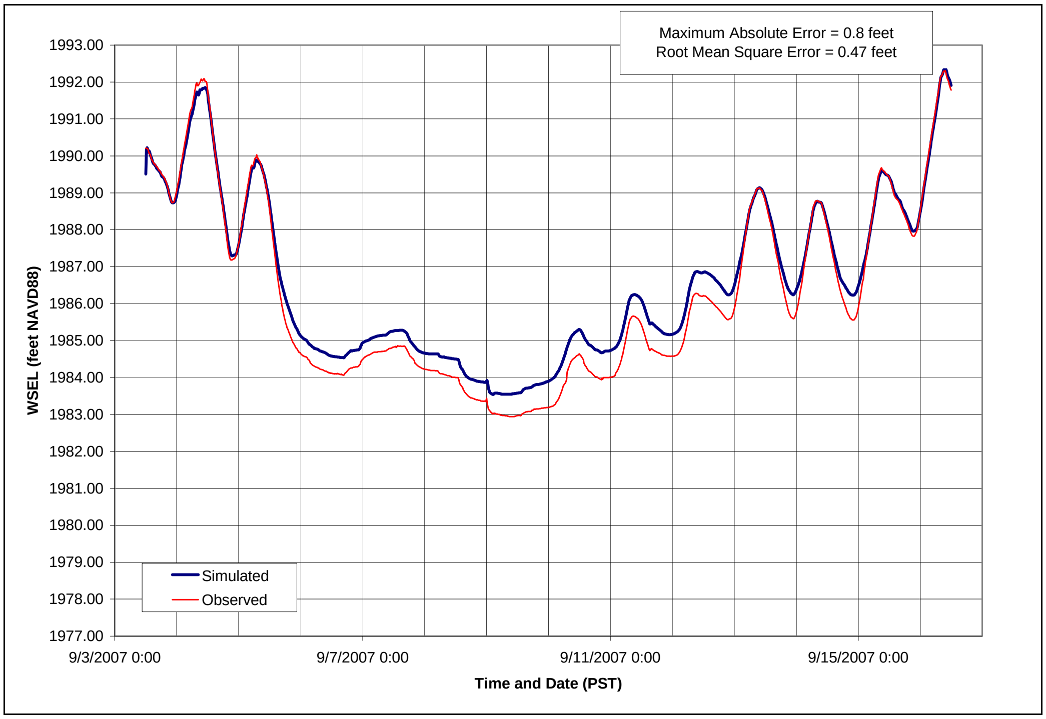


Figure A.1-33. Model calibration results for Lo_Lo Calibration Period at USGS Station 12396500 (Auxiliary) Location.

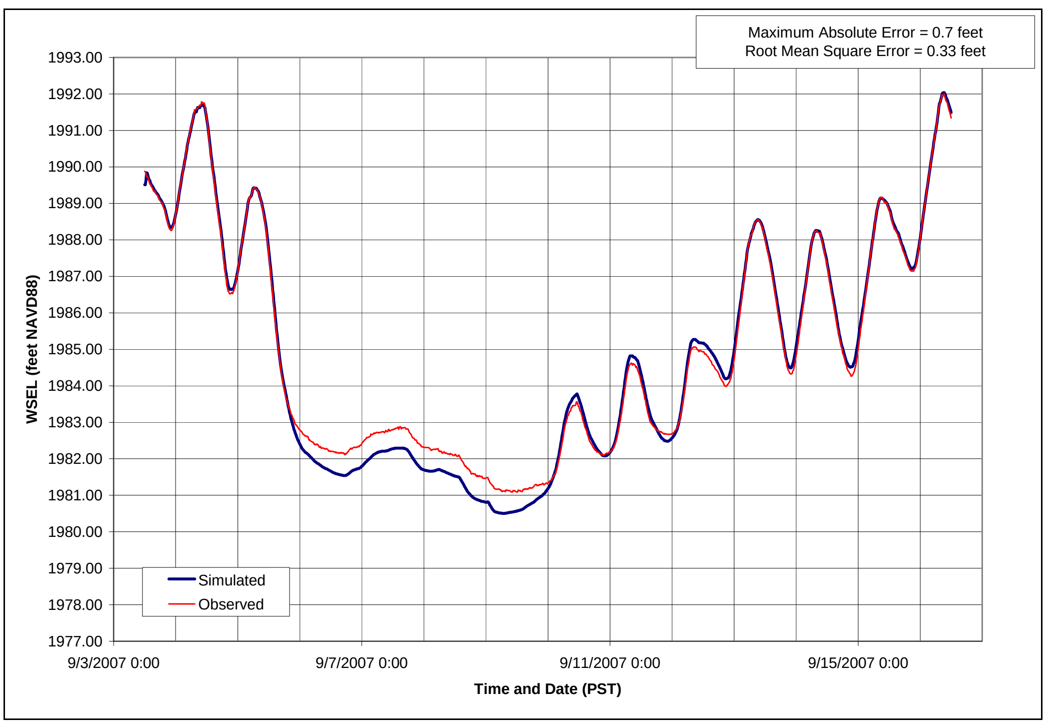


Figure A.1-34. Model calibration results for Lo_Lo Calibration Period at US_MET Pressure Transducer Location.

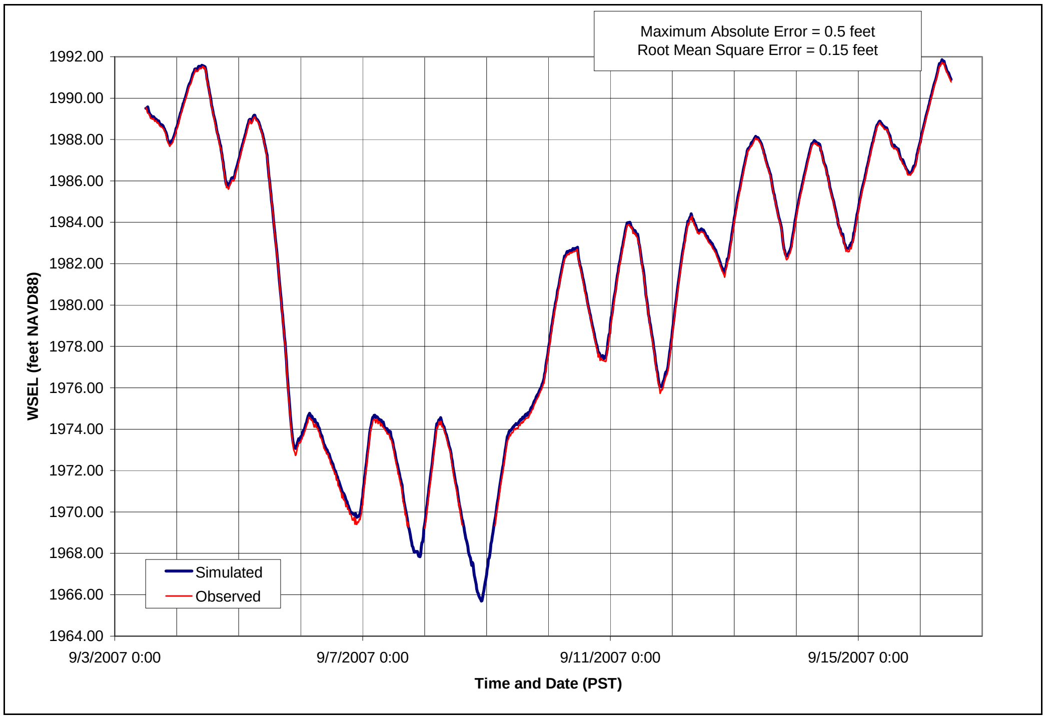


Figure A.1-35. Model calibration results for Lo_Lo Calibration Period at DS_MET Pressure Transducer Location.

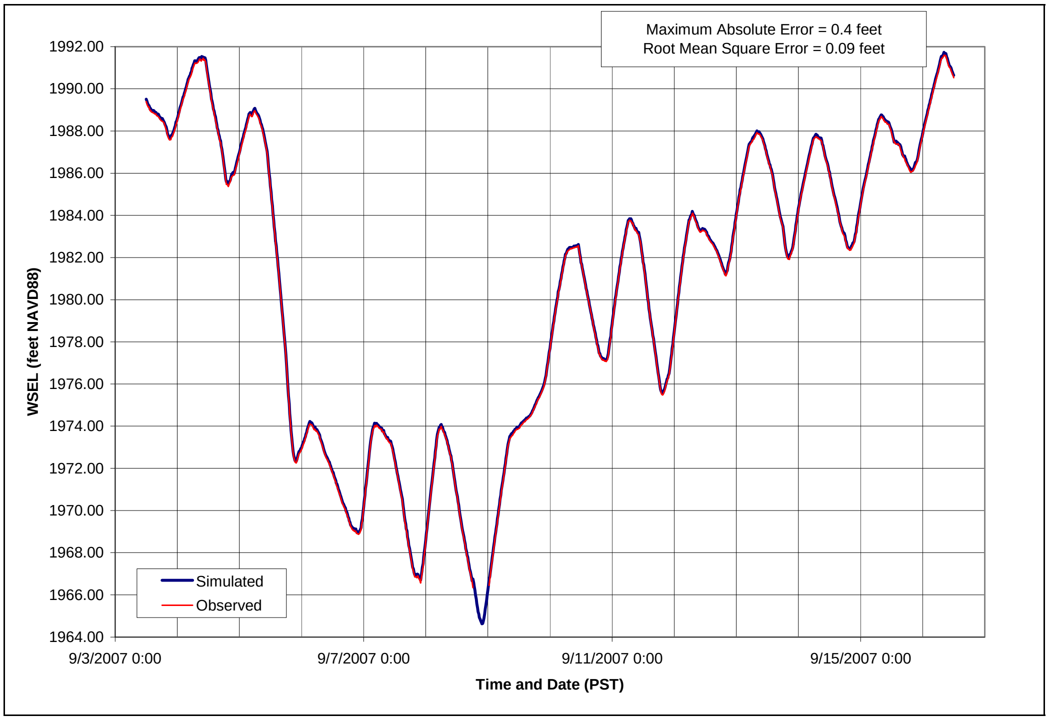


Figure A.1-36. Model calibration results for Lo_Lo Calibration Period at CANYON Pressure Transducer Location.

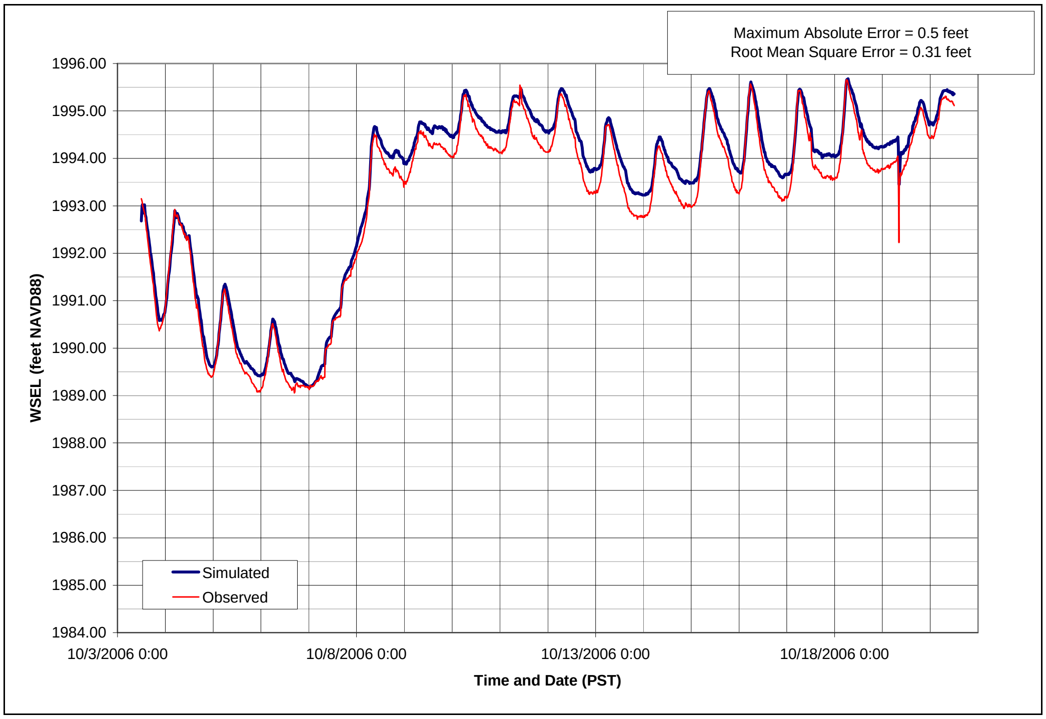


Figure A.1-37. Model calibration results for Lo_Mod Calibration Period at BOX_TR Pressure Transducer Location.

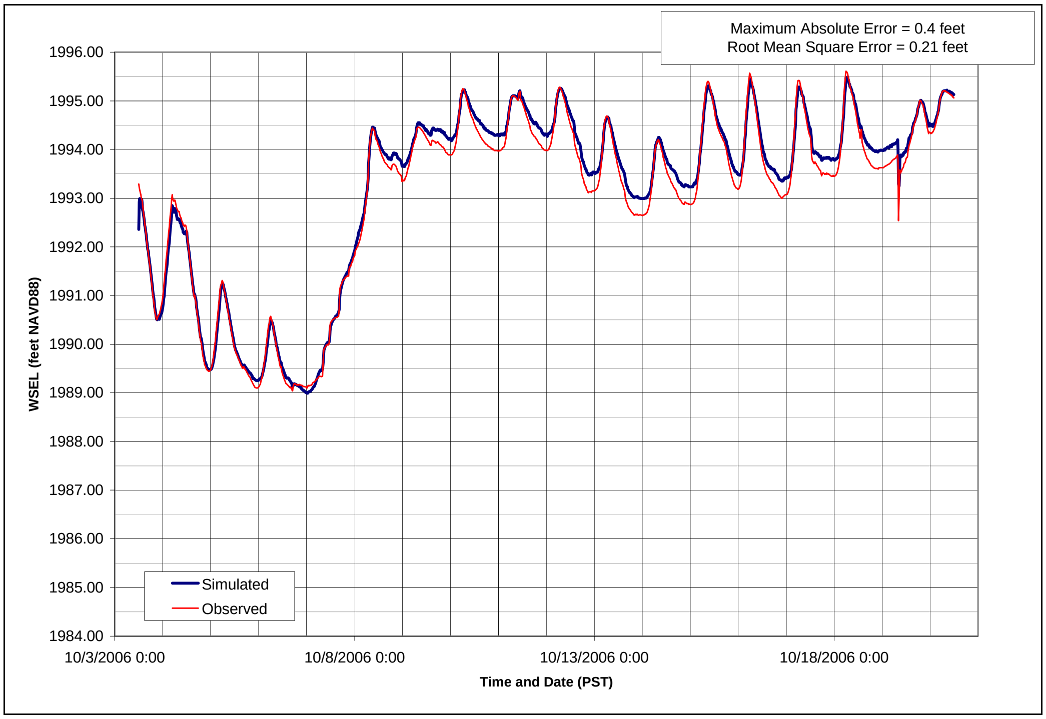


Figure A.1-38. Model calibration results for Lo_Mod Calibration Period at USGS Station 12396500 (Primary) Location.

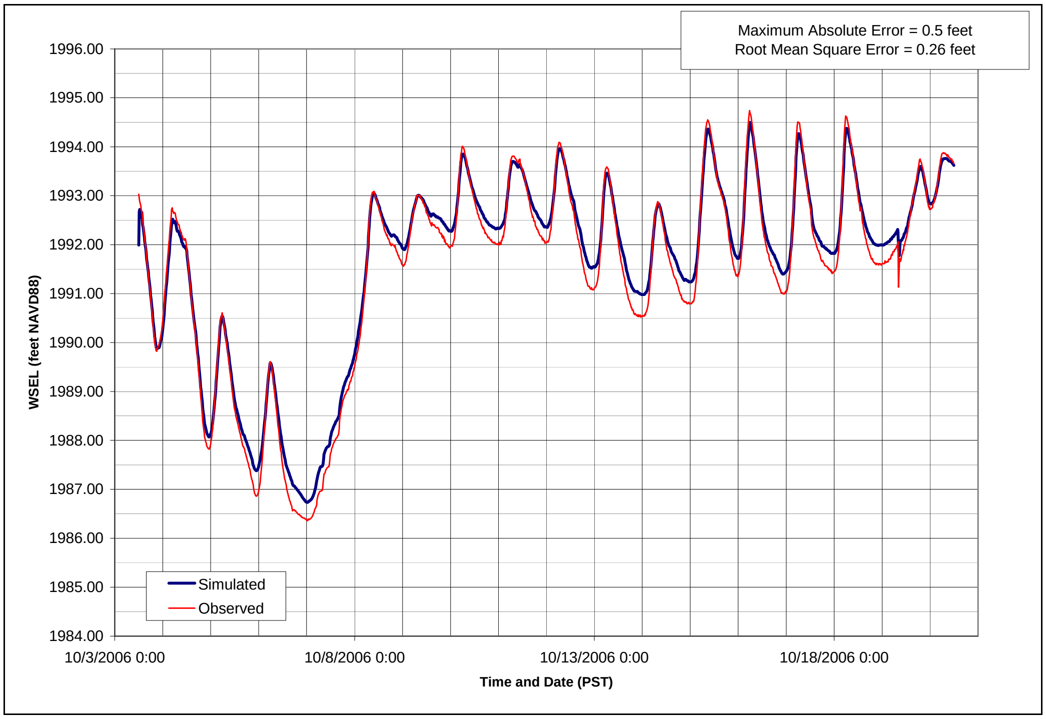


Figure A.1-39. Model calibration results for Lo_Mod Calibration Period at USGS Station 12396500 (Auxiliary) Location.

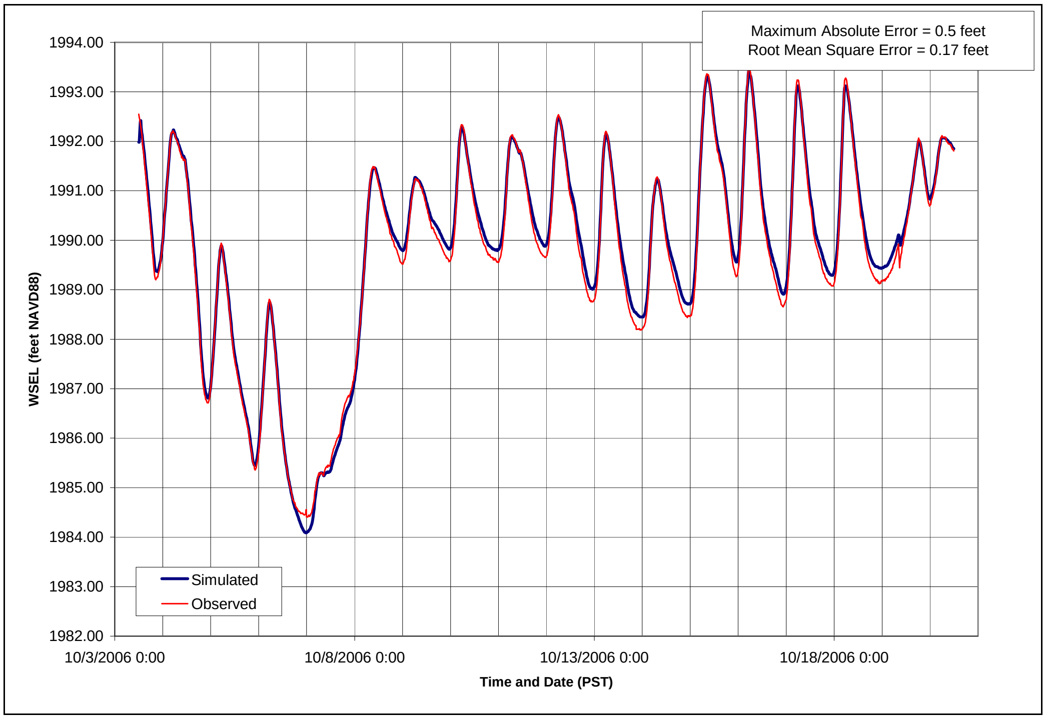


Figure A.1-40. Model calibration results for Lo_Mod Calibration Period at US_MET Pressure Transducer Location.

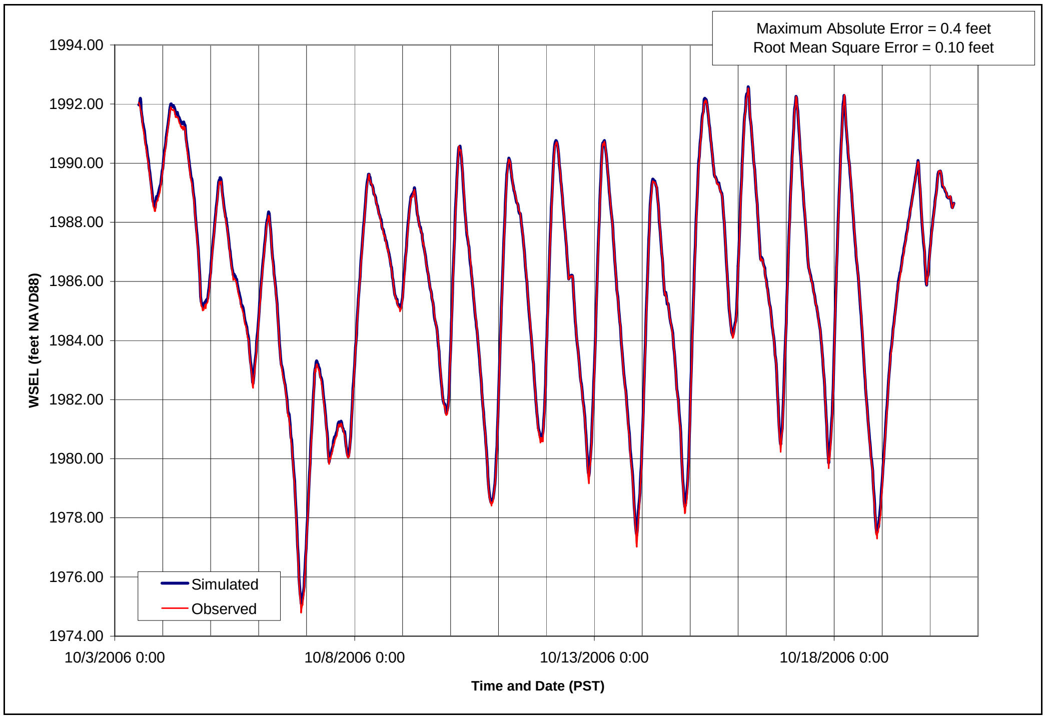


Figure A.1-41. Model calibration results for Lo_Mod Calibration Period at DS_MET Pressure Transducer Location.

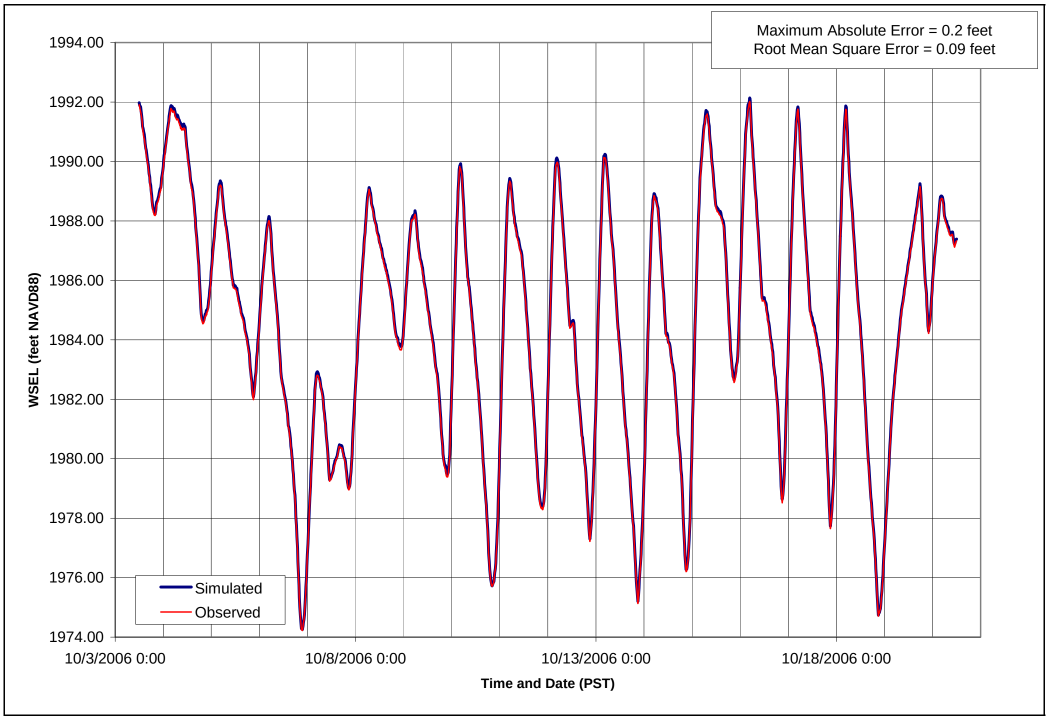


Figure A.1-42. Model calibration results for Lo_Mod Calibration Period at CANYON Pressure Transducer Location.

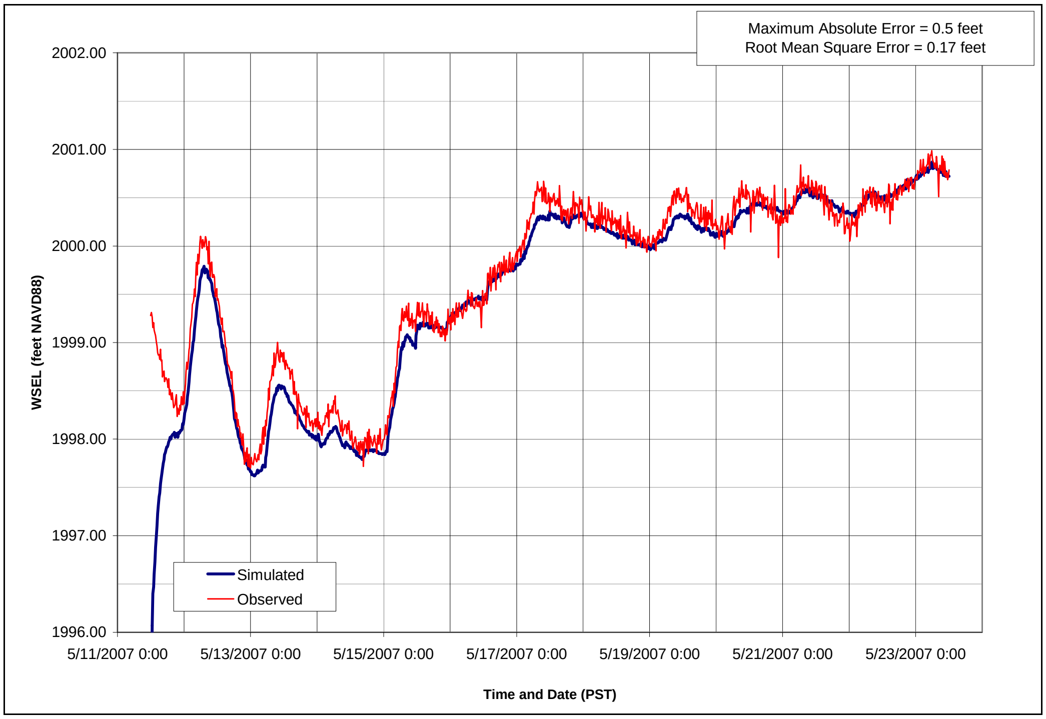


Figure A.1-43. Model calibration results for Lo_Hi Calibration Period at BOX_TR Pressure Transducer Location.

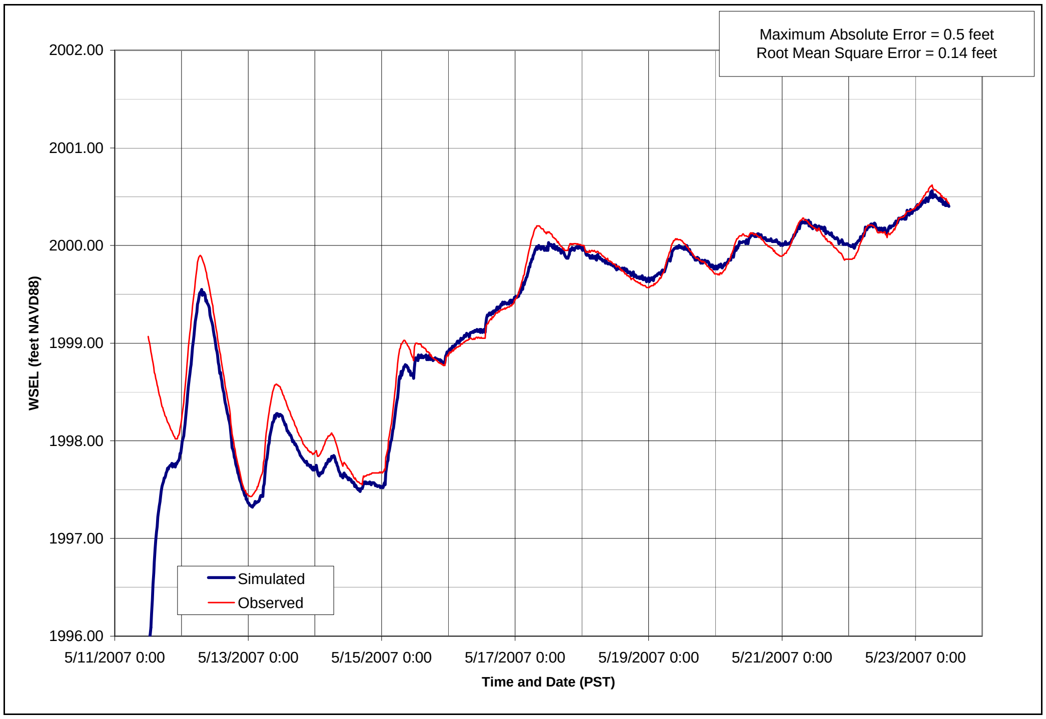


Figure A.1-44. Model calibration results for Lo_Hi Calibration Period at USGS Station 12396500 (Primary) Location.

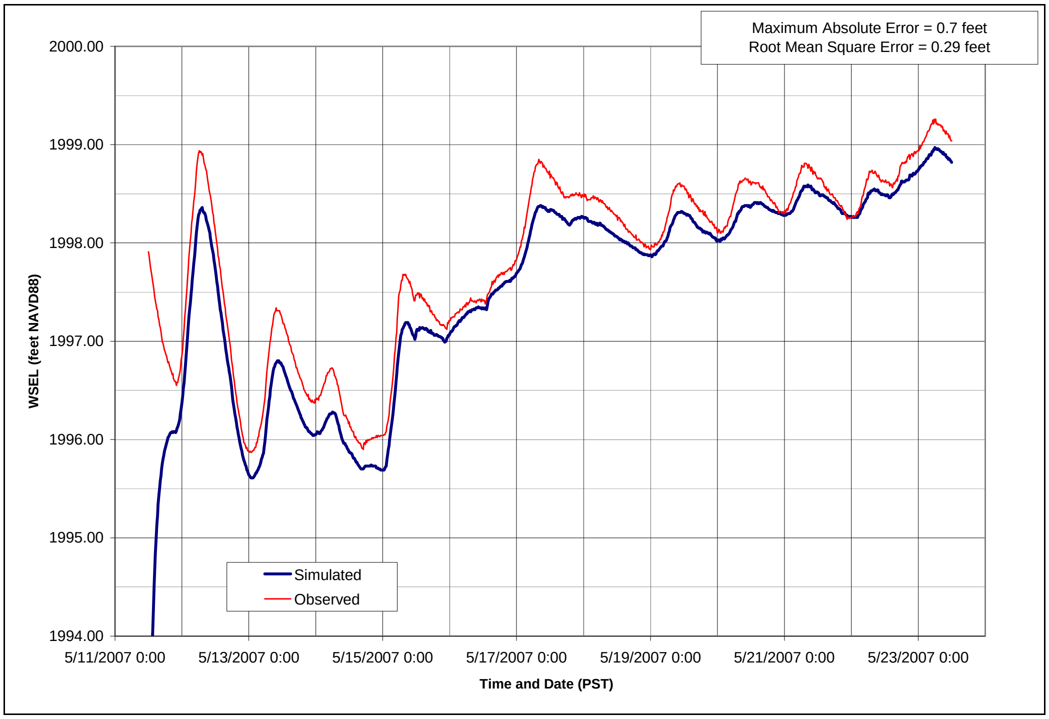


Figure A.1-45. Model calibration results for Lo_Hi Calibration Period at USGS Station 12396500 (Auxiliary) Location.

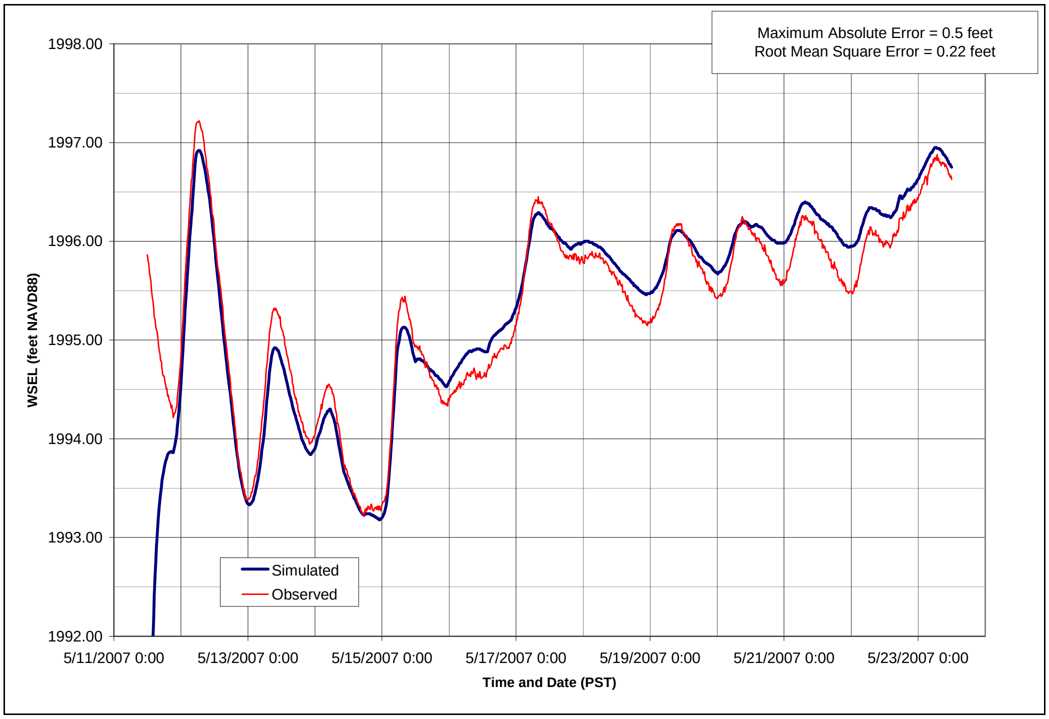


Figure A.1-46. Model calibration results for Lo_Hi Calibration Period at US_MET Pressure Transducer Location.

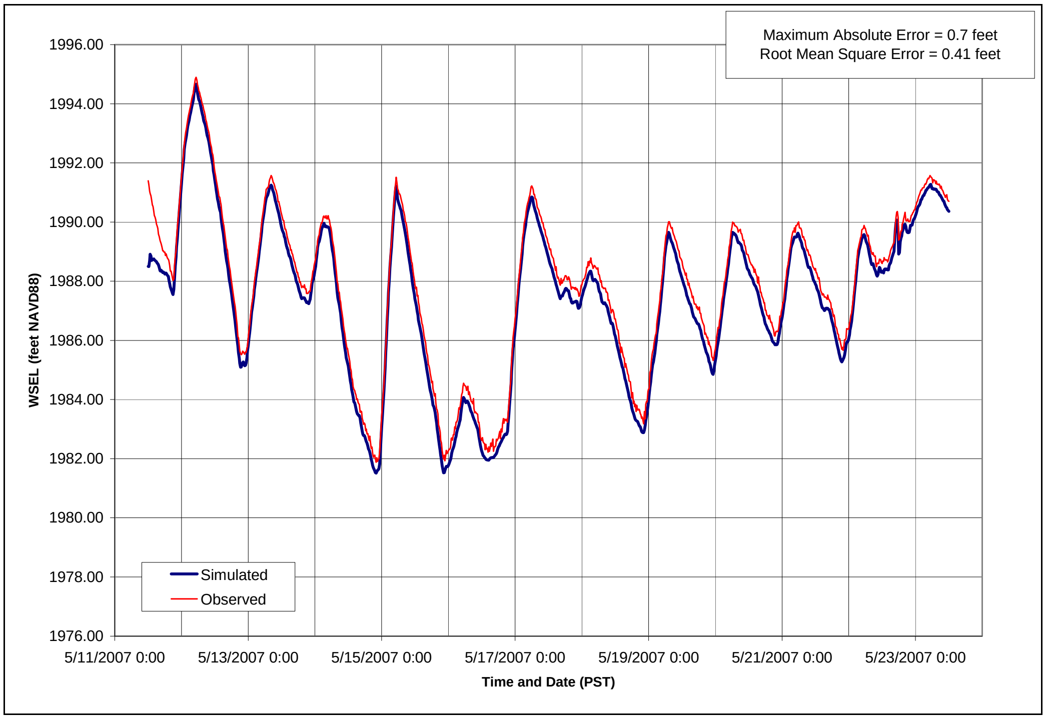


Figure A.1-47. Model calibration results for Lo_Hi Calibration Period at DS_MET Pressure Transducer Location.

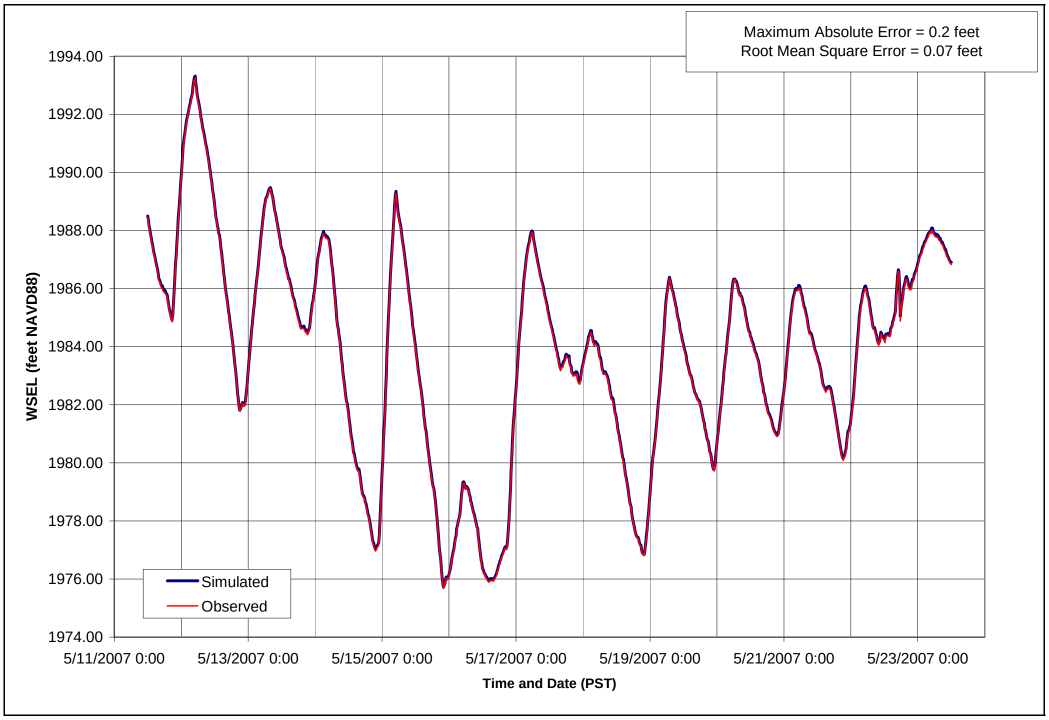


Figure A.1-48. Model calibration results for Lo_Hi Calibration Period at CANYON Pressure Transducer Location.

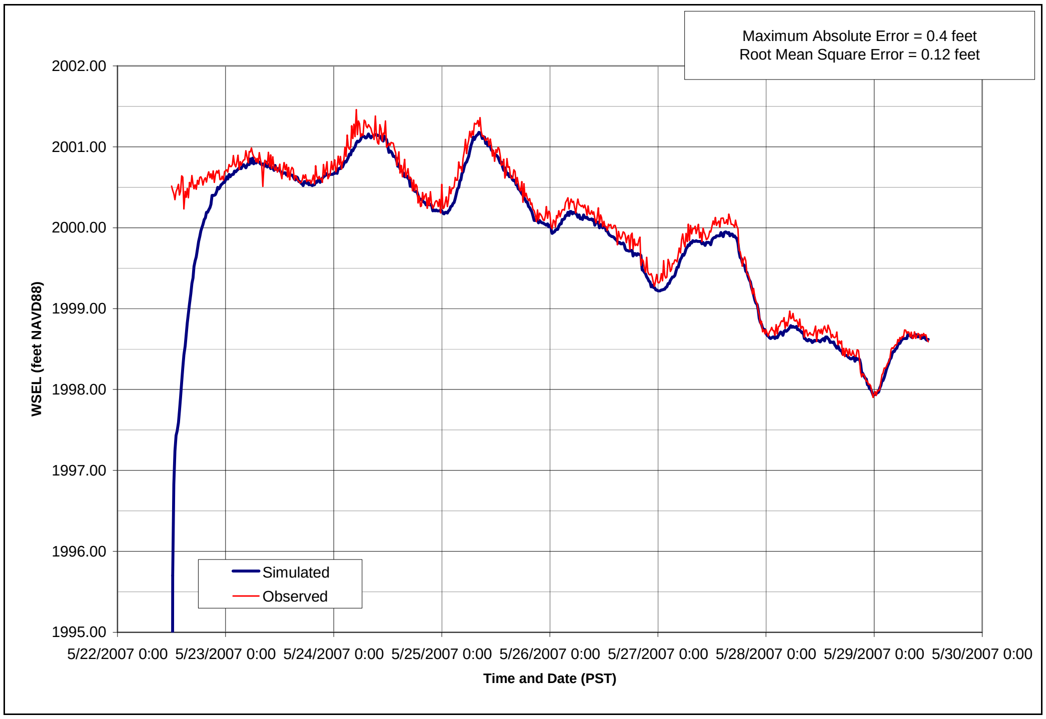


Figure A.1-49. Model calibration results for Hi_Hi Verification Period at BOX_TR Pressure Transducer Location.

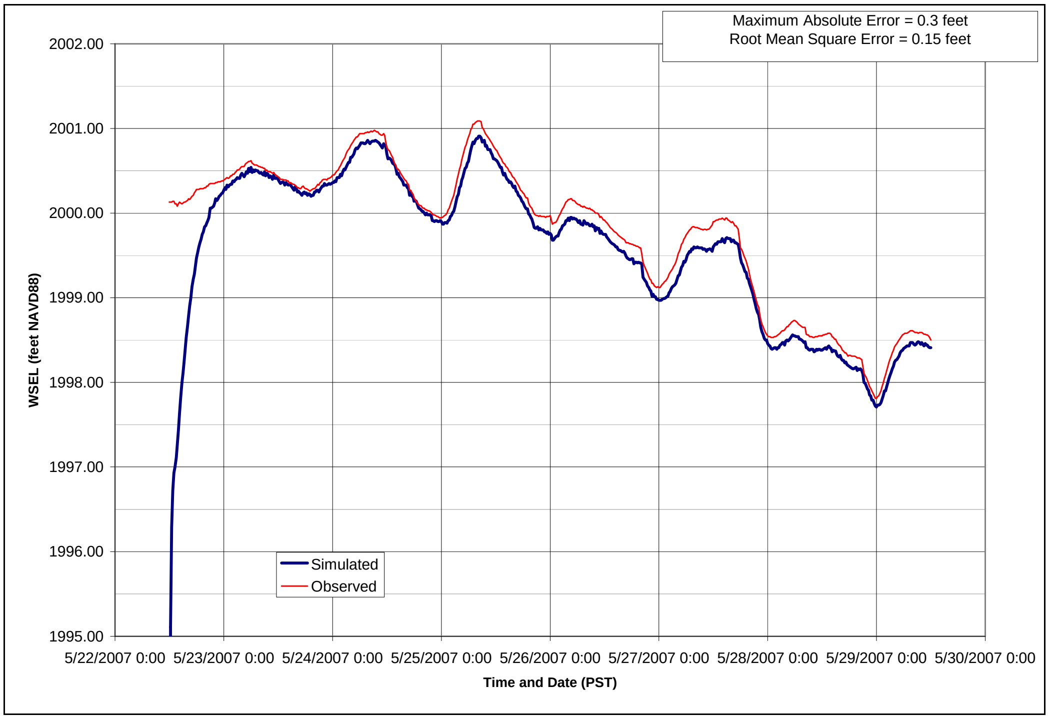


Figure A.1-50. Model calibration results for Hi_Hi Verification Period at USGS Station 12396500 (Primary) Location.

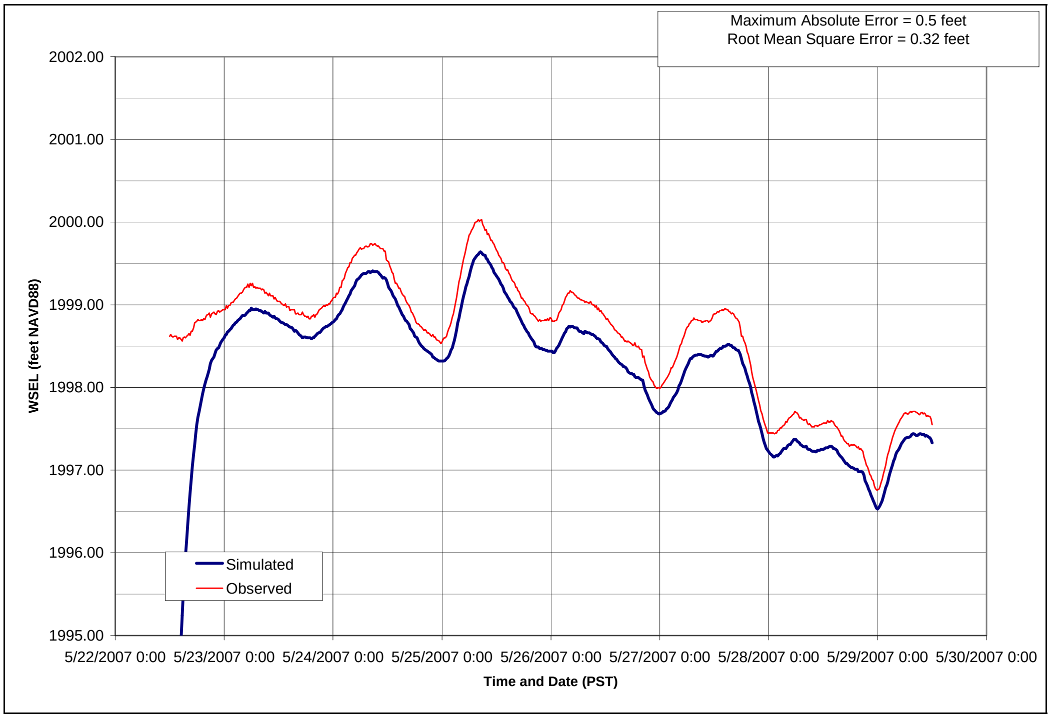


Figure A.1-51. Model calibration results for Hi_Hi Verification Period at USGS Station 12396500 (Auxiliary) Location.

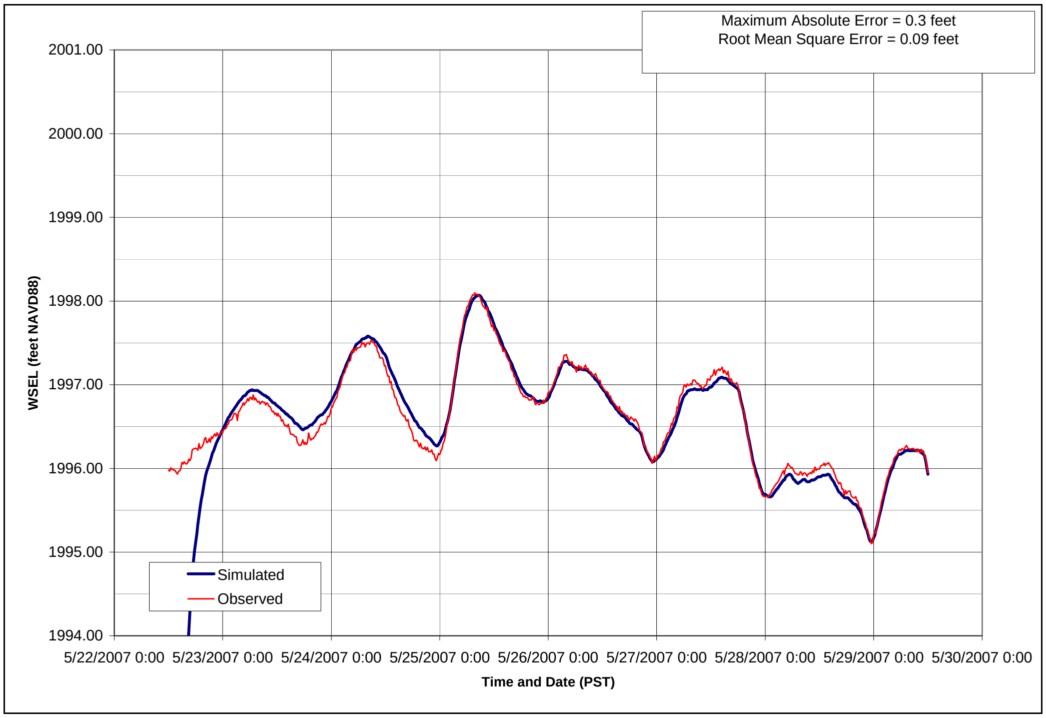


Figure A.1-52. Model calibration results for Hi_Hi Verification Period at US_MET Pressure Transducer Location.

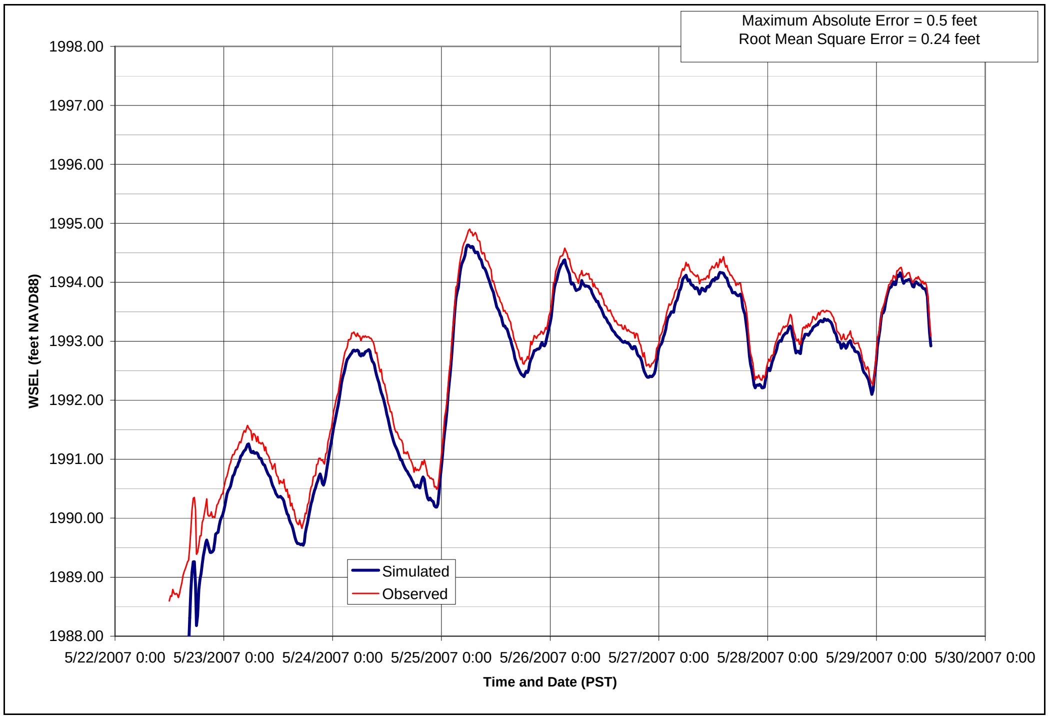


Figure A.1-53. Model calibration results for Hi_Hi Verification Period at DS_MET Pressure Transducer Location.

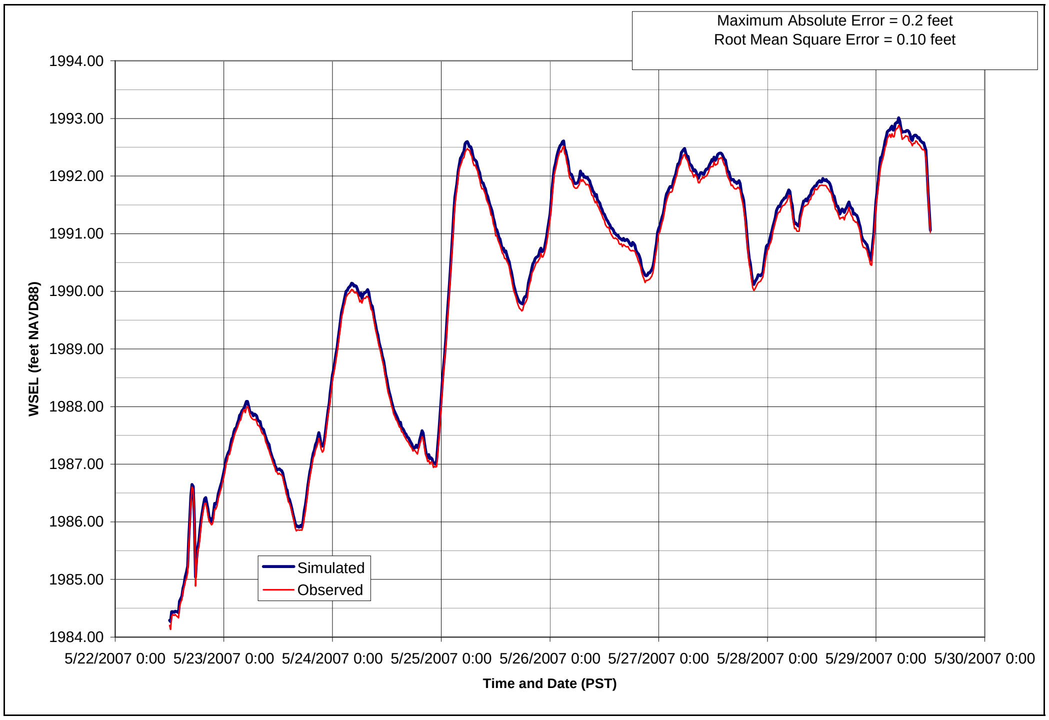


Figure A.1-54. Model calibration results for Hi_Hi Verification Period at CANYON Pressure Transducer Location.

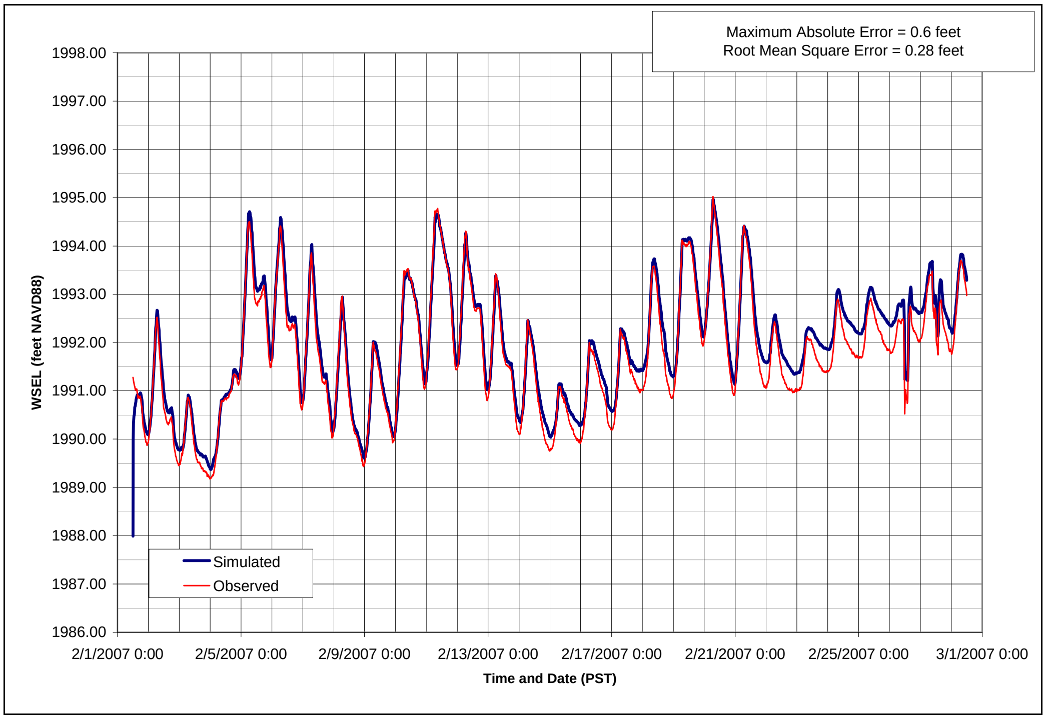


Figure A.1-55. Model calibration results for Var_Var Verification Period at BOX_TR Pressure Transducer Location.

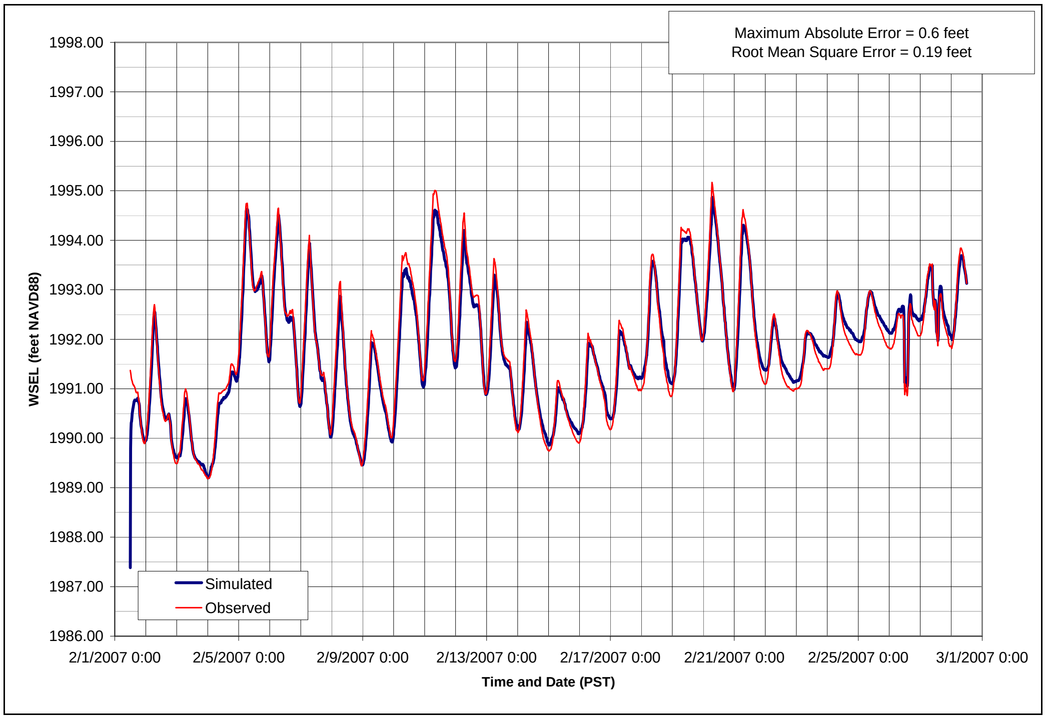


Figure A.1-56. Model calibration results for Var_Var Verification Period at USGS Station 12396500 (Primary) Location.

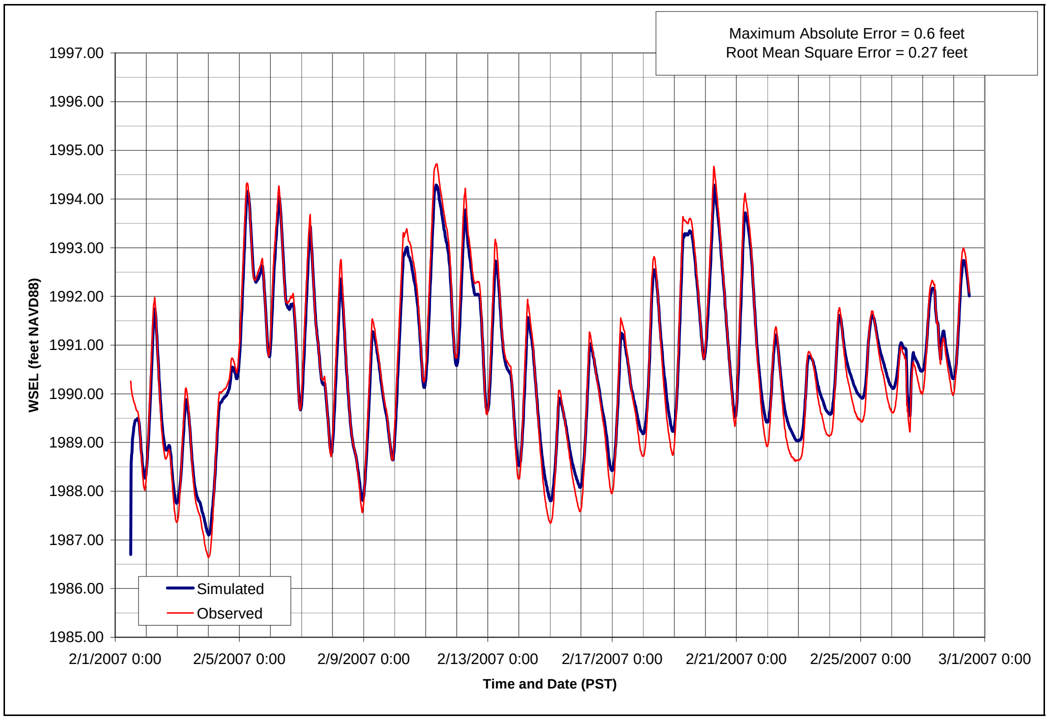


Figure A.1-57. Model calibration results for Var_Var Verification Period at USGS Station 12396500 (Auxiliary) Location.

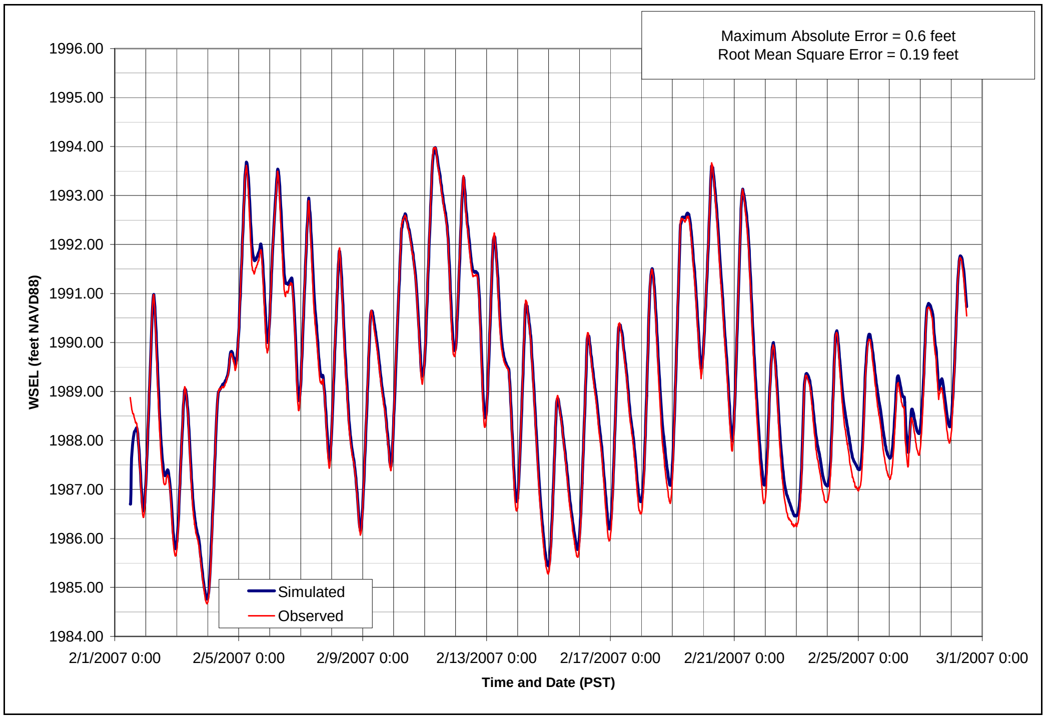


Figure A.1-58. Model calibration results for Var_Var Verification Period at US_MET Pressure Transducer Location.

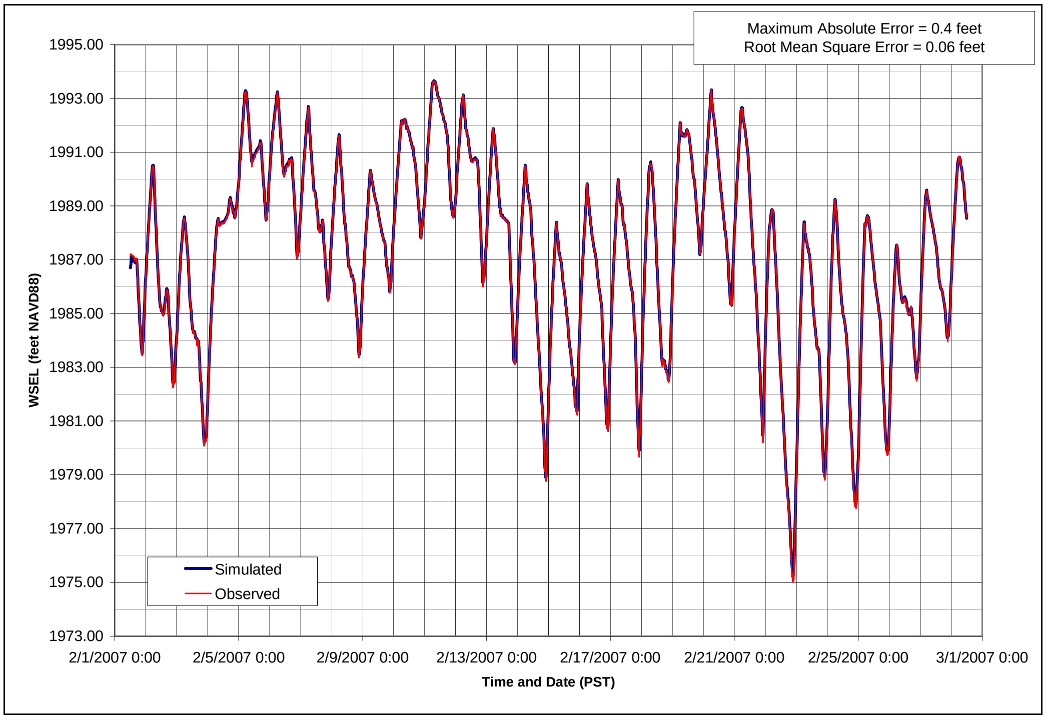


Figure A.1-59. Model calibration results for Var_Var Verification Period at DS_MET Pressure Transducer Location.

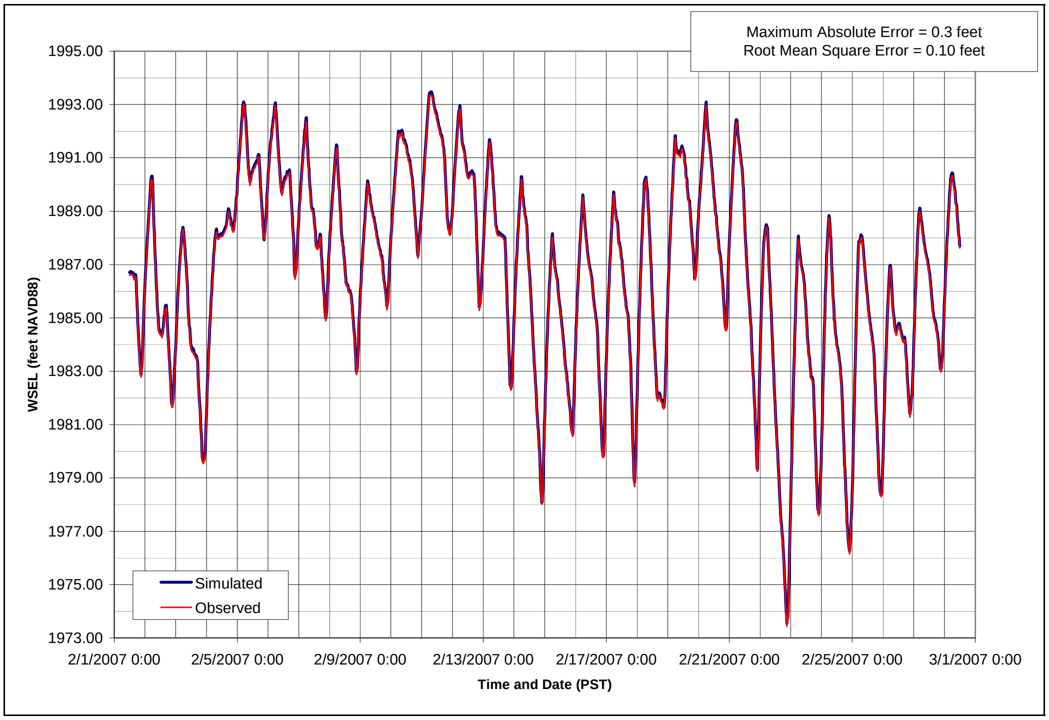


Figure A.1-60. Model calibration results for Var_Var Verification Period at CANYON Pressure Transducer Location.

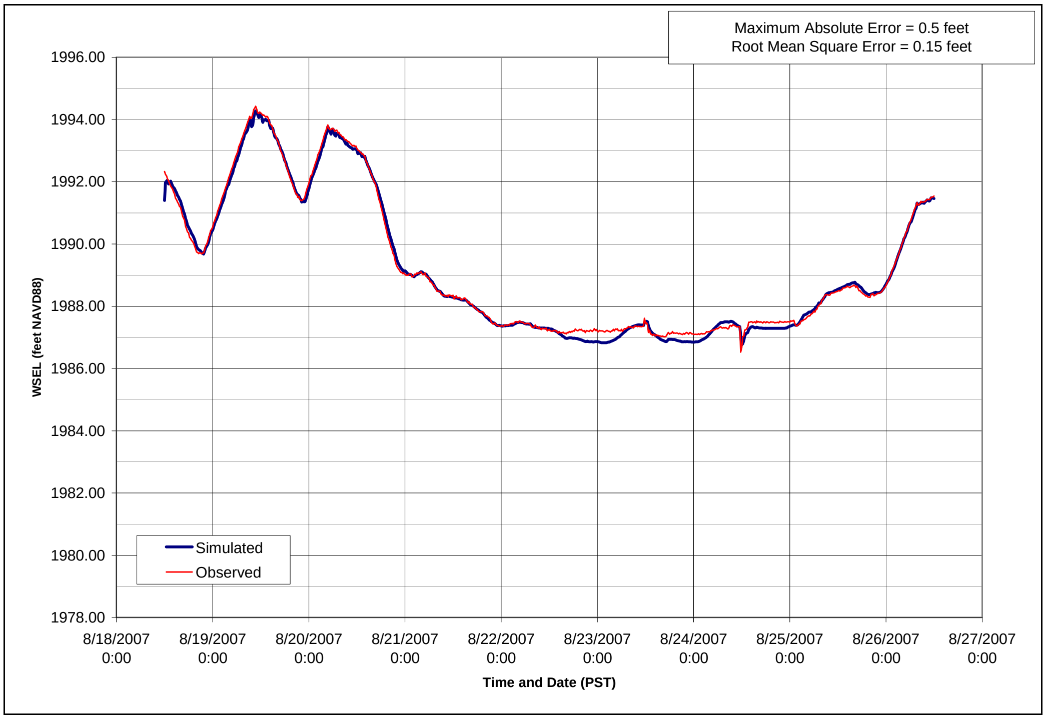


Figure A.1-61. Model calibration results for Lo_Lo Verification Period at BOX_TR Pressure Transducer Location.

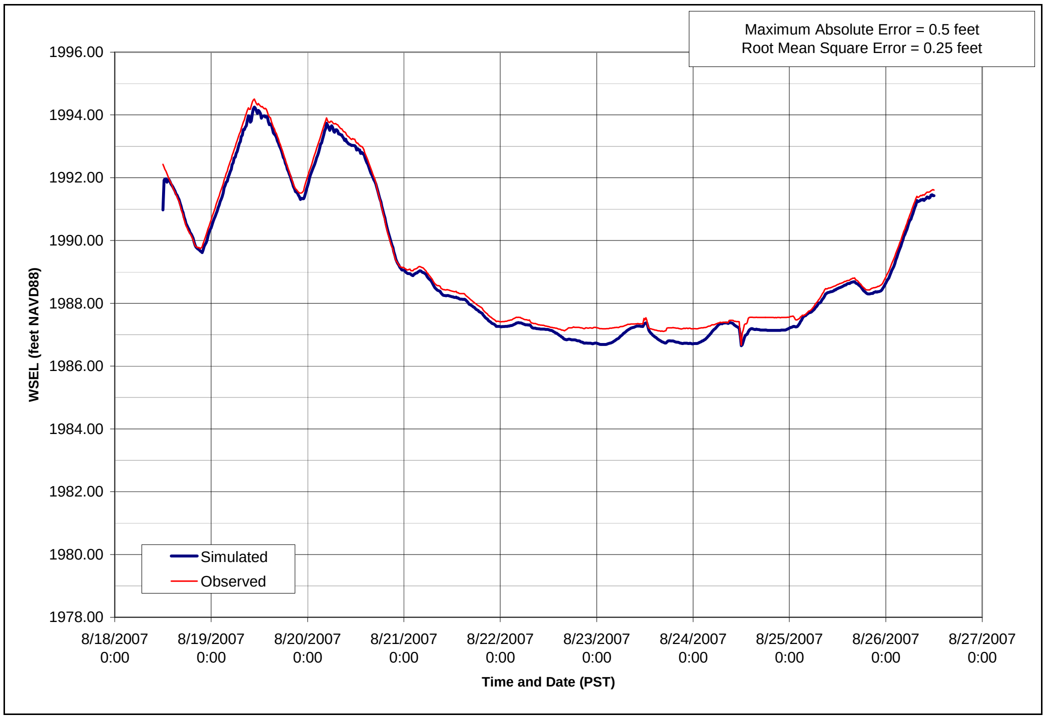


Figure A.1-62. Model calibration results for Lo_Lo Verification Period at USGS Station 12396500 (Primary) Location.

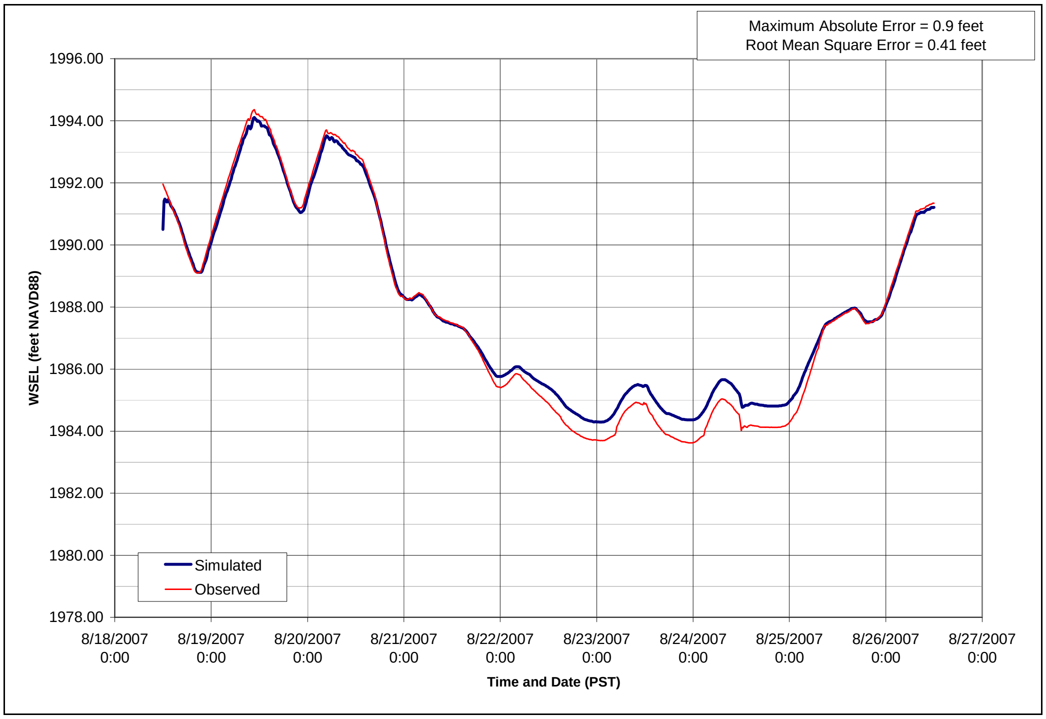


Figure A.1-63. Model calibration results for Lo_Lo Verification Period at USGS Station 12396500 (Auxiliary) Location.

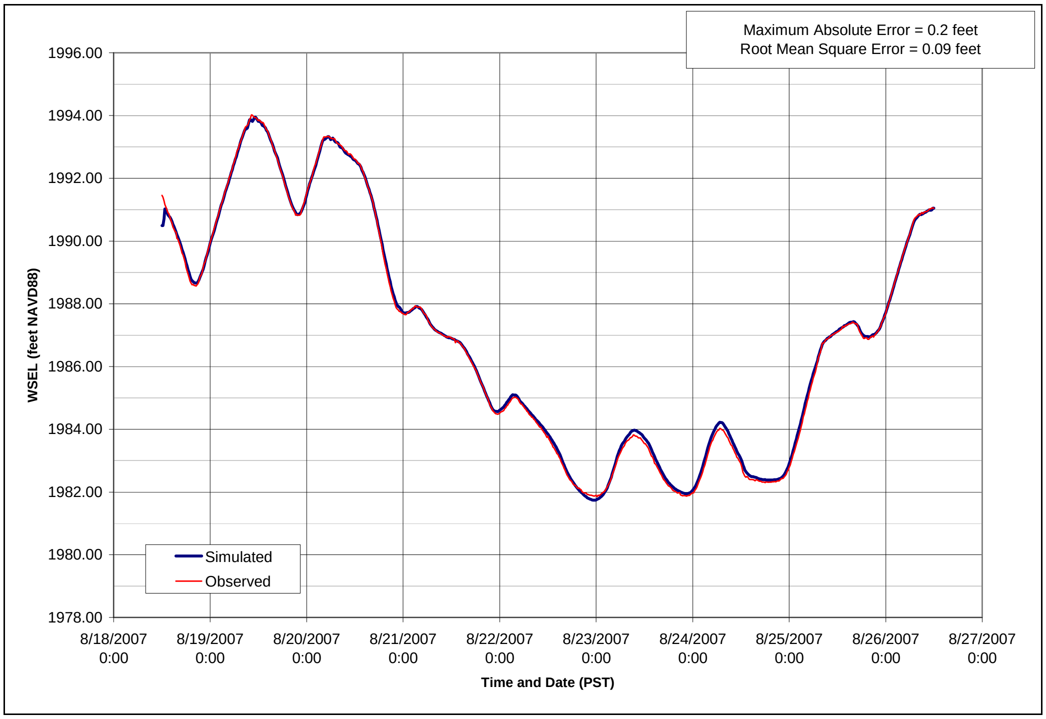


Figure A.1-64. Model calibration results for Lo_Lo Verification Period at US_MET Pressure Transducer Location.

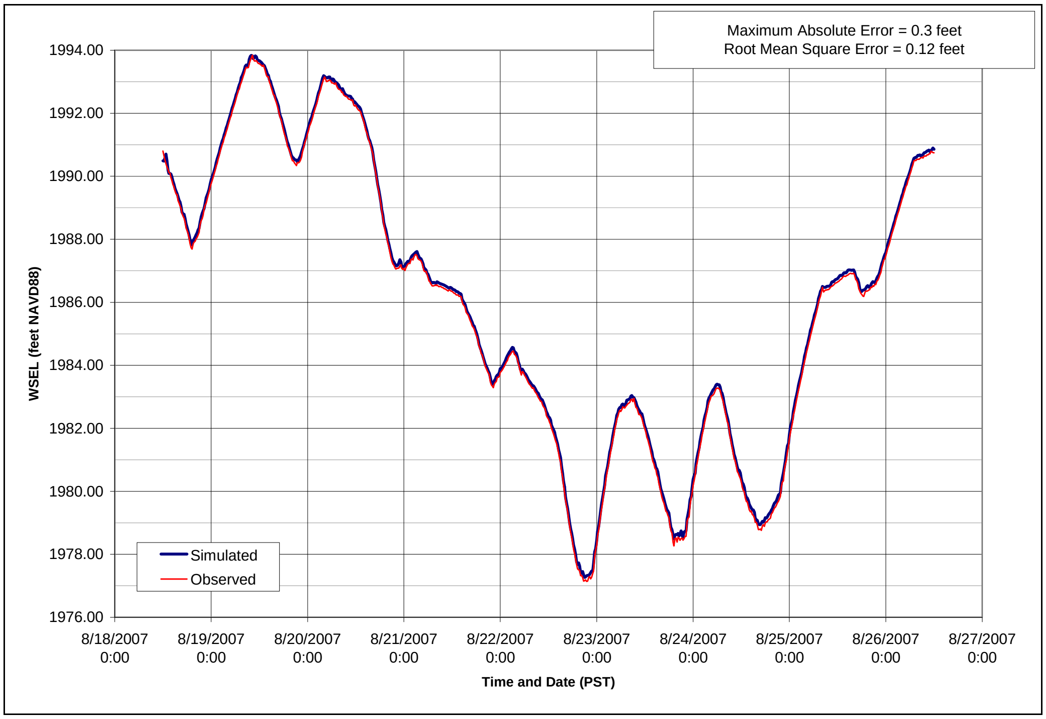


Figure A.1-65. Model calibration results for Lo_Lo Verification Period at DS_MET Pressure Transducer Location.

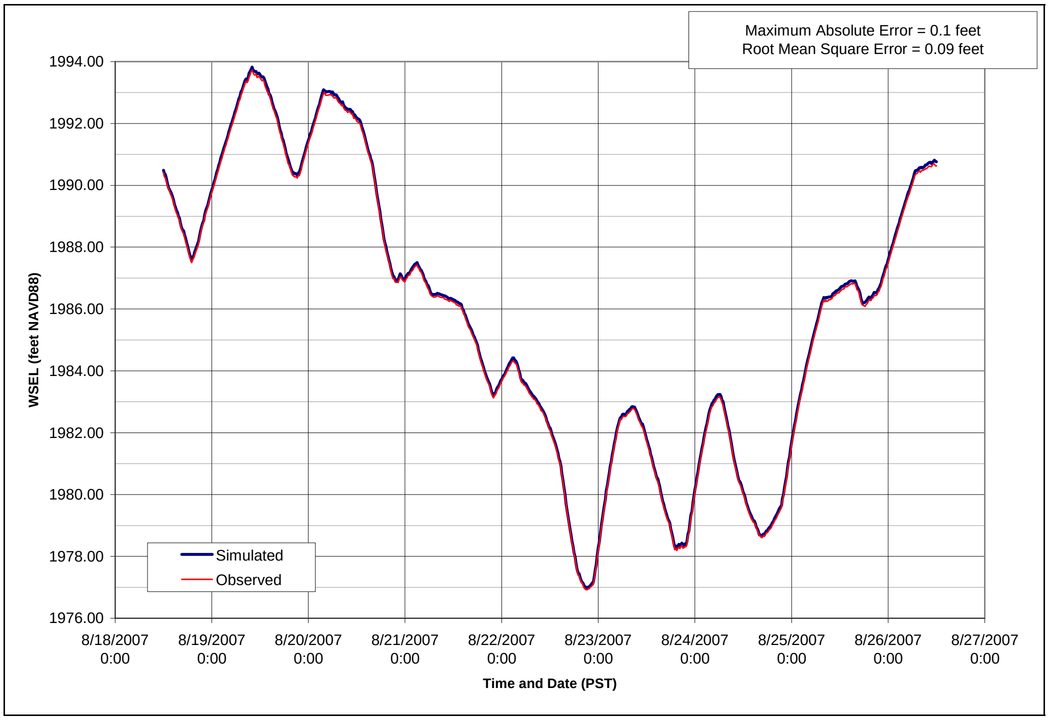


Figure A.1-66. Model calibration results for Lo_Lo Verification Period at CANYON Pressure Transducer Location.

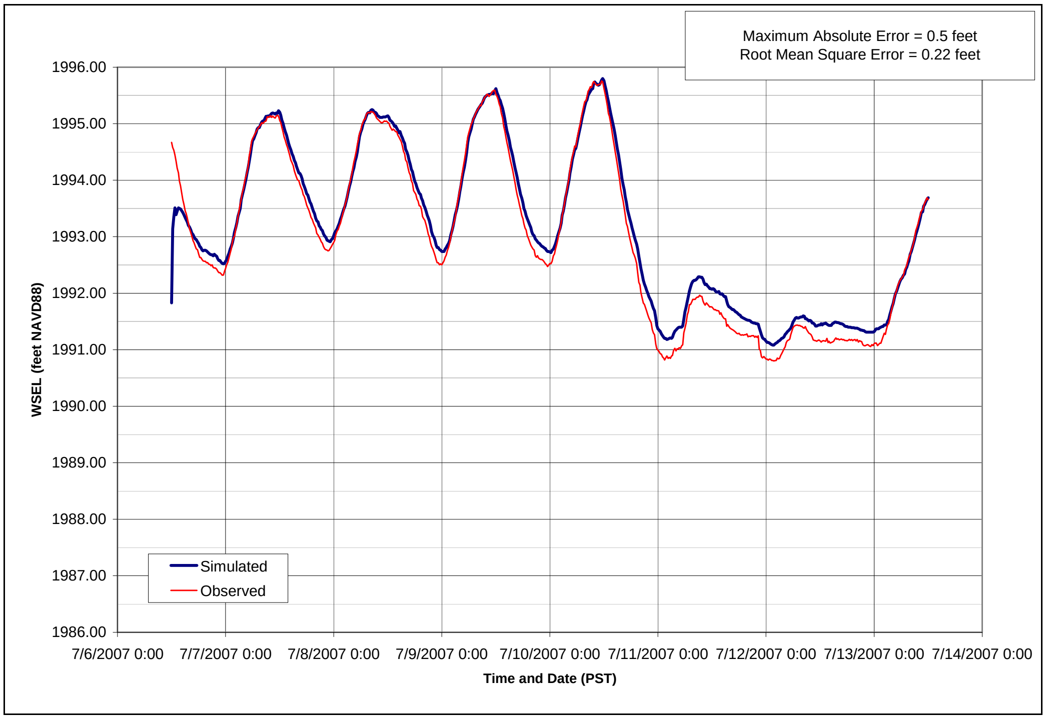


Figure A.1-67. Model calibration results for Lo_Mod Verification Period at BOX_TR Pressure Transducer Location.

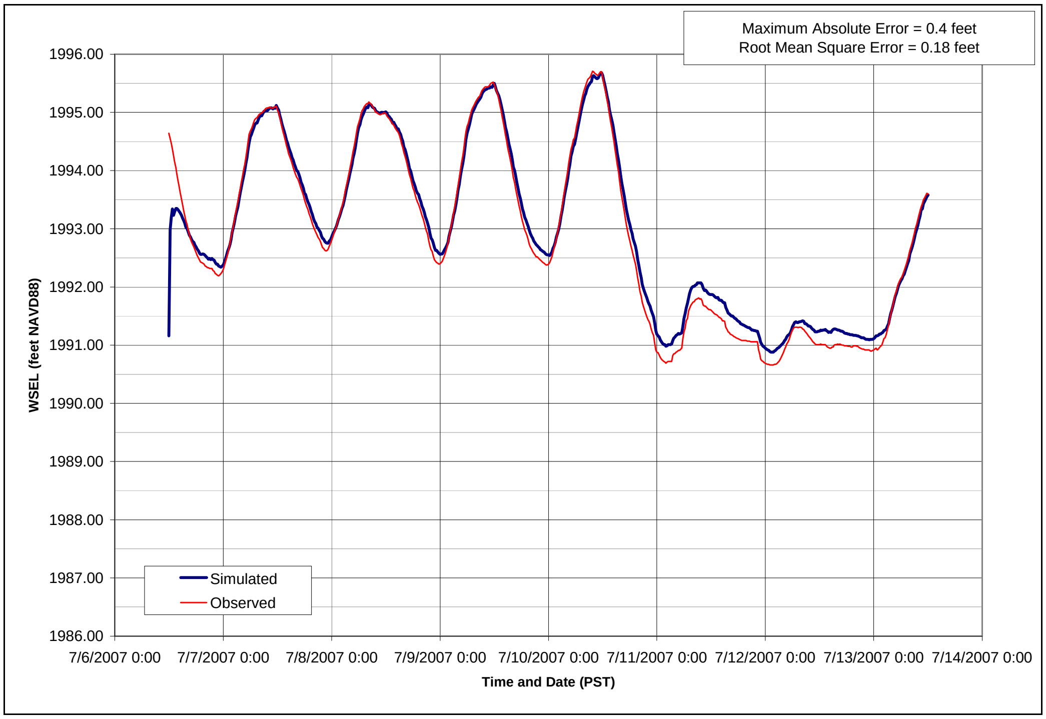


Figure A.1-68. Model calibration results for Lo_Mod Verification Period at USGS Station 12396500 (Primary) Location.

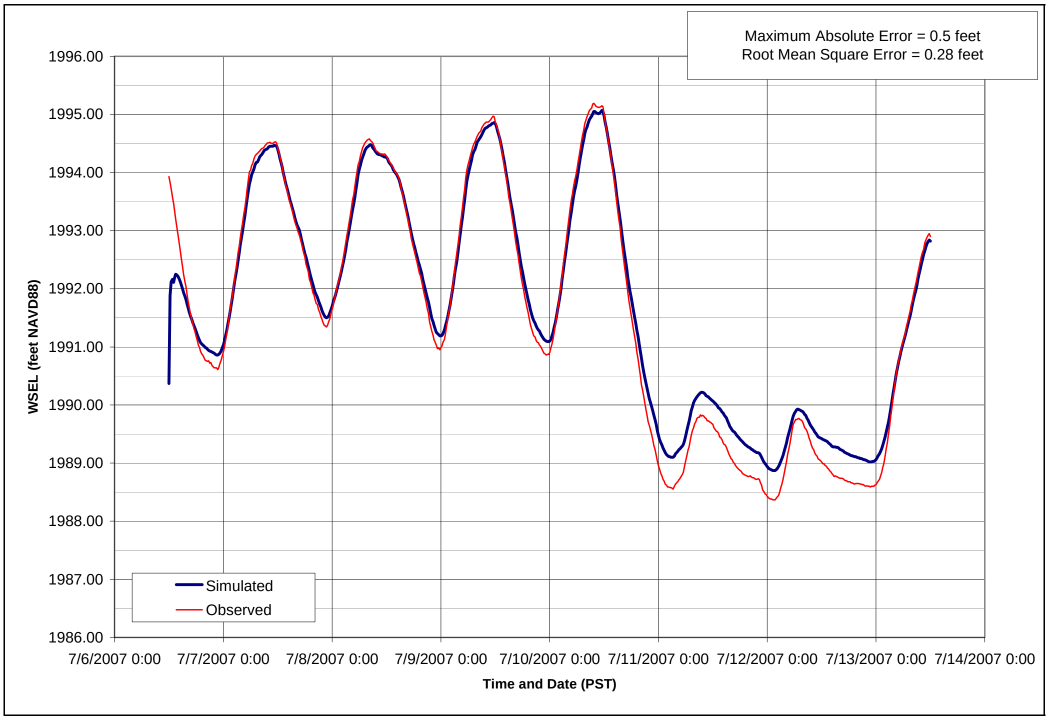


Figure A.1-69. Model calibration results for Lo_Mod Verification Period at USGS Station 12396500 (Auxiliary) Location.

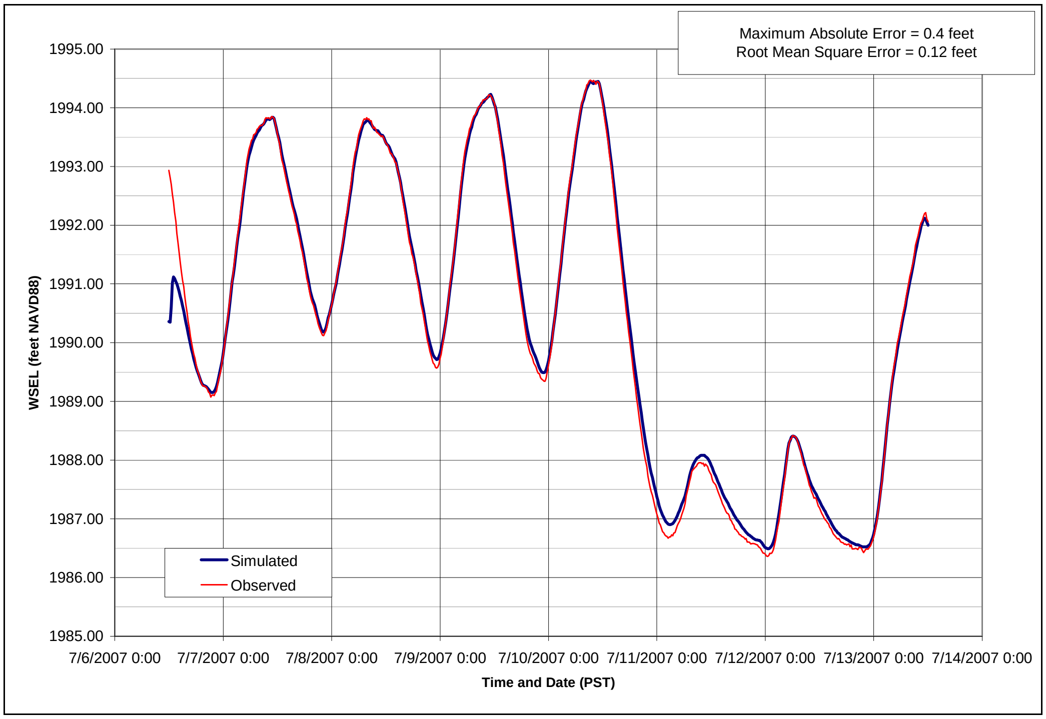


Figure A.1-70. Model calibration results for Lo_Mod Verification Period at US_MET Pressure Transducer Location.

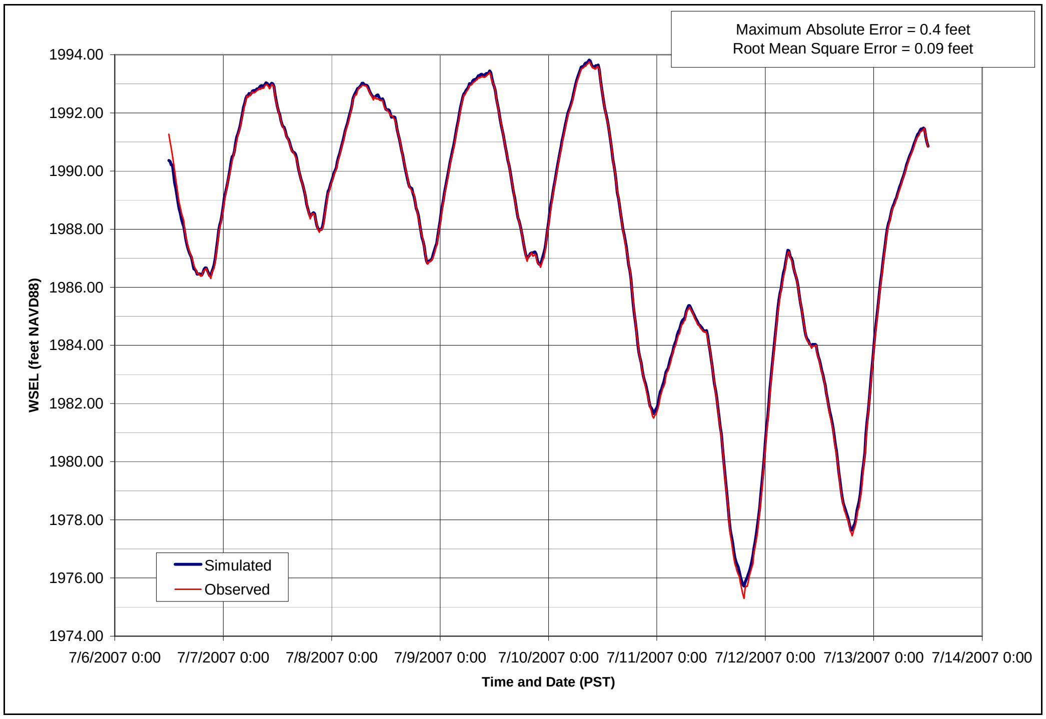


Figure A.1-71. Model calibration results for Lo_Mod Verification Period at DS_MET Pressure Transducer Location.

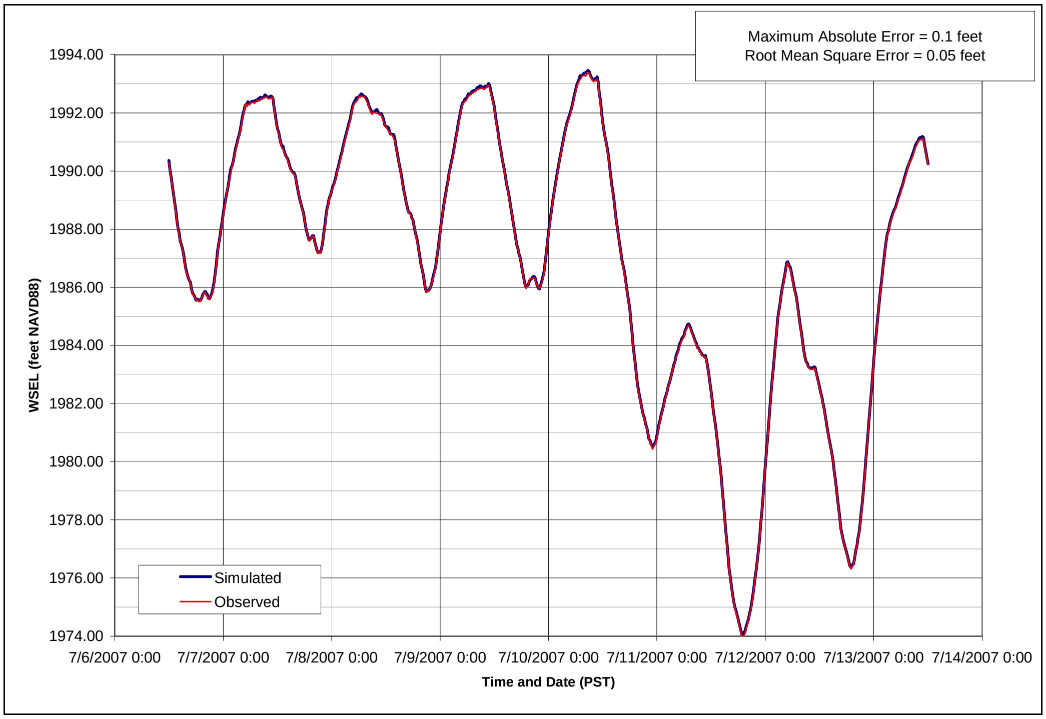


Figure A.1-72. Model calibration results for Lo_Mod Verification Period at CANYON Pressure Transducer Location.

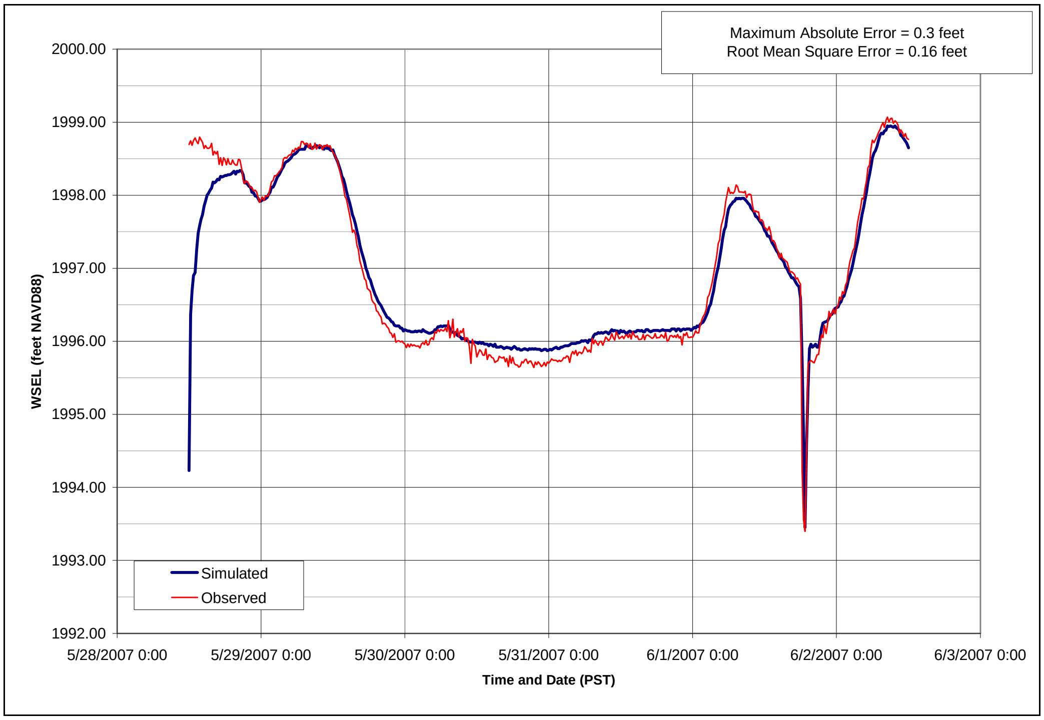


Figure A.1-73. Model calibration results for Lo_Hi Verification Period at BOX_TR Pressure Transducer Location.

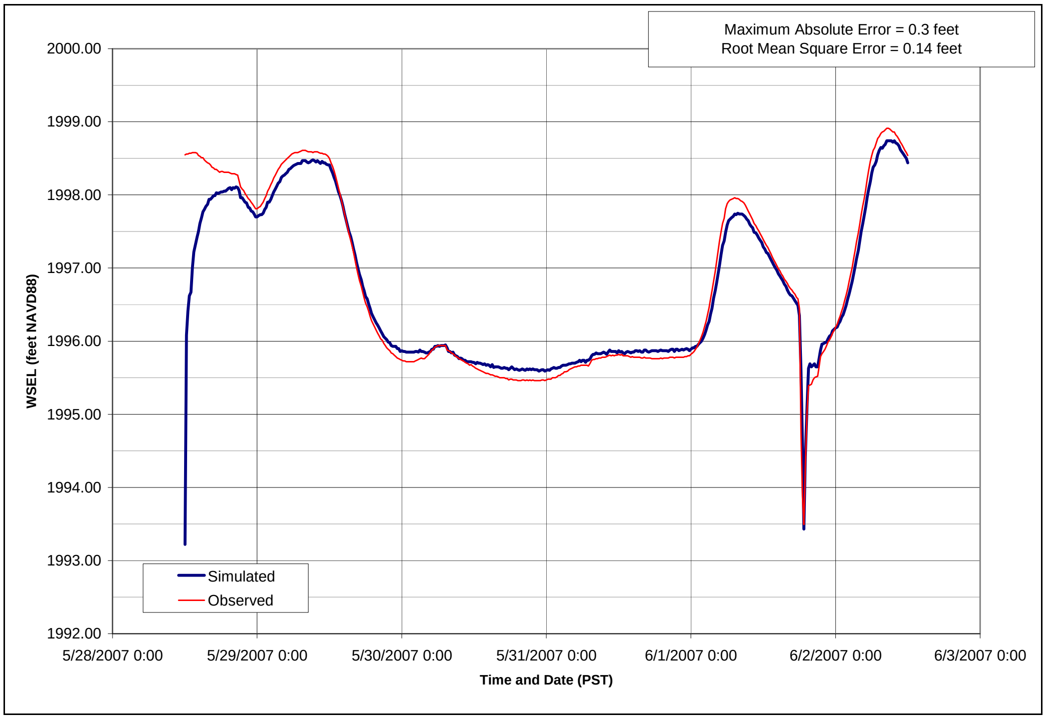


Figure A.1-74. Model calibration results for Lo_Hi Verification Period at USGS Station 12396500 (Primary) Location.

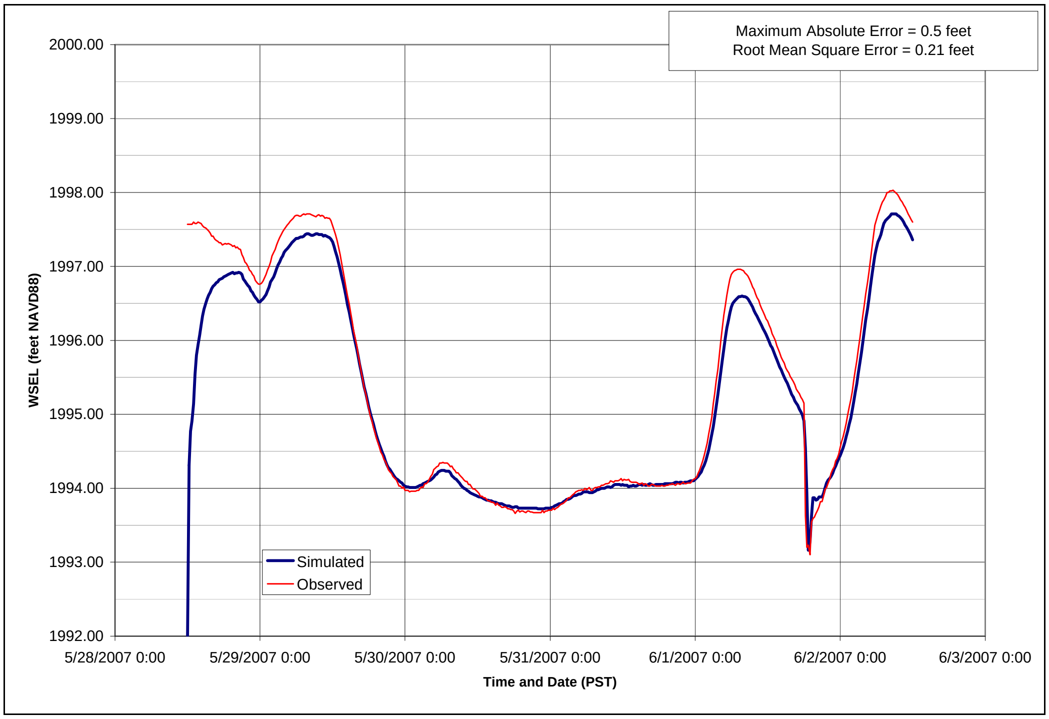


Figure A.1-75. Model calibration results for Lo_Hi Verification Period at USGS Station 12396500 (Auxiliary) Location.

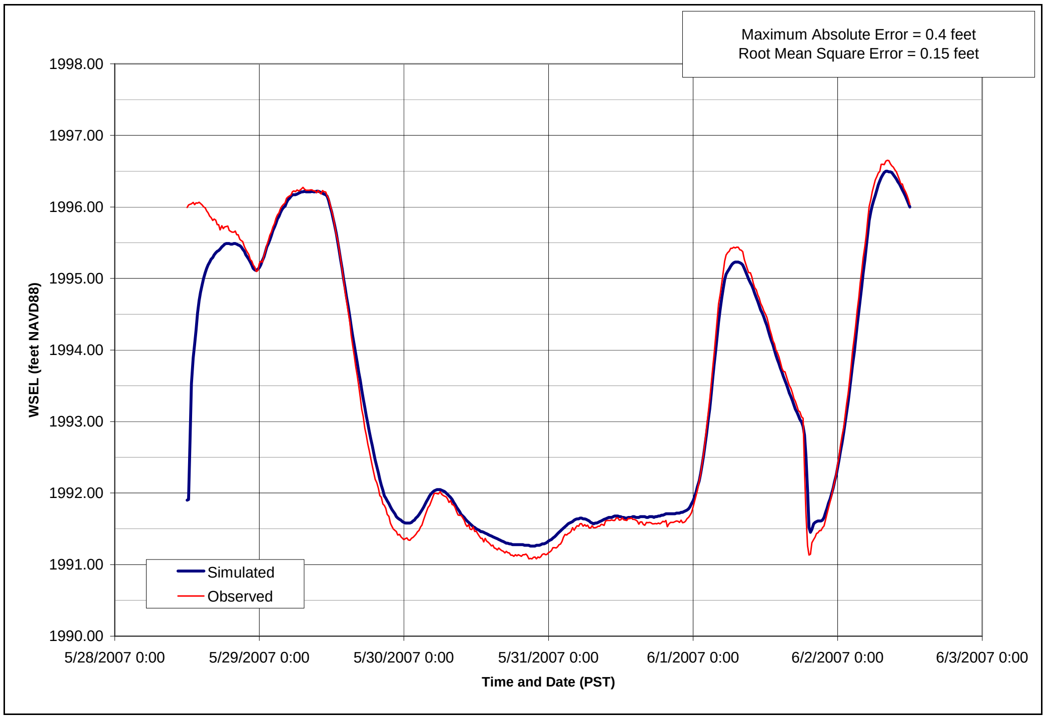


Figure A.1-76. Model calibration results for Lo_Hi Verification Period at US_MET Pressure Transducer Location.

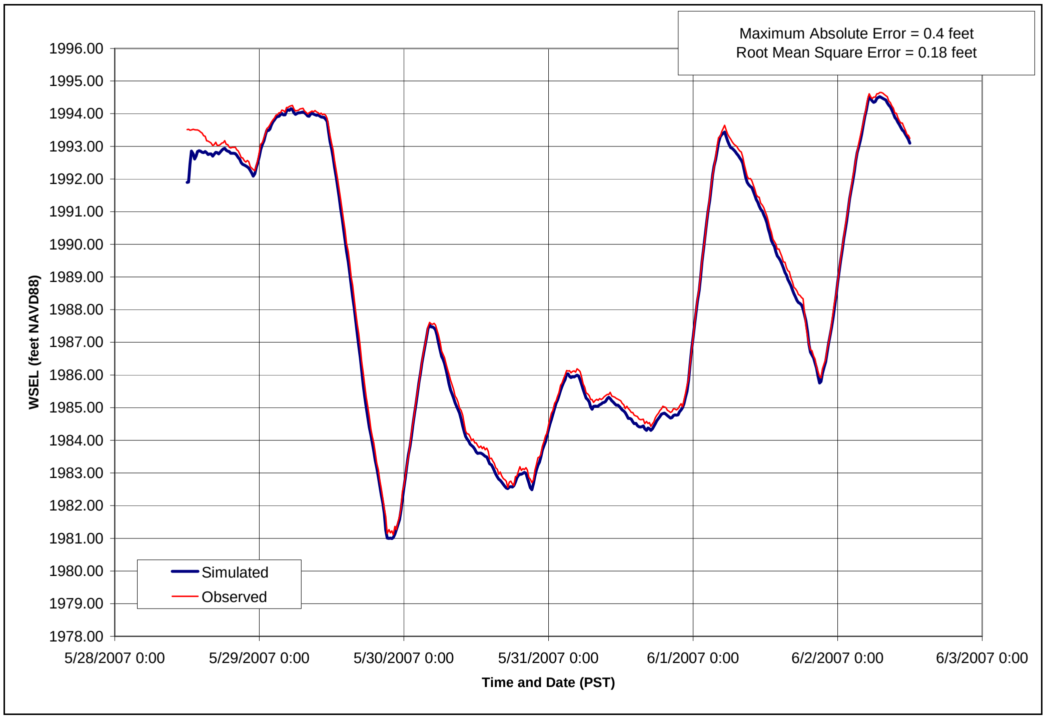


Figure A.1-77. Model calibration results for Lo_Hi Verification Period at DS_MET Pressure Transducer Location.

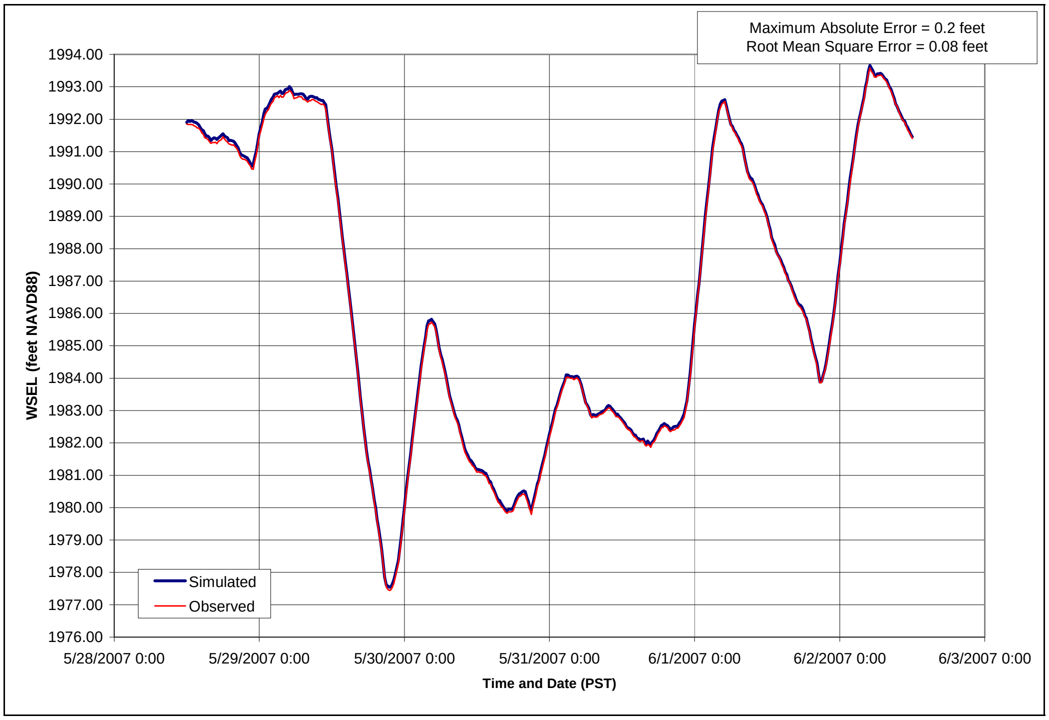
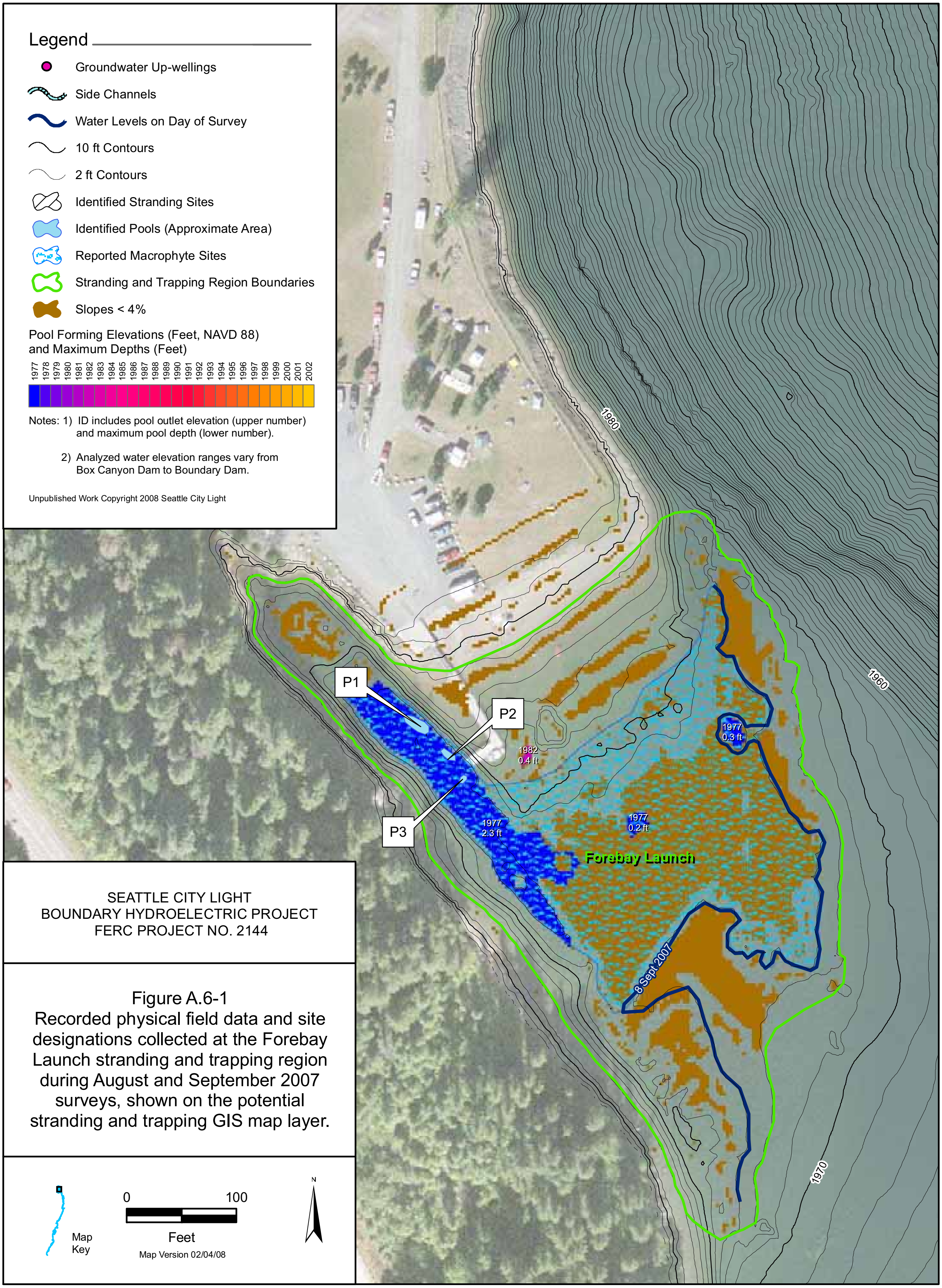


Figure A.1-78. Model calibration results for Lo_Hi Verification Period at CANYON Pressure Transducer Location.

Appendix 6. Stranding and Trapping Field Surveys (Study 7.5) Region Site Maps, Photographs, and Observation Table

List of Figures

List of Tables



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-1
Recorded physical field data and site designations collected at the Forebay Launch stranding and trapping region during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

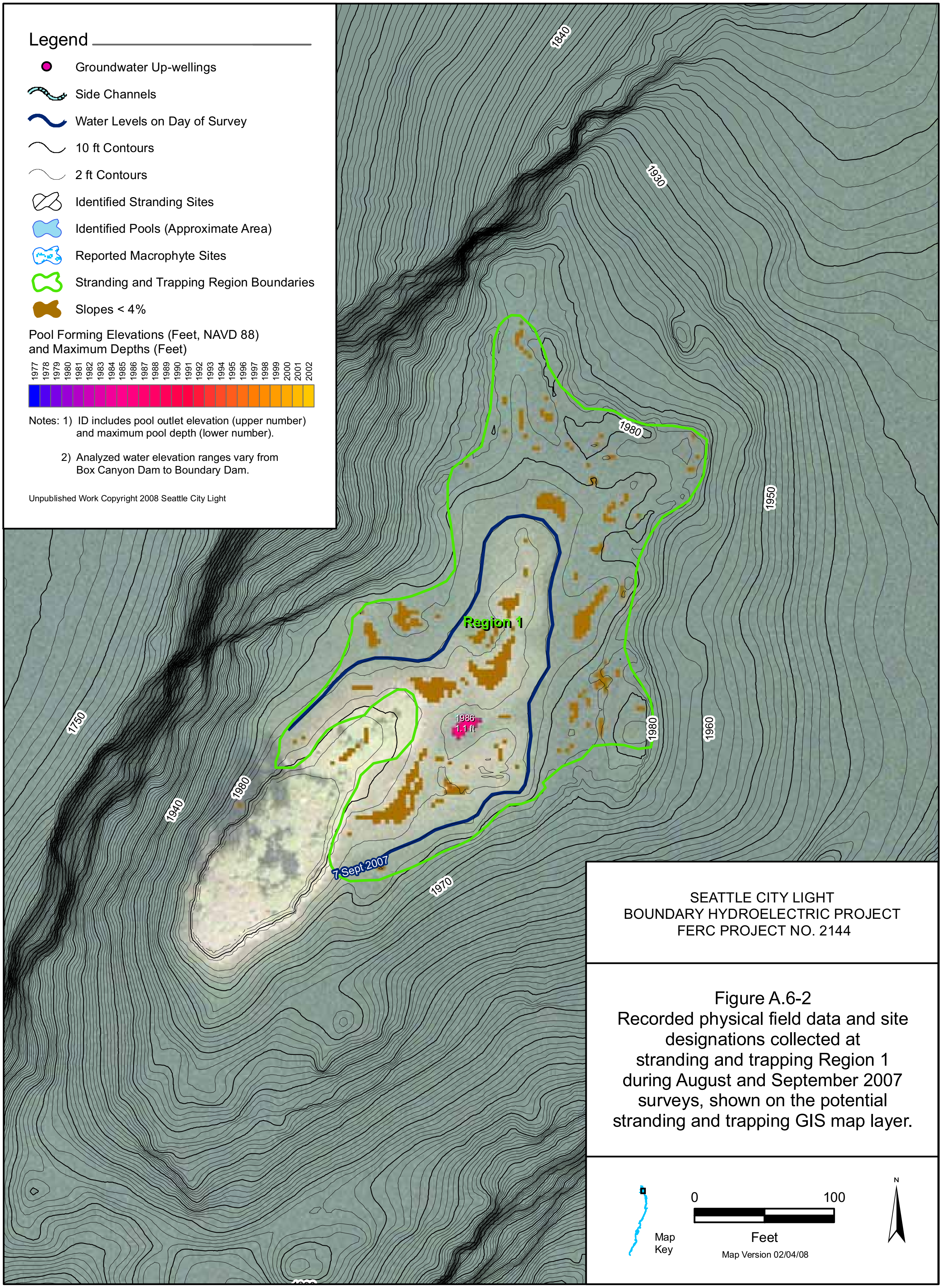
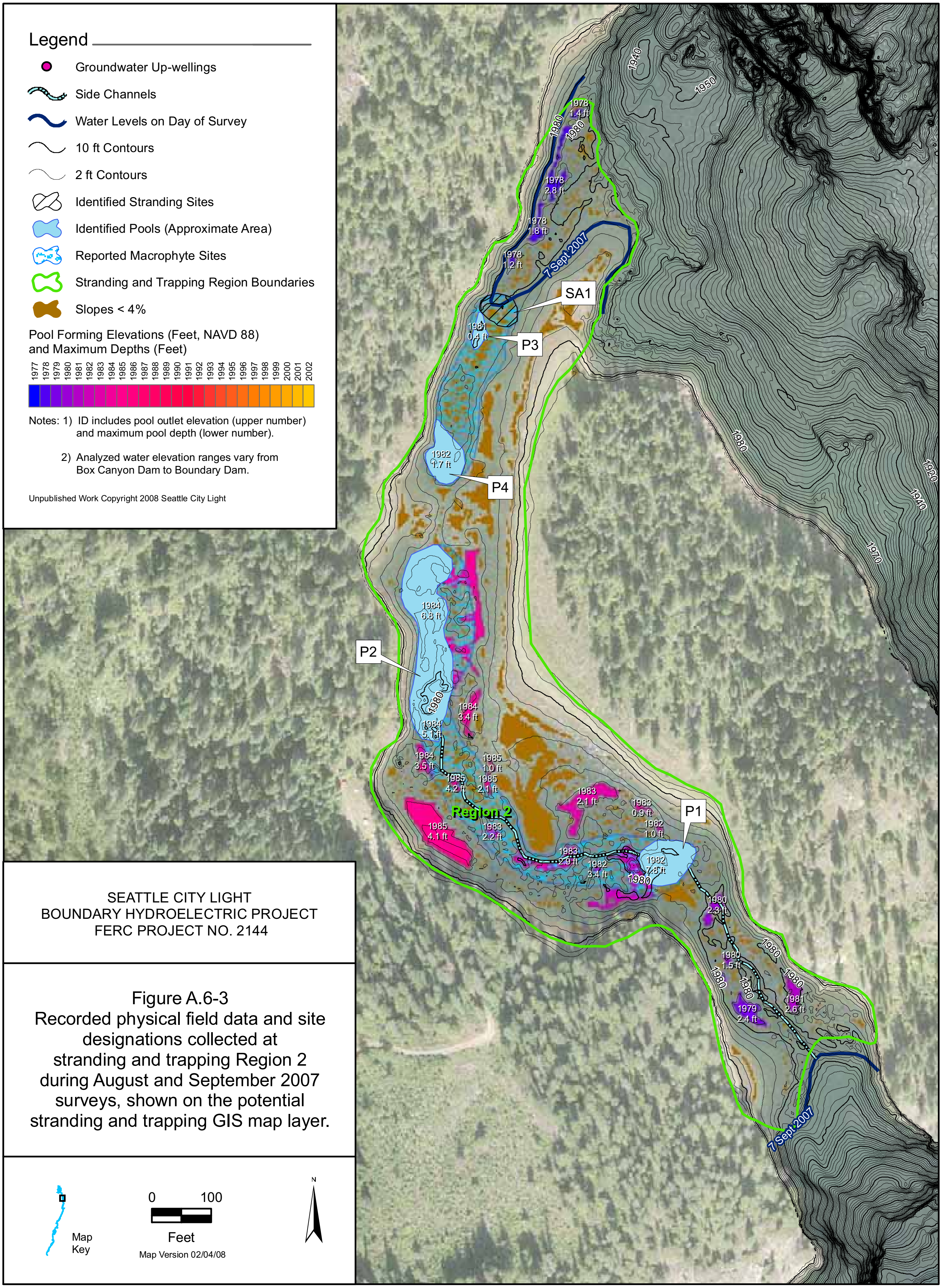
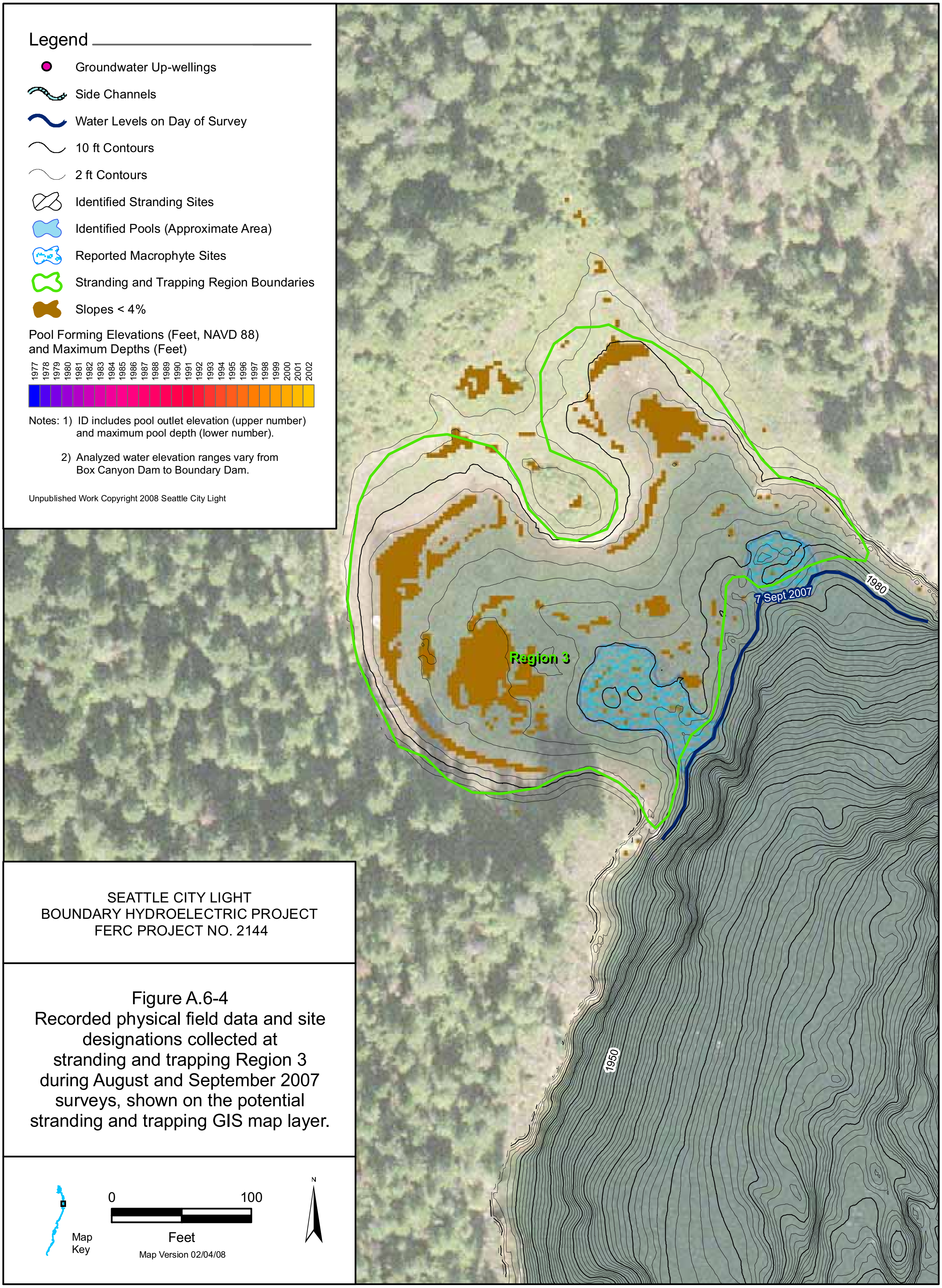


Figure A.6-2
Recorded physical field data and site designations collected at stranding and trapping Region 1 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



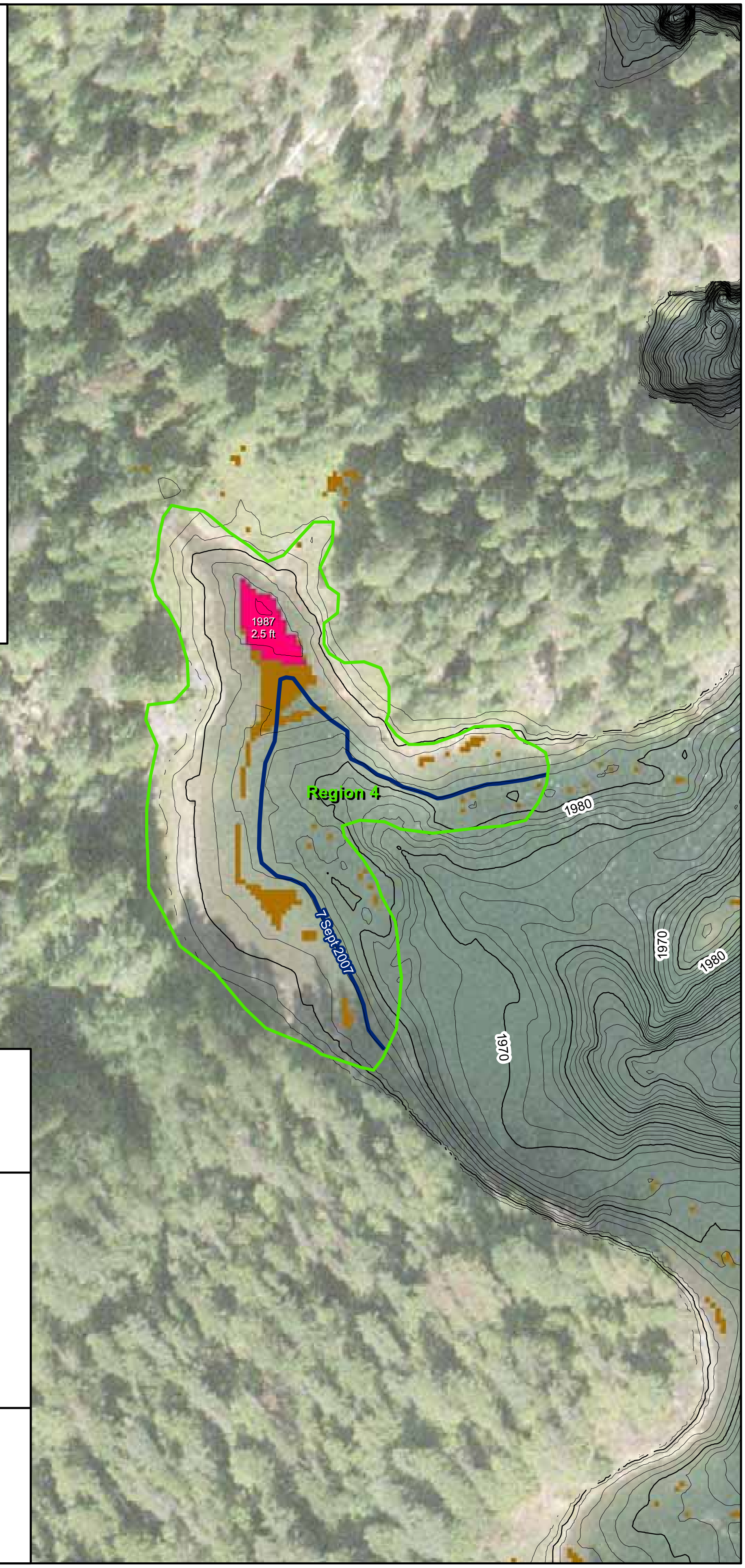
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-3
Recorded physical field data and site designations collected at stranding and trapping Region 2 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-4
Recorded physical field data and site designations collected at stranding and trapping Region 3 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



Legend

- Groundwater Up-wellings
- Side Channels
- Water Levels on Day of Survey
- 10 ft Contours
- 2 ft Contours
- Identified Stranding Sites
- Identified Pools (Approximate Area)
- Reported Macrophyte Sites
- Stranding and Trapping Region Boundaries
- Slopes < 4%

Pool Forming Elevations (Feet, NAVD 88)
and Maximum Depths (Feet)

1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002

Notes: 1) ID includes pool outlet elevation (upper number) and maximum pool depth (lower number).

2) Analyzed water elevation ranges vary from Box Canyon Dam to Boundary Dam.

SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-5
Recorded physical field data and site designations collected at stranding and trapping Region 4 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

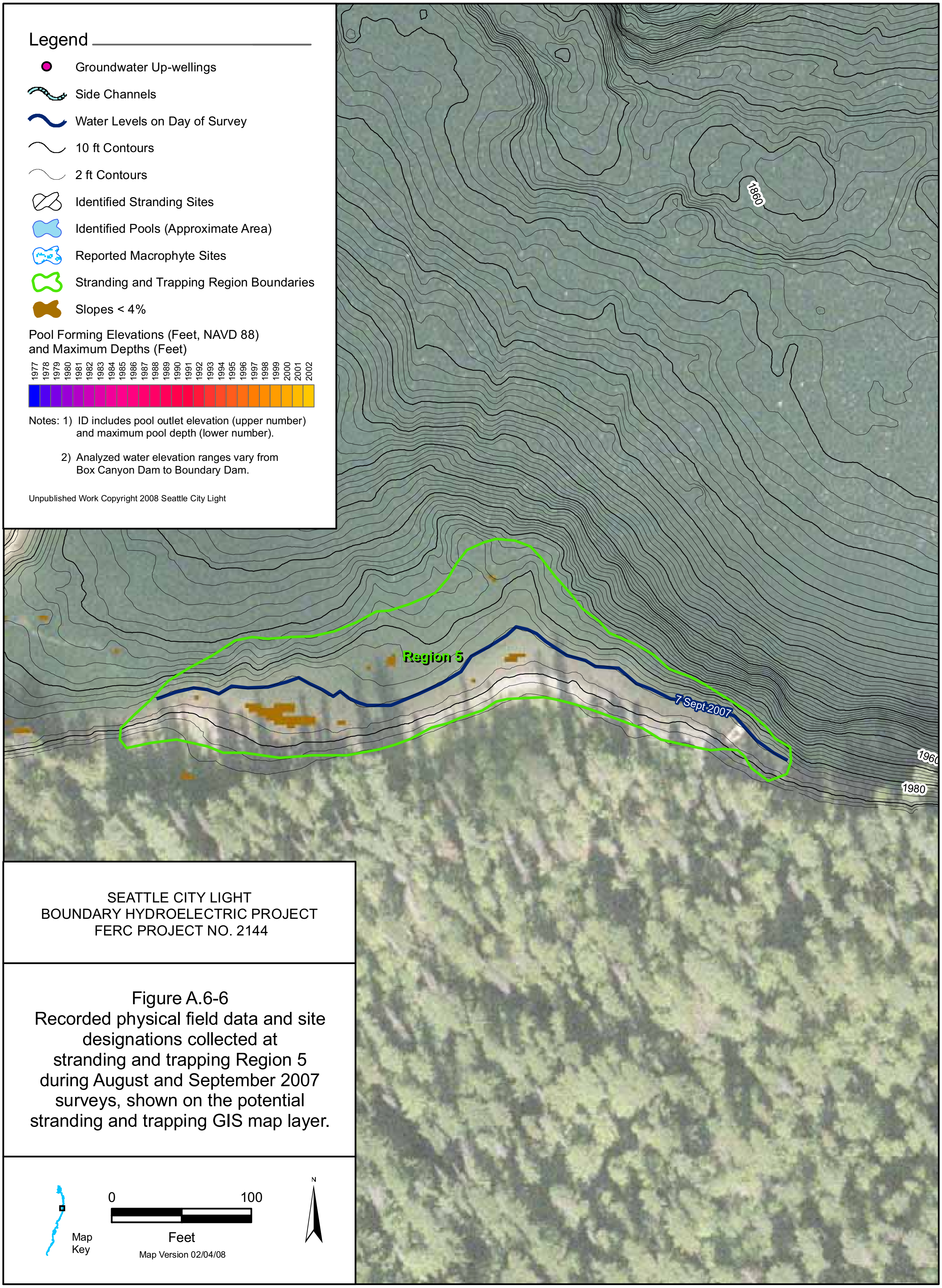
Map Key

0 100

Feet

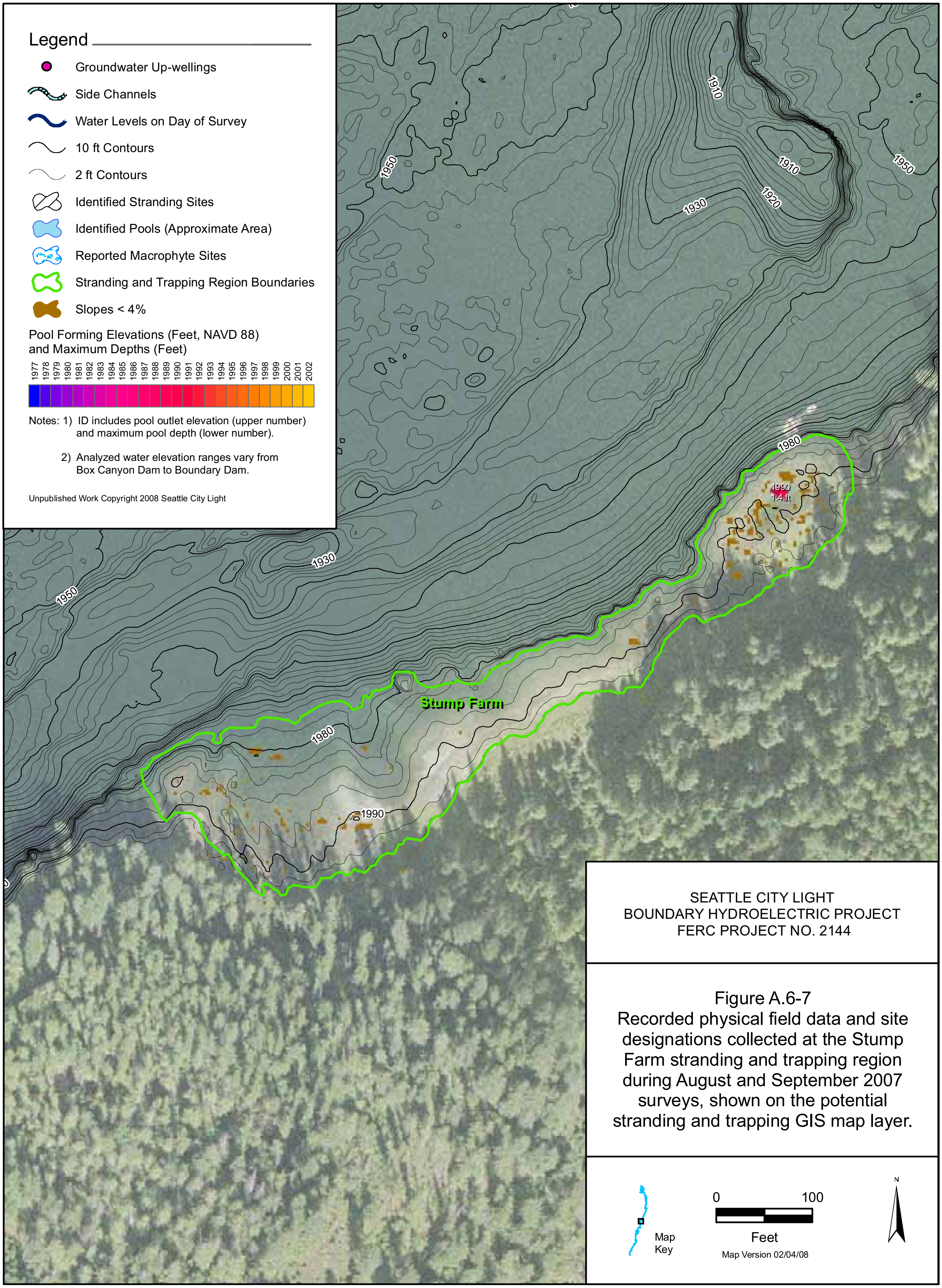
N

Map Version 02/04/08



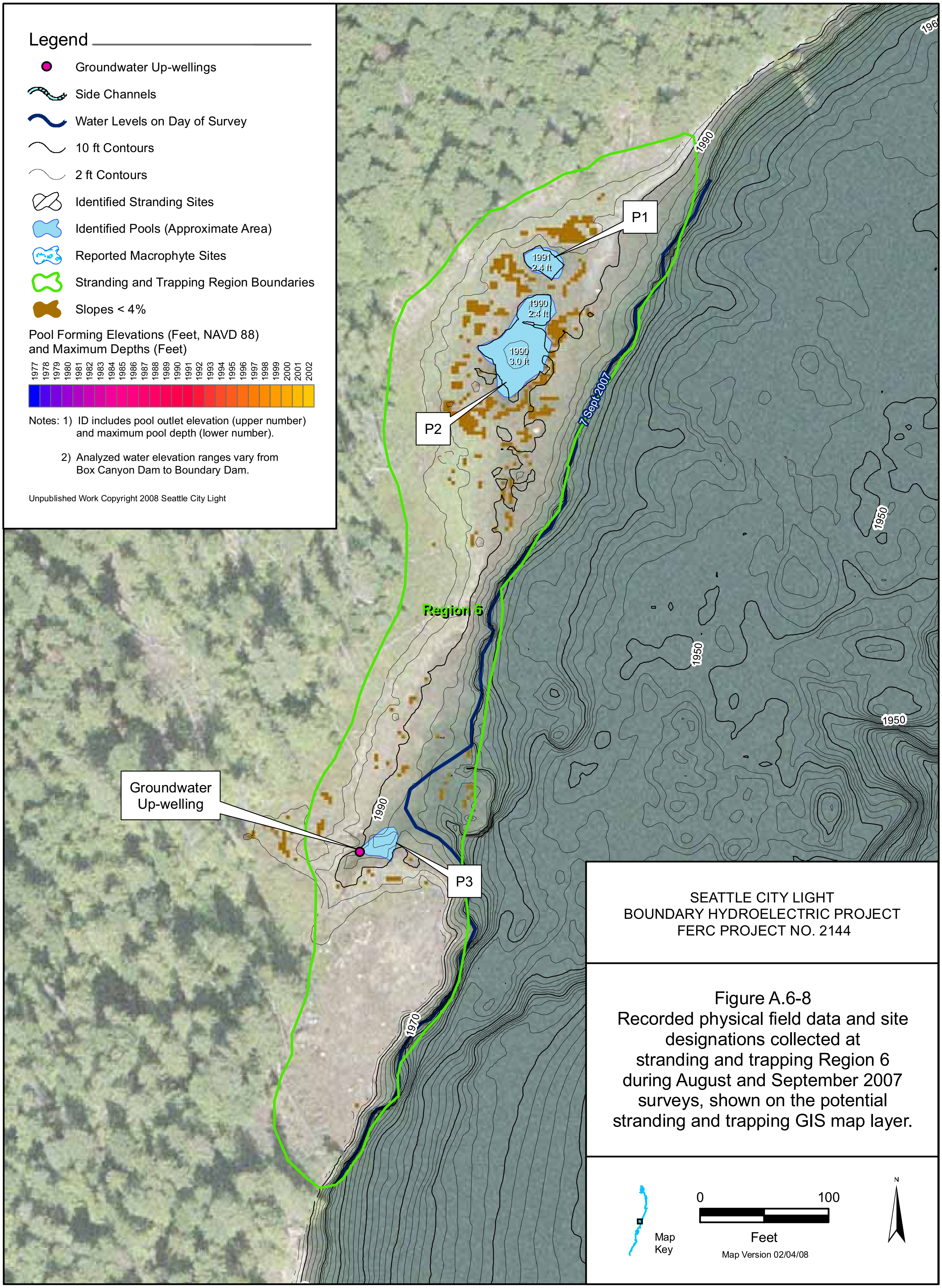
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-6
Recorded physical field data and site designations collected at stranding and trapping Region 5 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



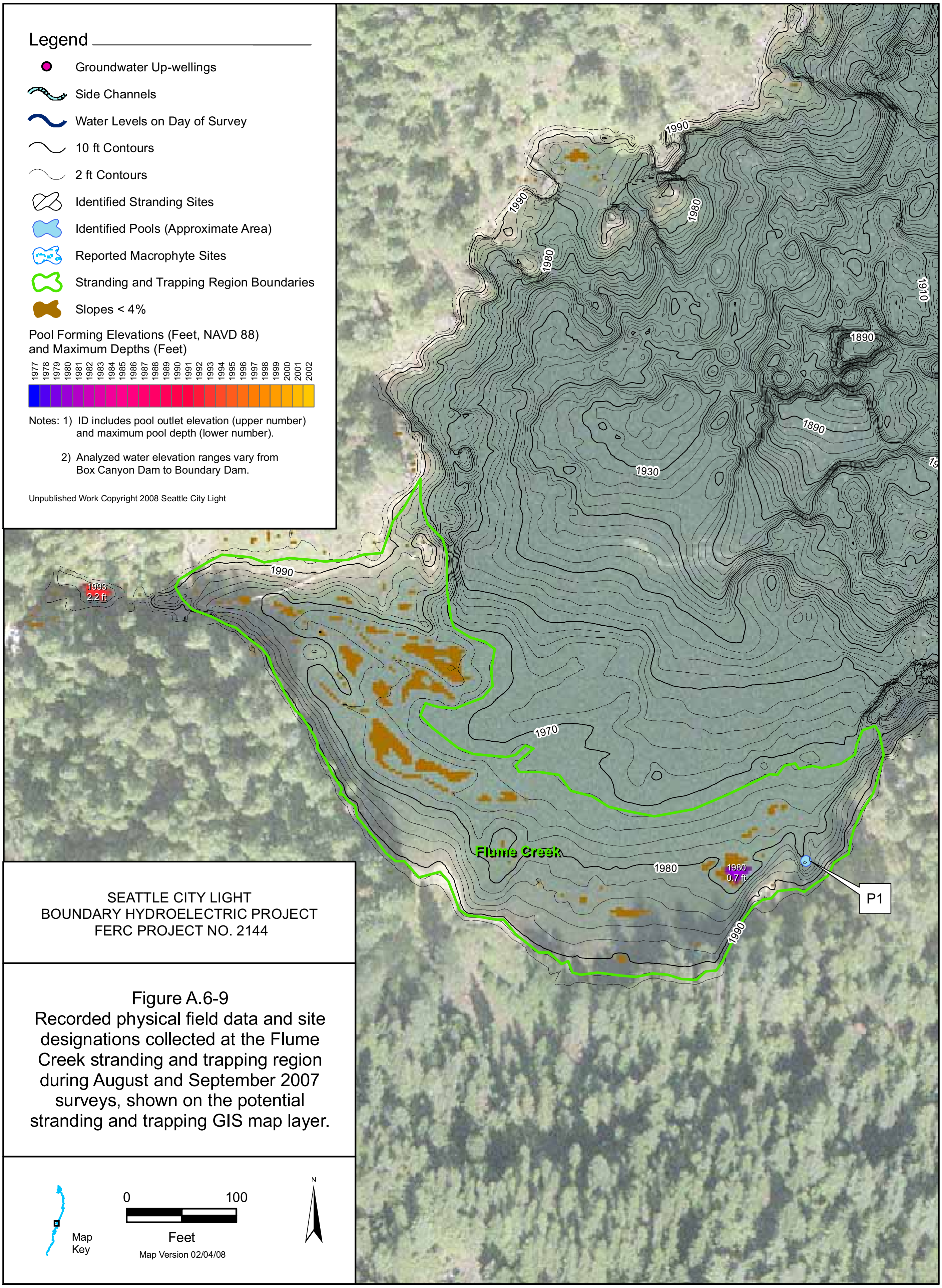
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-7
Recorded physical field data and site designations collected at the Stump Farm stranding and trapping region during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



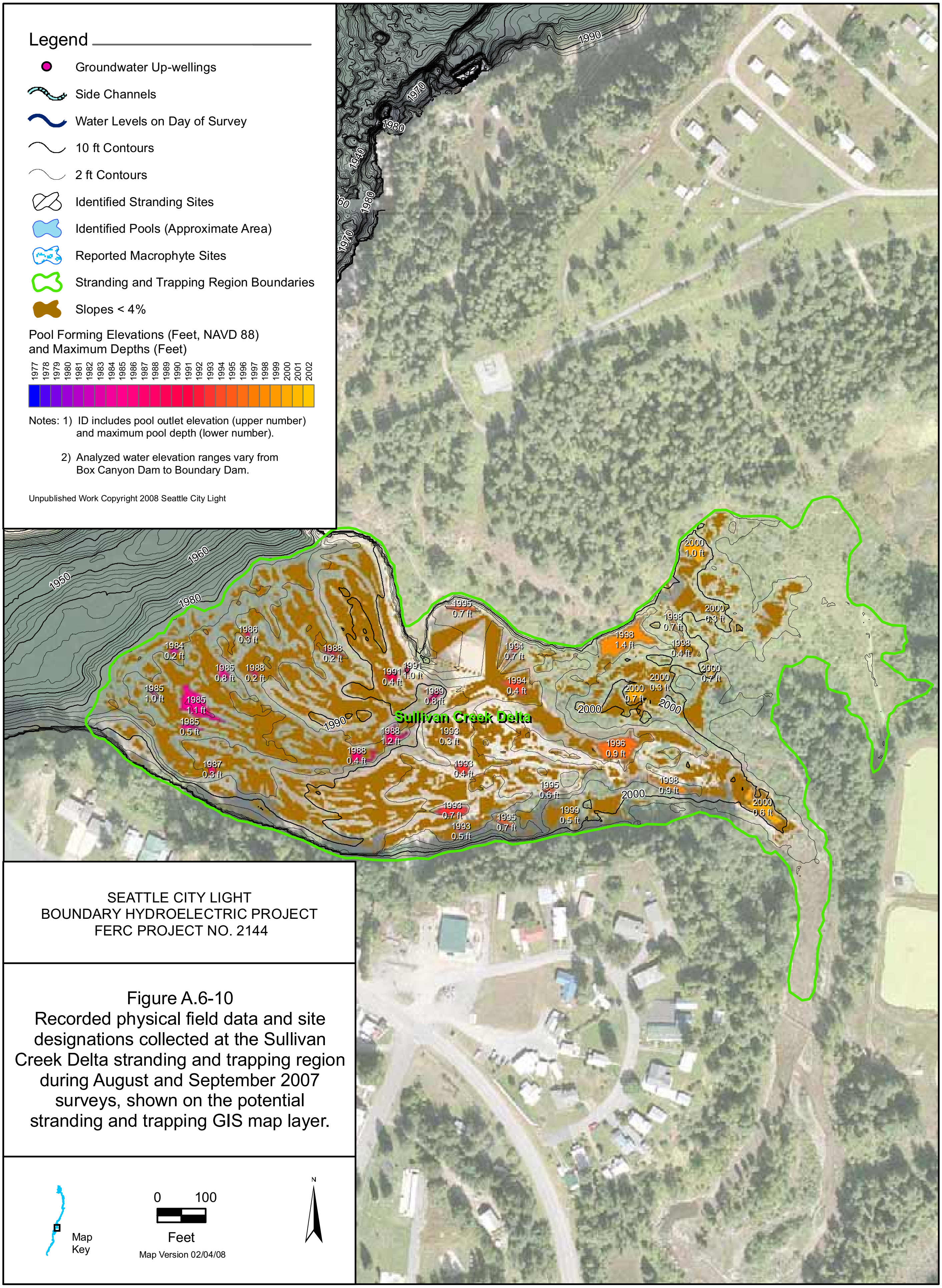
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-8
Recorded physical field data and site designations collected at stranding and trapping Region 6 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-9
Recorded physical field data and site designations collected at the Flume Creek stranding and trapping region during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-10
Recorded physical field data and site designations collected at the Sullivan Creek Delta stranding and trapping region during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

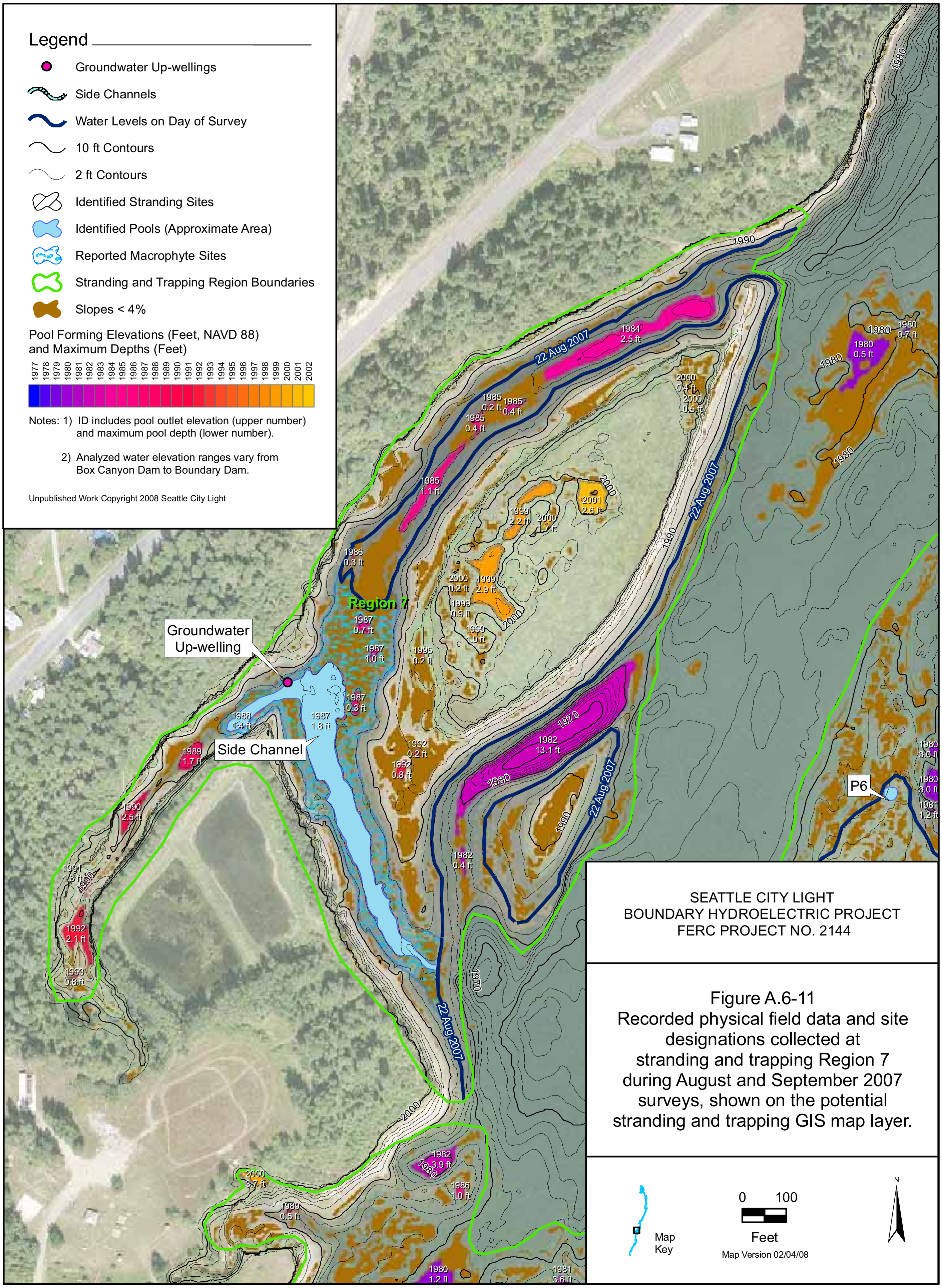
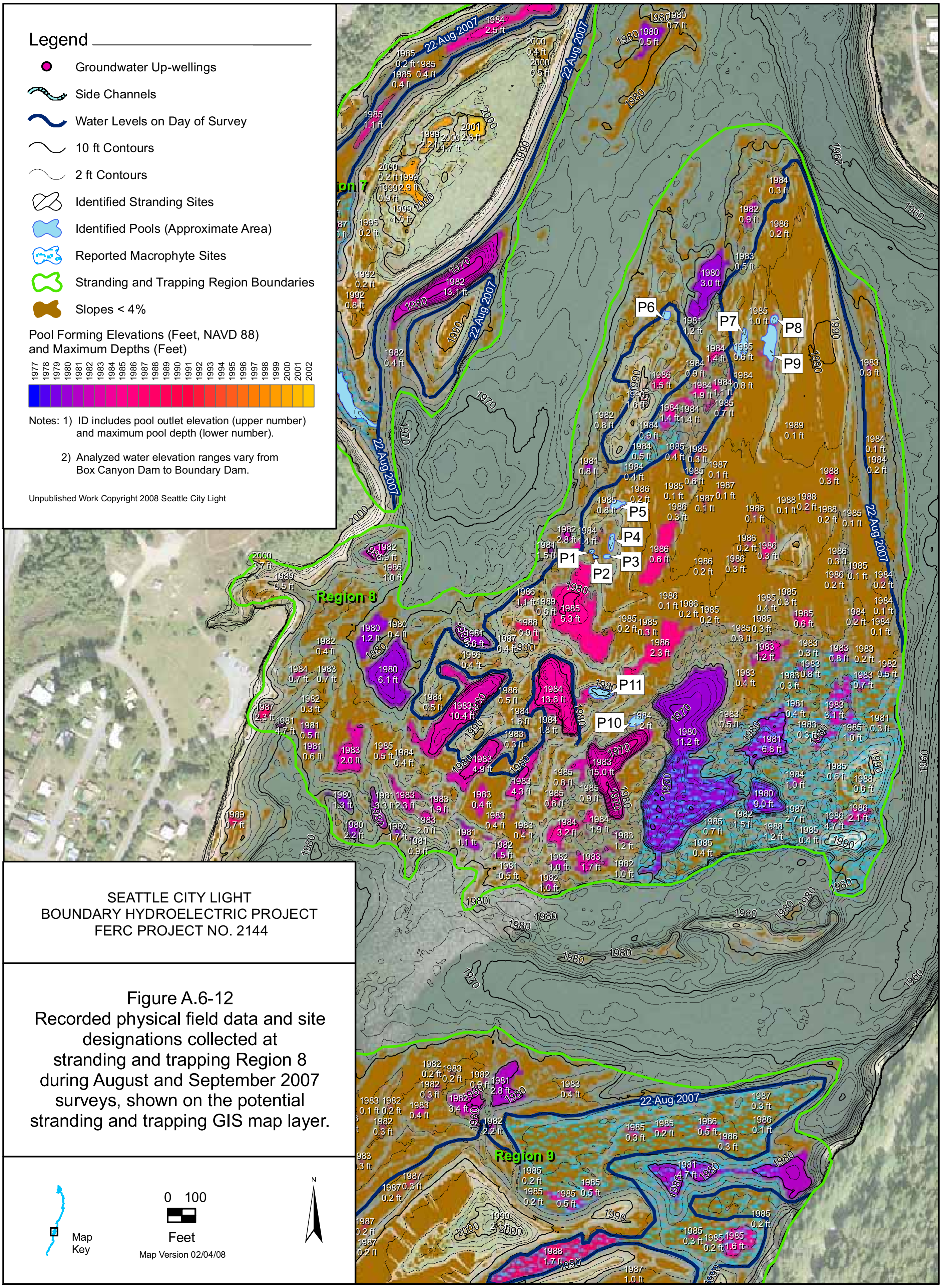
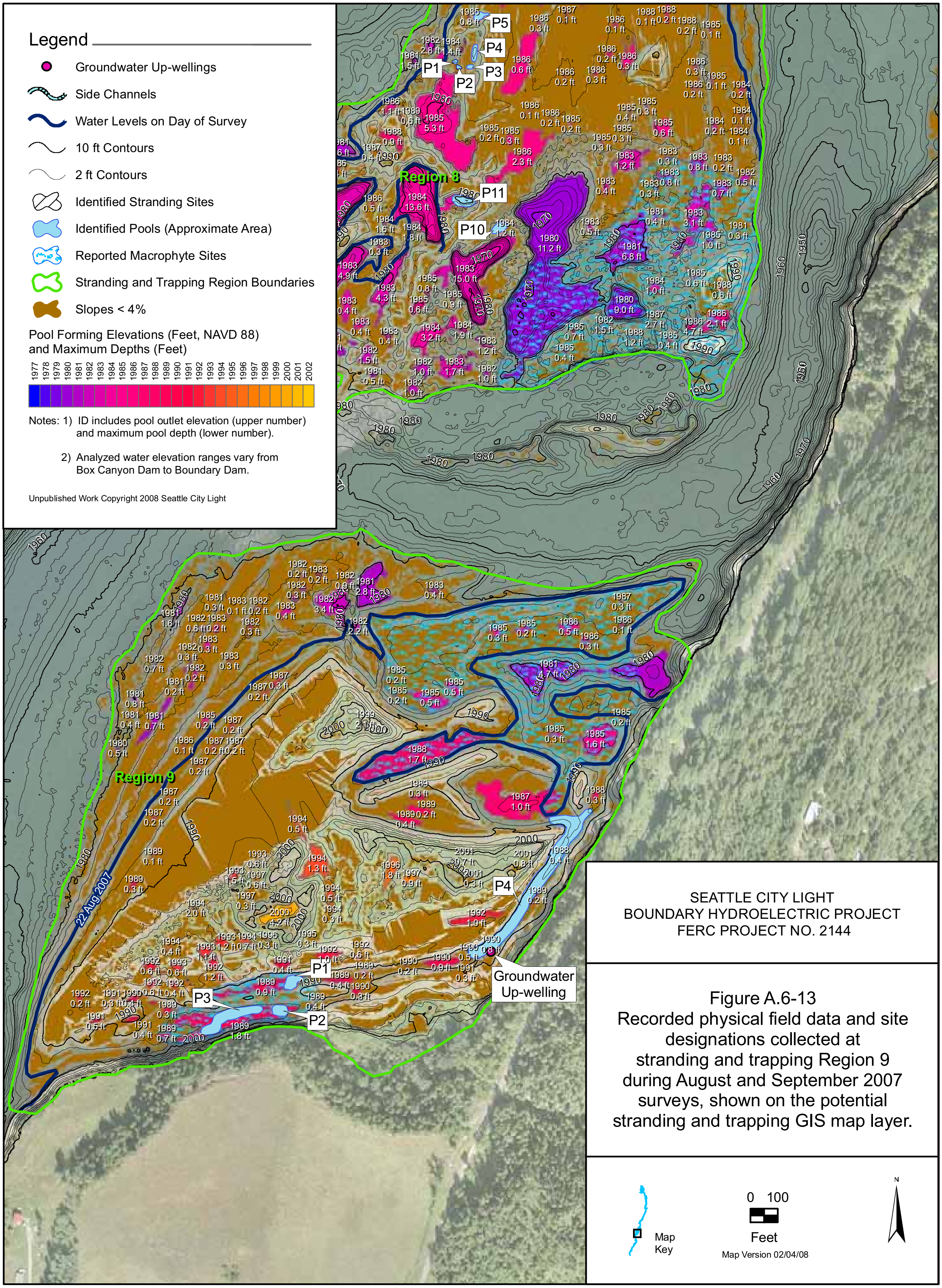


Figure A.6-11
Recorded physical field data and site designations collected at stranding and trapping Region 7 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



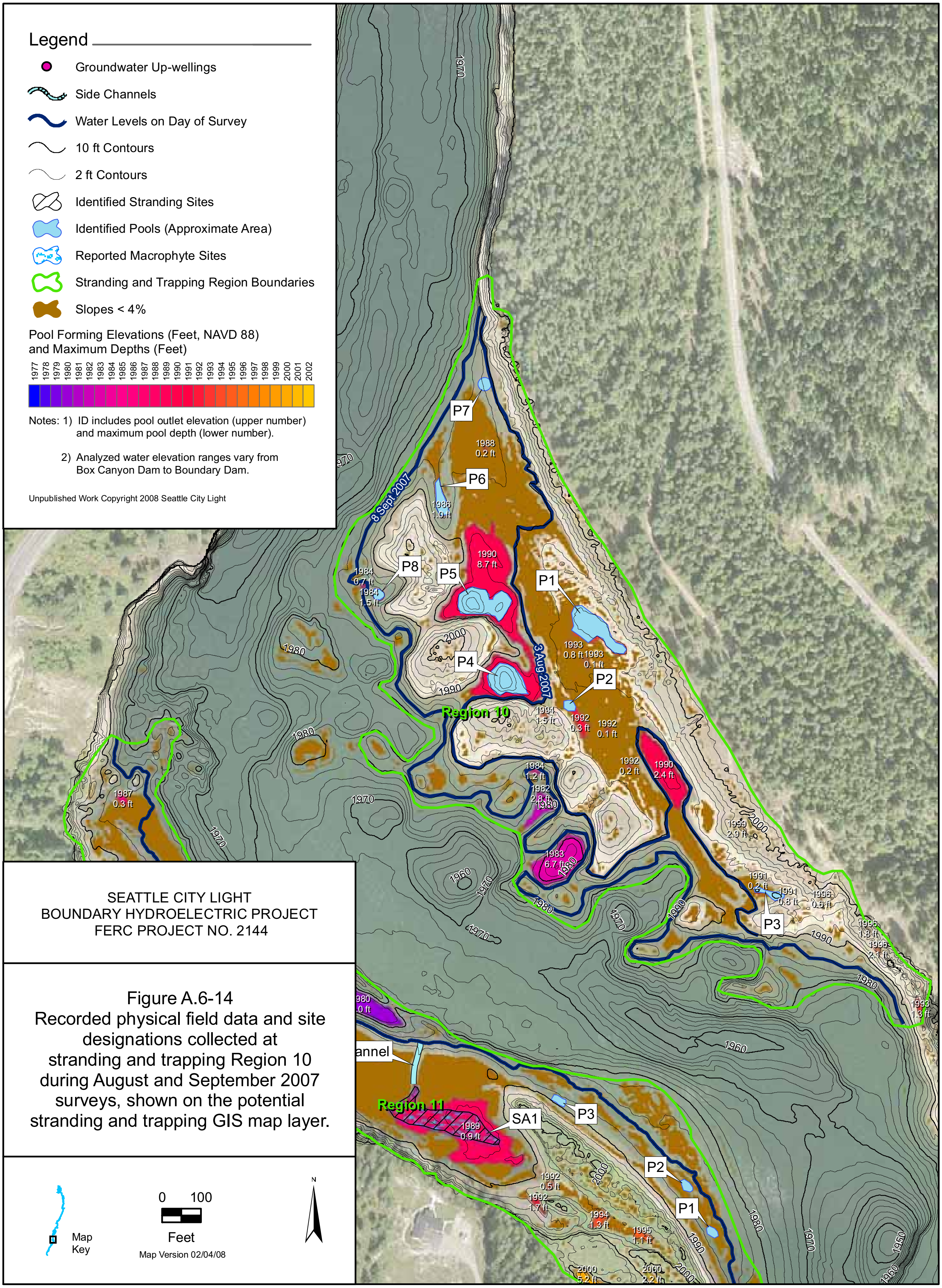
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-12
Recorded physical field data and site designations collected at stranding and trapping Region 8 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-13
Recorded physical field data and site designations collected at stranding and trapping Region 9 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-14
Recorded physical field data and site designations collected at stranding and trapping Region 10 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

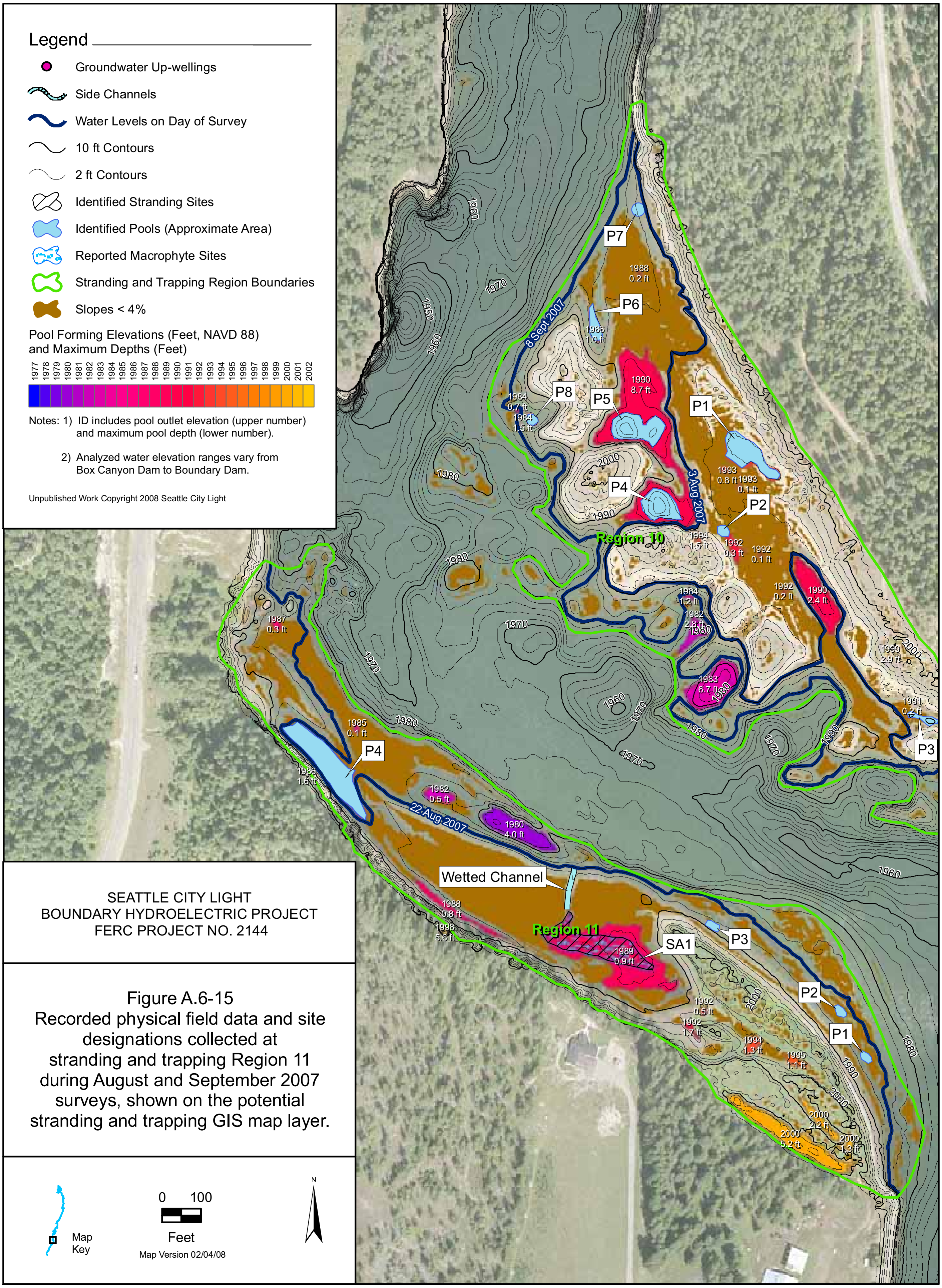
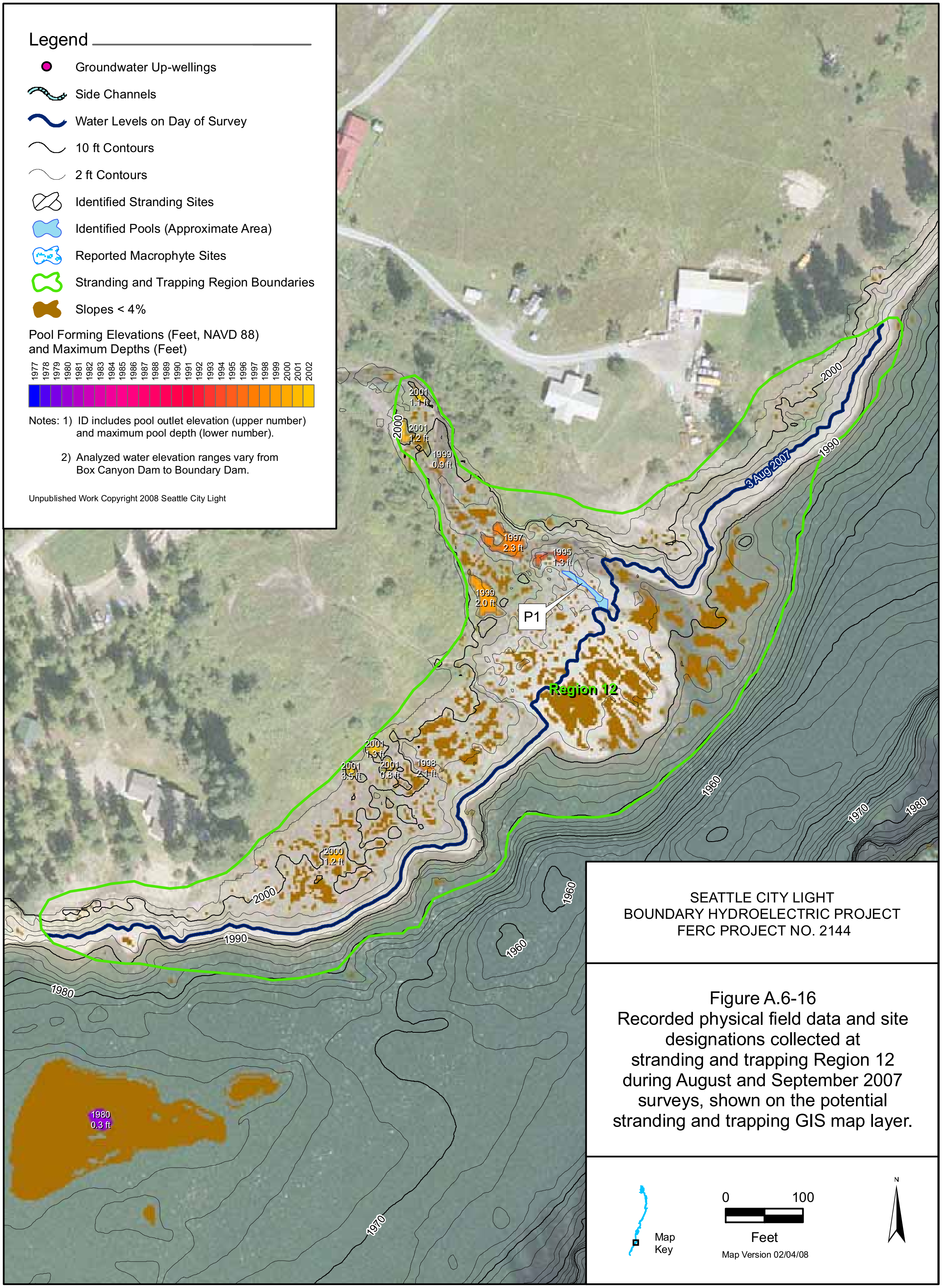
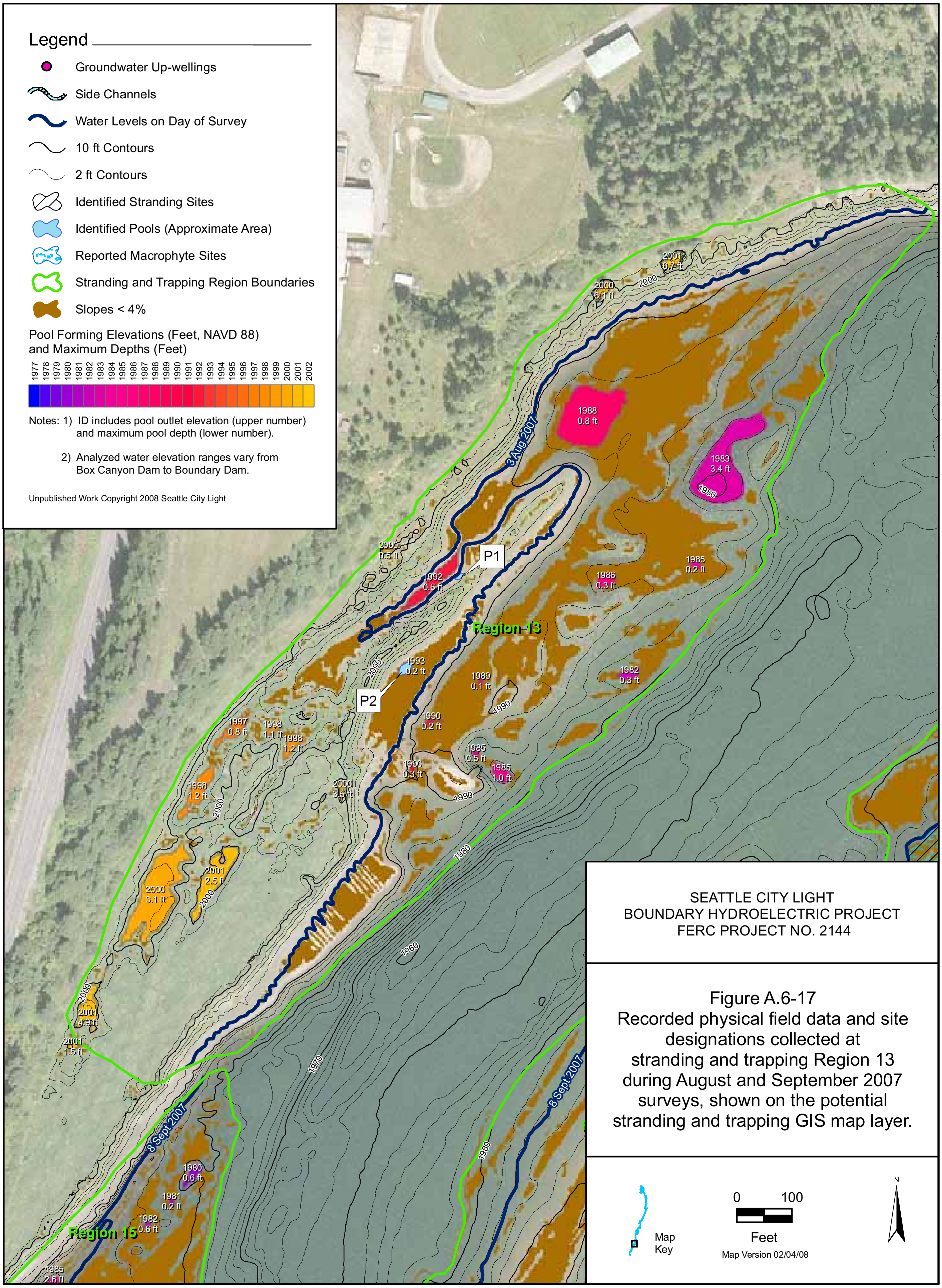


Figure A.6-15
Recorded physical field data and site designations collected at stranding and trapping Region 11 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-16
Recorded physical field data and site designations collected at stranding and trapping Region 12 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-17
Recorded physical field data and site designations collected at stranding and trapping Region 13 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

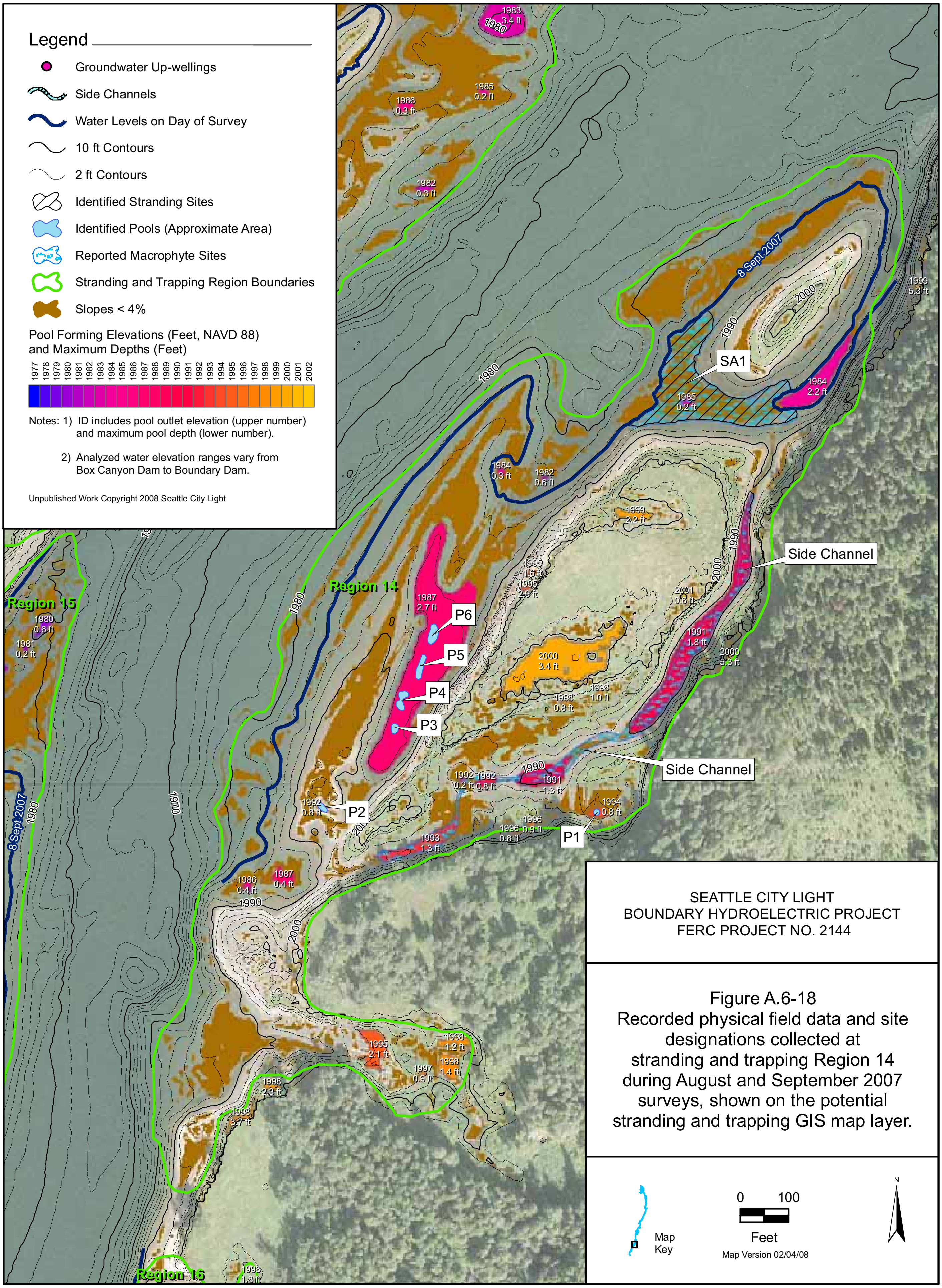
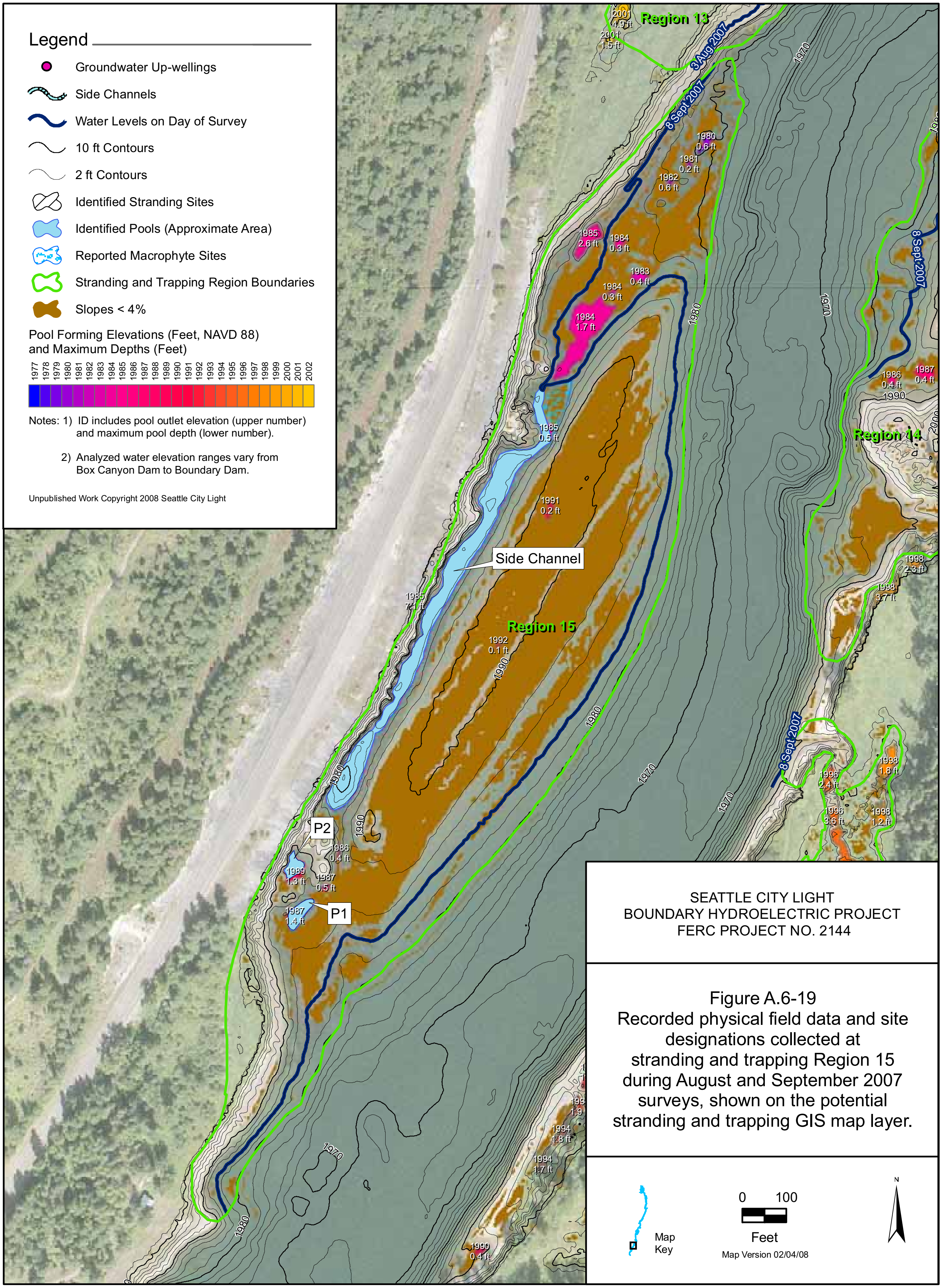
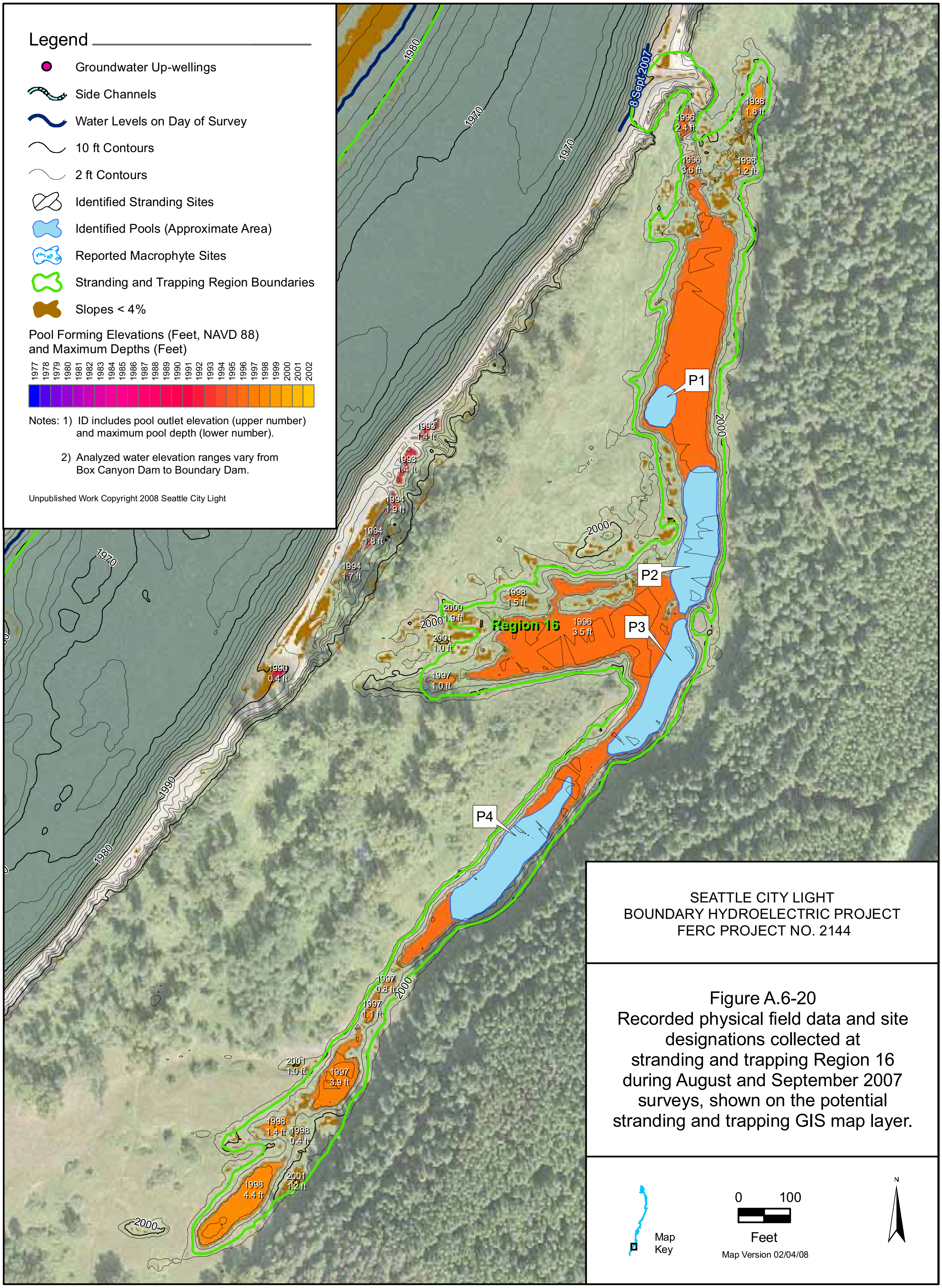


Figure A.6-18
Recorded physical field data and site designations collected at stranding and trapping Region 14 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-19
Recorded physical field data and site designations collected at stranding and trapping Region 15 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-20
Recorded physical field data and site designations collected at stranding and trapping Region 16 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

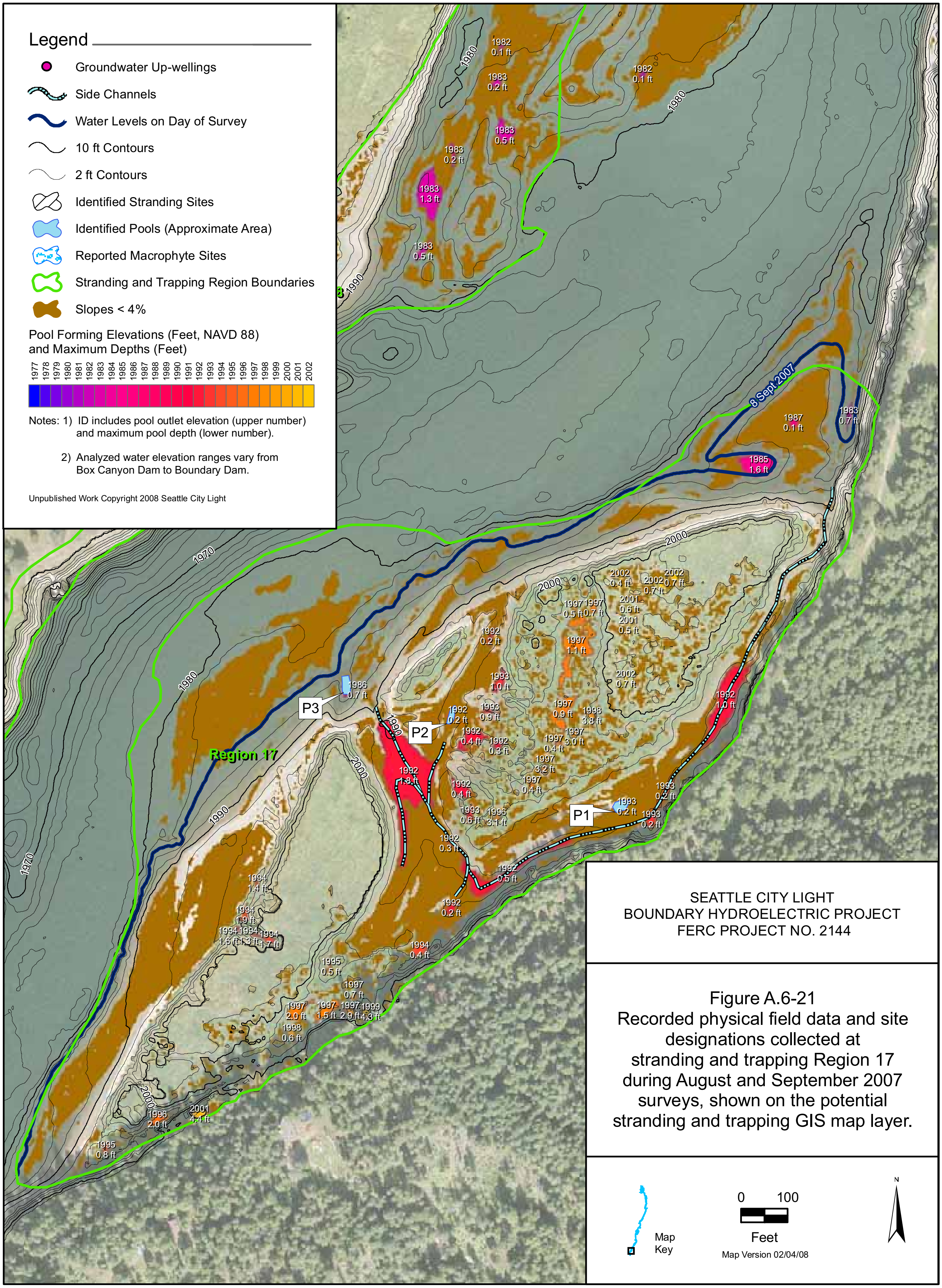
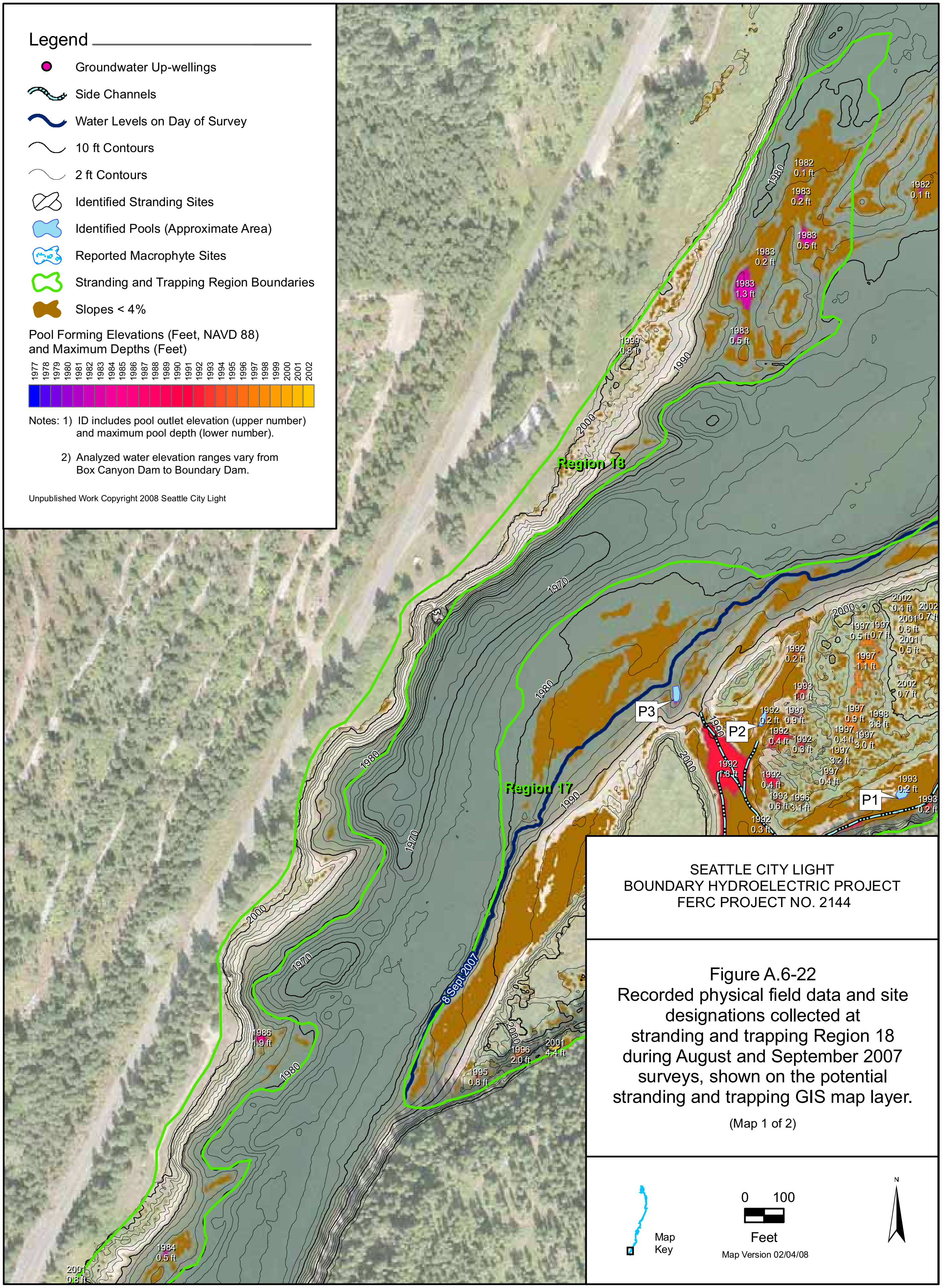
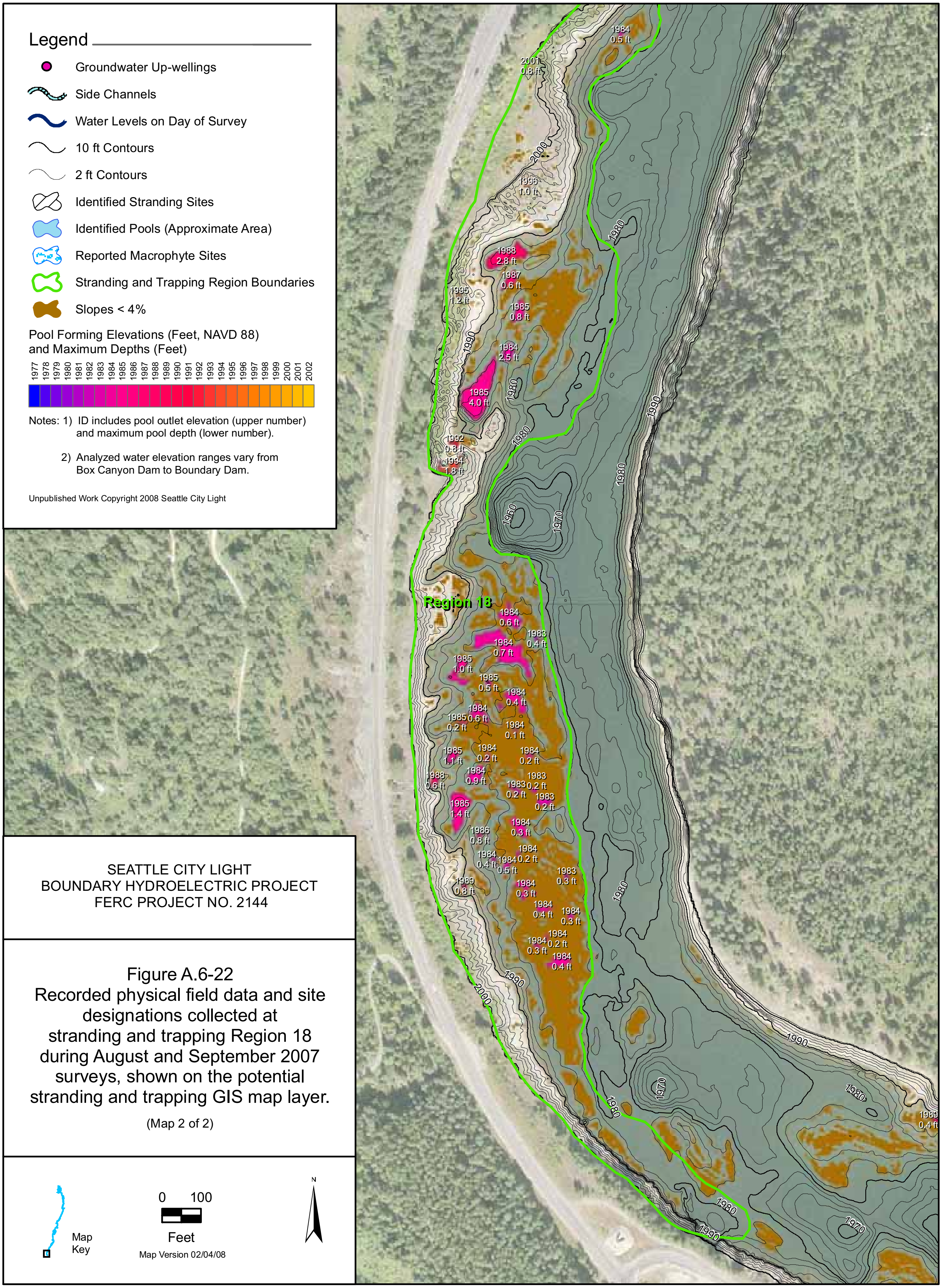


Figure A.6-21
Recorded physical field data and site designations collected at stranding and trapping Region 17 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.



SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-22
Recorded physical field data and site designations collected at stranding and trapping Region 18 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.
(Map 1 of 2)



Legend

- Groundwater Up-wellings
- Side Channels
- Water Levels on Day of Survey
- 10 ft Contours
- 2 ft Contours
- Identified Stranding Sites
- Identified Pools (Approximate Area)
- Reported Macrophyte Sites
- Stranding and Trapping Region Boundaries
- Slopes < 4%

Pool Forming Elevations (Feet, NAVD 88) and Maximum Depths (Feet)

1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002

Notes: 1) ID includes pool outlet elevation (upper number) and maximum pool depth (lower number).

2) Analyzed water elevation ranges vary from Box Canyon Dam to Boundary Dam.

SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144

Figure A.6-22
Recorded physical field data and site designations collected at stranding and trapping Region 18 during August and September 2007 surveys, shown on the potential stranding and trapping GIS map layer.

(Map 2 of 2)

Map
Key

0 100
Feet

Map Version 02/04/08

N

Figure A.6-23. Upstream view of Pool 2 from ridge in sidechannel at Region 2 (Everett Island) during survey on September 7, 2007.

Figure A.6-24. Pool 3 and Stranding Area 1 at Region 2 (Everett Island) during survey on September 7, 2007.

Figure A.6-25. Downstream view of sidechannel at Region 16 during survey on August 3, 2007.

.

Figure A.6-26. Downstream view of sidechannel at Region 16 during survey on September 8, 2007.

Figure A.6-27. Upstream view of Pool 8 and Pool 9 at Region 8 during survey on August 22, 2007.

.

Figure A.6-28. View towards West bank of Boundary Reservoir of Pool 8 and a pool still connected to the mainstem reservoir at Region 10 during survey on September 8, 2007.

Table A.6-1. Fish observations during stranding and trapping surveys on Boundary Reservoir, July 11 and 12, 2007.

Region	Region Description	Date	Species	Life Stage[1]	Number of Fish Observed	Length (mm)	Mortality	Habitat Association[2]	Comments
7	Downstream of Metaline Boat Launch	11-Jul	YP, SMB	yoy, juvenile	Hundreds	n/r[3]	N	Side Channel (connected to Mainstem)	Observed among vegetation, some appear entangled
8	Lateral bar on left bank upstream from Metaline launch	11-Jul	SU	yoy	50	n/r[3]	N	Isolated pool	Cobble Interstices, trapped
			SU	yoy, juvenile	100	n/r[3]	N	Isolated pool	Cobble Interstices, trapped
			SU	n/r[3]	50	n/r[3]	Y	Isolated pool	Cobble Interstices, stranded
10	Islands near Wolf Creek	11-Jul	SU	larval/yoy	~ 500	n/r[3]	Y	Isolated Pools	Stranded
			SU	yoy	200	n/r[3]	Y	Interstitial	Stranded, desiccated
10	Island bars near Wolf Creek	11-Jul	SMB	adult juvenile	4	381, 133, 343, 287	N	Isolated pool	Trapped
			SMB	yoy	20	43, 47, 39	N	Isolated pool	Trapped
			CSU	adult	2	410, 396	N	Isolated pool	Trapped
			CSU	adult	1	320	Y	Isolated pool	Stranded
			SMB	juvenile	50	n/r[3]	N	Isolated pool	Cold water upwelling surrounded by warm pools, trapped
Unnumbered	Sullivan Creek delta	12-Jul	CSU	yoy	50	n/r[3]	N	Side Channel	Muddy bottom with disconnected pools in area, trapped
11	Side channel across from Wolf Creek	12-Jul	SU	juvenile	25	n/r[3]	N	Isolated Pools in Side Channel	Stranded in Macrophytes
			SMB	yoy	1	44	N	Isolated Pools in Side Channel	Stranded in Macrophytes
			SMB	yoy	800	< 50	N	Isolated Pools in Side Channel	Stranded in Macrophytes
			YP	yoy	600	< 50	N	Isolated Pools in Side Channel	Stranded in Macrophytes
			SU	yoy	500	< 50	N	Isolated Pools in Side Channel	Stranded in Macrophytes
			SMB	adult	1	350	Y		Trapped
13	slough behind/near electrofish transect UR4E (below high school)	12-Jul	SU	yoy	300	< 35	Y	Connected Side Channel	Stranded
			SU	yoy	500	< 40		Connected Side Channel	
14	Slough downstream from Sand Creek Delta	12-Jul	RSC	juvenile	1	131	Y	Dry side channel	Stranded
			TR	juvenile	1	139	Y	Dry side channel	Stranded in side channel margin in emergent aquatic macrophytes (horsetails). Estimated elevation 1991 to 1992 feet NAVD88 (1987 to 1988 feet NGVD 29). Species identification not possible due to sever desiccation.
			SU	yoy	10	< 50	Y	Side Channel (connected to Mainstem)	Stranded
			SU	yoy	10	< 50	Y	Side Channel (connected to Mainstem)	Stranded in Macrophytes
			SU	yoy	1000	< 50	Y	Side Channel (connected to Mainstem)	Stranded in Macrophytes
			YP	yoy	25	< 50	Y	Side Channel (connected to Mainstem)	Stranded in Macrophytes
			YP	yoy	1000	< 50	N	Side Channel (connected to Mainstem)	Trapped in Macrophytes
			SU	yoy	10	< 50	Y	Side Channel (connected to Mainstem)	Stranded in Macrophytes
			SU	yoy	2000	< 50	Y	Side Channel (connected to Mainstem)	Stranded in Macrophytes
			SU	yoy	250	< 50	Y	Side Channel (connected to Mainstem)	Stranded
			YP	yoy	300	< 50	Y	Side Channel (connected to Mainstem)	Stranded
			CSU	juvenile	500	n/r[3]	Y	Isolated Pools in Side Channel	Stranded
			SU	yoy	500	< 50	Y	Isolated Pools in Side Channel	Stranded
			YP	yoy	200	35	Y	Isolated Pools in Side Channel	Stranded
15	Inside of long gravel bar, below steep slope of highway upstrm of high school slough	12-Jul	SU	yoy	12	< 40	N	Isolated Pools in Side Channel	Trapped
			SU	yoy	18	< 40	N	Isolated Pools in Side Channel	Trapped
16	Wildlife Refuge Area	12-Jul	YP	yoy	800	< 50	Y	Outlet of Side Channel	Stranded in Macrophytes
			CSU	yoy	1400	< 50	Y	Outlet of Side Channel	Stranded in Macrophytes
			SMB	yoy	250	< 50	n/r[3]	Outlet of Side Channel	
			CSU	juvenile	100	80 - 110	n/r[3]	Outlet of Side Channel	
			unknown	larvae	100	n/r[3]	n/r[3]	Side Channel Isolated Pool	
			YP	yoy	200	< 50	Y	Outlet of Side Channel	Stranded in Macrophytes
			SMB	yoy	150	< 50	Y	Outlet of Side Channel	Stranded in Macrophytes
			SMB	yoy	100	< 50	N	Outlet of Side Channel	Trapped in Macrophytes
			CSU	yoy	1750	< 50	Y	Outlet of Side Channel	Stranded in Macrophytes
			SMB	juvenile	1	155	Y	Outlet of Side Channel	Stranded
			SU	yoy	25	< 50	Y	Outlet of Side Channel	Stranded
			SU	yoy	20	< 50	Y	Dry Side Channel	Stranded
			SU	yoy	25	< 50	Y	Dry Side Channel	Stranded
			YP	yoy	25	< 50	Y	Dry Side Channel	Stranded
			CSU	yoy	500	< 50	N	Isolated pool	Trapped
			YP	yoy	250	< 50	N	Isolated pool	Trapped
			SU	yoy	500	< 50	N	Isolated pool	Trapped in Macrophytes
			SU	yoy	200	< 50	Y	Isolated pool	Stranded in Macrophytes
17	slough behind electrofish transect UR2E:	12-Jul	SU	yoy	50	n/r[3]	Y	Isolated Pools in Side Channel	Stranded in Macrophytes
			SU	yoy	25	n/r[3]	N	Isolated Pools in Side Channel	Trapped in Macrophytes
			YP	Adult	1	220	N	Isolated Pools in Side Channel	Trapped in Macrophytes
			SU	yoy	200	< 30	Y	Isolated Pools in Side Channel	Stranded
			YP	yoy	190	< 35	Y	Isolated Pools in Side Channel	At the edge of inundation zone of this central slough inlet, stranded
			SU	juvenile	12	65 - 90	Y	Interstitial	Stranded
			SU	yoy	130	35	Y		Stranded in Macrophytes

[1] Life Stage: yoy = young of the year most less than 50mm;. Larvae = very small sizes of yoy; Juvenile = usually 60-200mm; Adult>200mm

[2] Habitat Association: Interstitial = fish observed on exposed substrate not associated with aquatic macrophytes.

[3] n/r = not recorded.

Abbreviations: SU = Sucker spp., YP = Yellow Perch, SMB = Smallmouth bass, CSU = Largescale sucker, RSC = Redside shiner, TR = undetermined trout spp.