Boundary Hydroelectric Project (FERC No. 2144)

Study No. 8
Sediment Transport and
Boundary Reservoir Tributary Delta Habitats
Interim Report

Prepared for
Seattle City Light

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1 INTRODUCTION

Study No. 8, Sediment Transport and Boundary Reservoir Tributary Delta Habitats, is being conducted in support of the relicensing of the Boundary Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 2144, as identified in the Revised Study Plan (RSP; SCL 2007) submitted by Seattle City Light (SCL) on February 14, 2007, and approved by the FERC in its Study Plan Determination letter dated March 15, 2007. This is the interim report for the 2007 efforts of the Sediment Transport and Boundary Reservoir Tributary Delta Habitats Study.

1.1. Tributary Delta Habitat Modeling

Deltas are depositional features that form where flowing water, such as tributary streams, enters a static water body such as a lake or reservoir. Where tributary streams enter a flowing body of water, such as a larger river, sediments may be deposited at the confluence, forming a delta, or the tributary sediments may be transported downstream by mainstem river currents. The proportion of tributary sediments that is deposited as a delta or transported downstream is influenced by the volume and particle size distribution of the sediments, tributary and mainstem river flows and, in the case of the Project, the water surface elevation of the reservoir.

Tributary deltas are transition areas between the tributaries and reservoir that, depending upon their physical characteristics, provide a variety of ecological functions. Fish may congregate at the tributary confluence to feed on aquatic organisms transported downstream in the tributary flow, may use the deltas as temperature refugia, or may stage in delta habitats prior to spawning runs; fry and juvenile fish may rear in complex habitats associated with the deltas; and the influx of tributary water may provide protection from dewatering associated with reservoir water surface elevation fluctuations. Portions of tributary deltas are present in the varial zone, and therefore are affected by fluctuations in water surface elevations. The fluctuations in reservoir levels associated with Project operations change portions of the deltas from stream habitat to lacustrine habitat as the reservoir water surface elevation rises and then back to stream habitat as the reservoir water surface elevation falls.

There are 28 tributaries that drain to Boundary Reservoir, including 13 unnamed drainages. Most of the tributaries are very small, and some do not contain measurable surface flow during late summer months. However, some tributaries to the Boundary Reservoir represent potential year-round habitat for native salmonids. This study examines the potential effects of Project operations on the quantity and quality of tributary delta habitat and potential changes in tributary delta morphology for operations scenarios. Because the tributary deltas represent areas of potential high aquatic resource value and have a source of inflow separate from the mainstem

Pend Oreille River, the delta areas of major tributaries require a modeling approach specific to their physical characteristics.

1.2. Study Components

This study complements, but is separate from, the Mainstem Aquatic Habitat Modeling Study (Study 7). Study 8 comprises three modeling components: 1) Tributary Delta Habitat Modeling, 2) Tributary Delta Sediment Processes, and 3) Mainstem Sediment Transport.

The three interrelated modeling components are needed to evaluate the effects of operations scenarios on tributary delta habitats. The first component, physical habitat modeling of major tributary deltas, will translate hourly fluctuations in Boundary Reservoir water surface elevations into estimates of a habitat quality rating (HQR). The latter two sediment modeling exercises are needed to determine if, and how, tributary delta morphology might change over the potential 50-year term of a new FERC license for the Project. In addition, the Mainstem Sediment Transport modeling results will be used to evaluate potential changes to channel morphology from predicted erosion and accumulation of sediments in the mainstem, which will support interpretation of results for Study 7.

1.2.1. Tributary Delta Habitat Modeling

The Tributary Delta Habitat Modeling effort is being conducted to evaluate the effects of operations scenarios on aquatic habitats in the deltas of major tributary streams within the Boundary Reservoir drawdown zone. The Tributary Delta Habitat Modeling effort utilizes the hourly reservoir level changes from the hydraulic routing model (conducted in Study 7) to estimate changes in the HQR for selected tributary deltas. This component also involves the collection of data to represent the physical characteristics of the delta to support estimation of future delta conditions and to describe physical habitat conditions.

The methods to perform the work associated with the Tributary Delta Habitat Modeling study component are presented in Section 4.1. The results of efforts conducted into November 2007 are presented in Section 5.1. The primary work conducted through this period involved selection of the major tributary deltas to be modeled, collection of the data representing the physical characteristics of the deltas, and collection of the data to represent the physical habitat conditions.

1.2.2. Tributary Delta Sediment Processes

Because the erosion, transport, and accumulation of sediment within select tributary deltas of the Pend Oreille River may affect aquatic habitats by altering channel morphology, delta morphology, and the size and distribution of substrates, it is necessary to understand these processes to evaluate the effects of operations scenarios on associated aquatic habitats. The Tributary Delta Sediment Processes study component will evaluate the effects of Project operations on the delta morphology of representative tributaries within the Pend Oreille River from Box Canyon Dam downstream to Boundary Dam. The study component will support the habitat modeling by determining if the tributary deltas will change over the 50-year term of the license. If a delta is determined to evolve under future conditions, the resulting changes will be estimated in this study component. The net change in the volume of sediment deposited on the tributary deltas will be estimated and potential zones of erosion and accumulation of sediment within the deltas will be delineated. It will also be determined if the delta evolution is sensitive to operations scenarios, which may then result in developing different future delta conditions for each operation scenario.

The methods to perform the work associated with tributary delta sediment processes study component are presented in Section 4.2. The actual efforts to predict the potential for changes in tributary delta morphologies and the associated changes will be performed in 2008. Therefore, there are no results to report for this study component in Section 5.2.

1.2.3. Mainstem Sediment Transport

Because of the potential complex interactions between sediment transport conditions, morphology and reservoirs, the mainstem sediment processes study component was incorporated into Study 8. For example, the erosion, transport, and accumulation of sediment within the mainstem Pend Oreille River may affect aquatic habitats by altering channel morphology and the size and distribution of channel substrates. The mainstem sediment transport study effort will evaluate the effects of existing Project operations on channel morphology within the Pend Oreille River from Box Canyon Dam downstream to Red Bird Creek which is approximately 3.1 miles downstream of Boundary Dam. The evaluation will be conducted using a sediment routing model.

A significant portion of this effort involves estimating the sediment supply from multiple sources including the watershed upstream of Box Canyon Dam, shoreline erosion within the Boundary Reservoir drawdown zone, and the tributaries flowing into Boundary Reservoir. The latter source, tributary sediment supply, is an important part of the information to be utilized in the delta sediment processes to evaluate the potential evolution of the major tributary deltas over the 50-year license term. Conversely, the evolution of the deltas plays an important role in whether the sediment supplied to the deltas is deposited on the deltas or is transported to the mainstem of the Pend Oreille. Therefore, these two study components are closely linked.

The methods to perform the work associated with the Mainstem Sediment Transport study component are presented in Section 4.3. The results of efforts conducted into November 2007 are presented in Section 5.3. The primary work conducted through this period involved the collection of physical data to be incorporated into the mainstem sediment routing model and selection of the actual sediment routing model to be applied.

2 STUDY OBJECTIVES

The goal of this study is to evaluate the effects of operations scenarios on aquatic habitats in the deltas of major tributary streams within the Boundary Reservoir drawdown zone. The objectives of the study are to:

- Collect physical and hydraulic site information.
- Evaluate changes in delta morphology and characteristics over the potential term of the new FERC license.

- Develop models of delta habitats at the mouths of major tributaries that reflect potential changes in delta morphology.
- Evaluate the effects of operations scenarios on aquatic habitats in the tributary deltas.

3 STUDY AREA

The overall study area for this effort encompasses the Pend Oreille River and its tributaries from Box Canyon Dam to the confluence with Red Bird Creek. For the tributary delta portion of the effort, the study area is limited to the area from Boundary Dam and Box Canyon Dam. A total of 28 tributaries were identified for potential study. Based on characteristics of these tributaries, seven tributary deltas were identified for detailed study (Table 3.0-1). Additionally, two tributaries were identified for discussion of their characteristics and evolution over the future relicensing period, but not for detailed study. Table 3.0-1 provides a listing of the tributary drainage area and adfluvial habitat as well as where these values rank among the 28 tributaries considered. Figure 3.0-1 shows the location of the seven tributary deltas chosen for detailed study, including habitat modeling. The selection of these seven tributaries for detailed study was presented and agreed upon at the June 7, 2007, relicensing participants (RPs) meeting.

Table 3.0-1. List of Boundary Reservoir tributary deltas evaluated as part of Study 8.

Tributary	Project River Mile	Study Reach	Watershed Area (sq-mi)	Relative Rank[3]	Adfluvial Habitat Length (ft)	Relative Rank[3]
Pewee Creek[1]	17.9	Forebay	10.37	5	0	26[5]
Lime Creek[1, 2]	19.4	Canyon	2.93	9	6,746	4
Slate Creek	22.2	Canyon	32.33	2	3,474	5
Flume Creek	25.8	Canyon	19.33	3	1,056[4]	8
Sullivan Creek	26.9	Upper	142.46	1	21,729	1
Linton Creek	28.1	Upper	2.11	11	19,159	2
Pocahontas Creek	29.4	Upper	3.92	8	16,480	3
Sweet Creek	30.9	Upper	11.12	4	2,659[4]	6
Sand Creek	31.7	Upper	8.22	6	1,320[4]	7

Notes:

1 Pewee and Lime Creek will not be evaluated in detail, but a qualitative discussion of their condition and future evolution will be included in Study 8.

2 Current mouth of Lime Creek at Project river mile (PRM) 19.45. Approved GIS streams coverage shows mouth at PRM 19.0.

3 Relative rank of the values in the preceding column in relation to the values for all 28 tributaries. For example, the drainage area of Sullivan Creek is 142.46 square miles, and this is the greatest area of all 28 tributaries, so the relative rank is 1.

4 The length of adfluvial habitat is based on the distance from the mouth of the stream to the lowermost migration barrier reported in McLellan and O'Connor (2001) and/or Andonaegui (2003).

5 Three tributaries have zero feet of adfluvial habitat length, so the rank for all three is 26.

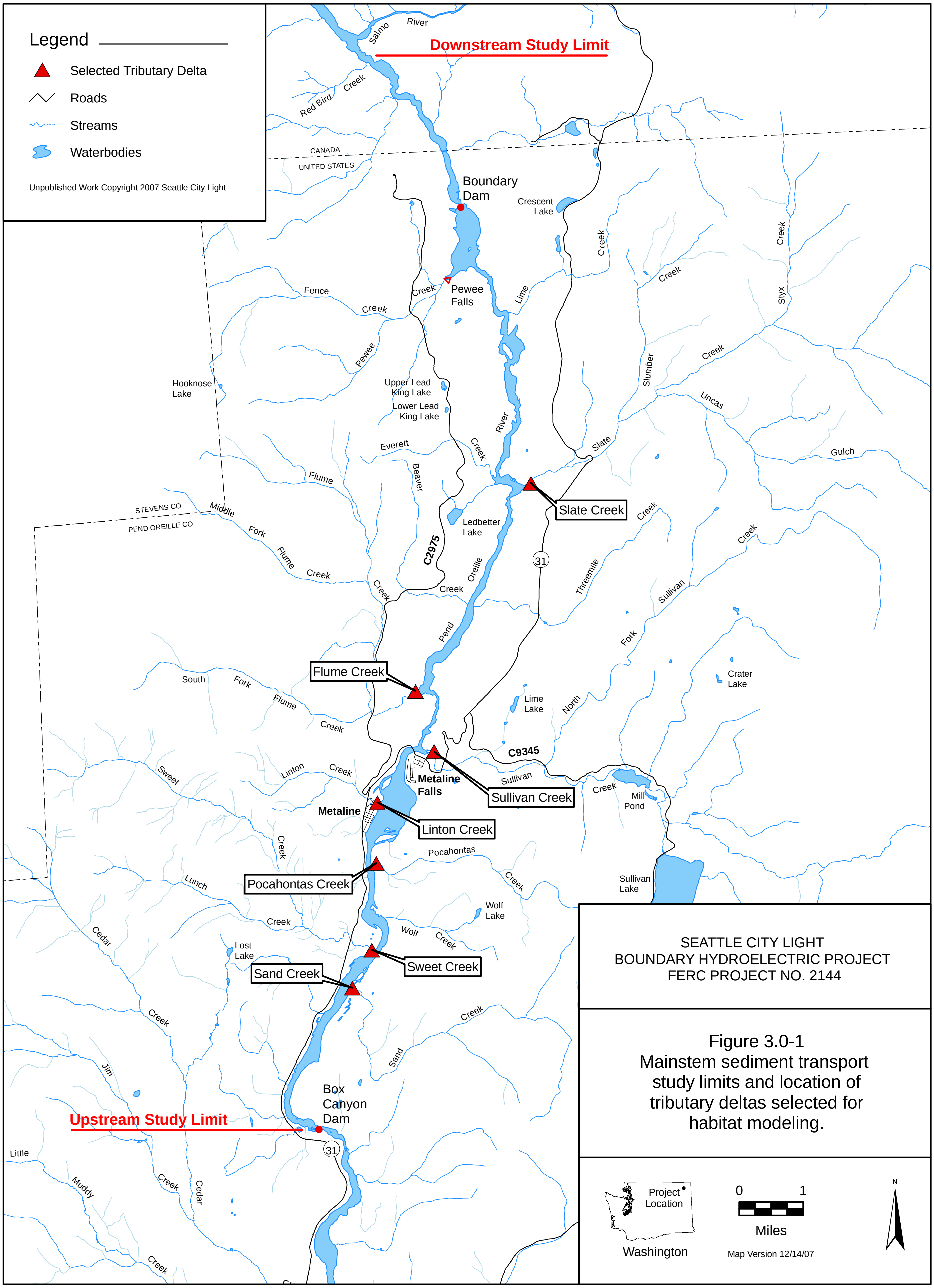

Figure 3.0-1
Mainstem sediment transport study limits and location of tributary deltas selected for habitat modeling.

4 METHODS

The Sediment Transport and Tributary Delta Habitats Study consists of three primary components: 1) Tributary Delta Habitat Modeling, 2) Tributary Delta Sediment Processes, and 3) Mainstem Sediment Transport. The methods for each of these components are presented in this section.

4.1. Tributary Delta Habitat Modeling

The goal of the Tributary Delta Habitat Modeling effort is to evaluate the effects of operations scenarios on aquatic habitats in the deltas of major tributary streams within the Boundary Reservoir drawdown zone. The Tributary Delta Habitat Modeling effort will utilize the hourly reservoir level changes from the hydraulic routing model (Study 7) to estimate changes in the HQR for selected tributary deltas. This study component also involves the collection of data to represent the physical characteristics of the delta to support estimation of future delta conditions and to describe physical habitat conditions. This modeling requires that the changes in tributary delta morphologies, for the deltas that may change over the 50-year term of a new license, be estimated. The identification of these changes is performed in the second component of Study 8, Tributary Delta Sediment Processes (Section 4.2). Four potential models of delta evolution have been developed for Study 8:

1. Type 1: No significant delta present or delta is below minimum reservoir water surface elevation surface. (Note: Type 1 tributary deltas will not be modeled.)
2. Type 2: Delta morphology is not expected to significantly change over the term of a new license. (These are deltas that have reached an equilibrium condition that will not be significantly influenced by operations scenarios.)
3. Type 3: Delta morphology is expected to change, but changes are not significantly influenced by operations scenarios. (These are most likely deltas that are still building into large sediment storage areas that are isolated from significant mainstem sediment transport conditions.)
4. Type 4: Delta morphology is expected to change and the changes will be significantly influenced by operations scenarios. (These are most likely deltas that have an intermediate level of potential sediment storage off the mainstem that could be filled dependent on dominant reservoir levels and/or are exposed to mainstem hydraulics that could be influenced by operations scenarios. An example is a delta where the majority of the potential delta sediment storage volume is in the reservoir fluctuation zone.)

If a tributary delta is not expected to change over the term of a new license (Type 2 model), then the current morphology of the tributary delta will be used directly for tributary delta habitat modeling. However, if the delta morphology is expected to change, the changes need to be quantified for the tributary delta habitat modeling. Therefore, it will be important to evaluate the potential for selected tributary delta morphologies to change over the potential term of the new license (see Sections 4.1.6 through 4.1.12).

Prior to initiating the studies in this section, very little information was available concerning the physical characteristics of tributary deltas in Boundary Reservoir. Fish surveys had suggested that some tributary deltas (e.g., Slate Creek) may provide thermal refugia for native salmonids when mainstem river temperatures become too warm. Aerial photography suggested that some of the tributaries have readily identifiable deltas (e.g., Sullivan Creek and Sweet Creek) whereas others deposit tributary sediments into deep portions of the reservoir or may not transport sufficient sediment to the mouth of the tributary to develop a delta. Scour and deposition in the mainstem may also affect the development of deltas at the mouth of tributaries.

The first three tasks in this study (see Sections 4.1.1 through 4.1.3) were developed to utilize existing information as well as field observations of delta conditions to help guide the details of executing the remaining efforts. This included identifying the tributaries that potentially provide high quality aquatic habitat or that potentially contribute sufficient quantities of sediment to affect reservoir habitats (Section 4.1.3). The next two tasks (see Sections 4.1.4 and 4.1.5, as well as portions of Section 4.1.2) consisted of site-specific data collection performed on the potentially important tributary deltas to support modeling of their physical habitat. The actual model development and application to evaluate the effects of operations scenarios on aquatic habitats in the drawdown zone of the selected deltas is conducted in the remaining eight tasks of this study (Sections 4.1.6 through 4.1.13).

4.1.1. Characterize Tributary Delta Conditions

The RSP (SCL 2007) lists 28 tributaries that drain to Boundary Reservoir, including 13 unnamed drainages. Most of the tributaries are very small, and some do not contain measurable surface flow during late summer months; however, some tributaries to the Boundary Reservoir represent potential year-round habitat for native salmonids. The hydrologic and physical conditions at each of the 28 tributaries were characterized to identify the potentially important deltas for modeling habitat and sediment transport processes. The characterization process included reviews of readily available data, desktop analyses, and field reconnaissance.

The review of readily available data focused on the length of adfluvial habitat along with tributary flow measurements. The length of adfluvial habitat as presented in the RSP (SCL 2007) is based on the distance from the mouth of the stream to the lowermost migration barrier reported in McLellan and O’Connor (2001), Andonaegui (2003), and/or the 2002 Washington Department of Fish and Wildlife (WDFW) SalmonScape (2007) Geographic Information System. The flow measurements were recorded during the late summer low flow period as reported in McLellan and O’Connor (2001).

The desktop analyses were conducted to characterize the following physical characteristics of the tributary deltas:

- Drainage area
- Drawdown zone habitat length
- Evidence of delta aggradation or degradation since construction of Boundary Dam
- Tributary water temperature

The drainages for the 28 tributaries were delineated using ESRI ArcGIS Version 9.2 software in a Geographic Information System (GIS) to view digital versions of the U.S. Geological Survey (USGS) 1:24k scale, 7.5-minute series topographic maps. The 20-foot interval contour lines were used to delineate the watershed boundary, and the ESRI software calculated the bounded drainage area.

The determination of the drawdown zone habitat length and evidence of aggradation or degradation could not be completed until the finalized bathymetric survey data became available in December 2007. Determination of the lengths of the drawdown zone habitat was performed using a GIS to evaluate the reservoir bathymetry along with results of the hydraulic routing model described in the Study 7 (Aquatic Habitat Model) Interim Report (SCL 2008a). The lengths were checked using aerial photographs of the confluence of each tributary with the reservoir. Evaluations of evidence of significant delta aggradation or degradation since construction of Boundary Dam were developed using bathymetric maps, aerial photographs, and observations made during the September 2007 tributary delta reconnaissance described in Section 4.1.2.

Although tributary water temperature was identified in the RSP (SCL 2007) as a parameter to characterize, insufficient monitoring information was available to allow for comparisons across all 28 deltas. To facilitate a more meaningful comparison, tributary water temperature was recorded during the September 2007 field reconnaissance (as described in Section 4.1.2.2).

In addition to reviewing available data and conducting desktop analyses, the characterization to tributary delta conditions also included a 2-day field reconnaissance effort that covered all 28 tributaries. Observations were made during the field reconnaissance of the potential for aquatic habitat and of the presence of geomorphic forms and processes consistent with delta formation.

4.1.2. Tributary Delta Reconnaissance

The tributary delta reconnaissance was conducted in September 2007. The purpose of the reconnaissance was to provide information to complete the selection of the six to eight tributary deltas to study in detail and to collect other information that would assist in developing the geomorphic and sediment transport aspect of the delta modeling effort. These efforts were conducted to build on the data compiled through the characterization of tributary delta conditions. The September 2007 tributary delta reconnaissance efforts were applicable to all 28 tributaries listed in the RSP (SCL 2007). The deltas were viewed at low pool condition so that their full extent could be accessed. Measurements of tributary flow (Section 4.1.2.1) and water temperature (Section 4.1.2.2) were recorded to further assess the potential of each delta to provide habitat.

The tributary delta reconnaissance at low pool elevation was also an opportunity to observe and record the presence of cultural resource features associated with streams. As part of the reconnaissance, the presence of any fire-cracked rock (FCR) or FCR clusters was to be noted and described (Section 4.1.2.3).

4.1.2.1. Measurement of Tributary Flow

The tributary reconnaissance occurred in September 2007 so that flow conditions were representative of summer lows. As a result, tributary flows could mostly be made with a stopwatch and either a graduated 5-gallon bucket or a 1-liter bottle. An appropriate location in the channel was selected where the bucket could capture the flow (i.e., outflow from a culvert, flow over an exposed ledge, a constriction in a steep section of the channel); if a single location was unavailable, multiple measurements were recorded and then summed. A stopwatch was used to record the amount of time required to fill the container. Measurements were recorded two to three times and the results were averaged. The flow in the channel was calculated in units of volume per time using these measurements.

An electromagnetic flow velocity meter was used to calculate tributary flow in tributaries with flow volumes too large to be measured with a bucket and stopwatch. The tributary was walked to identify a reasonably prismatic cross section. Flow volume was calculated through measurements of cross-section area and flow velocity. To minimize errors in the calculation of flow, velocity and depth were measured at approximately 20 equidistant points across the channel. Using this approach, it is unlikely that flow at a single measurement point represented more than 10 percent of the total flow through the section. A surveyors tape was stretched across the section perpendicular to the predominant direction of flow. A Marsh-McBirney Flo-Mate Model 2000 portable flow velocity meter mounted to a wading rod was used to measure flow velocity. The velocity was calculated over a 20-second interval at a depth of six-tenths of the total depth. In cases where the depth was greater than 2 feet, flow velocity was measured at two depths: two-tenths and eight-tenths the total depth. The zero stability of the Flo-Mate Model 2000 is ±0.05 feet/second and the measurement accuracy is 2 percent of the reading plus the zero stability.

4.1.2.2. Measurement of Tributary Water Temperature

Measurements were made of the water temperature of the tributary and the surface of the reservoir near the confluence with the tributary. A digital scientific thermometer was used to record temperature. The thermometer was held in the water until the reading stabilized. The thermometer is accurate to ±1°C between -20°C and 120°C and the resolution is 0.1°C. The tributary was measured in a freely flowing section of the channel located upstream of any backwater influence by the reservoir. The surface water temperature in the reservoir was recorded in a location far enough from the point of entry of the tributary that the localized thermal influence of the tributary was avoided.

4.1.2.3. Identification of Cultural Resource Features

In response to an observed correlation noted by the Cultural Resources Workgroup between certain topographic features and the potential for prehistoric archaeological deposits (e.g., prehistoric weirs and Native American fishing features), a trained geologist on the field crew was tasked with recording any of the following features observed during the reconnaissance of the tributary deltas:

- *Fire-cracked rock (FCR)* – This feature consists of an interior perpendicular "barb" between parallel sloughs that cannot be accounted for by natural landform development processes. If these features were found the geologist was instructed to examine the inundated margins of the barb for any indication of cultural deposits (e.g., FCR). FCR can be readily identified and differentiated from naturally occurring gravel substrates in the Pend Oreille valley in that it typically has at least one, more typically three, angular and crenulated facet(s) in an environment where naturally deposited gravels should have a smooth and rounded cross-sectional profile. The site of these observations and collections, if any, would be marked on aerial photographs and the Global Positioning System (GPS) coordinates recorded and provided to the Cultural Resources Workgroup. A simple description of the observations would also be recorded at the time of such discoveries: each description included the relative density of FCR (estimated number of rocks per square meter) and a best estimate of the FCR scatter's size in both length and width.

- *FCR clusters* – The geologist was instructed to make notation of the presence, relative density, and dimensions of any observed clusters of FCR on either the out-board or in-board meander scars in inundated tributary alluvial fans within the margins of the tributary's main channel. These observations would be marked on aerial photographs, the GPS coordinates recorded, and the data provided to the Cultural Resources Workgroup.

4.1.3. Identify Potential Study Tributary Deltas

Tributary deltas to study in detail were identified in this task using the findings from the characterization of tributary delta conditions (Section 4.1.1) and the tributary delta reconnaissance (Section 4.1.2). The general criteria used to identify the tributaries were the potential to provide high aquatic resource values, or the potential to contribute sufficient sediment volume to affect reservoir habitats. Tributaries that enter the reservoir where the shoreline water depth is deep enough to fully submerge the delta sediment deposits under all operations scenarios were eliminated from further analyses.

The tributary and delta-specific characteristics used to perform the identification were:

- Drainage area (relates to overall flow volume for the tributaries which are primarily ungaged)
- Flow (instantaneous measurement of late summer flow)
- Length of adfluvial habitat (indicates the stream length that fish in the reservoir can access before encountering a migration barrier)
- Water temperature (cooler tributary water, if it exists, in the late summer can provide thermal refugia from the warmer water in the reservoir)
- Drawdown zone habitat length (provides an indicator of the extent of habit that changes between riverine and lacustrine in response to reservoir fluctuations)
- Evidence of significant delta aggradation or degradation since construction of Boundary Dam (is an indicator of sediment load from the tributary and the interaction of the tributary and sediment transport processes in the reservoir)

The final selection of tributary deltas to be modeled using site-specific data will be confirmed with the RPs. The RPs had previously agreed with the initial selection of the seven tributary deltas at the June 7, 2007, Fish and Aquatics Workgroup meeting. The initial selection was presented in PowerPoint and documented in the Methods Outline (Tetra Tech and TRPA 2007) distributed for the Workgroup meeting.

4.1.4. Delta Water Temperature Monitoring

Two types of temperature measurements are being collected to characterize conditions at the tributary deltas. The first are continuous recorders of temperatures in the channel thalweg within the varial zone and upstream of the reservoir influence. These measurements also include mainstem temperatures. The second set of measurement were several sets of measurements taken at specific water surface elevations to identify whether thermal plumes of low temperature water occur across the delta thalweg beyond the channel thalweg. This second set of measurements was not originally included in the RSP, but was conducted in response to RP requests after presentation of the tributary delta study methods at the June 7, 2007, RP meeting. This variance to the RSP is also described in Section 7 (Variances from FERC-Approved Study Plan and Proposed Modifications). The initial findings were used to develop the proposed 2008 monitoring plan.

4.1.4.1. Continuous Tributary Delta Water Temperature Monitoring

Continuous water quality monitoring was performed in 2007 and will continue in 2008. Some slight modifications for the 2008 monitoring are proposed based on review of the results of the 2007 effort and are described in more detail in Section 7.

4.1.4.1.1. 2007 Monitoring

During the summer and early fall of 2007, anchored thermographs were deployed along the bed of the thalweg of the seven primary tributaries (Slate, Flume, Sullivan, Linton, Sweet, Pocahontas, and Sand) to assess the effects of fluctuating reservoir water surface elevations on temperatures of tributary water entering the reservoir. Locations included one point in the tributary upstream of the reservoir varial zone, one in the mainstem Pend Oreille River, and one to three locations in the varial zone. The thermographs upstream of the varial zone and within the varial zone were set within .05 foot of the bed. The mainstem thermographs were suspended from buoys at 3 feet below the water surface. The thermographs were installed July 11-12, 2007, during a period of low pool elevations (approximately 1,986.68–1,974.26 feet NAVD 88 [1,982.65–1,970.23 feet NGVD 29][1]) to identify the extent of the varial zone and locate the thalweg of the tributary delta. The deployed locations were recorded using a Trimble® GPS Pathfinder Pro XH receiver. The thermographs were removed from the reservoir on November 8-14, 2007.

A total of 26 Onset Hobo® Water Temp ProV2 data loggers were deployed. The data loggers recorded temperatures at a logging interval of 15 minutes with a resolution of 0.02°C ±0.2°C. Based on discussions with SCL, no formal calibration was performed; however, the data loggers were verified that they were in agreement over a range of temperatures prior to deployment (A.

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

Solonsky, SCL, personal communication, July 3, 2007). The data loggers were in operation from July 12 through October 31, 2007. The thermographs were inspected and the data downloaded each month.

4.1.4.1.2. 2008 Monitoring

Continuous temperature monitoring will be conducted on all seven tributary deltas in 2008. The continuous monitoring of water temperature at the tributary deltas will change only slightly in 2008. The proposed changes are based on reviewing the results from 2007 and are intended to enhance the information collected in 2008. The changes involve relocating several varial zone buoys to better represent the range of longitudinal conditions in the varial zone, relocating several of the mainstem buoys to ensure that they record mainstem temperatures and not thermal plume temperatures during low reservoir pool elevations, lowering the thermographs on the mainstem buoys to have them setting below the surface layer, and deploying the thermographs earlier to be more likely to collect some data on Pocahontas and Sand creeks prior to these streams drying up. A list of the proposed changes is provided below:

- Deploy the thermographs by June 15, 2008.
- Set the thermographs on all the mainstem (Main) thermograph buoys 6 feet below the surface rather than 3 feet.
- Move the Varial Zone 2 thermograph on Slate Creek downstream approximately 200 feet.
- Move the Sullivan Creek mainstem (Main) thermograph buoy approximately 250 to 300 feet upstream to prevent it from picking up the thermal plume or being stranded on the delta deposits during low flows.
- Add Varial Zone 1a thermograph approximately 200 feet upstream of Varial Zone 1 thermograph on Sweet Creek..
- Move the mainstem (Main) thermograph buoy on Sand Creek approximately 200 feet upstream.

4.1.4.2. Monitoring of Spatial Distribution of Tributary Delta Temperature Plume

Monitoring of tributary delta temperature conditions identified in the RSP consisted entirely of the continuous recording temperature probes described in Section 4.1.4.1. However, at the June 7, 2007 Fish and Aquatics Workgroup meeting, RPs introduced the potential need for additional delta temperature monitoring outside of the longitudinal thalweg profile and also in the vertical. The impetus for additional monitoring was to better understand the lateral and vertical extent of the lower temperature plume that could develop in the summer and early fall when tributary inflows may be substantially cooler than the mainstem. A July 17, 2007 conference call between SCL and the RPs was held to further discuss additional temperature monitoring at the tributary deltas. As a result of this call, SCL developed a proposed 2007 monitoring plan for the tributary delta thermal plumes and presented the plan to the RPs at the July 24, 2007, Fish and Aquatics Workgroup meeting. The 2007 data collection would be conducted mainly to gather general information about temperature patterns at the tributary deltas and based on the results more focused data collection could be undertaken in 2008 to address questions that arise as a result of the 2007 data. The Fish and Aquatic Workgroup members agreed that the proposed approach for monitoring temperature in tributary deltas in 2007 was acceptable.

Three tributary deltas were selected for the 2007 study based on either the observation of fish crowding at the delta or the relative size and configuration of the delta and its tributary making it most likely to develop a thermal plume. The three tributaries selected were Slate, Sullivan, and Sweet creeks. The first two creeks were selected because of their physical characteristics, whereas Sweet Creek was selected because fish crowding was observed at its mouth. Each tributary was evaluated in August at two or three pool levels during a period of relatively low and stable inflow from Box Canyon.

This section presents the methods for the initial monitoring of the spatial characteristics of tributary delta thermal plumes conducted in 2007 and the proposed plan for additional monitoring in 2008.

4.1.4.2.1. 2007 Monitoring

The thermal plume profiles were measured using an AquaCal® Clinefinder Model 411 temperature and depth sounder deployed on a 50-foot-long cable and reel. The probe displays temperatures to the nearest 0.1°C and it has an accuracy of ±0.3°C when recording temperatures in the range of 5 to 38°C (Catalina Technologies, Inc. 2000). The probe has a quick response to changing temperature gradients, with response times in the range of 1 to 2 seconds. Depths were recorded to an accuracy of ±0.05 foot using a 25-foot-long fiberglass stadia rod. If the depth exceeded 25 feet, the temperature probe cable was brought on board the survey boat and its deployed length (depth) measured against the stadia rod.

Reservoir surface water temperatures (i.e., depths of 0 to 10 feet) just offshore of the tributary delta area and the water temperature in the tributary just upstream of the confluence with the reservoir were recorded prior to measurements of the thermal plume profile. The thermal plume was defined for this effort by water temperatures that were *at least* 0.5 to 0.8°C cooler than the recorded water temperature at the reservoir surface. (Note: The original proposal called for measuring the temperature at the bottom, midpoint, and near surface to define the vertical component of the temperature plume. However, after observing conditions on the site, it was determined that the three-point approach could miss the presence of the shallower portions of the plume.) Water temperatures were monitored from the mouth of the tributary out into the reservoir. The probe was lowered to the surface of the delta and the temperature display was allowed to equilibrate. The water temperature was recorded along with the total depth. The probe was slowly raised toward the surface to a depth where the mixing zone was encountered and this depth was recorded. The depth of the mixing zone indicated the thickness of the thermal plume.

The position of individual monitoring locations was recorded using a Trimble® GPS Pathfinder Pro XRS receiver with OmniSTAR differential correction. This Differential Global Positioning System (DGPS) employed a boat-mounted antenna. This unit measures positions with sub-meter accuracy. All DGPS-determined positions were recorded as separate waypoints on a laptop that was used to display and record real-time positions. Where poor satellite reception (i.e., Slate Creek delta) or shallow water conditions (i.e., Sweet Creek delta at high reservoir pool) precluded use of the boat-mounted DGPS, locations were measured using distances and compass headings to a reference point that was recorded with the DGPS. Distances were measured using either a surveyors tape or a hand-held Advantage® laser range finder (Laser Atlanta, Inc.). The range finder has a range of 5 to 2,500 feet and an accuracy of ±0.5 foot. Water temperature monitoring locations were generally laid out along transects at intervals along the longitudinal direction of the tributary channel. The extent of the thermal plume was recorded until the water temperature monitoring indicated the plume was no longer evident, or the depth exceeded the length of the thermal probe (i.e., greater than 50 feet). The original proposal called for monitoring in a grid with the size to be determined by the field crew. However, due to the lack of DGPS coverage at two of the sites and the difficulty holding the boat still at grid points, the field crew decided to drop the grid pattern approach and survey along transects instead.

The thermal plume monitoring data for each monitoring location were recorded on data sheets. Results of the data collection are presented in Section 5.1.4.2.

4.1.4.2.2. 2008 Monitoring

Monitoring of the thermal plumes at the tributary deltas is proposed for 2008 as a continuation and expansion of the 2007 monitoring efforts. Results from the 2007 monitoring effort indicated the following:

- Distinct thermal plumes were present at each of the three tributaries monitored (Slate, Sullivan, and Sweet creeks) during warm summer months.
- The plumes persisted during fluctuating reservoir water surface elevations.
- The size of the plumes can be affected by interaction with the flow in the mainstem.
- The topography of the delta may influence the behavior of the plume at various reservoir levels.

In addition, results of Study 9 (Fish Distribution, Timing, and Abundance Study Interim Report [SCL 2008b]), as well as informal observations during field trips, have indicated fish congregated at the mouths of these tributaries during periods of high reservoir water temperatures.

The proposed delta thermal plume monitoring program for 2008 has been developed to address two primary goals. The first goal is to monitor the thermal plume conditions at the major Boundary Reservoir tributary deltas that have a high potential for the existence of a cool water plume being utilized as thermal refugia. The second goal is to monitor water temperatures over a range of water surface elevations to fully define plume response to changes in reservoir levels.

The recommendation to address the first goal is to expand the monitoring effort to include two additional tributaries, Flume and Linton creeks. Flume Creek is proposed because of observations of fish utilizing the tributary delta during periods of warm water in the mainstem. Linton Creek is proposed because its delta has similar physical characteristics to Sweet Creek. Flow measurements conducted in September 2007 also showed similar discharge levels during this late summer period. Therefore, fish may utilize its thermal plume, if it exists, similarly to Sweet Creek.

To address the second goal, the proposed monitoring effort will expand the ranges of forebay water surface elevations and associated water surface elevations at the tributary deltas investigated to include one additional set of measurements at each of the three creeks monitored in 2007. (Note: The water surface elevation in the reservoir below Metaline Falls during low summer flow conditions is very close to the forebay water surface elevation. However, upstream of Metaline Falls, the water surface elevation at a location is often a function of both the forebay water elevation and the flow in the river.) This set of measurements will be performed at a lower forebay water surface elevation and associated water surface elevation at the tributary deltas than sampled in 2007 to provide a characterization of the thermal plumes at the lower limit of existing operations.

The major activities to accomplish the goals of the 2008 major tributary thermal plume monitoring effort are:

- Expand the monitoring effort to include Flume and Linton creeks by performing measurements similar to 2007 at high, medium, and low water surface elevations at Flume and Linton Creeks.
- Perform measurements similar to 2007 at Slate Creek at a forebay water surface elevation of 1,976 feet NAVD 88 (1,972 feet NGVD 29) to define the conditions at the lower limit of normal water surface elevation fluctuations below Metaline Falls.
- Repeat measurements similar to 2007 for the medium and high forebay water surface elevation conditions at Sullivan and Sweet creeks.
- Perform measurements similar to 2007 at Sullivan and Sweet creeks at a forebay water surface elevation of 1,980 feet NAVD 88 (1,976 feet NGVD 29) or lower to define the conditions at the lower limit of normal water surface elevation fluctuations above Metaline Falls.

The above monitoring will be performed at a mainstem flow rate from Box Canyon of approximately 10,000 cfs or less if 2008 hydrologic conditions allow. The proposed measurements will be collected in August 2008. If mainstem flows are expected to remain above 10,000 cfs in August, the measurements will be performed during a period in August when the flow forecasts indicate the flows will be the lowest. The hydraulic routing model will be run to predict what influence the predicted flows may have on the water surface elevations at each of the tributary deltas. The concern over mainstem flow rates is only for the tributaries above Metaline Falls, because the water surface elevations at tributary mouths below Metaline Falls are close to Boundary forebay water surface elevations during summer low flow conditions.

During 2008, measurements of the cold water temperature plume at Slate Creek will be taken when the reservoir water surface elevation is lower than what was measured in 2007; repeating measurements at the 2007 water surface elevations at Slate Creek is not proposed for 2008. The 2007 results showed a consistent cold water temperature plume developed within the narrow confines of the side canyon inundated by the reservoir. Because of the consistency of the three sets of measurements in 2007, it is proposed that repetition of the previous three sets of Slate Creek measurements is not warranted. However, a survey during pool conditions lower than the lowest pool condition surveyed in 2008 is proposed to verify whether the plume persists under conditions approaching normal low water surface elevation limit of 1,974 feet NAVD 88 (1,970 feet NGVD 29) in the forebay. Because there was more change in the location and shape of the thermal plumes measured at Sullivan Creek and Sweet Creek between the two water surface elevations in monitored 2007 than at Slate Creek, it is proposed that measurements be repeated at these two locations along with the proposed measurements at the lower water surface elevation.

4.1.5. Physical Habitat Modeling Approach and Data Collection

The Boundary Reservoir contains several tributaries that may provide important habitat for native salmonids. These tributaries have deltas created by deposition of sediments and these deltas are alternately exposed and inundated as the Project is operated for power production. Depending on the surface area, substrate character, gradient/slope, woody debris deposits, flow rate, and reservoir elevation, the value of potential aquatic habitat of each tributary delta increases or decreases with respect to various species and life stages of resident fish. These changing values will be evaluated with a semi-quantitative habitat quality rating that will be integrated into habitat modeling conducted as part of the evaluation of the effects of operations scenarios on aquatic habitats.

4.1.5.1. General Physical Habitat Modeling Approach

A HQR will be calculated from representative individual tributary delta surface areas for native salmonids (i.e., bull trout, westslope cutthroat trout, and mountain whitefish). The HQR will be based on the percent lacustrine habitat and the percent riverine habitat that will exist at each specific water surface elevations during the period of Project operations being evaluated. Riverine habitat will be the habitat in the portion of the stream within the maximum pool fluctuation zone that is not inundated at that elevation. This portion of the stream will still be flowing. The lacustrine habitat will be the habitat in the portion of the delta surface area within the maximum fluctuation zone that will be inundated at the specific elevation. This portion of the delta will be ponded. This methodology was presented at the June 7, 2007 RPs meeting.

To support the calculation of the HQR, the value of the lacustrine Habitat Suitability Index (HSI) at full pool level will be determined. This will represent the area of the delta surface inundated at the maximum extent of the reservoir fluctuation zone. At this water surface elevation, no riverine habitat exists on the tributary delta within the fluctuation zone and 100 percent of the potential lacustrine habitat exists. An illustration of this condition and the associated area definitions is provided in Figure 4.1-1. Similarly, the HSI value for riverine habitat at low pool level will be calculated. This will represent the area of riverine habitat at the lowest water surface elevation within the fluctuation zone. At this pool level, no lacustrine habitat is present on the delta within the pool fluctuation zone, it is entirely riverine. Figure 4.1-2 illustrates the definition of the areas under the low pool elevation.

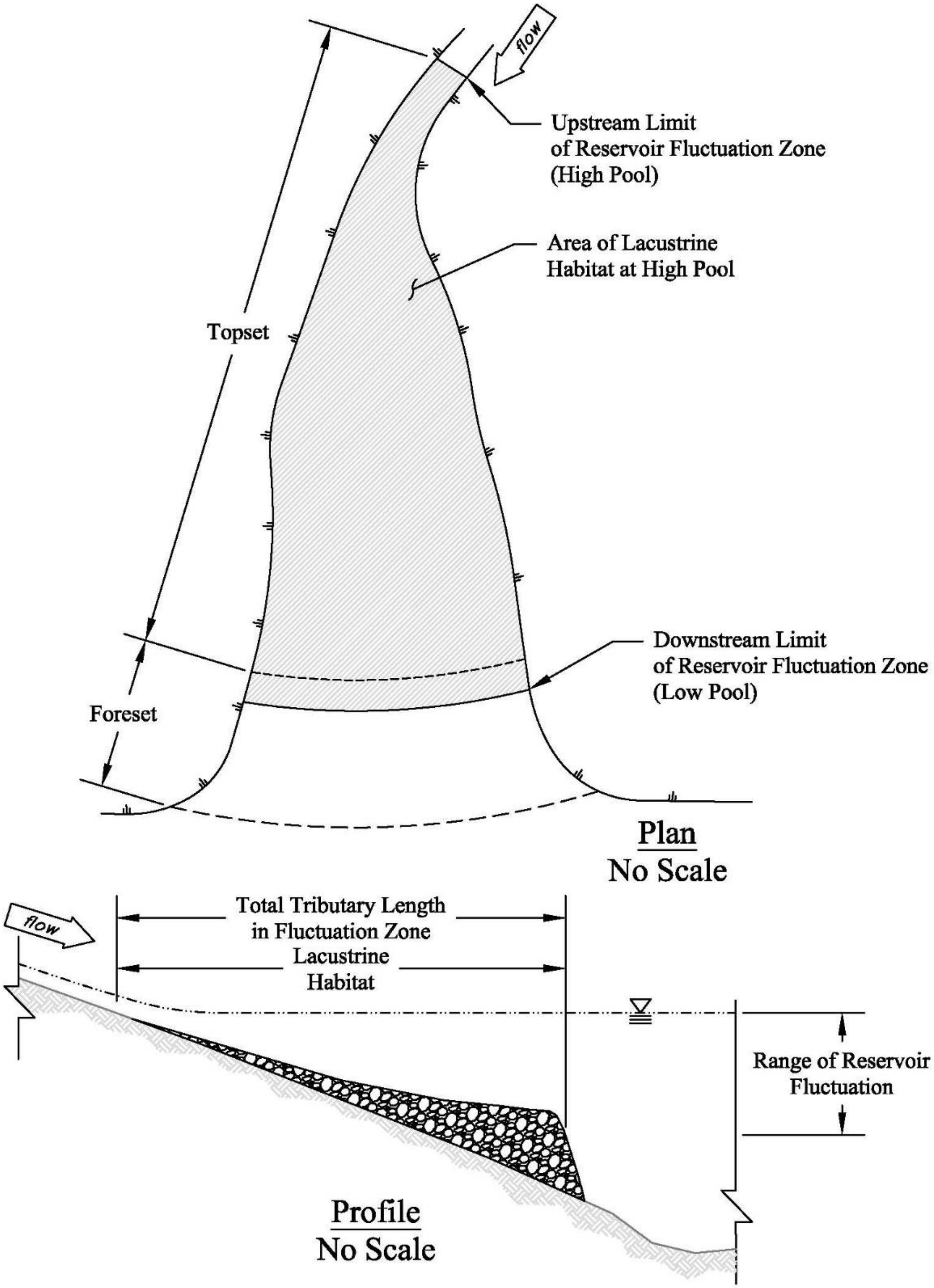

Figure 4.1-1. Conceptual model for determination of riverine and inundated habitat, plan, and profile views.

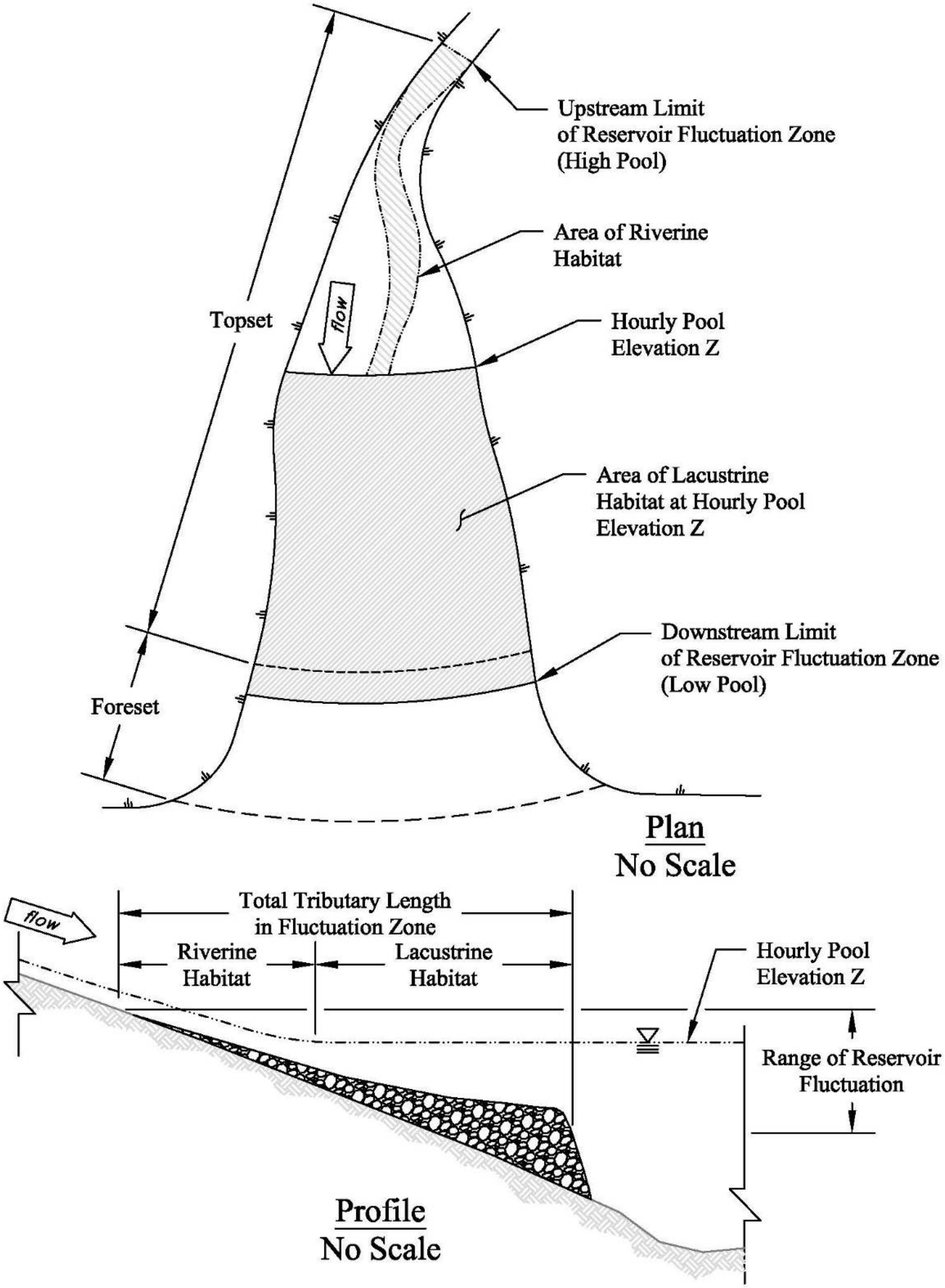

Figure 4.1-2. Conceptual model for determination of riverine and inundated habitat, example high pool and low pool conditions.

The corresponding equations are provided below (bold is for emphasis only):

> HQR $_{\textbf{lacustrine total}}$ = (area of **tributary delta** inundated at full pool) X (HSI for native salmonids in the **inundated delta** area)
>
> HQR $_{\textbf{riverine total}}$ = (area of **tributary stream** exposed at low pool) X (HSI for native salmonids in the **tributary riverine habitat** of delta area exposed at low pool)

At intermediate pool levels between the maximum extents of the reservoir pool fluctuation zone, the HQR will be calculated based on the percent of delta within the fluctuation zone that is inundated and the percent of riverine habitat that is exposed. Figure 4.1-3 illustrates the definition of the areas under an intermediate pool elevation Z.

The equation is as follows:

> HQR $_{\textbf{pool level Z}}$ = (% area of tributary delta inundated at pool level Z X HQR $_{\textbf{lacustrine total}}$) + (% area of **tributary riverine habitat** exposed at pool level Z X HQR $_{\textbf{riverine total}}$)

The percent of riverine area exposed at a specific hourly water surface elevation Z will be calculated by looking up percentages of exposed riverine habitat area and inundated delta area calculated based on the bathymetry and habitat mapping. Values will be tabulated at 1-foot intervals of elevation, with interpolation used to determine specific values for actual hourly reservoir elevations. The hourly reservoir elevations will be provided from the hydraulic routing model (Study 7).

Each representative tributary delta will be rated for habitat suitability index at full pool and at low pool. The different HSI were calculated for various salmonid life stages based on habitat characteristics and parameters within the tributary stream as it flowed through its delta area during the late summer when the maximum amount of the delta area was exposed during low reservoir pool conditions. A full reservoir pool (i.e., maximum delta inundation at full reservoir pool elevation) HSI was calculated for comparison to the HSI calculated under low reservoir pool and low tributary flow conditions.

This phase of the studies will only report on the preliminary HSI values derived from the habitat evaluation and water quality data. Future analyses will use the HSI data reported here in conjunction with the quantity of habitat areas (riverine or lacustrine habitat area) available at selected tributary delta study sites at various water surface elevations (using the hourly hydraulic routing model output) to generate a HQR for each tributary delta based upon the reservoir water surface elevation.

The HQR values are intended to provide an evaluation of the relative changes in tributary delta habitat for operations scenarios. The HQR values calculated for the tributary deltas are not comparable to the mainstem habitat indicators of environmental effects. Therefore, the tributary delta HQR results will be evaluated separately from the mainstem and will not be added to mainstem values.

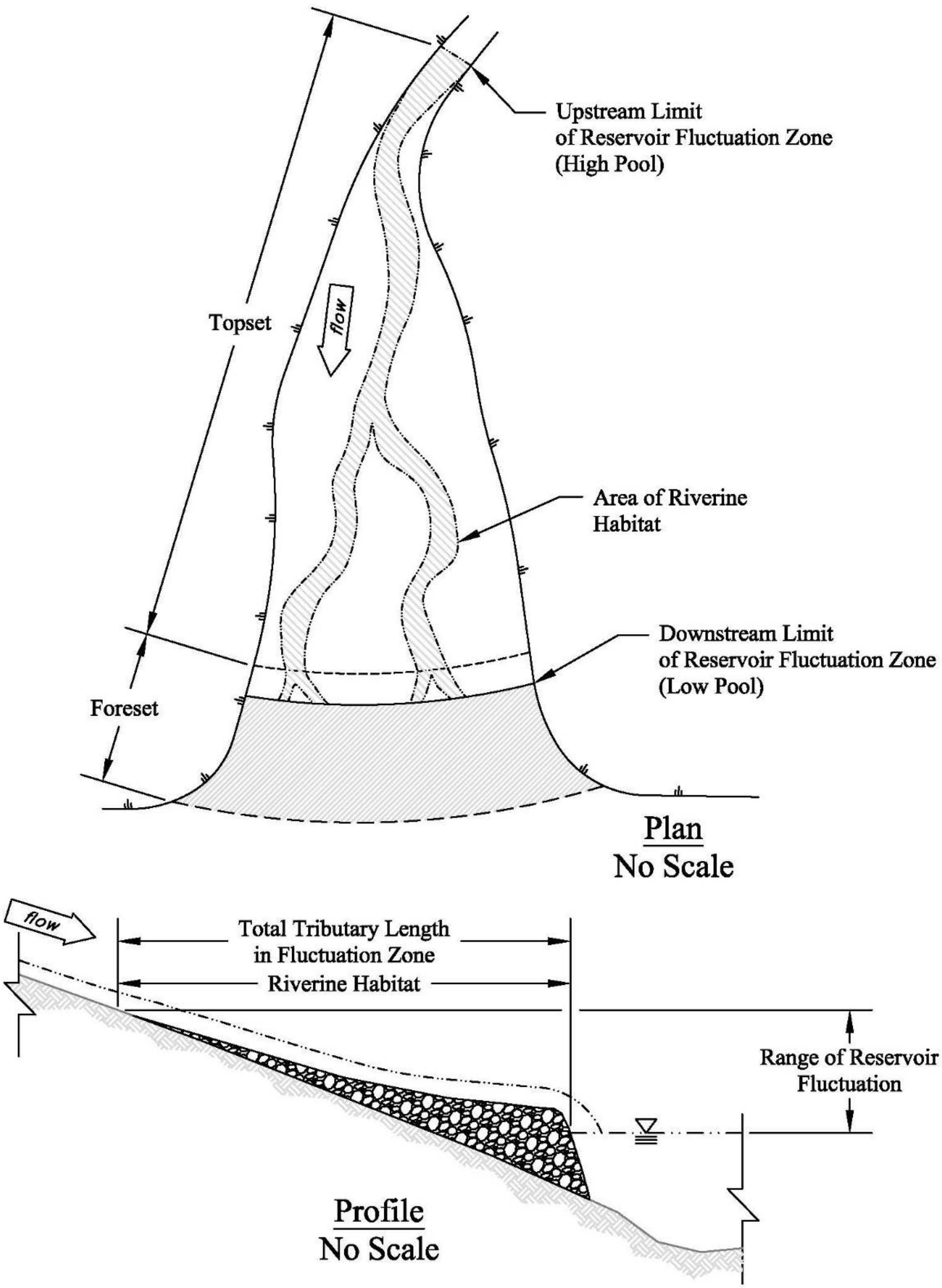

Figure 4.1-3. Illustration of lacustrine and riverine habitat areas at an intermediate pool elevation.

4.1.5.2. Tributary Delta Habitat Surveys

The habitat evaluations were conducted within the flowing tributaries at low reservoir pool during the late summer low tributary flow period. The habitat surveys were conducted within the pool inundation zone, that is, within the tributary delta between high and low reservoir pool elevations. The location of the high reservoir pool elevation for each of the tributaries was visually estimated from physical indicators such as changes in vegetation, substrate particle sizes, and/or deposition of debris. The following characteristics of tributary delta habitat were evaluated during the surveys:

- Macrohabitat
- Substrate
- Fish cover and fry habitat
- Pools
- Fine sediment
- Large woody debris (LWD)
- Channel geometry
- Flow
- Water quality

All of the physical data collected during the habitat surveys were used to quantify the amount and the location of riverine habitat available to fish in the tributary deltas during periods of low reservoir pool.

4.1.5.2.1. Macrohabitat

The habitat surveys included physically walking the entire tributary stream channel between the low and high reservoir pool elevations and describing the sequence of macrohabitat types within the flowing tributary. The macrohabitat types used in the Boundary Reservoir tributary delta surveys were adapted from the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 1998) and included:

- Low gradient riffle
- High gradient riffle
- Cascade
- Run
- Pocket water
- Step run
- Pool

The length of each of the macrohabitat types was measured to the nearest foot using a hip chain and was recorded on a data sheet. For Sullivan Creek, where channel braiding resulted in multiple tributary channels within the delta (Figure 4.1-4), habitat mapping was conducted within each of the secondary channels.

Figure 4.1-4. Sullivan Creek delta showing channel braiding at the time of the September 8, 2007, habitat evaluation (note: discharge was measured at 50.6 cfs).

4.1.5.2.2. Substrate

Visual estimates of the dominant substrate characteristics were made using the Washington Department of Fish and Wildlife Substrate code (Table 4.1-1). This three-digit code identifies the dominant substrate particle size (first digit), followed by the subdominant substrate size (second digit), and then the percent of the dominant substrate within the stream channel (third digit). The codes for the substrate sizes are presented in Table 4.1-1. For example, a code of 27.8 represents an area where sand is the dominant substrate and large cobble is the subdominant bed element, with sand comprising 80 percent of the stream bed. A substrate code of 11.5 denotes a channel composed entirely mud.

Table 4.1-1. Washington Department of Fish and Wildlife substrate coding.

Substrate Category	Particle Size (inches)	Code
Organics/Silt/Clay/Mud	NA	1
Sand	<0.125 (1/8")	2
Small gravel	0.125 – 0.5	3
Medium gravel	0.5 – 1.5	4
Large gravel	1.5 – 3.0	5
Small cobble	3.0 – 6.0	6
Large cobble	6.0 – 12.0	7
Boulder	> 12.0	8
Bedrock	NA	9

4.1.5.2.3. Fish Cover and Fry Cover

An evaluation of fish cover was included in the surveys. Fish cover elements included surface turbulence, instream object cover (e.g., cobbles and boulders), undercut banks, overhanging vegetation within 3 feet of the stream surface, aquatic vegetation, and LWD. The percentage of fish cover (estimated as the percentage of the total macrohabitat area) provided by each of the cover categories within each macrohabitat unit was visually estimated and recorded.

The percentage of fry (small juvenile fish <4 inches in length) escape and winter cover, which Hickman and Raleigh (1982) defined as cobble/boulder substrates (and their interstitial spaces) in the 4- to 16-inch range, was visually estimated for each of the macrohabitat units.

4.1.5.2.4. Pools

Another important habitat variable used in the HSI model is the amount and quality of pool habitat. Each pool identified was classified using the criteria described in Hickman and Raleigh (1982):

- 1st Class Pools are large and deep resting/holding pools defined as having greater than 30 percent of pool bottom obscured due to depth, surface turbulence, or cover (boulders/woody debris/overhead vegetation/aquatic vegetation) ***OR*** maximum depth greater than 5 feet.
- 2nd Class Pools are moderate resting/holding pools defined as having 5 to 30 percent of pool bottom obscured due to depth, surface turbulence, or cover (boulders/woody debris/overhead vegetation/aquatic vegetation).
- 3rd Class Pools are small and shallow resting/holding pools defined as having less than 5 percent of pool bottom obscured due to depth, surface turbulence, or cover (boulders/woody debris/overhead vegetation/aquatic vegetation).

Maximum pool depths and pool tail depths were also measured in each pool (to the nearest 0.05 foot) using a stadia rod. The difference between these two depth measurements provided an estimate of the residual pool depth.

4.1.5.2.5. Fine Sediment

The percentage of fine sediments present in each riffle and run habitat was visually estimated. Fine sediment was defined as any bed elements less than 0.125 inch, which included sand, mud, silt, clay, and organics (as defined in Table 4.1-1).

Substrate embeddedness was evaluated at select locations along the tributary channel using an embeddedness index. The index used is based on the visual methods described in the Flosi et al. (1998), where several large gravel/cobble elements are evaluated to determine the average amount of the gravel/cobble elements that are buried in fine sediment. The index values are presented in Table 4.1-2. Sand and mud substrates were given an index score of 4, or completely embedded.

Table 4.1-2. Embeddedness index (from Flosi et al. [1998]).

Percent Embedded	Embeddedness Index
0 – 25 percent	1
26 – 50 percent	2
51 – 75 percent	3
76 – 100 percent	4

4.1.5.2.6. Large Woody Debris

All LWD accumulations on depositional surfaces of the deltas and in the tributary channels within the normal reservoir fluctuation zone were identified and photographed during the habitat mapping survey. The number of pieces of wood and the size (in cubic feet) of each LWD accumulation were estimated and recorded along with the location (as a waypoint) using a small handheld Garmin® eTrex Venture global positioning system. Potential fish migration barriers were noted, GPS-located, and photographed.

4.1.5.2.7. Channel Geometry

Once habitat mapping of the tributary stream channels was completed, markers were placed at equidistant locations along the stream banks defining the upstream limit, downstream limit, and 10 percent increments of the total channel distance measured during habitat mapping. These markers denoted 11 locations where transects were established along the longitudinal length of the stream channel within the tributary delta. For Sullivan Creek, where multiple channels were present, additional transects were placed in each of the secondary channels.

At each of the transect locations, measurements were made of wetted channel width and toe of bank width. Wetted channel widths were measured to the nearest 0.1 foot using a surveyors tape. Toe of bank widths were measured to the nearest foot using either a surveyors tape or a handheld Advantage® laser range finder (Laser Atlanta, Inc.) with a range of 5 to 2,500 feet and an accuracy of ±0.5 foot. Depth measurements (to the nearest 0.05 foot) and mean column water velocities were made at ¼, ½, and ¾ distance across each transect. The maximum thalweg depth across each transect was recorded. Water velocities were measured at six-tenths of the water depth using a Marsh-McBirney® Flo-Mate Model 2000 portable electronic flow meter mounted on a wading rod. All velocity measurements were made over 10-second intervals.

A GPS waypoint location and a water surface elevation was recorded at the center point of each transect. The GPS data can be used in conjunction with GIS software to provide a trace of the tributary channel on an overlay of the delta area. The water surface data can be used to back calculate thalweg depths and to provide the gradient of the tributary channels. All water surface elevations were shot in reference to temporary survey control monuments. All elevations were shot from one or two instrument locations (that were also located using GPS waypoints). In addition to the GPS location for each water surface transect location, the distance (to the nearest foot) and compass bearing from the survey instrument were noted for each water surface elevation shot location. Distances were measured using the laser range finder.

4.1.5.2.8. Flow

Following the habitat mapping and physical channel surveys a stream flow measurement was conducted in the tributary channel immediately upstream of the delta area. Water velocities were measured at six-tenths of the water depth using a Marsh-McBirney® Flo-Mate Model 2000 portable electronic flow meter mounted on a wading rod. All velocities were recorded at 20-second intervals and the techniques for measuring discharge generally followed the guidelines outlined by Rantz et al. (1982). These guidelines include a goal of a measuring velocity at a minimum of 20 stations for each flow measurement transect. In the case of Linton Creek, the narrow channel width (6.3 feet) combined with the survey crew's use of a minimum cell width of 0.5 foot, resulted in fewer velocity measurements for this flow measurement.

4.1.5.2.9. Water Quality

Several water quality parameters were measured both in the tributary stream and in the reservoir just offshore of the tributary mouth. Water quality measurements included water temperature, pH, conductivity (microsiemens per centimeter [µS/cm]), specific conductivity (temperature standardized conductivity), salinity (ppt), and dissolved oxygen concentrations (milligrams per liter [mg/L]), and percent saturation. The pH measurements were made using a Tetratest® pH freshwater kit available at most aquarium stores. The remaining water quality parameters were measured using Yellow Spring Instruments® handheld electronic meters (Models 30 and 550).

Additional Boundary Reservoir water quality data used in the lacustrine portion of the HSI model (water temperature, dissolved oxygen, and pH) were derived from continuous water quality monitoring buoys anchored in the upper reservoir about 1.5 miles downstream of Box Canyon Dam. The monitoring buoys were deployed as part of Study 6 (Evaluation of the Relationship of pH and Dissolved Oxygen to Macrophytes in Boundary Reservoir).

4.1.5.3. Calculation of Tributary Delta Surface Areas

As described in Section 4.1.5.2.1, measurements of the extent of tributary habitat were recorded during the low reservoir pool elevation conditions. The 2007 bathymetric data will be used in conjunction with the physical mapping of the tributary channel habitat to quantify the delta surface area inundated and the stream channel exposed at various pool elevations. The physical habitat mapping was performed under low pool conditions; however, if the 2007 drawdown elevation did not expose the entire delta surface in the fluctuation zone for operations scenarios, the bathymetry will be used to extend the mapping of the delta and stream surfaces. Therefore, the 2007 bathymetric survey data will supplement the field data for complete mapping of the tributary delta areas. Once the data sources are combined, the percentage of representative tributary deltas exposed/inundated will be calculated across a range of reservoir water surface elevations.

4.1.5.4. Calculation of Habitat Suitability Indices

To assess the habitat quality of the riverine portions of the representative tributary deltas some of the physical data were applied to a HSI model. HSI values were calculated for individual representative tributary delta areas for three life stages (i.e., adult, juvenile, and fry) of "generic" native salmonids using the species-habitat relationships developed for cutthroat trout by Hickman and Raleigh (1982). The spawning and incubating life stages were not included in the analyses since the lower portions of the tributaries flowing through the delta areas (i.e., the varial zones) were not considered to be important spawning or incubation areas.

These habitat-based models evaluate a variety of habitat conditions or features (e.g., water quality, dominant substrate, pool quality) important to salmonid species in both riverine and lacustrine habitats. Suitability scores are synthesized into the HSI models, which are scaled to produce an index between zero (unsuitable habitat) and one (optimal habitat). These HSI values are then multiplied by the riverine or lacustrine habitat areas available at selected tributary delta study sites at various water surface elevations using the hourly hydraulic routing model output.

4.1.5.4.1. Riverine Model

The variables used in the generalized "salmonid" life stage-based HSI for the tributaries at low pool elevation (i.e., Hickman and Raleigh's [1982] riverine model) include channel depth, amount of fish cover, the amount and quality of pool habitat, amount of fry escape cover, and amount of fine sediment in the riffle and run areas (Figure 4.1-5 and Table 4.1-3).

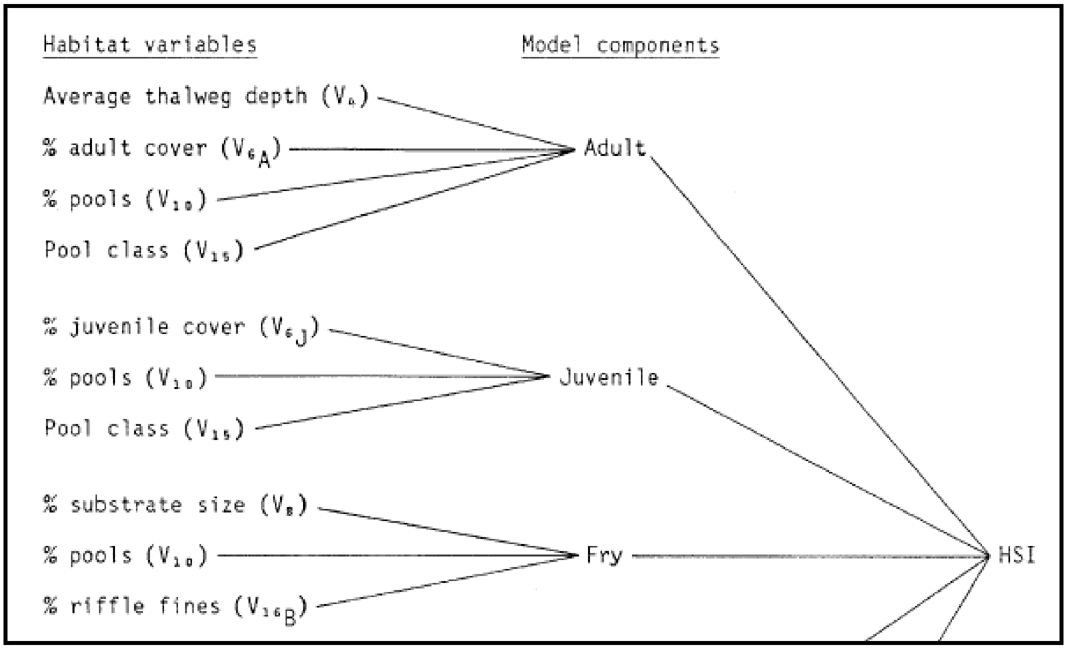

Figure 4.1-5. Relationships among Hickman and Raleigh's (1982) riverine model variables, components, and Habitat Suitability Index (HSI).

Table 4.1-3. Variables, descriptions, and applicable life stages for the riverine component of the Hickman and Raleigh (1982) cutthroat trout HSI model.

Variable	Description	Life Stage
V_4	Average thalweg depth	Adult
V_6	Percentage cover during late season low water growing period	Juvenile and Adult
V_8	Percentage of substrate in the 4 – 16-inch size class (winter escape cover)	Fry
V_{10}	Percentage pool habitat during late season low water growing period	Fry, Juvenile, and Adult
V_{15}	Pool class rating	Juvenile and Adult
V_{16}	Percentage of fines (substrates <1/8") in riffle run areas during low summer flow	Fry

The HSI suitability curves for each of the riverine variables are shown in Figures 4.1-6 through 4.1-10 and in Table 4.1-4.

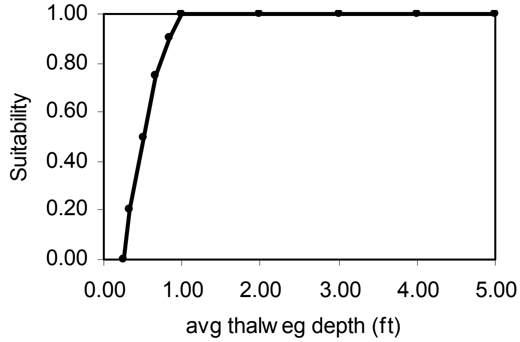

Figure 4.1-6. HSI suitability curve for average thalweg depth (V_4).

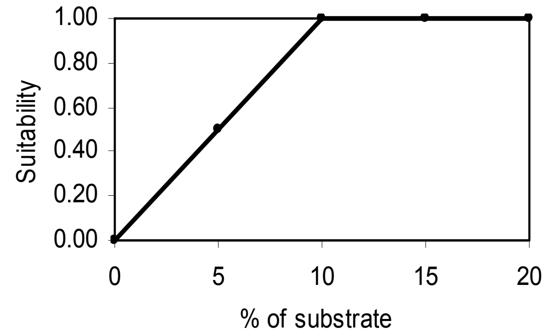

Figure 4.1-8. HSI suitability curve for percentage of substrate in the 4 to 16-inch size class (winter and escape cover) (V_8).

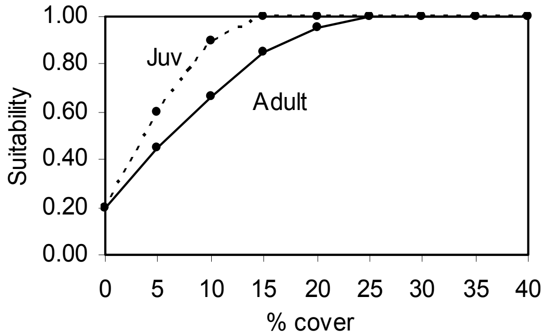

Figure 4.1-7. HSI suitability curve for percentage cover during late season low water growing period (V_6).

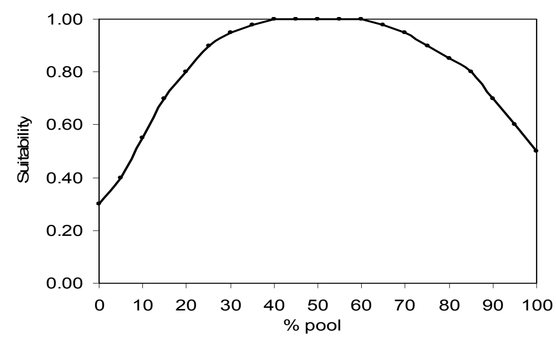

Figure 4.1-9. HSI suitability curve for percentage pool habitat during late season low water growing period (V_{10}).

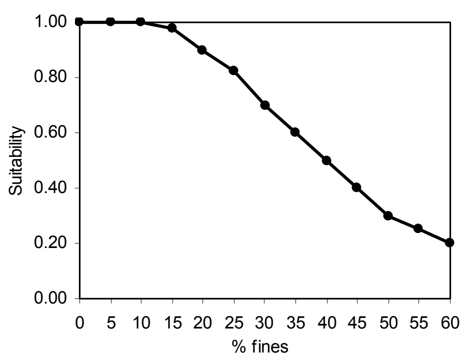

Figure 4.1-10. HSI suitability curve for percentage of fines (substrates <1/8 inch) in riffle run areas during low summer flow (V_{16}).

Table 4.1-4. HSI suitability metrics for pool class rating (V_{15}).

Pool Class	Suitability	Description
A	1.00	At least 30 percent of pools are 1st class
B	0.60	10 – 29 percent of pools are 1st class OR at least 50 percent are 2nd class
C	0.30	Less than 10 percent of pools are 1st class AND less than 50 percent are 2nd class

Computation of the overall riverine HSI scores for each of the three "salmonid" life stages was based upon various mathematical formulas that combined the suitability scores for the habitat variables of interest for each life stage. The formulas used for each of three life stages are:

Adult Salmonid HSI:

If $V_6 > \sqrt{V_{10} * V_{15}}$, then adult HSI = $\left[V_4 * V_6 * \sqrt{V_{10} * V_{15}}\right]^{1/3}$

If $V_6 \le \sqrt{V_{10} * V_{15}}$, then adult HSI = $\left[V_4 * \sqrt{V_{10} * V_{15}}\right]^{1/2}$

OR if either V_4 or $\sqrt{V_{10} * V_{15}}$ is less than or equal to 0.40, then adult HSI equals lowest factor score.

Juvenile Salmonid HSI:

Juvenile HSI = $\dfrac{V_6 + V_{10} + V_{15}}{3}$

OR if any of the three variables is less than or equal to 0.40, then juvenile HSI equals the lowest factor score.

Salmonid Fry HSI:

Salmonid Fry HSI = $\left[V_{10} * \sqrt{V_8 * V_{16}}\right]^{1/2}$

OR if either V_{10} or $\sqrt{V_8 * V_{16}}$ is less than or equal to 0.40, then salmonid fry HSI equals the lowest factor score.

4.1.5.4.2. Lacustrine Model

Hickman and Raleigh's (1982) lacustrine model was used to compute a HSI for the tributary delta areas at high reservoir pool (or at full delta inundation). The lacustrine model relies on three water quality parameters as shown in Table 4.1-5 and the resulting HSI score applies equally to all three life stages.

Table 4.1-5. Variables, descriptions, and applicable life stages for the lacustrine component of the Hickman and Raleigh (1982) cutthroat trout HSI model.

Variable	Description	Life Stage
V_1	Average maximum water temperature during the warmest part of the year	All
V_3	Average minimum dissolved oxygen during the late growing season	All
V_{13}	Annual maximum or minimum pH	All

The HSI suitability curves for each of the lacustrine model variables are shown in Figure 4.1-11 through Figure 4.1-13.

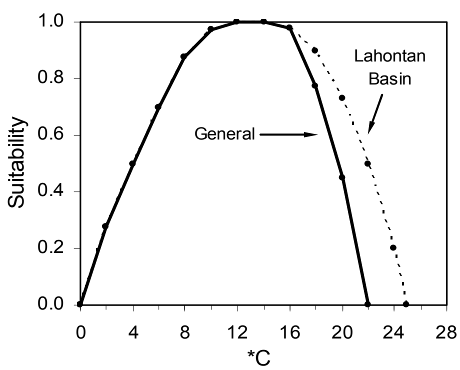

Figure 4.1-11. HSI suitability curve for average maximum water temperature (°C) during the warmest part of the year (V_1) – two different “regional” suitability curves.

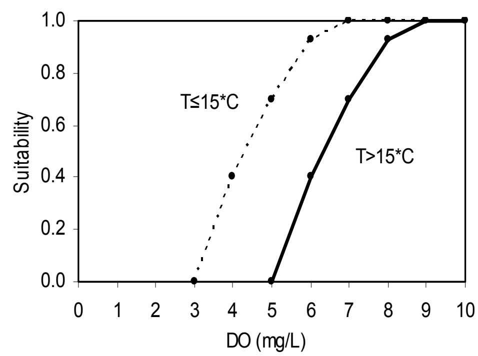

Figure 4.1-12. HSI suitability curve for average minimum dissolved oxygen (mg/L) during the late growing season – two different suitability curves depending on ambient water temperatures during late season period (V_3).

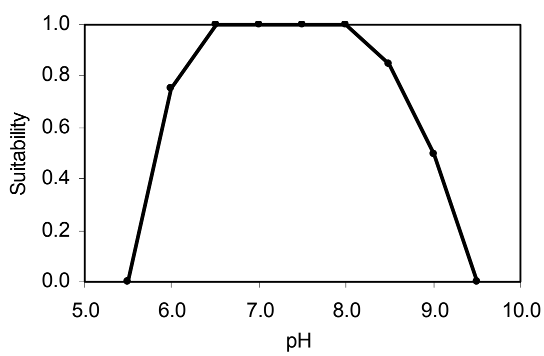

Figure 4.1-13. HSI suitability curve for annual maximum or pH (use the extreme with the lowest suitability index) (V_{13}).

Computation of the overall lacustrine HSI scores for all "salmonid" life stages was based upon the mathematical formula:

$$HSI = [V_1 * V_3 * V_{13}]^{1/3}$$

OR if either V_1 or V_3 is less than or equal to 0.40, then the HSI equals the lowest factor score for V_1 or V_3.

In application of the HSI, if the reservoir temperature exceeds 22°C, the lacustrine HSI goes to 0.0 as the temperature becomes unsuitable for salmonids. However, data collection efforts in 2007 indicated that areas of cooler water are present at several of the tributary deltas (see Section 5.1.4.2). Therefore, areas of water at suitable temperatures can provide thermal refugia at the tributary deltas. Additional data collection is recommended for 2008 to further characterize the thermal plumes at five of the most significant tributary deltas (see Sections 4.1.4.2.2 and 7.2.2.2) If the results of monitoring the thermal plumes at the tributary deltas provide characterization of the thermal plumes sufficient to incorporate in the HSI determination and estimation of area for HQR calculation, the presence of the thermal plumes will be incorporated into the evaluation of lacustrine habitat suitability.

4.1.6. Future Tributary Sediment Supply

The tributary deltas are dynamic environments that have the potential to change over time. The deltas may respond by either aggrading or degrading as a result of the interaction of upstream sediment supply, local hydraulic conditions created by Project operations, and the influence of flows in both the tributaries and the mainstem Pend Oreille.

The delivery of bed material load (both suspended load and bed load) to the tributary deltas requires quantification for the modeling of the deltas. Quantification includes not only the actual volume but an estimate of the size of material delivered. These factors, in conjunction with the hydraulic conditions created by Project operations, largely control the morphology of the tributary deltas. This includes the growth rate of the deltas, the slope of the delta surfaces, and the potential ultimate equilibrium conditions.

Three approaches will be applied to identify the volume of bed material load delivered to the deltas. The three procedures are:

- Estimate the volume of sediments that have accumulated in the deltas
- Calculate the bed material load transport based on stream hydraulics and substrate
- Apply regional sediment yield relationships

These estimates will be performed as part of the Mainstem Sediment Transport modeling effort described in Section 4.3.2 of this study, but the results will also be used in the Tributary Delta Habitat Modeling study. Ultimately, the estimates will be used to develop a time series of sediment supply on a grain-size specific basis to each representative tributary delta. The estimate of time series of sediment supply will be developed utilizing a time series of daily flows adopted as representative of long-term future hydrologic conditions for relicensing purposes for all studies.

Which procedure yields the best estimate of supply will depend on the conditions at the particular delta. For example, in the areas where the reservoir influence is predominant and a large area was available for deposition of material in the reservoir pool, the most accurate estimate of sediment supply can be obtained from an estimation of the volume of sediment deposited. However, in areas where the potential storage area is limited and the mainstem Pend Oreille River exhibits more riverine conditions for at least some operating conditions, a significant portion of the bed material load delivered to the delta area may be transported downstream. In this case, an estimate based on the bed material load calculations or regional equations would be more appropriate.

Applying each of the three procedures for estimating future tributary sediment supply requires tributary delta specific information. Detailed field data collection efforts occurred during the September 2007 reservoir drawdown to take advantage of exposed tributary delta features. Data collected included sketches and photographic documentation of delta morphology, mapping of depositional features, characterization of depositional material, and surveys of the tributary thalweg profile and tributary channel geometry at cross sections selected for calculating bed material load transport.

4.1.6.1. Sketches and Photographic Documentation

Delta features were sketched and photographed to document conditions at the deltas during the September 2007 reservoir drawdown. The delta sketches were recorded on field forms. Key features noted on the sketch included:

- Location, size, and orientation of depositional features in the tributary channels and on the tributary delta
- Composition/dominant substrate size of depositional features
- Locations of LWD (e.g., downed trees, logs, stumps)
- The planform of the tributary channel
- Locations of potential fish migration barriers
- Locations of survey control points

Photographs were taken using digital cameras. Photograph number, date and time taken, and brief notes were recorded on photograph logs. Key points of interest included:

- The tributary delta
- Substrate sizes, both for depositional features as well as the tributary channel
- Substrate sample locations
- The morphology of the tributary channel as documented in a series of photographs

4.1.6.2. Mapping of Depositional Features

The location, size, and orientation of depositional features were mapped using a Trimble® GPS Pathfinder Pro XH receiver. After post-processing the data, horizontal accuracy is sub-foot. The perimeters of various depositional features were walked as the GPS receiver recorded positions on a 2-second interval. The centerline of the tributary channel through the exposed delta was recorded with the GPS unit. Where exposed, the change in slope between the topset, foreset, and bottomset portions of the delta was recorded.

4.1.6.3. Characterization of Depositional Materials

Two different techniques were employed to characterize the particle size distribution of depositional material in the tributary channel and on the tributary delta. The first technique, as described by Wolman (1954) (commonly referenced as a Wolman count), entailed measurement of the intermediate axis of 100 pebbles randomly selected from the surface of interest. The second technique involved taking a volumetric sample of sediment and sending it to a laboratory that can sort the size fractions using sieves and a hydrometer. The laboratory analyses were performed by Cascade Testing Laboratory, Inc. in Kirkland, Washington following the American Society of Testing Materials (ASTM) International active standard D422 – Standard Test Method for Particle-Size Analysis of Soils. Cascade Testing Laboratory followed the sediment size distributions provided in ASTM active standards C136 – Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, and C117 – Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing, with the exception that a No. 270 wash was used instead of a No. 200 wash.

The advantages of the Wolman count as compared to a volumetric sample are applicability to very coarse materials and better representation of large sample area. The advantage of the volumetric sample as compared to a Wolman count is the ability to represent finer size fractions (i.e., fine gravels, sands, silts, and clays). During the detailed tributary delta characterization, the number of areas sampled on each delta and the type of sampling method varied as a function of the size and complexity of the depositional features.

4.1.6.4. Tributary Thalweg Survey

The distance along the thalweg of the primary tributary channel through the delta was marked off in 25-foot increments using a surveyors tape. Station 0+00 was assigned to an upstream location in the tributary channel upstream of the backwater influence of the reservoir (except in Flume Creek where the backwater influence extended to the base of a cascading waterfall that could not be safely navigated). The longitudinal profile along the stationed thalweg was surveyed using a level. A Topcon AT-G2 Auto Level was mounted on a tripod and elevations were read from a fiberglass stadia rod. The stadia rod was marked with divisions of 0.01-foot to a total length of 25 feet. The elevation of the level was calculated from temporary survey control monuments. The elevation of the monuments was provided with resolution to 0.01 foot, and the elevations reference the Project datum (NAVD 88). Significant changes in the grade of the thalweg were surveyed, along with geomorphic features (e.g., head of riffle, tail of riffle, maximum pool depth, pool tail out), and the elevation at the 25-foot stationing increments.

4.1.6.5. Tributary Bedload Cross Section Surveys

To support the estimation of bed material load transport based on hydraulic conditions and substrate, two cross sections will be surveyed near the upper end of the reservoir fluctuation zone or upstream in the tributary. The cross sections will be selected during the field reconnaissance to best represent sections that are in equilibrium, but not supply limited (armored or paved). The overall water surface slope will also be surveyed in the area of each transect. The actual flow in the channel will be measured at one cross section using an appropriate current meter for the conditions of velocity and depth encountered. Measurements will be per standard USGS procedures and guidelines (Rantz et al. 1982). A visual estimate of Manning's n-values will be performed. A Wolman pebble count (Wolman 1954) with a minimum of 100 particles will be collected in the area of each cross section to provide a quantitative description of the bed material sizes present. Hydraulic conditions for application of the bed material load equation will be determined from normal depth calculations. Appropriate bed material load equations will be selected based on the dominant sizes of sediments and hydraulic conditions at each study tributary. The average annual loading of bed material will be based on the integration of the synthesized hydrologic record for each tributary.

4.1.7. Mainstem Sediment Transport Capacity

Sediments carried to the downstream portions of the tributary deltas may be mobilized by mainstem channel hydraulics. This may occur as the tributary deltas grow to the point at which mainstem flows are capable of mobilizing the deposited sediments. When this condition is achieved, high flows in the mainstem will periodically remove tributary delta deposits. This will prevent any further long-term riverward growth of the delta. The tributary sediments may be transported downstream into the mainstem channel and not accumulate in the immediate tributary delta. The HEC-RAS model for the mainstem channel will be used to determine hydraulic conditions at the toe (typically the foreset slope) of the tributary delta. The output of the HEC-RAS model will be used to determine the point in the development of a tributary delta at which its encroachment on the mainstem Pend Oreille River channel will result in exposing the delta deposits to mainstem hydraulic conditions that can transport the deposited sediments downstream.

Incipient motion calculations (determination of the maximum particle size that can be mobilized under a given hydraulic condition) will be used to estimate the point at which hydraulic conditions on the mainstem limit further delta growth. Because of the size of the mainstem Pend Oreille River compared to its tributaries, it is expected that incipient motion will be a simpler and more accurate indicator of the delta reaching an equilibrium condition than attempting to isolate actual sediment transport rates at the delta toe. This conclusion is based on the several orders of magnitude larger flow in the Pend Oreille River having much higher sediment transport capacity than the tributaries.

The basis of incipient motion is that bed material particles will be mobilized when the hydrodynamic lift force applied on the particle exceeds the submerged particle weight. The Shields (1936) parameter is defined as the dimensionless number calculated as the ratio of the applied shear stress (i.e., the lift force) to the submerged weight (the resisting force). The Shields parameter is calculated using the following equation:

$$\tau_* = \frac{\gamma_w R_h S_f}{(\gamma_s - \gamma_s) d_s}$$

Where:

τ_* = Shields parameter (dimensionless)
γ_w = unit weight of water (pounds force/cubic foot [lbf/ft^3])
R_h = hydraulic radius (square foot/foot [ft^2/ft])
S_f = friction slope (ft/ft)
γ_s = unit weight of sediment (lbf/ft^3)
d_s = median dimension representing particle size s (feet [ft])

The critical value of this parameter, corresponding to the beginning of particle motion, depends primarily on flow conditions. Therefore the threshold state is not as straightforward as balancing forces. On hydraulically rough surfaces (such as the tributary delta foresets), the critical values typical range from 0.03 to 0.06, with 0.047 commonly used as a good approximation.

The tributary deltas will continue to accumulate sediments until hydraulic conditions reach a point in the Pend Oreille River when the coarsest size fractions in the delta deposits become mobile. As the tributary deltas accumulate sediment and extend farther into the Pend Oreille River, the cross-sectional area in the Pend Oreille River at the delta effectively decreases; however, the magnitude of the flow in the river past this point does not change. Consequently, flow velocity in the Pend Oreille River increases and hydraulic stresses applied on the channel boundary (including the delta foreset) increase. Data collected during the September 2007 field efforts will be used to determine the coarsest size fractions delivered to representative deltas. Alternative mainstem channel geometry corresponding to tributary delta growth will be input to the HEC-RAS model and the output hydraulic stress will be compared to critical values of the Shields (1936) parameter to determine whether the coarsest size fractions are stable or mobile. Using this approach, the maximum size of representative tributary deltas can be calculated, and the corresponding delta areas will affect the habitat areas represented in the tributary delta habitat models.

4.1.8. Identify Type 2 Tributary Deltas

A conceptualization will be made to support the modeling of how each tributary delta will evolve over the potential term of a new license. The conceptualization will address the size of the delta and potential effects of operations scenarios on delta morphology (see more detailed methods in Section 4.2. In general, determination of the tributary delta type will be based on the following data:

- Current topography and bathymetry
- Historic topography and bathymetry
- Estimated future sediment supply
- Estimated historic volumes of sedimentation
- Potentially available sediment storage volume
- Mainstem hydraulic and associated sediment transport conditions
- Current delta morphology (e.g., topset and foreset slope, and sediment size distributions)
- Estimated future equilibrium condition from advancement of the delta foreset slope to the mainstem
- Estimated equilibrium slope for transport of sediment across the foreset slope

Tributary deltas will be categorized as appropriate for Type 2 delta evolution models based on the criteria presented in Section 4.1. Type 2 tributary deltas may provide significant delta habitat, but the existing size and morphology of the delta is not expected to change substantially over the term of a new license.

4.1.9. Develop Type 2 Physical Habitat Models

The Type 2 tributary delta physical habitat models will be developed to evaluate the effects of operations scenarios on aquatic habitats. The morphology of Type 2 tributary deltas are not expected to change over the potential term of a new license, so the current morphology of the delta will be used to represent the delta morphology at all points in the modeling horizon. The operations scenarios are expected to affect the extent and duration of inundation of various surface areas on the delta and within the tributary channel.

For Type 2 tributaries, though the delta physical conditions will not change between operations scenarios, the range of reservoir water surface elevation fluctuations may. Therefore, each operations scenario will require calculation of its own set of values for the total lacustrine condition and the total riverine condition. For each operations scenario, the HQR at the maximum pool level will be calculated based on the lacustrine HSI times the area of the delta surface at full pool. Likewise, the HQR for the minimum pool level will be calculated based on the riverine HSI multiplied by the area of the stream channel exposed at minimum pool. Hourly calculation of the HQR will be performed by determining the percent of the total lacustrine habitat and the percent of the total riverine habitat exposed at the water surface elevation for that hour, then multiplying the corresponding HQR by these fractions.

4.1.10. Identify Type 3 and 4 Tributaries

In combination with the methods presented in Section 4.1, Type 3 and Type 4 tributaries will be identified by the expectation that the delta size and morphology significantly change over the potential term of a new license (i.e., net aggradation or degradation). Whether the size and morphology is expected to change in response to operations scenarios determines whether a tributary is classified as Type 3 or Type 4. Sediment transport processes, including delta dynamics, may be fairly insensitive to certain changes in Project operation since high flows that typically drive morphologic processes are minimally affected by Project operations. For example, seasonal flow records from the Salmo River, which is representative of most tributary flow regimes in the area[2], indicate that high flows (and tributary sediment transport) typically occur during the snowmelt season (May and June). The forebay in Boundary Reservoir is typically maintained at or near full pool level when there are high flows during May and June; thus, changes in tributary delta morphology may occur over time but may not be influenced by operations scenarios. If morphological changes in a tributary delta are expected to be the same under each operations scenario, it will be considered a Type 3 delta. Alternatively, if changes in tributary delta morphology are scenario-specific, the tributary delta will be considered a Type 4 delta.

[2] The exception within the Project area is Sullivan Creek, where flows near the confluence with the Pend Oreille River are regulated. Sullivan Lake is operated to store runoff during the spring for subsequent release in the fall.

4.1.11. Develop Type 3 Physical Habitat Models

The Type 3 tributary delta physical habitat models will be developed to evaluate the effects of operations scenarios on aquatic habitats. Type 3 tributary deltas are expected to undergo morphologic changes over the potential term of a new license, but these changes are not expected to be influenced by operations scenarios. To account for the changes in tributary delta morphology, a new delta morphology will be characterized for the mid-license and end of license periods, with the current delta morphology applied to the first third of the license period. These characterizations will each be used to represent one-third of the potential term of a new license. The operations scenarios are expected to affect the extent and duration of inundation of various surface areas on the delta and within the tributary channel.

For Type 3 tributaries, though the delta physical conditions will not change between operations scenarios, each operations scenario will require three delta morphologies to represent the evolution of the delta over the term of the new license. The delta morphologies will be identical for each scenario. In addition, as with Type 2 deltas, the range of reservoir water surface elevation fluctuations may change between operations scenarios. Therefore, each operations scenario will require calculation of its own set of values for the total lacustrine condition and the total riverine condition at three points in time: beginning of license, mid-license, and end of license. For each operations scenario and at each of the three time periods within the license term, the HQR at the maximum pool level will be calculated based on the lacustrine HSI multiplied by the area of the delta surface at full pool. Likewise, the HQR for the minimum pool level will be calculated based on the riverine HSI multiplied by the area of the stream channel exposed at minimum pool. Hourly calculation of the HQR will be performed by determining the percent of the total lacustrine habitat and the percent of the total riverine habitat exposed at the water surface elevation for that hour, then multiplying the corresponding HQR by these fractions.

4.1.12. Develop Type 4 Physical Habitat Models

The Type 4 tributary delta physical habitat models will be developed to evaluate the effects of operations scenarios on aquatic habitats. Type 4 tributary deltas are expected to undergo morphologic changes over the potential term of a new license, and these changes are expected to be influenced by operations scenarios. To account for the changes in tributary delta morphology, a new delta morphology will be characterized for the mid-license and end of license periods for each operations scenario, with the current delta morphology applied to the first third of the license period. These characterizations will each be used to represent one-third of the potential term of a new license for each operations scenario. In addition, the operations scenarios are expected to affect the extent and duration of inundation of various surface areas on the delta and within the tributary channel.

For Type 4 tributaries the delta's physical conditions will change between operations scenarios, so each operations scenario will require three delta morphologies to represent the evolution of the delta over the term of the new license. Unlike Type 3 tributaries, the delta morphologies may be different between operations scenarios. In addition, as with Type 2 and Type 3 deltas, the range of reservoir water surface elevations fluctuations may change between operations scenarios. Therefore, each operations scenario will require calculation of its own set of values for the total lacustrine condition and the total riverine condition at three points in time: beginning of license, mid-license, and end of license. For each operations scenario and at each of the three time periods within the license term, the HQR at the maximum pool level will be calculated based on the lacustrine HSI times the area of the delta surface at full pool. Likewise, the HQR for the minimum pool level will be calculated based on the riverine HSI multiplied by the area of the stream channel exposed at minimum pool. Hourly calculation of the HQR will be performed by determining the percent of the total lacustrine habitat and the percent of the total riverine habitat exposed at the pool elevation for that hour, then multiplying the corresponding HQR by these fractions.

4.1.13. Run Physical Habitat Models

As described in Sections 4.1.9, 4.1.11, and 4.1.12 the process for evaluating habitat conditions for operations scenarios using the delta habitat models will vary according to tributary delta type. The Scenario Tool (see Study 7 Interim Report [SCL 2008a]) will be used to predict hourly forebay water surface elevations for operations scenarios for three typical average annual runoff conditions:

- Greater than average annual runoff volume (i.e., wet conditions)
- Average annual runoff volume (i.e., average conditions)
- Less than average annual runoff volume (i.e., dry conditions).

The mainstem hydraulic routing model (Study 7) will be used to calculate water surface elevations at cross sections near each tributary mouth as a function of the hourly forebay water surface elevations generated by the Scenario Tool and upstream inflows from Box Canyon and tributaries. The HQR calculations will be used to evaluate the habitat conditions at each tributary delta as water surface elevations fluctuate, causing changes in the proportion of the delta representing lacustrine habitat and the proportion of the delta representing riverine habitat. These calculations will be performed for the seven tributary deltas chosen for detailed study: Slate, Flume, Sullivan, Linton, Pocahontas, Sweet and Sand creeks.

4.1.13.1. Hydraulic Modeling to Support Tributary Delta Habitat Evaluation

Hydraulic modeling will be used to support the evaluation of both the aquatic habitat under the HQR approach and the potential for fish passage barriers to develop within the tributary deltas. In both cases, the hydraulic routing model from Study 7 will be used to determine the water surface elevations of the mainstem Pend Oreille River channel adjacent to the tributary delta.

Modeling will be conducted to determine which portion of the tributary delta area is experiencing reservoir conditions and which portion of the tributary delta is experiencing riverine conditions. The effort will not be used to develop transect-based estimates of velocity and depth, but rather to identify which portion of the tributary delta is experiencing riverine conditions and which portion is experiencing reservoir or lacustrine conditions at a given time step in the simulation.

The mainstem HEC-RAS-based hydraulic routing model will be used to determine the water surface elevation at each tributary mouth, based on a nearby cross section, on an hourly time step. From this elevation and the tributary delta profile, the point at which the stream transitions from the riverine condition to the reservoir condition will be determined. The amount of stream habitat will be based on the portion of the stream exhibiting riverine conditions. The portion of tributary experiencing reservoir habitat will be based on the modeled elevation applied to an elevation versus surface area curve derived from the contour mapping. For the case of Type 3 and 4 tributaries, the delta profile and the area-elevation curve will be updated for middle and ending periods of the potential 50-year new license.

An issue to evaluate at the tributary deltas is whether temporary fish passage barriers develop for operations scenarios. One potential mechanism for a barrier to develop is Project operations dropping the water surface elevation below the top of the foreset slope, exposing this steep slope. Another potential situation in which a barrier can be created is deposition of large materials such as cobbles and small boulders that result in very porous substrate in which all the flow may be infiltrated during lower flow periods and temporarily eliminate the connection with the upstream channel.

To address the potential for fish passage barriers to occur, each of the tributary delta's current profile and substrate condition will be evaluated for potential zones in which either of the barrier types may be present. The evaluation will be based on the delta habitat survey, bathymetry, and field observations at low flow conditions during the tributary delta reconnaissance. If the evaluation shows conditions exist that temporarily create a fish passage barrier, the modeling effort will track the periods when the potential barrier zone is exposed resulting in limited or reduced fish passage. This will be accomplished by tracking the hourly water surface elevations generated in the hydraulic routing model.

In the case of the Type 3 and 4 tributaries, the evaluation of fish passage barriers will also be performed for the future morphologies identified for the middle and end periods of the potential 50-year new license.

4.1.13.2. Post-Processing

For each operations scenario, the results of the HEC-RAS hydraulic model will be used to determine the water surface elevation of the mainstem adjacent to each tributary. This water surface elevation will be used to look up the portion of the tributary delta that experiences riverine habitat conditions and the portion that experiences inundated or lacustrine conditions. This process was described and illustrated in Section 4.1.5.1. The individual HQR for these two distinct conditions will be computed by multiplying the appropriate HSI for the species and life stage of interest by the area of that condition. The total HQR for the delta at the particular time interval will then be the sum of the riverine and inundated HQRs. The resulting hourly HQR ratings can then be used to compute the average HQR over a given period or used to evaluate the variation in HQR as the reservoir water surface elevation changes in response to Project operations and upstream inflows.

4.2. Tributary Delta Sediment Processes

Because the erosion, transport, and accumulation of sediment within selected tributary deltas of the Pend Oreille River may affect aquatic habitats by altering channel morphology, delta morphology, and the size and distribution of substrates, it is necessary to understand these processes to evaluate the effects of operations scenarios on associated aquatic habitats. This study effort will evaluate the effects of Project operations on the delta morphology of selected tributaries within the Pend Oreille River from Box Canyon Dam downstream to Boundary Dam. This study component will also support the habitat modeling (described in Section 4.1) by determining if the tributary delta areas will change over the 50-year term of a new license, how the deltas will change, and how these changes will be translated into the areas used to calculate HQR.

In particular, the Tributary Delta Sediment Processes study component will provide morphological information (i.e., the percentage of tributary delta area submerged at various reservoir water surface elevations) that will feed into the development of HQRs calculated in the Tributary Delta Habitat Modeling study component (Section 4.1.5.1). This study effort will determine whether the morphology of each delta is expected to change over the term of a new license and whether any expected changes are likely to depend on operations scenarios. If the deltas are expected to evolve under future conditions, the resulting changes in habitat area and substrate character will be estimated. The net change in the volume of sediment deposited on the tributary deltas will be estimated and potential zones of erosion and sediment accumulation will be delineated within the deltas. For deltas where physical changes are expected over the term of a new license, the changes will be evaluated to determine their sensitivity to operations scenarios. Different future delta conditions will be developed for each distinct operations scenario for deltas that are sensitive to Project operations so that the spatial component of the HQR is appropriately represented in the tributary delta habitat models.

As the delta accumulates sediment over the term of a new license, the leading edge of the delta (i.e., the foreset) will advance further toward and possibly even into the mainstem portion of the reservoir. The result would be an increase in the length of the delta. If the delta is confined within a narrow canyon, then it would advance forward in one direction. Otherwise, the tributary would intermittently avulse, and the accumulated sediment would spread laterally and form a delta fan (Parker et al. 1998a and 1998b, Sun et al. 2002, and Kostic and Parker 2003a and 2003b). Sediment may accumulate along the top of the delta, increasing the elevation of the topset. Thus, sediment accumulation can affect both the length of the delta and the elevation of the topset surface. The sediment accumulated within tributary deltas may also be eroded by several different potential mechanisms. The erosional processes include the following:

- Direct erosion from the main current of the Pend Oreille River. If the leading edge of the topset slope advances far enough into the reservoir to where it is exposed to the main current of the Pend Oreille River, then bed material transported by the tributary would become available for transport by the Pend Oreille River.
- Headcutting erosion in the tributary channel when the water surface elevation in the reservoir drops below the tributary delta channel (Morris and Fan 1997). This process would rework the sediment that had previously accumulated on the topset slope of the delta and transport it further into the reservoir.

- Shoreline erosion of the leading edge of the tributary delta associated with fluctuations of water surface elevation in the reservoir.

Both accumulation and erosion of sediment may shape the morphology of the tributary delta. The sediment transport regime of the tributary deltas would also be linked with fluvial processes in the mainstem Pend Oreille River (see Section 4.1.7). The wash load in the tributaries (clay and silt) would be available for transport by the mainstem Pend Oreille River. Depending on how far the topset slope of the tributary delta has advanced into the reservoir, the bed-material load (sand, gravel, and cobbles) may also become available for transport by the Pend Oreille River.

The sediment transport processes associated with tributary deltas can be complex, especially if the delta spreads laterally as it forms when it enters a reservoir. Tributary delta sediment processes have attracted the recent attention of various researchers (Parker et al. 1998a and 1998b, Sun et al. 2002, and Kostic and Parker 2003a and 2003b). Current knowledge of the physical processes associated with tributary delta morphology is sufficient to develop a simplified model to analyze the effects of operations scenarios on the sediment processes of the Pend Oreille River tributary deltas. A procedure will be applied to estimate potential changes to tributary delta morphology based on estimates of daily flow and sediment supply to each tributary mouth, confining topography from adjacent canyon walls or terraces, and hourly water surface elevation in the mainstem Pend Oreille River from the hydraulic routing model (Study 7).

A phased approach will be used in the Tributary Delta Sediment Processes study to provide morphological information to be used for each representative tributary selected in the tributary habitat study. The proposed phased approach is outlined in the following three sections.

4.2.1. Phase 1, Evaluate Potential Delta Change

The process used to evaluate potential for change in tributary delta morphology includes three components. The first component includes an evaluation of sediment supply to the delta and the maximum potential delta sediment storage volume. The second component is an assessment of existing delta morphology relative past mainstem flows and Project operations. The third component uses relationships derived in the previous component to predict how delta morphology is expected to change as a result of operations scenarios over the term of a new license. Each of these components is described in more detail in the following sections.

4.2.1.1. Tributary Sediment Supply and Tributary Delta Storage Volume

The relationship between tributary sediment supply and tributary delta sediment storage volume will be used to evaluate whether a tributary is in, or is predicted to be in, a state of dynamic equilibrium. The 2007 bathymetric data will be compared to historic bathymetric data to estimate the existing volume of sediment stored on a selected delta. The bathymetric data will describe the existing delta morphology as well as the existing slopes of the topset, foreset, and bottomset. The maximum potential sediment storage volume will be calculated to determine if the tributary delta is likely to change over the term of a new license. This process includes two primary components: determining the location of the foreset under conditions of dynamic equilibrium and determining the equilibrium slope of the topset. The location of the foreset determines the maximum length of the delta; the equilibrium slope of the topset determines the maximum elevation of the top of the delta. These two parameters can be used with the confining topography to calculate the maximum potential tributary delta volume.

As described in Section 4.1.7, future sediment supplied by a tributary to its delta will result in either: 1) adjustments to the elevation of the topset until an equilibrium slope is achieved, or 2) the riverward migration of the delta until a point is reached where the hydraulic forces in the mainstem channel are sufficient to mobilize the material on the foreset slope. The ultimate location of the foreset, and thus the maximum potential length of the delta, will be calculated using incipient motion criteria, field data describing the sediment size distributions, and the HEC-RAS model developed in Study 7. The equilibrium slope of the topset of a selected delta, which will define the maximum potential surface elevation of the top of the delta, can be calculated either as a function of incipient motion criteria or based on sediment transport. Under equilibrium conditions, the sediment delivered to the delta equals the sediment removed from the delta. Using incipient motion criteria or equilibrium transport rate, the equilibrium slope of the topset can be calculated to transport the coarser size fractions of the bed material load delivered to the delta. The potential sediment storage volume in a tributary delta can be calculated using the ultimate foreset location, foreset slope (taken to be equal to the existing foreset slope), the topset equilibrium slope, and the elevation where the maximum reservoir pool intersects the original tributary channel bed. At its ultimate location, the slope of the foreset is extended up until it intersects the extension of the equilibrium topset slope from elevation where the maximum reservoir pool meets the original tributary channel bed. The potential tributary storage volume will be calculated using the resulting geometry and the confining bathymetric data.

In the event that the actual sediment volume of a delta matches the potential volume, the delta will be considered in dynamic equilibrium such that the sediment load supplied by the tributary balances the erosion and transport by the Pend Oreille River. In this case, the tributary delta will change only if operations scenarios affect the state of equilibrium.

If the actual sediment volume of a delta is less than the potential volume, the difference between the two will be the volume of sediment required to reach a state of dynamic equilibrium. The sediment supplied by the tributary on an annual basis (as described in Section 4.3.2) will be compared to the available sediment storage volume to determine when the delta is expected to achieve dynamic equilibrium conditions. Both the volume of sediment supplied as well as the sediment size distribution will be important. The size distribution of future sediment supply will be quantified using samples collected in September 2007.

4.2.1.2. Actual Tributary Delta Morphology and Past Project Operations

Once the actual sediment storage volume is calculated for selected tributary deltas, the influence of past Project operations will be compared to delta morphology to see if significant relationships exist. The objective of this study component is to determine the combination of tributary inflows and Project operations that determine the state of dynamic equilibrium for a delta. For example, if a delta is in a state of dynamic equilibrium, does the elevation of the intersection of the topset slope and foreset slope correlate with the lower end of the range of reservoir water surface elevations under common past Project operations? Similarly, other parameters of past Project operations (e.g., minimum, average, and maximum reservoir water surface elevations over a year or over only the high flow period) will be considered in light of tributary delta features. Of particular interest is the relationship between the timing of high flows in the mainstem Pend Oreille River (and associated high reservoir water surface elevations) and high flows in the tributaries. When the reservoir water surface elevation is highest, the deltas will typically be submerged continuously by high mainstem flows that exceed the Project's powerhouse capacity. Under these conditions, the reservoir pool level does not fluctuate. Bed material sediments are more likely transported across the deltas either as mainstem flows recede but flow in the tributaries is still sufficient to transport bed material load, or at the beginning of the runoff season when tributary flows can transport bed material load but the reservoir is drawn down for load following. The relationship between the timing of significant flows in the tributaries and low reservoir pool elevations may be key in relating the morphology of a delta to past Project operations. It is expected that drawdowns can cause the movement of considerable volumes of sediment through cutting and reworking of depositional material in the deltas. Additionally, it is expected that the influence of Project operations will shape delta morphology differently upstream and downstream of Metaline Falls due to the hydraulic control provided by the Falls. Thus, although currently not quantified, linkages between sediment moving flows and mainstem Pend Oreille River water surface elevations are expected.

4.2.1.3. Influence of Operations Scenarios on Delta Morphology Over the Term of a New License

The third component of the approach used to evaluate potential delta change will be to consider the progression of change in delta morphology over the term of a new license. As described in the previous section, Project operations can influence delta morphology. Relationships developed for current delta morphology and past Project operations can be applied to operations scenarios to predict how a delta may change over the term of a new license. These predicted changes will be considered within the physical bounds of the potential delta sediment storage volume as imposed by topset and foreset slope and location as calculated under dynamic equilibrium conditions. The influence of operations scenarios on delta morphology, and thus surface area of aquatic habitats, can be reviewed to determine whether predicted changes in delta morphology are independent of, or dependent upon, operations scenarios.

4.2.2. Phase 2, Predict Delta Change Common to All Scenarios

If the tributary delta morphology is expected to change using the methods outlined in Section 4.2.1, the next step is to determine whether the change in morphology is expected to differ among operations scenarios. As identified in Section 4.2, the timing of high flows in the tributaries and high flows in the mainstem (when the influence of Project operations is minimized) may be a key period in the development of tributary deltas. If the changes in delta morphology occur when the Project operations have minimal influence, it is logical that these changes will be common to all operations scenarios (Type 3 delta evolution model). In this case, the changes to tributary delta morphology will be estimated for use in the tributary delta habitat study for mid-license term (i.e., 2036) and at the end of the potential new license period (i.e., 2061).

The process used to predict the delta change at the mid-license and end of license periods follows the approach presented in Section 4.2.1.1 for calculating equilibrium topset slope and ultimate foreset location. These calculations will be used with characterizations of sediment supply delivered by the tributary to determine how the volume and distribution of sediment sizes are accumulated on the delta. For example, the annual volume of sediment delivered to the delta aggregated over the first half of the license period will accumulate on the delta, but the amount of delta habitat will depend on how the sediment accumulates. Calculations of the topset equilibrium slope will be used with the foreset slope to determine the location of the foreset given the incoming sediment load. The location of the foreset determines the length of the tributary delta and the elevation of the topset surface under equilibrium influences the percentage of the delta inundated at various reservoir water surface elevations. The delta change over the second half of the license period will build on the morphology characterized at mid-license, and the same equilibrium slope calculations will determine a new delta length and topset surface elevation.

4.2.3. Phase 3, Predict Delta Change Associated with Specific Scenarios

If operations scenarios alter the relationship between the timing, or duration of time, when the reservoir gets drawn down and when sufficient tributary flows are transporting bed material load, the changes in delta morphology may be different under each operations scenario (Type 4 delta evolution model). In cases such as these, the predicted delta morphology will be estimated for use in the tributary delta habitat study for mid-license term (i.e., 2036) and at the end of the potential new license period (i.e., 2061) for each operations scenario.

Similar to the process outlined in Section 4.2.2, the sediment delivered to a tributary delta will be coupled with calculation of topset and foreset equilibrium slopes to predict changes in delta morphology, and associated area of aquatic habitat, for the mid-license and end of license periods for specific operations scenarios. However, unlike the approach used in Section 4.2.2, the calculations of equilibrium topset and foreset slopes may depend upon the operations scenario, particularly for scenarios in which the timing, duration, and magnitude of drawdown changes. Additionally, the location of a tributary delta in relation to Metaline Falls could affect the significance of the Project operations on the delta formation. For example, tributary deltas located downstream of Metaline Falls may be more sensitive to the effects of Project operations, whereas tributary deltas located upstream of Metaline Falls may be less sensitive due to the hydraulic control of the falls. Therefore, the effects of specific operations scenarios will need to be accurately represented at each tributary delta, so that equilibrium conditions are calculated appropriately and the mid-license and end of license delta morphologies are correctly represented in the models of tributary delta habitat.

4.3. Mainstem Sediment Transport

The construction of a dam and impoundment of water can impact the channel morphology and sediment transport regime in both the upstream and downstream directions. Upstream from the dam, some of the incoming sediment will be trapped as it enters the reservoir, and the remainder of the sediment will be passed downstream. The ratio of the weight of sediment trapped in the reservoir divided by the total weight of incoming sediment is referred to as the “trapping efficiency” of the reservoir. The sediment trapped in the reservoir will be coarser than the sediment passed downstream. The sediment deposited in the reservoir will generally be sorted longitudinally with the coarser sediment accumulating further upstream from the dam, and the finer sediments accumulating closer to the dam.

Downstream from the dam, the sediment transport regime will be impacted by two confounding processes: reduced supply of sediment to the river just downstream from the dam, and altered flow regime. Just below the dam, the substrate may become coarser and the channel may become incised. Further downstream from the dam, these processes will diminish and possibly reverse, as the river receives additional sediment from downstream tributary sources.

In addition, there may also be impacts to tributary channel morphology and substrate texture in the vicinity of the confluence of tributaries with the mainstem river channel. Upstream from the dam, delta formation and accumulation of fine sediments may be the result. Downstream from the dam, tributaries may become perched above the incised mainstem channel and the substrate of the tributary may coarsen. The response of the tributaries, which are linked to processes that occur in the mainstem, will be the focus of the Tributary Delta Sediment Processes study component (see Section 4.2).

Because of the potential complex interactions between sediment transport conditions, morphology, and reservoirs just discussed, the Mainstem Sediment Transport study effort was incorporated into Study 8. For example, the erosion, transport, and accumulation of sediment within the mainstem Pend Oreille River may affect aquatic habitats by altering channel morphology and size and distribution of channel substrates. This study effort will evaluate the effects of operations scenarios on channel morphology within the Pend Oreille River from Box Canyon Dam downstream to approximately Red Bird Creek.

The objective of this study component is prediction of erosion, transport, and accumulation of sediments in the mainstem Pend Oreille River over the potential 50-year term of a new license. The first major task required to achieve this objective is to examine patterns of erosion and accumulation of sediment in the river from 1967 to 2006 to serve as a guide for predicting future process patterns.

The second major task is to estimate future input of sediment to the Pend Oreille River. Sediment supply to the study reach can come from the following sources:

- Releases from Box Canyon Dam
- Tributary input, and
- Shoreline erosion (to be estimated in the Erosion Study, Study 1)

The third major task is to develop a sediment transport model to route sediment input from the various sources through the study reach, and to track where sediment is eroded and accumulated. The model will be calibrated to reproduce the historical patterns of erosion and accumulation (from 1967 to 2006). Historical supply of sediment will be assumed to be similar to estimated future inputs. A one-dimensional hydraulic model (see hydraulic routing model in the Study 7 Interim Report [SCL 2008a]) will be used to help determine sediment transport capacity, based on historical flow releases from Box Canyon Dam, historical reservoir levels in the forebay of

Boundary Project, historical flow releases from Boundary Dam to the Pend Oreille River, and historical reservoir levels in the forebay of the Seven Mile Project.

The fourth major task is predicting future patterns of erosion and accumulation of sediment in the Pend Oreille River over the potential 50-year term of a new license.

Each of these four tasks is described in more detail in the following sections.

4.3.1. Delineate Zones of Erosion and Accumulation of Sediment from 1967 to 2006

The results of bathymetry and topographic surveys conducted prior to Project construction will be compared to current (i.e., 2007) bathymetry to guide the identification of zones of erosion and accumulation of sediment between 1967 and 2006 in the Pend Oreille River from Box Canyon Dam to approximately Red Bird Creek.

In developing the approach to performing the comparison of the current and historic data sets, it is important to note the differences in their coverage and resolution. The historic topography collected in 1957 covered the area from just upstream of Box Canyon Dam downstream to the international border at elevations greater than the water surface in the Pend Oreille River. The topography was represented using 20-foot interval contour lines. The only known bathymetric data (below water level survey) available prior to construction of the dam was a single thalweg profile indicating an "approximate river bottom" (Sewell and Sewell date unknown). The thalweg profile covered the length of the Pend Oreille River from Box Canyon Dam to the international border. The topography and bathymetry between the international border and Red Bird Creek were represented on a 100-foot interval contour map (BCDMPR 1950).

The resolution of the existing topography and bathymetry is at the other end of the spectrum. 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. This bathymetric and scanning laser data were combined with topographic surveys conducted using light detection and ranging (LiDAR) technology.

Due to the differences in resolution and coverage of the historical vs. current surveying techniques and equipment, and the higher uncertainties in the vertical control for the historical data, it will be inappropriate to simply overlay digital terrain models from the data sets and translate the volumetric differences as zones of erosion or accumulation of sediment. These two datasets will serve as the basis for estimating the net change in the volume of sediment deposited within the study reach and for delineating zones of erosion and accumulation of sediment. However, visual evaluations and best professional judgment will be critical when identifying actual changes in sediment volume opposed to apparent changes in volume associated with "noise" generated by different resolution data. Areas of apparent significant erosion or deposition will be highlighted and each will be evaluated as to whether the difference may be due to actual changes or resolution and coverage of the datasets. In particular, the lack of definition below the water surface in the historic information will require careful interpretation of potential deposition in this important zone. Other areas of particular interest will be the tributary deltas.

4.3.2. Characterize Sediment Supply

In support of predicting erosion, transport, and accumulation of sediments in the mainstem Pend Oreille River over the potential term of a new license, the future supply of sediment to the mainstem will be characterized. The approach used assumes that the average annual volume of sediment estimated since construction of Boundary Dam can represent average annual volume of sediment over the potential term of a new license. Sediment rating curves will be developed for sediment inflows at the tributaries and through Box Canyon Dam so that the annual sediment supply will be sensitive to future hydrologic conditions that differ from past conditions. Therefore, it is first necessary to characterize the historic supply of sediment delivered to the mainstem Pend Oreille River from Box Canyon Dam to Red Bird Creek. The sediment supply to the study reach can be delivered from releases through Box Canyon Dam, direct input from tributary channels, and shoreline erosion. A variety of approaches will be applied to characterize sediment supplied from these three sources.

4.3.2.1. Releases from Box Canyon Dam

The key components of the sediment supply released from Box Canyon Dam and delivered to Boundary Reservoir are the volume and size distribution of sediment. Two approaches will be considered to characterize the volume and sediment size distribution:

- Calculating the bed material load transport based on river hydraulics and substrate
- Application of appropriate regional sediment yield relationships

Ultimately, the estimated volume and size distribution of sediment input to the Project from the Pend Oreille River will be used to develop a time series of sediment supply. A thorough review will be conducted of available data for Box Canyon Dam and Reservoir to determine the influence of physical constraints (i.e., bathymetric data, sediment size distribution) and Box Canyon Project operations on the volume and size distribution of sediment released from Box Canyon Dam.

4.3.2.1.1. Calculating Bed Material Load Transport

The Box Canyon Dam Project is operated in a run-of-river mode, so the Box Canyon Reservoir water levels are primarily controlled by the flow in the Pend Oreille River. As flows increase above turbine capacity (27,400 cfs), water is spilled over the dam through the spillway gates. The spillway has four bays, each with a gate containing three vertically stacked leaves (the leaves are the panels that slide up and down in the tracks within each gate). When gates are opened to spill flow, first the top leaves in each gate are removed, followed by the middle leaves, and then the bottom leaves. It is not possible to remove only the bottom leaves and operate the gates like a sluice. When flow rates exceed 90,000 cfs, the bottom leaves in all four bays are removed. Under these high flow conditions, the dam is expected to have only minor hydraulic influence on sediment transport in the Pend Oreille River. Thus, Box Canyon Dam is assumed to pass all of the incoming bed load and suspended load conveyed to the Pend Oreille River between Albeni Falls Dam and Box Canyon Dam.

A sediment supply versus flow rating curve will be developed for flow releases from Box Canyon Dam for each of the sediment size fractions. The sediment supply rating curve will be assumed to have the following form:

$$Q_s = a(Q - Q_c)^b$$

Where:

- Q_s = sediment transport rate
- a = scaling coefficient
- Q = flow discharge rate
- Q_c = critical flow rate to mobilize sediment
- b = power coefficient

A value of 2.0 will be used for the exponent b as recommended by the U.S. Army Corps of Engineers (1995). The coefficient a will be determined by applying the rating curve to the daily flows from 1967 to 2006 to match the average annual sediment supply. The critical flow, Q_c, for silt and clay will be assumed to be zero. A critical flow will be estimated for sand, gravel, and cobbles using available information on the operations of Box Canyon Dam as well as through discussions with operators of Box Canyon Dam. As the Box Canyon Project is operated in run-of-river mode, the average daily flows released through the Box Canyon Project will be derived from the USGS gage below Box Canyon (Gage No. 12396500). The sediment rating curve developed for releases from Box Canyon Dam will be used to calculate daily average sediment supply, which will be aggregated over individual years to represent average annual sediment supply.

4.3.2.1.2. Application of Regional Sediment Yield Relationships

Regional sediment yield relationships will be reviewed to determine whether any are appropriate for characterizing sediment supply delivered to the Pend Oreille River between Albeni Falls Dam and Box Canyon Dam. Sediment yield relationships usually provide a volume of sediment but not the size distribution, so the sediment yield will be subdivided into components based on grain size (clay, silt, sand, gravel, and cobble). Guidelines established by the U.S. Bureau of Reclamation (USBR 1987) will be used to estimate bed load (gravel and cobble) as a portion of suspended load (clay, silt, and sand). These guidelines provide the percent bedload relative to the suspended load given suspended sediment concentration, streambed material, and the texture of suspended material. The silt, sand, and gravel components will be further subdivided into size classes based on the phi classification scale (Lane 1947).

Lake Pend Oreille is impounded by Albeni Falls Dam, the next dam upstream of Box Canyon Dam on the Pend Oreille River. Due to the relative large storage volume and depth of the lake, it is assumed that no bed material load from upstream of the lake is delivered to the Pend Oreille River. The Priest River enters the downstream canyon area of Lake Pend Oreille, approximately 6 miles upstream from Albeni Falls Dam. The size of Priest Lake relative to the contributing watershed indicates that no bed material load is transported through the lake. The portion of the

Priest River watershed downstream of Priest Lake will generate sediment for transport to the Pend Oreille River, and Albeni Falls Dam is assumed to pass all of the incoming bed load and suspended load generated between Lake Pend Oreille and the dam. Additional tributaries enter the Pend Oreille River between Albeni Falls Dam and Box Canyon Dam.

The sediment supply from the sources upstream of Box Canyon Dam will be estimated using watershed-based methods such as Rainwater (1962), Dendy and Bolton (1976), or USBR (1987). The methods estimate sediment yield from a watershed on an average annual basis; each method is described in more detail in the following sections. The results developed using these watershed-based methods will be compared with available literature and discussed with RPs (in particular, local land and water management agencies).

Rainwater (1962) Method

Rainwater (1962) is an atlas comprising three maps, one of which shows the average sediment concentration of rivers. This atlas was developed to provide a starting point for evaluating surface water resources on a nationwide scale. The map of average sediment concentrations provides the average annual, discharge weighted mean concentration. This mean concentration value represents only the suspended portion of the total sediment supply.

The Rainwater (1962) estimates will be used to calculate of the volume of suspended sediment supplied from any tributary given an annual runoff volume. The bed load volume can be derived using the guidelines established by the USBR (1987).

Dendy and Bolton (1976) Method

The Dendy and Bolton (1976) method was developed from sediment data collected from 500 reservoirs with watershed areas of at least 1 square mile. The method specifies a runoff threshold of 2 inches, below which sediment yield is directly related to annual runoff volume and above which sediment yield is inversely related to annual runoff volume. As such, sediment yield increases as annual runoff approaches the threshold of 2 inches. The method requires only the annual runoff volume (inches), and drainage area (square miles) to produce annual sediment yield (tons per square mile per year).

The Dendy and Bolton (1976) method was developed for small to midsize catchments in the United States, so it is appropriate for preliminary evaluations on a regional basis; application to prediction of sediment from individual watersheds may produce errors as much as 10 to 100 times larger or smaller than the actual sediment yields. Therefore, best professional judgment will be used when assessing the volume of sediment predicted using this method.

USBR (1987) Method

The USBR (1987) developed a relationship between drainage area and average annual sediment yield rate. The relationship requires only drainage area in square miles as input and provides sediment yield rates in units of acre-feet per square mile per year. Because this relationship was developed from selected reservoir resurvey data in the semi-arid climate of the southwestern

United States and provides sediment yield rate independent of runoff volume (meaning that the sediment yield is the same every year), it will be carefully scrutinized before applying to tributary drainages areas within the Project study area.

4.3.2.2. Tributary Input

The key components of the sediment supply from tributaries to the Project between Box Canyon Dam and Boundary Dam are the volume and size distribution of sediment. Four approaches will be considered to characterize the volume and sediment size distribution:

- Estimating the volume of sediments that have accumulated in the deltas
- Calculating the bed material load transport based on stream hydraulics and substrate
- Application of appropriate regional sediment yield relationships
- Estimating sediment input using reservoir trapping efficiency

Ultimately, the estimated volume and size distribution of sediment input to the Project from tributaries will be used to develop a time series of sediment supply.

4.3.2.2.1. Estimating Tributary Delta Sediment Volume

The approach described in Section 4.3.1 for identifying zones of erosion and sediment accumulation will be appropriate for estimating the volume of sediments that have accumulated in representative tributary deltas. Most of the accumulated sediment in the deltas will be bed material load transported by the tributary (e.g., sand, gravel, and cobble). The distribution of size fractions will be evaluated on a delta-specific basis. As the majority of the sediment transported in the tributaries is conveyed at high flows during the same time of year when high flows in the Pend Oreille River increase the reservoir water surface elevation, some of the finer size fractions (e.g., sand) that are not true tributary bed material can be deposited on the delta. The estimated total volume of sediment accumulated in the deltas can be converted to an annual rate of delivery using the period of time over which the sediment accumulation occurred. Rather than relying only on an average annual rate, the sediment load can be apportioned based on average annual runoff volume. In this manner, the supply of sediment will increase during high runoff years and decrease in lower runoff years. This approach allows for better characterization of future sediment volume and size distribution based on modeled future hydrologic conditions over the term of a new license.

4.3.2.2.2. Calculating Bed Material Load Transport

Similar to the approach described in Section 4.3.2.1.1 for calculating sediment releases from Box Canyon Dam, calculations of bed material load transport in the tributaries can be made through the development of sediment supply rating curves. The volume and size distribution of sediment supplied from tributaries can be calculated using these rating curves in conjunction with tributary hydraulics (as a function of runoff hydrology) and bed material size distributions. These calculations of bed material load transport will only be valid for the portion of the sediment load that is not supply limited (e.g., the coarser size fractions). This may be of significant importance since the coarsest size fractions may ultimately control the delta geometry, but they may be only a small portion of the total load entering the system, and they may only be significant during high runoff years. Thus, application of bed material load transport equations will be carefully considered with respect to limited supply of finer size fractions. The average daily rate of flow was developed for the tributaries between Box Canyon Dam and Boundary Dam (R2 Resource Consultants 2008). The average daily bed material load will be calculated on a size fraction basis using these daily flow volumes. The annual loading of bed material will be based on the integration of the daily sediment supply calculated by the rating curve. Further discussion of the development of tributary hydraulics, tributary hydrologic records, and sediment supply rating curves is provided in the following paragraphs.

Development of Tributary Hydraulics

The bed material load will be estimated using an appropriate bed material load equation. The dominant sizes of sediments and the hydraulic conditions at the tributaries will determine which equations are applicable. During the September 2007 tributary delta field efforts, two cross sections were surveyed for selected tributaries near the upper end of the reservoir fluctuation zone or upstream in the tributary. The locations were selected to best represent sections where the sediment transport regime is in equilibrium. Aggradation or the presence of an armor layer indicated excess or limited sediment supply, respectively, and sections with these characteristics were avoided. The overall water surface slope was surveyed in the area of each section. The geometry of the cross sections and the water surface slope were surveyed using the equipment and approach described in Section 4.1.3. The size distribution of the bed material at each section was characterized using one of the methods described in Section 4.1.3. The channel roughness was visually estimated at each section and represented as a Manning n-value. These hydraulic parameters will be applied to the bed material load equation under normal depth conditions.

Synthesis of Tributary Hydrologic Record

The hydraulic conditions that affect bed material transport in the tributaries are a function of hydrologic conditions. Sullivan Creek is the only tributary to the Pend Oreille River between Box Canyon Dam and Boundary Dam where a flow gage is maintained and long-term historic flow records have been recorded. The generation of a hydrologic record is required to calculate bed material transport in tributaries other than Sullivan Creek. Documentation of the process used to synthesize hydrologic records for study area tributaries is currently being compiled in a hydrology report (R2 Resource Consultants 2008). A brief summary of the process is presented here.

A commonly used approach to create hydrologic records for ungaged watershed is to scale hydrologic records from a gaged watershed with similar characteristics to the watershed of interest. Hydrologic characteristics typically considered include precipitation regime, contributing drainage area, and mean annual volume of precipitation; other characteristics that may be considered include land cover, watershed shape, watershed slope, and geology/soils.

Gaged watersheds in the Pend Oreille River basin were evaluated to identify an appropriate "reference" gage for extending the record on Sullivan Creek and for creating hydrologic records for the ungaged watersheds between Box Canyon Dam and Boundary Dam. The evaluations started with a comparison of the hydrologic record of the candidate gage to the period of record on Sullivan Creek. It is important to note that flows in Sullivan Creek are regulated by Sullivan

Lake, so the gage on the unregulated stream was used (USGS Gage No. 12396900). The closer geographically the candidate gage to the study area, the greater the likelihood of similar precipitation regime, land cover, watershed slope, and geology/soils. A scaling factor derived as a ratio of contributing drainage areas was applied to the candidate gage to evaluate how well the Sullivan Creek record is replicated. An additional scaling factor derived as a ratio of mean annual volume of precipitation was also evaluated, but it did not improve the representation of the Sullivan Creek record. The scaling relationship for the candidate gage that best replicated the Sullivan Creek gage (i.e., the reference gage) was located on the Salmo River. The parameters in the relationship (e.g., contributing drainage area and a seasonal adjustment factor) were quantified to generate a long-term hydrologic record for all ungaged tributary watersheds to the Pend Oreille River between Box Canyon Dam and Boundary Dam. Additional details on the method are available in the hydrologic report (R2 Resource Consultants 2008).

4.3.2.2.3. Application of Regional Sediment Yield Relationships

The previous two methods of characterizing sediment supply from tributaries are primarily applicable to estimation of the bed material load, although individual deltas may have accumulations of finer sediment size fractions that can be deposited under high reservoir pool conditions. These wash load components of the total load, although not a significant influence in the morphology of tributary deltas, may be deposited in Boundary Reservoir, if not washed through the Project altogether. As described in Section 4.3.2.1.2, regional sediment yield relationships can be applied to characterize sediment supply from tributaries in the same manner as applied to characterize the sediment supply upstream of Box Canyon Dam. Watershed-based methods such as Rainwater (1962), Dendy and Bolton (1976), or USBR (1987) will be applied. The methods estimate sediment yield from a watershed on an average annual basis and the results developed using these watershed-based methods will be compared with available literature and discussed with RPs (in particular, local land and water management agencies).

4.3.2.3. Shoreline Erosion

The sediment supplied to the study reach from shoreline erosion is being characterized under Study 1 Erosion (SCL 2008c). The average annual sediment supply estimated in Study 1 will be added to the sediment supplied from releases through Box Canyon Dam and to the sediment supplied from tributaries. Sediment samples were collected from various erosion sites representing the major types of materials entrained by shoreline erosion. These samples were analyzed for grain size distribution which will allow estimation of the contribution of shoreline erosion to reservoir sediment supply by size fractions.

4.3.2.4. Application of Reservoir Trapping Efficiency

The concept of reservoir trapping can be used in conjunction with either sediment loads passing through Boundary Dam or sediment loads trapped in Boundary Reservoir to estimate the total sediment supply to the system. The concept of reservoir trapping efficiency allows for a refinement of the estimated sediment load.

The reservoir trapping efficiency is defined as the ratio of the weight of sediment trapped in the reservoir divided by the total weight of incoming sediment. The trapping efficiency of Boundary

Reservoir will be calculated using methods such as Churchill (1948), Brune (1953), Borland (1971), and the modified Brune curve method (Linsley et al. 1986). The total weight of incoming sediment can be "back calculated" using either weight of sediment trapped in the reservoir or the weight of sediment passing through the dam.

4.3.2.4.1. Sediment Estimation Methods Linked to Reservoir Trap Efficiency

Although the weight of sediment trapped in Boundary Reservoir is not readily quantified, the volume of sediment trapped in the reservoir will be estimated as described in Section 4.3.1. The density of accumulated reservoir deposits will be needed to convert the volume of sediment to a weight. The density will be estimated using methods developed by the USBR (1987). Densities estimated using this method typically ranges between 80 to 90 pounds per cubic foot. With a calculated reservoir trapping efficiency and an estimate of the weight of sediment trapped in the reservoir, the weight of the incoming sediment can be calculated as follows:

$$W_{in} = \frac{V_{st} * \gamma_{st}}{E_f}$$

Where:

W_{in} = weight of incoming sediment (pounds force [lbf])
E_f = reservoir trapping efficiency (dimensionless)
V_{st} = volume of sediment stored in the reservoir (cubic feet [ft^3])
γ_{st} = unit weight of accumulated reservoir deposits (pounds force/cubic feet [lbf/ft^3])

Another calculation of incoming sediment can be made using the reservoir trapping efficiency and the sediment load that passes though Boundary Dam. Between February 26, 1974, and November 6, 1985, the USGS recorded approximately 100 measurements of suspended sediment discharge in units of tons per day at the international border downstream of Boundary Dam (Gage No. 12398600). These measurements were collected during flows rates of 5,400 to 131,000 cfs. A sediment rating curve can be developed from this data to calculate sediment discharge as a function of flow. Average daily flow volumes will be used with this rating equation to calculate the daily weight of suspended sediment passing Boundary Dam (assuming all suspended sediment in the Pend Oreille River at the international boundary originates in Boundary Reservoir). The daily weight of sediment will be aggregated over a year to estimate an annual weight of sediment passing through Boundary Reservoir. In combination with the calculated reservoir trapping efficiency, the weight of incoming sediment can be calculated as follows:

$$W_{in} = \frac{W_o}{1 - E_f}$$

Where:

W_{in} = weight of incoming sediment (lbf)
W_o = weight of sediment passing through the reservoir (lbf)
E_f = reservoir trapping efficiency (dimensionless)

The concept of reservoir trapping will be applied using the two equations in this section to refine the estimates of sediment supply entering Boundary Reservoir.

4.3.2.5. Refinement of Future Sediment Supply

The approaches described in Sections 4.3.2.1 through 4.3.2.3 for characterizing sediment supply are based on identifying various sediment sources and estimating their relative contribution to the total sediment supply. The approaches described in Section 4.3.2.4 characterize the total sediment load to the system, but do not distinguish sources of sediment or the sediment size distribution. Therefore, the sediment supply estimated using all of these approaches will be reviewed, particularly in light of their limitations, to calculate annual sediment loads. For example, the estimation of load based on identification of zones of sediment accumulation (Section 4.3.1) will provide an estimate that excludes size fractions transported through the reservoir. The sediment rating curves developed for the Pend Oreille River through Box Canyon Dam (Section 4.3.2.1) and for the tributaries (Section 4.3.2.2) will be used to calculate sediment transport assuming that the calculated volume is actually available. Finer size fractions are expected to be supply limited, so the rating curve approaches will likely overestimate the volume of finer size fractions delivered to the reservoir. The application of the various regional sediment yield relationships (Section 4.3.2.2.3) will be carefully scrutinized to verify that conditions in the study area are comparable to conditions on which the relationships are based. Some relationships only apply to suspended sediment whereas others apply to the total load. Although expected to be a relatively minor contribution to the total sediment supply, the sediment derived from shoreline erosion (Section 4.3.2.3) needs to be included. The summation of various components of the total load will be compared to the estimates of total incoming load as derived from the calculations of reservoir trapping efficiency to refine the total load. However, it is noted that the measurements of suspended sediment load are coarse, and given tributary input between Boundary Dam and the international boundary, may overestimate the incoming sediment load to Boundary Reservoir.

4.3.3. Develop and Calibrate Sediment Transport Model

The erosion, transport, and accumulation of sediment within the mainstem Pend Oreille River may affect aquatic habitats by altering channel morphology and size and distribution of channel substrates. The Mainstem Sediment Transport study effort will evaluate the effects of Boundary Project operations on channel morphology within the Pend Oreille River. However, in the study reach, the influence of Project operations on reservoir water surface elevations is generally greatest when flows in the Pend Oreille River are lowest. The majority of the sediment moving within the Project occurs when flows in the Pend Oreille River are greatest. The maximum capacity of the Boundary Dam turbines is approximately 50,000 cfs. Flow rates above this threshold are spilled over the dam so that the Project is essentially operated in a run-of-river mode. When operated as such, reservoir water surface elevations are predominantly controlled by flow in the Pend Oreille River, not operation of the Project. Therefore, operations scenarios may have little influence on major sediment deposition because little can change in operations when flows are greater than 50,000 cfs. The vast majority of sediment is typically transported at these higher flows, and because the influence of Project operations will essentially be the same, there is little chance that the operations scenarios will alter the overall sediment transport response of the system. This does not mean that Project operations will not alter the sediment transport regime of the Pend Oreille River, but that changes will not be substantially affected by differences between operations scenarios.

Computer models used to analyze erosion, transport, and accumulation of sediment were reviewed for applicability to the study reach of the Pend Oreille River. The study reach will be subdivided into sediment routing reaches to include and correspond with selected habitat transects as delineated for Study 7 (SCL 2008a). The selected model will be calibrated to reproduce the historical patterns of erosion and sediment accumulation based on the gross changes in volume calculated as described in Section 4.3.1. The calibrated model will facilitate predictions of sediment transport processes in the mainstem Pend Oreille River over the potential term of a new license under the existing Project operations.

4.3.3.1. Review of Sediment Transport Models

Public-domain, one-dimensional computer models developed to analyze erosion, transport, and deposition of sediment were reviewed to assess their applicability to the objectives of Study 8 and the conditions of the study reach of the Pend Oreille River. The primary objective of this component is to evaluate the effects of existing Project operations on channel morphology within the Pend Oreille River from Box Canyon Dam downstream to approximately Red Bird Creek. Therefore, the following model requirements were considered when evaluating applicability:

- Representation of sediment mobilization, transport, settling, and re-suspension
- Routing of sediment by size fraction

Desirable aspects of sediment routing models include:

- Consolidation of settled sediment
- Flexibility in selecting sediment transport routines for various sediment size fractions
- Representation of the development of a streambed armor layer

Considerations that were taken into account include:

- Time requirements for running the sediment routing model
- Variable computation intervals depending on boundary conditions
- Simulation time horizon of long periods (e.g., the potential 50-year term of a new license)

One-dimensional, public-domain sediment transport models were reviewed in consideration of these requirements, desirable aspects, considerations, and known conditions in the study reach of the Pend Oreille River. The following models were considered as candidates:

- HEC-6 – Scour and Deposition in Rivers and Reservoirs (USACE 1993)
- HEC-6T – Sedimentation in Stream Networks (MBH Software, Inc. 2002)
- EFDC1D – Environmental Fluid Dynamics Code – One Dimensional (Hamrick 2001)
- SRH-1D – Sedimentation and River Hydraulics – One Dimension (Huang and Greimann 2007)

A brief overview of each model is presented in the following subsections.

4.3.3.1.1. HEC-6 – Scour and Deposition in Rivers and Reservoirs

HEC-6 (USACE 1993) is a one-dimensional, movable boundary, open channel flow and sediment model designed to simulate changes in river profiles due to scour and deposition over fairly long time periods. The continuous flow record is broken into a sequence of steady flows of variable discharge and duration. For each flow, a water surface profile is calculated, thereby providing energy slope, velocity, depth, etc. at each cross section. Potential sediment transport rates are then computed and the cross-section shape adjusted accordingly. The computations then proceed to the next flow in the sequence and the cycle is repeated beginning with the updated geometry. The sediment calculations are performed by grain size fraction, thereby allowing for the simulation of hydraulic sorting and armoring.

4.3.3.1.2. HEC-6T – Sedimentation in Stream Networks

HEC-6T was written by William Thomas, previous Chief of the Research Branch at the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). Mr. Thomas planned, designed, wrote, and applied the first version of HEC-6, and HEC-6T is an enhancement of HEC-6 (Thomas 1991).

4.3.3.1.3. EFDC1D – Environmental Fluid Dynamics Code – One Dimensional

EFDC1D is a one-dimensional hydrodynamic and sediment transport model that can be applied to stream networks (Hamrick 2001). EFDC1D can simulate bi-directional unsteady flows and has the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model also includes representation of hydraulic structures such as dams and culverts. For sediment transport, the model includes settling, deposition, and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density, and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.

4.3.3.1.4. SRH-1D – Sedimentation and River Hydraulics

The USBR's Sedimentation and River Hydraulics Group has a long history of developing numerical models for sediment transport in rivers (Huang and Greimann 2007). SRH-1D was originally named GSTAR-1D; in June 2007 the model name was changed to SRH-1D to better identify the USBR's Sedimentation and River Hydraulics Group as the developer and to accommodate other models under development in the group. SRH-1D is a one-dimensional hydraulic and sediment transport model for use in natural rivers and manmade canals. It is a mobile boundary model that simulates changes caused by sediment transport. It can estimate sediment concentrations throughout a waterway given the sediment inflows, bed material, hydrology, and hydraulics of that waterway.

4.3.3.2. Selection of Mainstem Sediment Transport Model

The selection of the Mainstem Sediment Transport model was based on the relative strengths and limitations of the candidate models in light of the objectives within Study 8.

4.3.3.3. Model Calibration and Application

The sediment transport model will be developed to route sediment input, by size fraction, from the various sources (e.g., releases from Box Canyon Dam, tributaries, and shoreline erosion) through the study reach, and to estimate approximate areas where sediment is eroded and accumulated. The effort involves a one-dimensional model, so the results will not account for deposition due to two- and three-dimensional features such as eddies, side channels, and backwaters. Instead, the model will provide areas along the study length where erosion or deposition is likely to occur. It will not identify lateral estimates or specific locations in a cross section where sediments are likely to accumulate.

The model will be calibrated to reproduce the historical patterns of erosion and accumulation based on the gross changes in volume calculated through comparisons of pre-dam and 2007 bathymetric data. A component of the calibration will consist of selecting appropriate methods for transport and bed load (i.e., gravel and cobble) and bed-material load (i.e., sand, gravel, and cobble) to match historical accumulation patterns.

As described in Section 4.3.2.5, the actual volume of sediment input to the Boundary Project, as well as the volume trapped in Boundary Reservoir, will be characterized using a range of approaches because there is no individual method that will best quantify these volumes. While this could appear problematic in that the volume of sediment accumulation since dam construction will serve as the criteria against which the sediment transport model will be calibrated, instead the sediment model will serve as a check of the estimated volume of sediment accumulation. If differences exist between the sediment accumulation volume calculated using the sediment routing model and the volume calculated using the approaches presented in Section 4.3.2, best professional judgment will be used to identify the best estimate of the volume of sediment accumulation. Once the model calculates a volume that matches the best estimated sediment volume, model calibration will focus on accurate representations of the locations and particle size distributions of the delineated zones of erosion and sediment accumulation.

4.3.4. Predict Future Patterns of Erosion and Accumulation

The calibrated sediment transport model will be run for the potential 50-year term of a new license to predict future patterns of erosion and accumulation based on the existing Project operations. As outlined in Section 4.3.3, the vast majority of sediment transport occurs at flow rates exceeding the capacity of the Project powerhouse, so operations scenarios will have only minor influence on erosion and sediment accumulation within Boundary Reservoir. The long-term historical hydrologic conditions will be used to create a 50-year record of flows for tributaries and for releases from Box Canyon Dam. Records of historic Project operations will be referenced to match up with the created 50-year hydrologic record. These hydrologic conditions will be coupled with bed material size distributions and sediment inputs (both volumes and size distributions) from releases through Box Canyon Dam, tributaries, and shoreline erosion, to predict the effects of future patterns of erosion and sediment accumulation on channel morphology within the Pend Oreille River from Box Canyon Dam downstream to approximately Red Bird Creek.

5 PRELIMINARY RESULTS

This section provides information on the preliminary results of the Sediment Transport and Boundary Reservoir Tributary Delta Habitats study effort conducted throughout much of 2007. Data collection efforts are covered through early November 2007. Analysis of the information continued into early December 2007. As with the methods presented in Section 4, the results are subdivided into three main categories: Section 5.1 discusses Tributary Delta Habitat Modeling, Section 5.2 discusses Tributary Delta Sediment Processes, and Section 5.3 discusses Mainstem Sediment Transport. The 2007 results primarily consist of data collection efforts with the most significant effort represented by the fieldwork conducted to support the tributary delta habitats modeling. Fieldwork was also conducted to support the Mainstem Sediment Transport study effort. Results for the Tributary Delta Sediment Processes component are not provided in this report. Analysis of tributary delta processes uses the results of work performed in the other two components of Study 8. Because results for those components were not available, work on the delta processes component will be conducted in 2008.

5.1. Tributary Delta Habitat Modeling

The Tributary Delta Habitat Modeling effort is being conducted to evaluate the effects of operations scenarios on aquatic habitats in the deltas of major tributary streams within the Boundary Reservoir drawdown zone. The Tributary Delta Habitat Modeling effort will utilize the hourly reservoir level changes from the hydraulic routing model (Study 7) to estimate changes in the HQR for selected tributary deltas (Section 4.1.5). This study component also involves the collection of data to represent the physical characteristics of the delta to support estimation of future delta conditions and to describe physical habitat conditions. The data collection effort performed in 2007 is primarily presented in this section.

Specific study efforts for which results are presented in this section include:

- Characterization of tributary delta conditions (Section 5.1.1)
- Tributary delta reconnaissance (Section 5.1.2)
- Selection of tributary deltas for detailed study (Section 5.1.3)
- Delta water temperature monitoring (both continuous and detailed spatial [Section 5.1.4])
- Tributary delta physical habitat data collection (Section 5.1.5)
- Future tributary sediment supply field data collection (Section 5.1.6)

5.1.1. Characterization of Tributary Delta Conditions

The RSP (SCL 2007) lists 28 tributaries that drain into Boundary reservoir; however, not all of these tributaries warrant inclusion in the Tributary Delta Habitat Modeling effort. Tributaries to study in detail were identified so that study efforts could be directed to those tributaries that provide potential high aquatic resource values or that potentially contribute sufficient sediment volume to affect reservoir habitats.

Tributary delta conditions were characterized at two levels as described in this section. The first level of characterization, the initial characterization (Section 5.1.1.1), utilized existing information from the RSP (SCL 2007), information from previous studies (McLellan and O'Connor 2001, Andonaegui 2003, WDFW SalmonScape 2007), data derived from desktop analyses, and a preliminary field reconnaissance conducted in March 2007. This level of characterization was conducted to provide the basis for an initial selection of tributaries to be studied in detail (Section 5.1.3.1), ultimately leading to habitat modeling. The second level of characterization, the detailed characterization, was based on review of aerial photography, bathymetric surveys, and field observations during the general reconnaissance (Section 5.1.2.1). This information was used to support the proposed final selection of tributary deltas to be studied (Section 5.1.3.2).

5.1.1.1. Initial Characterization

The initial characterization of the 28 tributaries was performed in March 2007. It was based on information provided in the RSP (SCL 2007) regarding the length of adfluvial habitat, the delineation and calculation of drainage areas using GIS, and the results of preliminary field reconnaissance conducted on March 20 and 21, 2007. The information from the RSP and the results of the drainage area calculations are presented in Table 5.1-1. The initial characterization supported the planning and implementing 2007 data collection efforts conducted prior to September 2007 drawdown, an event that allowed actual observation of the delta features within the normal drawdown zone. One of the most important efforts in this time period was the deployment of thermographs in the channel thalweg of selected deltas to monitor water temperature (Section 5.1.4)

Table 5.1-1. Summary findings of initial tributary delta characterization.

Tributary Name	Project River Mile	Drainage Area (sq-mi)	Relative Rank[2]	Adfluvial Habitat Length (ft)	Relative Rank[2]	Tributary Flow (cfs)	Date Flow Measured
Unnamed 1	17.2	0.61	20	82	16		
Pewee	17.9	10.37	5	0	26[6]	0.4	9/25/2000
Unnamed 2	17.9	0.02	27	129	14		
Lime[1]	19.45	2.93	9	6,746	4	2.8	9/26/2000
Everett	21.9	2.18	10	60	21		
Whiskey Gulch	21.9	0.70	18	547	10		
Slate	22.2	32.33	2	3,474	5	10.9	7/31/2000
Beaver	24.3	1.77	12	0	26[6]		
Threemile	24.3	4.91	7	0	26[6]		
Unnamed 3	25.4	0.15	23	58	22		
Flume	25.8	19.33	3	1,056[3]	8	8.8	9/6/2000
Sullivan	26.9	142.46	1	21,729	1	77.7	8/16/2000
Unnamed 4	27.1	0.08	24	77	18		
Linton	28.1	2.11	11	19,159	2		
Unnamed 5	28.9	0.62	19	130	13		
Unnamed 6	29.2	0.01	28	955	9		
Pocahontas	29.4	3.92	8	16,480	3		
Unnamed 7	29.6	0.30	21	53	23		
Unnamed 8	30.1	0.07	25	66	20		
Wolf	30.3	1.57	14	236	11		
Sweet Lunch	30.9	11.12	4	2,659[3]	6	5.3	9/11/2000
Unnamed 9	31.1	0.04	26	67	19		
Sand	31.7	8.22	6	1,320[3]	7	0.4	9/7/2000
Lost	32.2	1.20	15	165	12		
Unnamed10	33.5	0.93	16	99	15		
Unnamed11	33.6	0.23	22	78	17		
Unnamed12	34.0	0.93	17	<100[4]	24		
Unnamed13	34.3	1.72	13	<100[5]	25		

Notes:

1 Current mouth of Lime Creek at Project river mile (PRM) 19.45. Approved GIS streams coverage shows mouth at PRM 19.0. Flow of 0.03 cfs measured at PRM 19.0 on 9/6/2007.

2 Relative rank of the values in the preceding column in relation to the values for all 28 tributaries. For example, the drainage area of Sullivan Creek is 142.46 square miles, and this is the greatest area of all 28 tributaries, so the relative rank is 1.

3 The length of adfluvial habitat is based on the distance from the mouth of the stream to the lowermost migration barrier reported in McLellan and O'Connor (2001) and/or Andonaegui (2003).

4 The original length of 102 feet of adfluvial habitat for Unnamed Tributary 12 was based on the 2002 WDFW SalmonScape (2007) Geographic Information System; however, during a September 2007 site visit, a natural fish migration barrier (a culvert perched higher than 15 feet) was observed near the reservoir margin. The length of adfluvial habitat was estimated as less than 100 linear feet of stream.

5 The original length of 4,184 feet of adfluvial habitat for Unnamed Tributary 13 was based on the 2002 WDFW SalmonScape GIS; however, during a September 2007 site visit, the outlet of the culvert through which the tributary flows was blocked by riprap. Seepage flow was observed due to the low water conditions. Due to this natural fish migration barrier the length of adfluvial habitat was estimated as less than 100 linear feet of stream.

6 Three tributaries have zero feet of adfluvial habitat, so the relative rank for all three is 26.

5.1.1.2. Detailed Characterization

The detailed characterization of the tributary deltas was performed to calculate the drawdown zone habitat length and to identify evidence of delta aggradation or degradation since construction of Boundary Dam. These parameters were characterized when the finalized bathymetric data became available and after the September 2007 field reconnaissance. The combination of low pool and low flow during the September 2007 drawdown exposed all delta features within the normal reservoir fluctuation zone for observation and characterization. The delta characterizations were also supplemented by desktop analyses of historical aerial photographs and the bathymetry. The detailed characterization was not performed for the unnamed tributaries since none had significant deltas and other characteristics did not indicate that these were candidates that warranted further expenditure of study efforts. The results of the detailed characterization are presented in Table 5.1-2.

The information presented in Table 5.1-2 did not provide characteristics that would indicate any of the omitted tributaries should be elevated to detailed study (see Section 5.1.3.2 for additional detail).

Table 5.1-2. Summary findings of detailed characterization of tributary deltas.

Tributary Name	Project River Mile	Site Visit Date	Tributary Temperature (°C)	Tributary Flow (cfs)	Existing Delta Present	Significant Aggradation/ Degradation	Drawdown Zone Habitat Length (ft)
Unnamed 1	17.2	9/6/2007	11	0.1	No	N/A	--[3]
Pewee	17.9	9/6/2007	11	2[2]	Yes	Yes	100
Unnamed 2	17.9	9/6/2007	12	0.004	No	N/A	--[3]
Lime	19.45	9/6/2007	11	2.7	No	N/A	380
Everett	21.9	9/6/2007	10	0.3	Yes, minor	No	360
Whiskey Gulch	21.9	9/6/2007	Dry	Dry	No	N/A	240
Slate	22.2	9/6/2007	11	6.8	Yes	Yes	510
Beaver	24.3	9/7/2007	11	0.9	No	N/A	30
Threemile	24.3	9/7/2007	9	0.5	No	N/A	40
Unnamed 3	25.4	9/7/2007	13	0.04	No	N/A	--[3]
Flume	25.8	9/7/2007	10	5.0	Yes	Yes	570
Sullivan	26.9	9/10/2007	15	40.5	Yes	No	1,510
Unnamed 4	27.1	--[1]	--	--	--	--	--
Linton	28.1	9/8/2007	11	1.9	Yes	Yes	640
Unnamed 5	28.9	9/8/2007	9	0.1	No	N/A	--[3]
Unnamed 6	29.2	9/11/2007	Dry	Dry	No	N/A	--[3]
Pocahontas	29.4	9/9/2007	Dry	Dry	Yes	No	260
Unnamed 7	29.6	9/11/2007	Dry	Dry	No	N/A	--[3]
Unnamed 8	30.1	9/11/2007	Dry	Dry	No	N/A	--[3]
Wolf	30.3	9/11/2007	Dry	Dry	Yes	No	240
Sweet Lunch	30.9	9/11/2007	12	2.5	Yes	No	570
Unnamed 9	31.1	9/11/2007	Dry	Dry	No	N/A	--[3]
Sand	31.7	9/11/2007	Dry	Dry	Yes	No	800
Lost	32.2	9/12/2007	11	0.03	Yes	No	380
Unnamed 10	33.5	9/12/2007	11	0.001	No	N/A	--[3]
Unnamed 11	33.6	9/12/2007	14	0.002	No	N/A	--[3]
Unnamed 12	34.0	9/12/2007	10	0.06	No	N/A	--[3]
Unnamed 13	34.3	9/12/2007	8	0.4	No	N/A	--[3]

Notes:
1 No tributary channel could be found in September 2007.
2 Flow rate at the base of Pewee Falls was visually estimated.
3 Based on initial characterization and delta reconnaissance findings (e.g., no flow and no existing delta present), calculations of drawdown zone habitat length were not warranted.

5.1.2. Tributary Delta Reconnaissance

The tributary delta reconnaissance was conducted in September 2007. The preliminary findings of the characterization of tributary delta conditions identifying the deltas as most likely to provide potential high aquatic resource values or that potentially contribute sufficient sediment volume to affect reservoir habitats were used to guide the field efforts. The reconnaissance was performed to support the selection of the tributary deltas to be studied in detail. The reconnaissance involved observation of delta features at low pool and low flow and the collection of additional parameters to aid in the characterization of the 28 tributaries. Parameters of interest included tributary flow rate and tributary water temperature. The results of the tributary flow measurements and the recorded water temperature are presented in Table 5.1-2. In addition, if certain types of cultural resources were observed, their presence was noted. During the reconnaissance, a trained geologist was tasked with recording cultural resources features such as FCR and FCR clusters; however, none were observed. The apparent absence of these features was communicated to the lead for Study 24, Cultural Resources, Greg Greene of Tetra Tech.

5.1.3. Selection of Tributary Deltas for Detailed Study

The selection of the tributary deltas with characteristics warranting site-specific studies has been performed. This selection builds on the outcome of the characterization presented in Section 5.1.1 and the observations and measurements recorded during the field reconnaissance described in Section 5.1.2. Modeling of the selected deltas will be conducted with the goal of evaluating the effects of operations scenarios on aquatic habitats associated with these features. The selection of the deltas for the detailed studies involved a two-stage process with an initial selection that was presented to RPs in June 2007 and the proposed final selection completed as part of this report. This section presents the information used to perform both levels of selection and the results of each.

5.1.3.1. Initial Selection of Tributary Deltas for Detailed Study

The initial selection of seven tributaries for detailed study was presented and agreed upon at the June 7, 2007 RPs meeting. The selection was documented in Tetra Tech and TRPA (2007).

The initial screening was performed in March 2007. It was based on information provided in the RSP (SCL 2007) regarding the length of adfluvial habitat, delineation and calculation of drainage areas using GIS, and the results of a field reconnaissance conducted on March 20 and 21, 2007. The information from the RSP and the results of the drainage area determinations were presented in Table 5.1-1.

During the March 20–21 field reconnaissance, observations were made about the potential for aquatic habitat and the presence of geomorphic processes consistent with delta formation. As a result of this screening, the seven tributaries listed below were initially identified for study under the Tributary Delta Habitat Modeling effort:

- Slate Creek
- Flume Creek
- Sullivan Creek

- Linton Creek
- Pocahontas Creek
- Sweet Creek
- Sand Creek

In addition to these seven tributaries, it was also proposed during the initial screening process that two other creeks would be discussed qualitatively as to their habitat conditions and their geomorphic evolution, but would not be included in the habitat modeling effort. These two tributaries are Pewee Creek and Lime Creek. Both of these tributaries have significant drainage areas, but other conditions exclude them from the initial list of tributaries identified for modeling of aquatic habitat.

Peewee Creek pours over a falls directly into Boundary Reservoir and has no adfluvial habitat. There is deposition of gravel, cobble, and small boulders in a pile at the base of the falls (Figure 5.1-1). At least a portion of this pile is in the reservoir fluctuation zone. However, it is not expected that the character of this sediment deposit will change in respect to aquatic habitat over the new license period. An upcoming discussion with the RPs on Pewee Creek will include an estimate of the evolution of the deposit, and if the evolution does significantly influence aquatic habitat, Pewee Creek will be added back into the tributaries to be modeled.

Figure 5.1-1. Deposition at the base of Pewee Falls as seen on September 6, 2007.

Note: The elevation of the reservoir water surface shown in this figure is approximately 1,973 feet NAVD 88 (1,969 feet NGVD 29).

Lime Creek was excluded from the initial list of tributary deltas for aquatic habitat modeling because it does not have a delta or a defined channel at its confluences with the reservoir (Figure 5.1-2). These aspects of Lime Creek's morphology are partially due to the chemical characteristics of Lime Creek, which result in the formation of travertine deposits that spread the stream out into shallow flow paths over a steep hillside slope. The stream has many shallow braids and lacks a typical stream channel across the reservoir fluctuation zone. The upstream pools and wetland created by these formations farther upstream are trapping sediments, resulting in the lack of sediment deposits at the reservoir.

Figure 5.1-2. Confluence of main Lime Creek channel (PRM 19.45) with Boundary Reservoir as seen on September 6, 2007.

Note: The reservoir water surface elevation shown is approximately 1,973 feet NAVD 88 (1,969 feet NGVD 29). Note the boat at the edge of the reservoir for scale.

Table 5.1-1 included the relative rank of each of the 28 tributaries considered in terms of their watershed areas and adfluvial habitat lengths. Of the 10 tributaries with the largest drainage areas, 6 were identified for study in the initial screening. The seventh tributary selected was Linton Creek, which ranks eleventh in drainage area. Linton Creek was included because of its second ranking for adfluvial habitat length and the presence of a delta extending into the mainstem of the Pend Oreille River. Of the 4 tributaries in the top 10 that were not selected for detailed study, 2 have already been discussed, Pewee and Lime creeks, which ranked fifth and ninth. The other two tributaries in the top 10 watershed areas that were not selected were Everett

(10th) and Threemile (7th). Everett Creek had minimal evidence of delta deposits during the reconnaissance and its adfluvial habit is identified as 60 feet (23rd). Threemile Creek sheets down a steep bedrock outcrop into Boundary Reservoir, does not have a delta present in the reservoir fluctuation zone, and has no adfluvial habitat. In contrast, the seven initially selected tributaries represent seven of the top eight tributaries in adfluvial habitat length. The other top eight tributary for adfluvial habitat length is Lime Creek (4th).

5.1.3.2. Proposed Final Selection of Tributary Delta for Final Study

The detailed characterization presented in Section 5.1.1.2 and the general delta reconnaissance presented in Section 5.1.2.1 were conducted to provide the information necessary to make the final selection of the tributary deltas to be studied in the tributary delta habitat component of Study 8. The results of the characterization performed for supporting the final selection of tributary deltas for detailed study were provided in Table 5.1-2.

The final selection process did not provide information that would indicate any of the omitted tributaries should be elevated to detailed study. The most likely candidate to have been elevated was Lime Creek; however, the field reconnaissance confirmed that there are only minor delta sediment deposits in the fluctuation zone, with stumps from reservoir clearing still exposed to their base, indicating minimal sedimentation (Figure 5.1-2). The other tributary candidate considered for elevation to detailed study was Pewee Creek. In this case, the field reconnaissance revealed the steep pile of coarse sediment deposits extended throughout the fluctuation zone without a milder sloping delta surface present (Figure 5.1-1). Another possible candidate for elevation to detailed study was Everett Creek. In this case, the field reconnaissance indicated only a minor delta had formed at its mouth and confirmed the presence of the waterfall that limits its adfluvial habitat to 60 feet.

The final selection process can also be used to drop tributaries from the list proposed for detailed study. The observations during delta reconnaissance and the results in Table 5.1-2 suggest the possibility that it may be appropriate to drop Pocahontas and Sand creeks. Both of these tributaries were dry during the September reconnaissance. This would indicate the tributaries may have little or no value as thermal refugia. However, these two tributaries have been retained in the seven proposed for detailed study because thermal refugia is not the only potential habitat value for these tributaries. Stream flows were generally low in September 2007 compared with the limited values in 2000 (Table 5.1-1) so the tributaries may have late summer flows in other years, and the possibility of dropping these tributaries had not been coordinated with the RPs.

Based on the final selection evaluation, the same seven tributaries initially selected are proposed for the Tributary Delta Habitat Modeling study. These are:

- Slate Creek
- Flume Creek
- Sullivan Creek
- Linton Creek
- Pocahontas Creek
- Sweet Creek
- Sand Creek

As a result of this selection, all seven of these tributaries had physical habitat data collected during the September 2007 drawdown period. Additionally, mapping of the various deposits and other geomorphic features was also performed for each delta. The maps for all seven proposed detailed study tributary deltas are provided in Appendix 1. These figures also show locations of sediment samples, continuous temperature monitoring points, bed load calculation cross section locations, and stream channel location. This information is overlaid on both the 2005 aerial photography and current bathymetry.

5.1.4. Tributary Delta Temperature Monitoring

As described in Section 4.1.4, two types of temperature monitoring were conducted in 2007. The first was monitoring of the seven selected study tributaries with continuous recording thermographs placed in the channel thalweg and mainstem of the Pend Oreille River. The second was a set of measurements conducted on Slate, Sullivan, and Sweet creeks to identify whether thermal plumes existed in these tributary deltas and if so, to provide information on their vertical and lateral distribution on the three tributary deltas. The preliminary results of these investigations are presented in this section.

5.1.4.1. Continuous Temperature Monitoring Results

The influence of Project operations on water temperature within the varial zone at the seven representative tributaries was monitored from July 12 through October 31, 2007. Thermographs were deployed along the thalweg of the longitudinal profile at each tributary delta in three distinct zones: upstream, varial, and mainstem. The upstream zone was defined as the region of the tributary where there is no backwater influence from Pend Oreille River. The varial zone was defined as the region where fluctuations in water surface elevation from Project operations at Boundary Dam occur. Thermographs located within the mainstem zone were placed to represent ancillary water temperature of the Pend Oreille River adjacent to the tributary deltas. A summary of the total number of thermographs deployed at each of the seven representative tributaries is presented in Table 5.1-3; locations are shown in figures presented in Appendix 1.

Table 5.1-3. Summary of number of thermographs deployed from July through October 2007.

Tributary Delta	Number of Thermographs Deployed per Zone		
	Upstream	**Varial**	**Mainstem**
Slate Creek	1	2	1
Flume Creek	1	2	1
Sullivan Creek	1	3	1
Linton Creek	1	1	1
Pocahontas Creek	1	1	1
Sweet Creek	1	2	1
Sand Creek	1	1	1
TOTAL	7	12	7

During the deployment period of the thermographs, the ambient air temperature recorded at Boundary Dam (National Weather Service [NWS] Gage No. 450844) ranged from approximately 40 to -2°C with a mean daily temperature of 17.1°C. Water temperatures recorded at USGS Gage No. 12398550 located in the reservoir forebay at the upstream face of Boundary Dam ranged from approximately 25.4 to 15.2°C. Conditions of the Pend Oreille River recorded at the Continuous Water Quality Buoy No. 1 (see the Study 6 Interim Report [SCL 2008d]) ranged from 25.1 to 14.8 °C.[3]

Raw data reported at each thermograph were reviewed to identify anomalous data points that occurred during periods of exposure to air. Exposure to air could occur from several factors including the tributary going dry at the thermograph locations, the thalweg shifting from the thermograph location, or displacement of the thermograph from the thalweg. Because continuous air temperature readings are not recorded at Boundary Dam, hourly temperature records at Sandpoint Airport (NWS Gage No. 720322) were used. Sandpoint Airport is located approximately 36 miles southeast of Boundary Dam and is at an elevation of 2,127 feet above mean sea level.

Review of the preliminary data indicates that Project operations are one of several factors that have an influence on the distribution of temperatures within the varial zone. Additionally, where sufficient flows and depth exist, the temperature gradient within the varial zone along the thalweg increases as thermal mixing between reservoir and tributary water occurs. In general, temperatures will range between the temperatures of the inflow and mainstem waterbodies. A summary of conditions recorded during the 2007 monitoring period is presented in Table 5.1-4.

[3] At the time of this report, data at USGS Gage No. 12398550 and Continuous Water Quality Buoy No. 1 (Study 6) were not available from October 1 through October 31, 2007. Data presented above do not reflect this period.

Table 5.1-4. Summary of continuous temperature data from July 12, 2007, through October 31, 2007.

Tributary	Gage	Maximum Recorded Temperature (°C)	Minimum Recorded Temperature (°C)	Mean Temperature (°C)	Maximum Fluctuation within a 24-hour Period (°C)
Slate	Upstream	14.6	1.9	9.2	3.2
	Varial No. 1	18.3	2.0	9.9	5.7
	Varial No. 2	19.0	3.6	12.1	5.2
	Mainstem	25.7	9.1	18.8	1.3
Flume	Upstream	16.0	2.5	9.5	5.3
	Varial No. 1	17.6	4.1	11.5	4.7
	Varial No. 2	20.2	3.9	12.7	10.4
	Mainstem	25.3	8.9	18.6	7.6
Sullivan	Upstream	20.3	7.9	13.9	4.3
	Varial No. 1	20.5	7.5	13.9	4.2
	Varial No. 2	21.8	9.2	15.4	5.4
	Varial No. 3	22.6	8.3	14.3	6.1
	Mainstem	25.4	9.1	18.3	7.7
Linton	Upstream	14.2	4.2	9.6	3.6
	Varial No. 1	22.2	4.4	11.7	12.1
	Mainstem	25.4	7.7	18.3	14.1
Pocahontas[1]	Upstream	---	---	---	---
	Varial No. 1	---	---	---	---
	Mainstem	25.5	9.1	18.6	1.8
Sweet	Upstream	12.5	0.6	6.8	4.3
	Varial No. 1	18.8	1.9	10.5	6.2
	Varial No. 2	19.8	2.4	10.8	7.6
	Mainstem	25.6	8.6	18.5	3.5
Sand[1]	Upstream	---	---	---	---
	Varial No. 1	---	---	---	---
	Mainstem	25.5	9.1	18.5	5.8

Notes:

1 Water depths at Upstream and Varial No. 1 Gages at this creek were insufficient to record water temperatures; these locations were dry by the end of July.

The influence of Project operations on the mixing zone at each delta is shown in the two examples presented in Figure 5.1-3 and Figure 5.1-4. The first example, occurring July 21–28, 2007, at Sullivan Creek shows temperatures within the varial zone increasing in the downstream direction as the influence of mixing with the warmer water from the mainstem increases. Varial Zone 1, the most upstream thermograph in the varial zone, nearly coincides with the upstream tributary gage located above the varial zone. Varial Zone 3, the thermograph closest to the mainstem, showed the largest increase in temperature as the reservoir forebay elevation rises. (Note: In 2008 actual water surface elevation predicted by the hydraulic routing model will be used in analyzing the tributary delta thermal regime. Actual fluctuations at Sullivan Creek may be less than and delayed from those presented for the forebay.) Varial Zone 2, the thermograph located between 1 and 3, had a response between the other two varial zone thermographs. It is also noted that the timing of the response followed a similar pattern. Varial Zone 3 responded first as the reservoir rose and Varial Zone 1 responded last. The reverse appeared to hold as the reservoir fell.

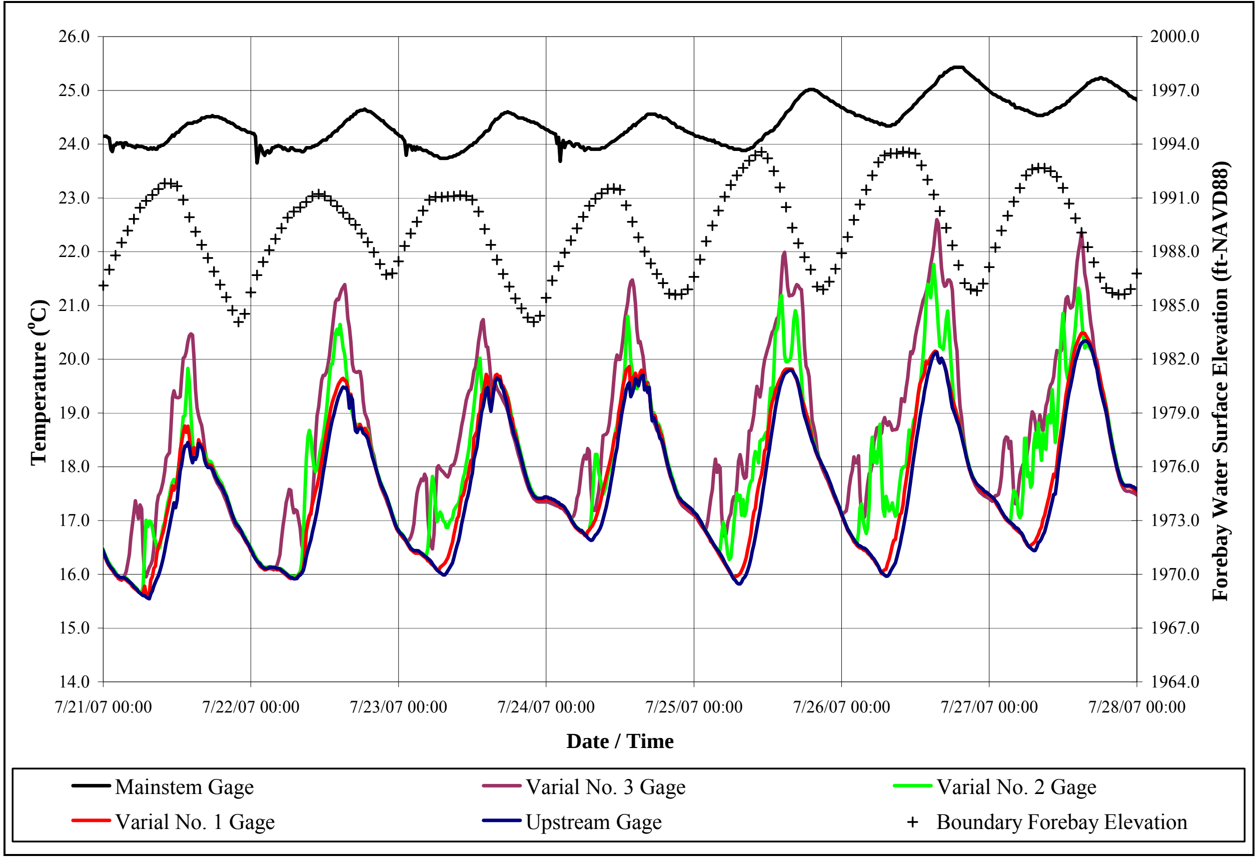

Figure 5.1-3. Water temperatures at Sullivan Creek, July 21–28, 2007.

The second example, presented in Figure 5.1-4, occurred September 4–21, 2007, at Slate Creek during a period when reservoir elevations were drawn down to support the technical studies. During September 6 through 10, 2007, reservoir pools had no influence on the two varial zone thermographs. However, as water surface elevations rose the location of the thermal mixing zone progressed upstream. During the increasing water surface elevations, Varial Zone 2, the downstream thermograph, first started to respond on September 10, 2007. Farther upstream, Varial Zone 1 did not start to respond until September 13, 2007, but only during the portion of the day when the reservoir water surface elevation was highest. The response became apparent for the majority of each day starting on September 16, 2007, indicating that the thermograph was inundated throughout the full range of fluctuations in the daily reservoir water surface elevation.

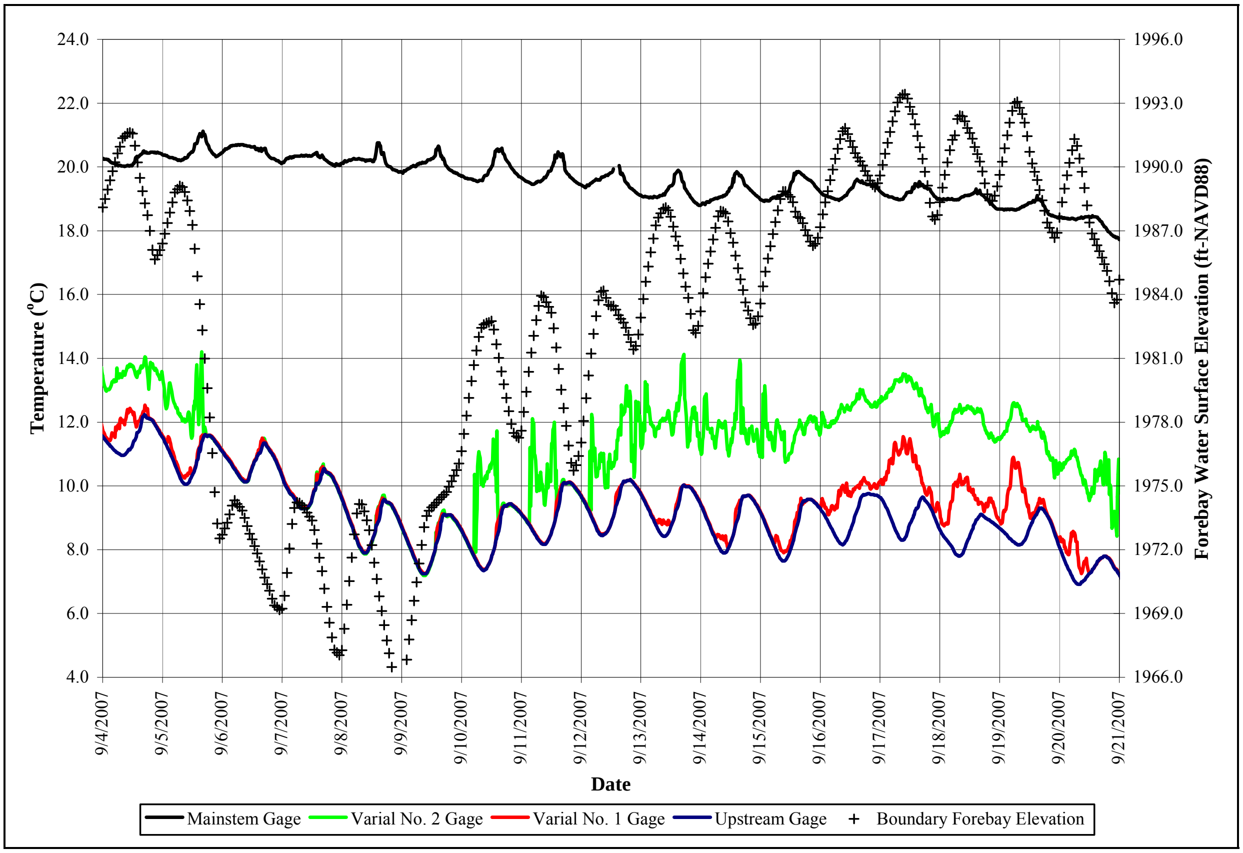

Figure 5.1-4. Water temperatures at Slate Creek, September 4-21, 2007.

Several difficulties were encountered during the monitoring period that prevented appropriate data from being collected at certain times. The difficulties are listed with the most common first: 1) lack of sufficient water depth to record water temperatures, resulting in the thermograph recording air temperature; 2) theft of the temperature gages; and 3) burial of one thermograph to the point that it could not be retrieved.

As a result of the first type of difficulty, there are insufficient temperature readings on Pocahontas Creek due to lack of flow within the channel to assess the influence of Project operations on the water temperature within the varial zone. The varial zone thermograph installed on Pocahontas Creek was dry for the duration of the monitoring period as supported by the plot within Appendix 2 comparing the data recorded by the thermographs and the air temperature recorded at Sandpoint Airport (NWS No. 720322). Initial readings at the upstream thermograph reflect Pocahontas Creek water temperature. However, by the first download period occurring in early August, flows had decreased to a trickle. The exact date when flows became non-existent is unknown. Due to the installation location in the thalweg adjacent to an undercut bank, it is believed that temperatures from August through October were biased by an unknown variable(s) (e.g., groundwater, soil, air).

Similar to Pocahontas Creek, flows in the upstream and varial zone of Sand Creek were minimal to absent resulting in a high variability in measurements. Review of the data suggests that the upstream thermograph was completely dry and exposed to air temperature from early August 2007 through the middle of October 2007. Influenced by the water surface elevation of the Pend Oreille River, the varial thermograph experienced discontinuous periods of water temperature measurements throughout the duration of the monitoring period. Large fluctuations in temperature occurred depending on the river water surface elevation, depth of water, and tributary inflow from Sand Creek (when present).

5.1.4.2. Detailed Monitoring of Tributary Delta Temperature

The presence and extent of thermal plumes extending into Boundary Reservoir were measured at two different reservoir elevations during periods of relatively low and steady inflow from Box Canyon Reservoir for three tributaries: Slate Creek, Sullivan Creek, and Sweet Creek. These tributaries were selected based upon physical characteristics that would be likely to support a low temperature thermal plume or based on observations during the summer of 2007 of trout "crowding" at these tributary deltas. Thermal plumes were profiled on August 20, 2007, at high reservoir pool (i.e., elevation 1,993.3 feet NAVD 88 [1,989.0 feet NGVD 29]) and on August21, 2007, at medium reservoir pool (i.e., elevation 1,987 feet NAVD 88 [1,983 feet NGVD 29]). Mean daily inflow into Boundary Reservoir from Box Canyon Dam during the 2-day period as measured at USGS Gage No. 12396500 was approximately 8,710 cfs. The thermal plume at the mouth of Slate Creek was also evaluated on August 24, 2007, at low reservoir pool (i.e., elevation 1,980 feet NAVD 88 [1,976 feet NGVD 29]). The mean daily inflow into Boundary Reservoir from Box Canyon Dam as measured at USGS Gage No. 12396500 was 9,650 cfs. As shown in Table 5.1-5, a discrete thermal plume was measured at each tributary delta at each reservoir pool elevation by water temperatures that were 6 to 11°C cooler than the reservoir water temperature.

Table 5.1-5. Comparison of reservoir and tributary water temperatures at the time of tributary delta thermal plume monitoring.

Date	Tributary Delta	Reservoir Water Surface Elevation (feet, NAVD 88[1])	Reservoir Water Temperature (°C)	Tributary Water Temperature (°C)	Water Temperature Difference (°C)
08-20-2007	Slate Creek	1,989.25	21.9	10.7	11.2
08-20-2007	Sullivan Creek	1,989.25	21.1	10.6	10.6
08-20-2007	Sweet Creek	1,989.25	21.3	9.9	11.4
08-21-2007	Slate Creek	1,983	21.1	15.0	6.1
08-21-2007	Sweet Creek	1,983	21.9	15.8	6.1
08-21-2007	Sullivan Creek	1,983	20.9	11.8	9.1
08-21-2007	Slate Creek	1,976	21.7	12.8	8.9

Notes:
1 Subtract 4.03 feet for NGVD 29.

Figures showing the temperature data collected are provided in Appendix 2. Table 5.1-6 provides an overview of the dimensions and size of the thermal plumes at each of the three tributaries under the varying reservoir conditions. This table also provides the change in reservoir water surface elevation during the measurement period. The water surface elevation was considered stable for nearly all the measurements periods with the pool falling less than 0.25 foot except for the low pool monitoring at Slate Creek where the pool dropped 1.52 feet. The information in Tables 5.1-5 and 5.1-6 and the Appendix 2 figures provide the basis for the following discussion of the observed thermal plume characteristics.

Table 5.1-6. Tributary thermal plume characteristics, August 2007.

Tributary Delta	Forebay Pool Level	Average Forebay Water Surface Elevation (feet, NAVD 88[1])	Change in Water Surface Elevation (ft)	Plume Dimensions			
				Length (ft)	Area (Acres)	Typical Depth (ft)	Approximate Volume (ac-ft)
Slate	High	1,993.05	-0.20	560	0.37	4	1.5
Slate	Medium	1,986.58	-0.03	450	0.58	3	1.7
Slate	Low	1,980.00	-1.52	420	0.62	2.5	1.6
Sullivan	High	1,992.30	-0.14	750	2.1	2.5	5.2
Sullivan	Medium	1,986.40	-0.08	390	1.4	2.5	3.5
Sweet	High	1,992.65	-0.24	130	0.08	1.5	0.12
Sweet	Medium	1,986.47	-0.05	15	0.04	1	0.04

Notes:
1 Subtract 4.03 feet for NGVD 29.

5.1.4.2.1. Slate Creek

The temperature of Slate Creek was the lowest of the three tributaries at approximately 11°C, resulting in the largest temperature gradient with the mainstem (see Table 5.1-5). The Slate Creek thermal plume had the least variability between pool levels even though it was monitored over the broadest range of water surface elevations as well as having the highest temperature gradient. It was the only tributary delta plume measured under the “low pool” conditions. The Slate Creek low pool measurements were the only ones collected during a significant pool level drop. However, the fluctuation does not appear to have resulted in significant difference in plume characteristics compared with the other two sets of measurements taken at nearly constant pool elevations.

The extent of the thermal plumes varied somewhat according to tributary delta and reservoir pool elevation. At high reservoir pool, the thermal plume was approximately 560 feet long compared to approximately 450 feet long at the medium reservoir pool level and approximately 420 feet at the low reservoir pool level. These plume lengths were measured from the point where the reservoir water surface intersects the tributary flow (the location of this point varies as a function of reservoir water surface elevation and tributary flow volume) down to the location in the reservoir where a discernable plume could no longer be detected (i.e., bottom water temperatures less than 0.5 to 0.8°C (1.0 to 1.5°F) cooler than the temperature at the reservoir surface). The increased length of the plume under the high pool condition is due to the inundation of the narrow portion of the stream channel. The plume depth (measured from the delta bed to the top of the thermal plume) increased with increasing pool elevation. However, the area of the plume had the opposite trend with the plume surface area decreasing with increasing pool elevation. These opposite trends resulted in the estimated volume of the plume being roughly constant at the three pool levels.

The physical morphology of the Slate Creek cove is likely the primary factor in maintaining the extent of the thermal plume by limiting mixing with the main body of the reservoir. It is likely that the plume will occupy the 400- to 600-foot length of the confined portion of the cove independent of reservoir level within the normal operating range.

5.1.4.2.2. Sullivan Creek

The flow in Sullivan Creek was the warmest of the three tributaries measured at approximately 15 to 16°C, which was approximately 6°C cooler than the mainstem. At high pool the Sullivan Creek plume was the longest of the three tributaries at 750 feet. The thermal plume measured at Sullivan Creek under both the high pool and medium pool conditions had the greatest volume and area when compared to the plumes measured at the other tributary deltas under similar pool conditions. The volume of the Sullivan Creek thermal plume was 5.2 acre-feet under high pool conditions and it was 3.5 acre-feet under medium pool conditions. Under the same respective pool conditions, the plume area was 2.1 and 1.4 acres, with the typical depth being estimated at 2.5 feet for both pool levels.

Though the areas are somewhat similar, the location of the thermal plumes shifted considerably from the high to medium pool conditions. In the case of the high pool condition, the plume started near the upper end of the delta and ended approximately 200 feet before reaching the downstream end of the delta topset slope. Under this condition, the plume shape was long and narrow. However, under the medium pool condition, the plume started near the middle of the delta and extended to the end of the topset slope at the edge of the mainstem. In the case of Sullivan Creek, it appears that pool level influences the size of the thermal plume by reduced pool levels shifting the plume downstream to the point where the mainstem can mix with and sweep away the cooler tributary water.

5.1.4.2.3. Sweet Creek

The thermal plumes measured at Sweet Creek were by far the smallest with volumes of 0.12 and 0.04 acre-foot, and areas of 0.08 and 0.04 acre at high and medium pool levels, respectively. The typical depths were also the smallest and varied from 1.5 to 1 feet for the high and medium pool levels. The smaller relative plume size is likely the result of the low flow in Sweet Creek coupled with the low flows in the Pend Oreille River which created low water surface elevations. These conditions caused the creation of the plume on the lower portion of the delta topset slope, even at the high pool condition.

At high pool, the Sweet Creek plume was confined to the footprint of the tributary channel and a small side channel. This is in contrast to both Slate and Sullivan Creeks where the measured plumes spread out from their channels across their deltas. Under the medium pool condition, the Sweet Creek plume was measured at the downstream edge of the topset slope and persisted only along the interface between the mainstem and the tributary. Due to this location, the mainstem flow quickly mixed with and swept the thermal plume downstream.

5.1.4.2.4. General Observations Across All Three Creeks

Several general observations about the characteristics of the tributary delta thermal plumes can be made using the data collected in August 2007:

- The size of the plumes varies and is at least partially a function of the tributary inflows, shape of the delta (typically controlled by the canyon walls or terraces), and the delta gradient.
- Though the three tributaries represented a wide range of flows, delta characteristics, locations within Boundary Reservoir, and water temperatures, a cool water thermal plume existed at each tributary delta.
- The thermal plumes were present at all pool elevations sampled, though the sizes varied at each tributary at the various pool elevations sampled.
- The location of the terminus of the topset slope relative to the mainstem channel influences the behavior of the thermal plume. In cases where the topset slope extends to (Sullivan Creek) or into (Sweet Creek) the mainstem, the mainstem current can sweep the thermal plume away, effectively limiting the plume area and volume.
- The largest relative changes in plume area and volume were for Sweet Creek where the volume was three times greater and the area 1.5 times larger at high pool than low pool. At Sullivan Creek, the area and volume were approximately 50 percent larger at high pool than medium pool. In contrast, the Slate Creek plume retained a similar volume for high, medium, and low reservoir pool levels, though the area changed by about 40 percent.

5.1.5. Tributary Delta Physical Habitat Data Collection

Habitat mapping and profiling surveys were conducted in early September 2007 during a period of low reservoir pool and low tributary outflow at all seven of the tributary deltas selected for study. The Sullivan Creek delta was resurveyed on November 9, 2007, during a higher tributary outflow, after Pend Oreille County Public Utility District No. 1 began to augment creek flows from Sullivan Lake. This late fall resurvey of the Sullivan Creek delta at high tributary outflow was also conducted during a period of low reservoir pool. Table 5.1-7 lists the tributaries surveyed, date surveyed and some of the general parameters measured.

Stream flows in the various tributaries surveyed were generally low at the time of the late summer habitat surveys and ranged from completely dry (Sand and Pocahontas creeks) to over 50 cfs (Sullivan Creek). Water quality parameters in each of the five flowing tributary delta areas at the time of the late summer surveys appeared to be at levels suitable for resident trout with cool water temperatures, high dissolved oxygen concentrations, and pH levels in the 7 to 8 range (Table 5.1-7). Small juvenile trout in the 3- to 6-inch size range were noted in several of the lower tributaries at the time of the surveys, including Flume, Sullivan, and Sweet creeks. Sand and Pocahontas creek deltas were dry at the time of the survey and were obviously incapable of supporting fish populations during periods of low reservoir water surface elevation.

Table 5.1-7. List of tributaries, date of the habitat survey, reservoir water surface elevation, tributary discharge, and selected tributary stream water quality parameters during surveys conducted for the 2007 Boundary Reservoir tributary delta studies.

Tributary	Date	Res. Water Surface Elev. (feet) NAVD 88[1]	Tributary			
			Discharge (cfs)	Water Temp. (°C)	Dis. Oxygen (mg/L - % sat.)	pH
Slate Creek	September 6	1,974	7.4	10.6	9.37 (84.1%)	8.0
Flume Creek	September 6	1,974	4.7	11.2	10.05 (91.8%)	7.5
Linton Creek	September 7	1,974	2.3	9.4	10.61 (92.9%)	8.0
Sweet Creek	September 7	1,974	1.8	13.2	9.97 (95.3%)	8.0
Sullivan Creek	September 8	1,974	50.6	12.8	9.02 (84.4%)	7.5
Sand Creek	September 9	1,974	Dry	---	---	---
Pocahontas Creek	September 9	1,974	Dry	---	---	---
Sullivan Creek	November 9	1,980	309.5	9.4	nm[2]	nm[2]

Notes:
1 Subtract 4.03 feet for NGVD 29
2 nm = Measurements not recorded during second survey.

Except for Sullivan Creek, tributary outflows through the deltas were confined to single channels and the distances between high and low pool elevation were less than six hundred feet in length (Table 5.1-8). Stream flow through the Sullivan Creek delta was more complex and flowed through braided channels at low pool elevation at both the low and high tributary flow levels (Figure 4.1-4). One noteworthy observation made during the habitat survey in the Sullivan Creek delta during the November 2007 high tributary outflow was the dynamic nature of the channels. During this survey, which was conducted over about an 8-hour time span, bank erosion was continually occurring along the main tributary channel, resulting in sediment transport into the reservoir and an observable movement of the leading edge of the delta into the reservoir. The high stream flow through the easily eroded mud sand substrates of the lower delta resulted in areas of down-cutting, which tended to concentrate flow into the main tributary channel and reduce or even eliminate flow into some of the secondary channels by the end of the habitat survey period.

Accumulations of LWD were found within most of the tributary deltas, though the larger basins with the higher late summer flows had the highest levels of large woody debris in terms of numbers of pieces and volume of material (Table 5.1-8). The number of pieces and volume of material represent only those LWD accumulations observed on depositional surfaces of the tributary deltas and observed in the tributary channel within the normal reservoir fluctuation zone.

Table 5.1-8. List of tributaries, channel complexity, length of stream surveyed, and amount of large woody debris in the entire delta area during the late summer 2007 Boundary Reservoir tributary delta studies.

Tributary	Channel Complexity	Length Surveyed (ft)	LWD		
			Accumulations	Number of Pieces	Volume (ft^3)
Slate Creek	Single	518	10	81	656
Flume Creek	Single	526	12	48	475
Sullivan Creek (8 Sept)	Braided	2,954	21	38	362
Linton Creek	Single	530	1	4	7
Pocahontas Creek	Dry	234	0	0	0
Sweet Creek	Single	444	1	1	3
Sand Creek	Dry	578	0	0	0
Sullivan Creek (9 Nov)	Braided	3,035	nm[1]	nm[1]	nm[1]

Notes:
1 nm = Measurements not recorded during second survey.

Six separate habitat variables were calculated from the habitat survey data at each of the tributary delta areas (Table 5.1-9). The resulting habitat variables were used to calculate life stage specific suitability indices from the suitability index curves presented in Hickman and Raleigh (1982). The resulting suitability for these variables were then used in the Hickman and Raleigh (1982) riverine model to generate a separate habitat suitability index (HSI) for the adult, juvenile and fry life stages of generic resident "salmonids" within each of the tributary delta areas surveyed (Table 5.1-10).

Table 5.1-9. List of tributaries, values of habitat variables calculated from the survey data, and their respective suitability indices as derived from Hickman and Raleigh (1982), 2007 Boundary Reservoir tributary delta studies.

Tributary	V_4		V_6			V_8		V_{10}		V_{15}		V_{16}	
				Suitability									
	Value	Suitability	Value	Adult	Juv.	Value	Suitability	Value	Suitability	Value	Suitability	Value	Suitability
Slate Cr.	0.83	0.90	78.44	1.00	1.00	50.18	1.00	17.37	0.77	A	1.00	4.62	1.00
Flume Cr.	0.60	0.66	49.77	1.00	1.00	20.36	1.00	15.38	0.70	A	1.00	34.29	0.61
Sullivan Cr. (8 Sept)	0.79	0.85	10.85	0.70	0.92	0.2	1.00	2.23	0.34	A	1.00	26.53	0.78
Linton Cr.	0.42	0.33	3.92	0.39	0.53	0.00	0.00	0.00	0.00	C	0.30	9.68	1.00
Pocahontas Cr.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00
Sweet Cr.	0.29	0.10	5.20	0.46	0.61	4.76	0.48	9.01	0.52	C	0.60	7.02	1.00
Sand Cr.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00
Sullivan Cr. (Nov 9)	0.94	0.97	16.62	0.89	1.00	9.55	0.96	7.41	0.47	A	1.00	15.44	0.97

Notes:
V_4 – average thalweg depth.
V_6 – percentage cover during late season low water growing period.
V_8 – percentage of substrate in the 4 to 16-inch size class (winter and escape cover).
V_{10} – percentage pool habitat during late season low water growing period.
V_{15} – pool Class Rating.
V_{16} – percentage of fine sediment (substrates <1/8-inch) in riffle and run areas during low summer flow.

Table 5.1-10. List of tributaries, their calculated Habitat Suitability Indices, and their relative ranking for generic "salmonid" adult, juvenile, and fry life stages in the tributary delta areas of Boundary Reservoir derived from the Hickman and Raleigh (1982) riverine model.

Tributary Name	Adult "Salmonid"		Juvenile "Salmonid"		"Salmonid" Fry	
	HSI	Rank	HSI	Rank	HSI	Rank
Slate Cr.	0.924	1	0.923	1	0.878	1
Flume Cr.	0.820	3	0.900	2	0.739	2
Sullivan Cr. (8 Sept)	0.703	4	0.753	4	0.548	5
Linton Cr.	0.300	5	0.300	6	0.000	6
Pocahontas Cr.	0.000	---	0.000	---	0.000	---
Sweet Cr.	0.236	6	0.577	5	0.600	4
Sand Cr.	0.000	---	0.000	---	0.000	---
Sullivan Cr. (Nov 9)	0.840	2	0.823	3	0.673	3

Note:
HSI – Habitat Suitability Index

The use of the Hickman and Raleigh (1982) riverine model for cutthroat trout suggests that the Slate Creek delta had the highest HSI scores for each of the different life stages of trout (Table 5.1-10). Flume Creek and Sullivan Creek deltas had the next highest HSI values for the three different life stages of trout. The Pocahontas and Sand Creek deltas scored as totally unsuitable by virtue of their dry channel beds at the time of our late summer surveys.

After conducting the habitat surveys in each of the tributary deltas and having walked and inspected the stream channels at each site, the overall impression of the lead field biologist is that the riverine habitat model output is accurate in its ranking of the late summer habitat available to resident fish during periods of low reservoir pool. For example, of the seven deltas evaluated, Slate Creek certainly appeared to provide the best combination of stream habitat (adequate stream flow and stream depth, nice pool habitats, instream cover, large woody debris) and good water quality suitable for all three stages of resident trout — the HSI values reflect these observations. The Flume Creek delta was judged as a close second in terms of capacity to support limited populations of resident trout during late summer periods of low reservoir pool conditions — again, the calculated HSI values support this impression. The dry channels (and lack of fish habitat) in the Pocahontas and Sand Creek deltas obviously result in the lowest ranking for these two streams. Based on the agreement between the calculated HSI values and the observations and impressions of the lead field biologist, the Hickman and Raleigh (1982) riverine habitat model as applied to the Boundary Reservoir tributary deltas provides a realistic representation of available late summer rearing habitat for resident trout during periods of low reservoir pool. These HSI values are therefore expected to provide a sound basis comparing the effects of operations scenarios on habitat available to resident fish.

The Hickman and Raleigh (1982) lacustrine model for salmonid habitat in the shallow water areas of the deltas during periods of inundation at times of high reservoir pool suggest poor habitat quality (Table 5.1-11). The model output is completely driven by the poor suitability suggested by the maximum daily water temperature variable (V_1). During the hottest period of the year, there was consistency in water temperatures measured in the mainstem at Study 7 buoys and the mainstem thermographs at the delta mouths. Thus, the mean maximum daily water temperature measured at the Study 7 monitoring buoys was used for calculating suitability, and the value of 24.6°C exceeds the suitability provided for in the Hickman and Raleigh (1982) "general" cutthroat trout model, suggesting no suitable habitat, outside of area of thermal refugia created by tributary inflow of cooler water, at reservoir temperatures in excess of 22.0°C.

Table 5.1-11. Boundary Reservoir water quality variables, their associated suitability, and final reservoir Habitat Suitability Index using Hickman and Raleigh's (1982) lacustrine model.

	V_1 [1]		V_3 [2]		V_{13} [3]		
	Value	**Suitability**	**Value**	**Suitability**	**Value**	**Suitability**	**HSI**
Reservoir (using general V_1 suitability)	24.60	0.00	8.54	0.98	8.79	0.65	0.00
Reservoir (using Lahontan Basin V_1 suitability)	24.60	0.10	8.54	0.98	8.79	0.65	0.10

Notes:
The first HSI is for the reservoir using the general temperature variable; the second HSI is based upon calculations using the higher water temperature criteria in the Lahontan Basin thermal suitability.
1 V_1 - average maximum water temperature (°C) during the warmest part of the year (14-day period: July 17-30, 2007).
2 V_3 - average minimum dissolved oxygen (mg/L) during the late growing season (30-day period: August 17 – September 15, 2007).
3 V_{13} - annual maximum or minimum pH (88-day period of record: June 22 – September 17, 2007).

Because of the influence of the potential presence of thermal plumes at the tributary mouths, the suitability for a reduced portion of the lacustrine area may be greater than 0.00. The presence of thermal plumes at Slate, Sullivan, and Sweet creeks was observed during August sampling (Section 5.1.4.2.). Additional study of the thermal plumes will be conducted in 2008 to provide estimates of their areas and allow the incorporation of the influence of the cooler water in the delta mixing zones between the tributaries and the reservoir in the calculation of the HSI and HRQ values.

5.1.6. Future Tributary Sediment Supply Field Data Collection

Section 4.1.6 provides an overview of how the tributary deltas may either aggrade or degrade as a result of the interaction of upstream sediment supply, local hydraulic conditions created by Project operations, and the influence of flows in both the tributaries and the mainstem Pend Oreille. Section 4.1.6 also describes the approaches that will be used to estimate the volume of bed material load delivered to the deltas. These approaches require substrate size distribution, tributary channel geometry, and delta morphology (e.g., topset and foreset slopes, topset length). The field data collected to represent these parameters are summarized by delta for each of the seven deltas selected for tributary delta habitat modeling.

The field data were collected during low reservoir pool elevations in September 2007. The efforts included the following tasks:

- Sketching each tributary delta area
- Recording low pool conditions through photographs
- Mapping depositional features using a GPS unit
- Characterizing the particle size distribution of depositional materials
- Surveying the thalweg of the channel across the delta
- Surveying tributary bed load cross-section geometry

A summary of these results is presented in the following sections for the tributaries evaluated as candidates for more detailed study. Figures of these tributary deltas showing mapped depositional features, sediment sampling locations, thalweg location, and bed load cross sections are provided in Appendix 1. An example of the Sullivan Creek Delta is presented in Figure 5.1-5.

Seventy-five sediment samples were collected across the seven tributary delta areas. The sediment samples were collected to quantify the particle size distribution at various places of interest to describe the dominant materials both within the tributary delta stream beds and the depositional features. Though samples were all designated "BM" referring to bed material (except for those at the bed load cross sections at Slate Creek, which were designated BL), these samples represent both bed material and materials deposited on various fan surfaces. In some cases, both surface and subsurface gradations of the bed material were sampled. These selected subsurface bed material samples were collected when there was a distinct armor layer and conditions allowed retrieval of a subsurface sample.

A description of the location and type of material represented by the samples were noted in the field and are presented in tables by tributary delta. The sample locations are shown on the maps of the tributary deltas presented in Appendix 1. The size distribution can be characterized using particle size diameter for which a standard percentage of the sample is finer (as measured by weight). Percent finer fractions selected for this study include d_{85}, d_{50}, and d_{15}. Plots of the sediment size distribution for each of these samples are presented in Appendix 3. The following subsections provide a summary of important characteristics from the detailed reconnaissance and review of aerial photographs and mapping.

The hydraulic calculations of bed material load transport in the tributaries will be performed in 2008 using the tributary flow rates presented in a separate draft report prepared by R2 Resource Consultants (2008). In September 2007, the tributary thalweg was surveyed from the intersection of the topset and foreset to a point above any backwater influence from Boundary Reservoir. Flume Creek was an exception in that the upper limit of the reservoir fluctuation zone was the base of a cascading waterfall. Upstream reaches of the channel were inaccessible, so the thalweg survey extended upstream only to the base of the cascading waterfall. Tributary channel geometry was surveyed at two cross sections located near the upper end of the reservoir fluctuation zone or upstream in the tributary on each of the seven representative tributaries. Again, Flume Creek was an exception in that only one cross section was surveyed, and the location was within the reservoir fluctuation zone due to the cascading waterfall. Plots of the cross-section geometry are provided in Appendix 4; the locations of the sections are presented on

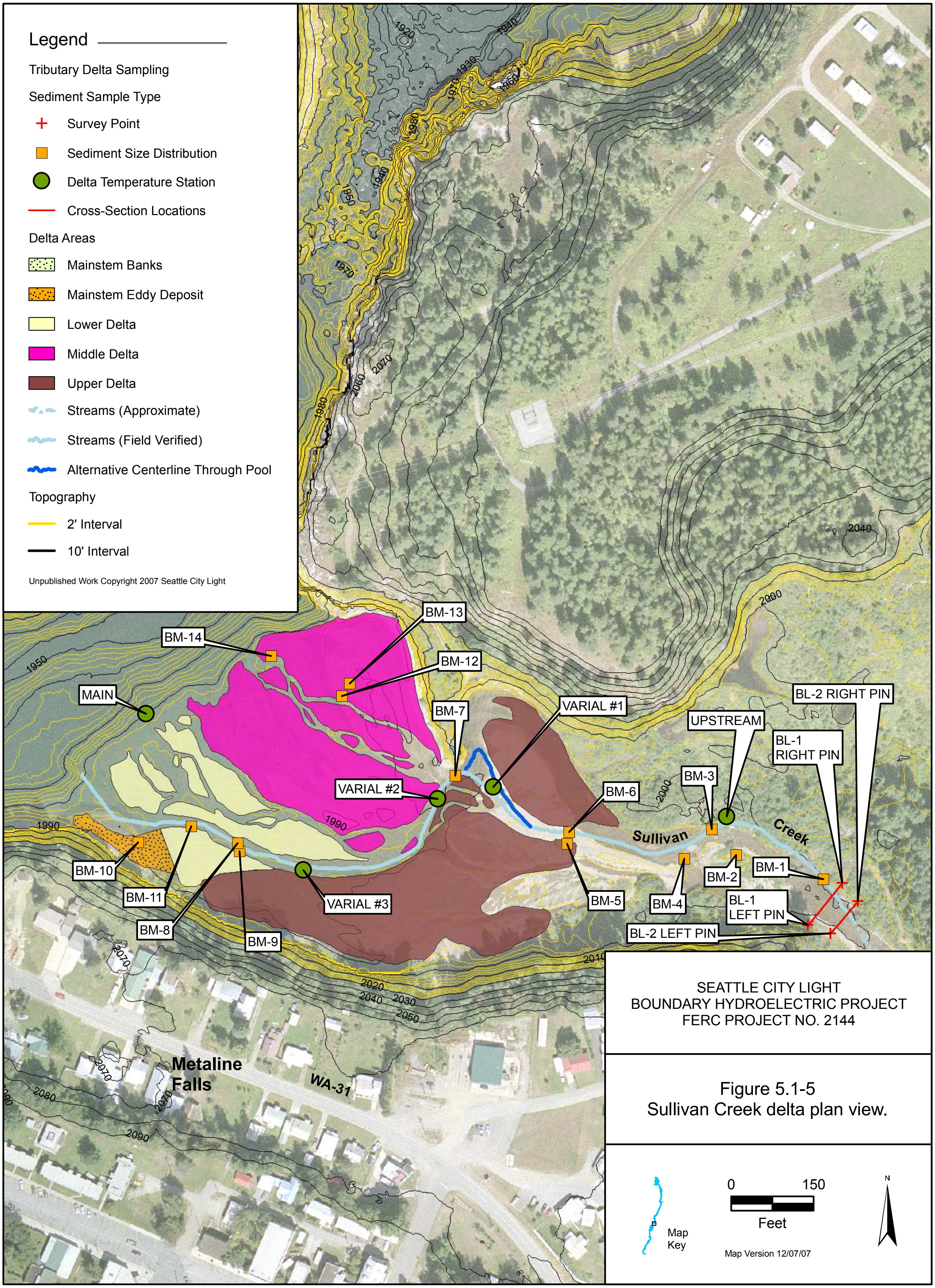

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Figure 5.1-5
Sullivan Creek delta plan view.

the figures in Appendix 1. Water surface slopes at the bed load cross-section survey locations were measured and a Manning roughness coefficient visually estimated. For calculations of tributary bed material transport, the measurements of water surface slope made in September 2007 will be applied to all flows under the assumed normal depth conditions. The visual estimates of flow resistance as quantified through the Manning roughness coefficient will also be applied to all flows.

5.1.6.1. Slate Creek

Slate Creek is one of two tributaries located within the canyon reach of the study area where development of a significant delta was observed. A view of the delta as taken from the south side of the Slate Creek embayment on September 7, 2007, is shown in Figure 5.1-6.

Figure 5.1-6. Slate Creek delta as seen on September 7, 2007.

Note: The shown reservoir water surface elevation is approximately 1,974 feet NAVD 88 (1,970 feet NGVD 29).

As seen in Figure 5.1-6, the delta is confined on the sides by canyon walls. As evidenced in Figure 5.1-7, the delta is still filling the canyon with sediment, indicating that the delta is not currently in a state of dynamic equilibrium. A comparison of historic (pre-dam) and current aerial photography and bathymetry reveals that significant delta aggradation has occurred. The current delta, although approximately 500 feet in length, is set so far back from the mainstem that there is no regular interaction with mainstem flows. If the delta was to eventually build to reach the mainstem, velocities and shear stresses would initially be too low to mobilize significant amounts of deposited sediment because the reservoir depth is approximately 70 feet. Three delta surfaces were mapped, but there were several additional small surfaces. These surfaces result from the interaction of tributary inflows (both water and sediment) and reservoir levels. Depending on reservoir levels, sediments may be deposited at higher levels, and then eroded by headcutting when the reservoir water surface elevation falls. The average topset slope of the surface calculated from the bathymetry is 2.3 percent. Appendix 1, Figure A.1-2 shows the various delta surfaces mapped, the bathymetry, and the location of bed material sampling locations.

Figure 5.1-7. Slate Creek delta as seen on September 7, 2007.

Note: The elevation of the water surface shown in the embayment is approximately 1,974 feet NAVD 88 (1,970 feet NGVD 29).

Figures 5.1-6 and 5.1-7 also illustrate the general progression of the fining of the depositional material toward the mouth of the tributary canyon. Eleven sediment size distribution samples were collected; nine samples were taken in the bed of the tributary channel and two from depositional features on the delta. A summary of the particle size distributions for each sample is presented in Table 5.1-12. In the upper reaches of the channel the bed material is dominated by boulders and cobbles (BL-1.1, 1.2, 2.1, and BM-3 to BM-6). The BL-1.2 sample was collected upstream of a substantial debris jam that likely trapped the gravel-sized material represented by this sample. The bed material grades to gravel-sized material in the downstream direction (BM-7 and BM-8). Deposition at the downstream end of the delta contained primarily coarse sands and fine gravel (BM-9 and BM-10).

Table 5.1-12. Summary particle size statistics of tributary delta deposits at Slate Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BL-1.1	Wolman Count	Downstream bedload section	120	70	30
BL-1.2	Volumetric	Downstream bedload section	60	36	7.9
BL-2.1	Wolman Count	Upstream bedload section	220	120	52
BM-3	Wolman Count	Station 0+00 – 1+00	950	220	110
BM-4	Wolman Count	Station 1+00 – 2+00	700	320	150
BM-5	Wolman Count	Station 2+00 – 3+00	590	280	110
BM-6	Wolman Count	Station 3+00 – 3+50	190	100	31
BM-7	Volumetric	Station 3+50 – 4+00	71	14	2.2
BM-8	Volumetric	Station 4+00 – 4+55	78	31	4.3
BM-9	Volumetric	Station 3+25, subsurface, 10-ft right of channel	21	7.5	0.86
BM-10	Volumetric	Station 4+25, subsurface, 10-ft right of channel	10	2.9	1.0

Table 5.1-13 summarizes the measurements of surveyed water surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections.

Table 5.1-13. Slate Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Slate BL-1	0.0051	0.045
Slate BL-2	0.036	0.045

5.1.6.2. Flume Creek

Flume Creek is the other tributary located within the canyon reach of the study area where development of a significant delta was observed. A view of the downstream portion of the delta as taken from the mainstem on September 7, 2007, is shown in Figure 5.1-8.

Figure 5.1-8. Flume Creek delta as seen on September 7, 2007.

Note: The elevation of the shown reservoir water surface is approximately 1,973 feet NAVD 88 (1,969 feet NGVD 29). The round, orange buoy seen in the creek channel has a diameter of approximately 1 foot.

The mainstem currents in Deadman's Eddy during high flow conditions may influence the morphology of the Flume Creek delta. At high flows, the eddy currents may remove sediment from the delta, thereby limiting its riverward growth. A comparison of historic (pre-dam) and current aerial photography and bathymetry reveals that significant delta aggradation has occurred, so it does not appear that the delta has reached conditions of dynamic equilibrium. The length of the drawdown zone on the delta is approximately 570 feet and the average topset slope is 2.5 percent. Flume Creek flows down a cascading falls and the base of the falls appears subject to backwater effects from high reservoir pool elevations. As with Slate Creek, three major delta surfaces were mapped, but other smaller surfaces were observed. Appendix 1, Figure A.1-3 illustrates these surfaces as well as the locations of the sediment samples.

Nine sediment-size distribution samples were collected; five samples were taken in the bed of the tributary channel and four from below the surface of depositional features. A summary of the particle size distributions for each sample is presented in Table 5.1-14. In the upper reaches of the channel the bed material is dominated by boulders and cobbles (BM-1 through BM-3). The bed material grades from these boulders and cobbles to gravel sized material in the downstream direction. Several subsurface samples were collected due to observed layers of sand, fines, and organic material (BM-6 through BM-9). The samples revealed gravel material underneath these layers, indicating that the finer material is likely deposited by eddy current during high flow events in the mainstem. The depth of deposition along the channel in the middle of the delta appears to only be several feet. This assessment was based on an exposed stump and a rock outcrop in the cut channel banks.

Table 5.1-14. Summary particle size statistics of tributary delta deposits at Flume Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Station 0+00 – 0+70	900	300	100
BM-2	Wolman Count	Station 0+70 – 1+70	300	120	36
BM-3	Wolman Count	Station 1+70 – 2+85	200	80	22
BM-4	Wolman Count	Station 2+85 – 4+00	90	40	17
BM-5	Volumetric	Station 4+00 – 4+50	54	21	2.0
BM-6	Volumetric	Station 3+10, subsurface, 10-ft right of channel	49	14	1.9
BM-7	Volumetric	Station 3+10, subsurface, 20-ft right of channel	13	2.7	0.50
BM-8	Volumetric	Station 4+40, subsurface, 10-ft left of channel	8.9	1.3	0.42
BM-9	Volumetric	Station 4+40, subsurface, 45-ft left of channel	58	7.9	0.57

Table 5.1-15 summarizes the measurements of surveyed water surface slope and the visual determination of the Manning roughness coefficient at the bed material load cross section.

Table 5.1-15. Flume Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Flume BL-1	0.014	0.035

5.1.6.3. Sullivan Creek

The delta observed at Sullivan Creek was the largest of any tributary within the study area (delta length of approximately 1,500 feet). Figure 5.1-9 illustrates the delta as observed on September 10, 2007, from the Highway 31 bridge. As shown in this figure, the Sullivan Creek delta has a complex system of distributary channels. Other deltas had a single channel, or possibly a single split; the Sullivan delta had a main channel with several overflow channels. As a result, many depositional features were mapped across the complex delta (see Appendix 1, Figure A.1-4). One of these features, the delta topset, has a slope of 1.4 percent as calculated using the bathymetric data.

The riverward extent of the Sullivan Creek delta is constrained by flows in the mainstem and the sides of the delta are confined within terraces. A comparison of historic (pre-dam) and current aerial photography and bathymetry data shows that the extents of the delta appear relatively consistent over time, indicating a lack of significant aggradation or degradation. As summarized in Table 5.1-16, 14 sediment samples were collected on the delta. Upstream of the delta, channel bed samples are dominated by cobbles (BM-1 and BM-2); on the delta, the stream bed was gravel – starting upstream as coarse gravel and grading to medium gravel toward the downstream end. Gravel bar samples taken at the upper end of the delta (BM-4 and BM-5) have similar gradation to bar samples at the downstream end of the delta (BM-11 and BM-12); in fact, the downstream samples were a bit coarser. The consistency in the depositional materials indicates that this delta is in equilibrium with existing hydrology and Project operations. Further, the gradation of the upstream depositional bars and the channel bed within the delta were similar. Two locations were sampled to represent the layer of material deposited by mainstem eddy flows in the delta embayment (due to constrictions on the mainstem through Metaline Falls). These samples were dominated by fine sand and silt (BM-9 and BM-10).

Figure 5.1-9. Sullivan Creek delta as seen from the Highway 31 bridge on September 10, 2007.

Note: The elevation of the reservoir water surface shown in this figure is approximately 1,981 feet NAVD 88 (1,977 feet NGVD 29).

Table 5.1-16. Summary particle size statistics of tributary delta deposits at Sullivan Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Station 0+00 – 1+75	260	130	60
BM-2	Wolman Count	Station 2+00 – 3+00, bar sample	210	120	66
BM-3	Wolman Count	Station 1+75 – 5+00	92	50	20
BM-4	Volumetric	Near Station 3+75	19	2.9	0.72
BM-5	Volumetric	Near Station 5+90, left bank	17	2.6	0.40
BM-6	Wolman Count	Station 5+00 – 7+00	110	61	24
BM-7	Wolman Count	Station 7+00 – 10+50	94	50	19
BM-8	Wolman Count	Station 10+00 – 17+00	70	31	12
BM-9	Volumetric	Station 13+50, in channel, left edge	0.17	0.067	0.014
BM-10	Volumetric	Finer material on high bench	0.14	0.057	0.011
BM-11	Volumetric	Station 14+50, bar sample, left side of channel	23	8.6	1.7
BM-12	Volumetric	Bar sample, right side of delta, 200-ft from POR	22	7.5	0.98
BM-13	Volumetric	200-ft from topset-foreset intersection	0.28	0.17	0.075
BM-14	Volumetric	50-ft from topset-foreset intersection	26	5.3	0.43

Table 5.1-17 summarizes the measurements of surveyed water surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections.

Table 5.1-17. Sullivan Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Sullivan BL-1	0.016	0.035
Sullivan BL-2	0.016	0.035

5.1.6.4. Linton Creek

The delta at Linton Creek is one of the smaller study deltas (see Appendix 1, Figure A.1-5). The drawdown zone length of the delta is approximately 650 feet, with a 2.9 percent slope calculated for the topset. The flows in the mainstem limit the riverward growth of the delta (see Figure 5.1-10), the sides are confined within a terrace of the Pend Oreille River. A review of historic aerial photography shows that a delta existed prior to construction of Boundary Dam and it appears that significant reworking of delta sediment has since occurred. The bed material load, including considerable amounts of medium and finer gravels, transported by Linton Creek appears finer than the other tributaries with significant deltas (although the bed material in the Sand Creek delta is similarly sized). The finer size fractions that make it to the delta are most likely mobilized by the mainstem Pend Oreille River, resulting in the reworking of the delta observed in the historic aerial photography. Due to low sediment supply delivered to the delta, it is unlikely that the Linton Creek delta is in equilibrium with existing hydrologic conditions.

Figure 5.1-10. Linton Creek delta as seen on September 8, 2007.

Note: The shown water surface elevation in the reservoir is approximately 1,981 feet NAVD 88 (1,977 feet NGVD 29). Note the car parked on a bar in the river for scale.

During the reconnaissance, the bed of the channel on the delta was gravel the entire way, except for the finer material near the mainstem. The last 50 feet of the delta in the mainstem appeared to have been built up since the recent drawdown events in August and September 2007 drawdown event. This material appeared to be deposition from the mainstem channel, so it is likely that these size fractions can be washed away by mainstem currents during higher flows. As shown in Table 5.1-18, 10 sediment samples were collected on the delta. Sample BM-5 represents the finer size fractions at the mouth of the delta that were eroded from the delta during drawdown, likely covering a layer of coarser gravel.

Unlike other deltas, a sample was collected that represented fine, over-consolidated, lacustrine materials (BM-9). The gradation is very similar to BM-7, which is believed to be silt from the mainstem deposited on the delta surface. BM-9 had roots and other organic materials in it.

Table 5.1-18. Summary particle size statistics of tributary delta deposits at Linton Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Both bedload sections	41	20	11
BM-2	Volumetric	Both bedload sections	27	6.2	0.40
BM-3	Wolman Count	Station 0+00 – 2+10	47	22	11
BM-4	Wolman Count	Station 2+10 – 5+00	50	22	11
BM-5	Volumetric	Station 5+00 – 6+70	21	8.3	0.99
BM-6	Volumetric	Station 2+75, bar sample, 25-ft right of channel	5.2	0.66	0.28
BM-7	Volumetric	Station 3+70, bar surface, 25-ft right of channel	0.098	0.043	0.0079
BM-8	Volumetric	Station 3+70, bar subsurface, 25-ft right of channel	0.59	0.14	0.023
BM-9	Volumetric	Station 4+50, clay/silt lens at toe of right bank	0.091	0.039	0.0025
BM-10	Volumetric	Station 4+30, bar subsurface, 6-ft right of channel	8.2	0.92	0.18

Table 5.1-19 summarizes the measurements of surveyed water surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections.

Table 5.1-19. Linton Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Linton BL-1	0.021	0.030
Linton BL-2	0.021	0.030

5.1.6.5. Pocahontas Creek

Like Linton Creek, the delta at Pocahontas Creek was one of the smaller study deltas. A large deposit on the downstream (in relation to the flow in the mainstem) side of the delta is likely the result of sediment mobilized during an infrequent flood event in Pocahontas Creek. Figures 5.1-11 and 5.1-12 illustrate the delta as viewed from the large deposit. The mobilization of this material is not associated with a typical flow conditions (note the coarser sizes in the lower left corner of the Figure 5.1-11). The delta extends to the edge of the river, or slightly beyond if the flood deposit just mentioned is considered. The length of the drawdown zone on the delta is approximately 260 feet, and the topset slope was calculated as 3.1 percent. The lateral extent of the delta is confined by the terrace along the mainstem. Three primary depositional surfaces were mapped as shown on Figure A.1-6.

Figure 5.1-11. Pocahontas Creek delta as seen on September 9, 2007.

Note: The water surface elevation in the reservoir at the tributary mouth was approximately 1,981 feet NAVD 88 (1,977 feet NGVD 29).

Figure 5.1-12. Upriver view of Pocahontas Creek downstream delta deposits as seen from large depositional feature.

Note: The shown water surface elevation in the reservoir is approximately 1,981 feet NAVD 88 (1,977 feet NGVD 29).

A significant delta with the large depositional feature is apparent on aerial photographs taken prior to construction of Boundary Dam. Although the stream appears to be a relatively moderate producer of sediment, it is likely that the mainstem current mobilizes depositional material. Given the consistent morphology of the delta, it is likely that the delta is in equilibrium with hydrologic conditions and Project operations.

The data in Table 5.1-20 shows that the bed of the channel was dominated by cobbles in the upper reaches (BM-1 and BM-2), then grades to gravels on the topset and foreset surfaces. The riverbed material (BM-7) at the toe of the foreset is much coarser than the material on the delta.

Pocahontas Creek was dry during the September 2007 reconnaissance. An adjacent landowner indicated the creek was flowing further upstream, but the flow disappears when it encounters the coarse glacial material in the lower portions of the creek.

Table 5.1-20. Summary particle size statistics of tributary delta deposits at Pocahontas Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Station 0+00 – 0+75	290	120	37
BM-2	Volumetric	Both bedload sections	25	4.2	0.83
BM-3	Wolman Count	Station 0+75 – 1+50	130	60	13
BM-4	Wolman Count	Station 1+50 – 2+25	81	32	11
BM-5	Volumetric	Station 2+25 – 2+53, foreset	17	6.2	1.2
BM-6	Wolman Count	Station 2+53 – 2+75, mainstem bed	300	160	70
BM-7	Volumetric	Station 1+75, bar subsurface, 16-ft right of channel	7.8	0.57	0.21
BM-8	Volumetric	Finer surface material in upper delta	10.0	3.1	0.69
BM-9	Volumetric	Coarser surface material in upper delta	33	17	6.50

Table 5.1-21 summarizes the measurements of surveyed thalweg surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections. The Pocahontas Creek channel was dry during the September 2007 survey, so the thalweg slope was measured instead of the water surface slope.

Table 5.1-21. Pocahontas Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Pocahontas BL-1	0.054[1]	0.040
Pocahontas BL-2	0.054[1]	0.040

Note:

1 Pocahontas Creek was dry at the time of survey, so the thalweg slope was measured instead of the water surface slope.

5.1.6.6. Sweet Creek

The tributary delta at Sweet Creek is of significant size and is well developed (see Figure 5.1-13). The lateral extents are confined by terraces and the riverward extent is limited by mainstem flows. Sweet Creek enters the west side of the Pend Oreille River in a narrow section, with bedrock observed in the opposite (east) bank. A comparison of current delta extents to historic extents as shown on aerial photography reveals consistent length and width. Thus, it is likely that the delta has encroached as far as possible under current conditions. The length of the drawdown zone on this delta is approximately 570 feet. The average topset slope is approximately 1.9 percent, but the slope of the upper topset is calculated as approximately 3.4 percent whereas the lower topset slope is calculated as approximately 0.7 percent.

Figure 5.1-13. Sweet Creek delta as seen on September 11, 2007.

Note: The elevation of the shown reservoir water surface is approximately 1,985 feet NAVD 88 (1,981 feet NGVD 29). Note the orange, 5-gallon bucket at the right of the figure for scale.

The Sweet Creek and Lunch Creek watersheds appear to produce moderate to high sediment loads. A log jam upstream of the delta with significant accumulation of sediment stored behind it had recently broken, releasing a pulse of sediment. Some of the gravels deposited downstream on the delta may have been a result of this event. Summary statistics of the sediment size distribution at the sample locations are presented in Table 5.1-22. The bed of the channel on the delta was predominantly gravel- and cobble-sized material. Excepting BM-7 (terrace material) the depositional bars tended to grade from cobbles at the upstream end to fine gravel at the mouth. The foreset slope had gravel on the surface (BM-12), but was sandy beneath (BM-13) the surface pavement layer.

Table 5.1-22. Summary particle size statistics of tributary delta deposits at Sweet Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Station 0+00 – 0+50	120	62	20
BM-2	Wolman Count	Station 0+00 – 0+60	250	110	51
BM-3	Wolman Count	Station 0+60 – 1+40	110	60	18
BM-4	Volumetric	Station 1+50, bar sample, right side of channel	110	35	3.3
BM-5	Wolman Count	Station 1+40 – 2+20	110	60	25
BM-6	Wolman Count	Station 2+20 – 4+00	81	34	12
BM-7	Volumetric	Station 3+50, bar sample, 60-ft left of channel	0.15	0.063	0.0057
BM-8	Wolman Count	Station 4+00 – 7+25	70	30	12
BM-9	Volumetric	Station 5+50, bar sample, 20-ft right of channel	22	4.6	0.60
BM-10	Volumetric	Station 7+25 – 8+56	62	27	3.6
BM-11	Volumetric	Station 7+25, bar sample, 20-ft right of channel	13	3.3	0.66
BM-12	Wolman Count	Gravel-cobble material across foreset	74	34	18
BM-13	Volumetric	Sand-gravel material across foreset	11	2.2	0.72

At the upper end of the delta, the elevation of the bar deposits appears to be greater than the maximum reservoir pool elevation. This indicates that the bar materials are laid down above the influence of the reservoir, making the upper area more of an alluvial fan. An example of these potential alluvial depositional features is presented in Figure 5.1-14. Consequently, Sweet Creek has one of the most complex delta areas, probably only matched by Sullivan Creek. The delta extents, depositional features, and sediment sampling locations are presented in Appendix 1, Figure A.1-7.

Figure 5.1-14. Downstream view of Sweet Creek in the upper delta area; the elevation of the depositional bar on the right bank may indicate this area is more of an alluvial fan than a delta.

Table 5.1-23 summarizes the measurements of surveyed water surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections.

Table 5.1-23. Sweet Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Sweet BL-1	0.017	0.045
Sweet BL-2	0.017	0.045

5.1.6.7. Sand Creek

The tributary delta at Sand Creek was the most upstream of study deltas (Figure 5.1-15). The watershed appears to produce a relatively moderate supply of sediment. A large deposit extends into the mainstem channel on the downstream side of the delta (Figure 5.1-16). The deposit is assumed to be representative of sediment transported in Sand Creek during infrequent, large flood events, not typical flows. This is similar in nature to the large depositional feature noted at Pocahontas Creek.

The lateral extent of the delta is confined by terraces and the riverward extent is limited by mainstem flows. The leading edge of the delta aligns well with the mainstem bank (see Appendix 1, Figure A.1-8). Given the similarity of existing delta morphology including the large depositional feature with pre-dam morphology, the sediment supplied to the delta appears to be in equilibrium with the sediment removed by the mainstem. The drawdown zone length of the delta is approximately 800 feet. The average calculated topset slope is approximately 1.8 percent.

Figure 5.1-15. Sand Creek delta as seen on September 9, 2007.

Note: The elevation of the shown reservoir water surface is approximately 1,982 feet NAVD 88 (1,978 feet NGVD 29). Note the figure with a stadia rod on the right side of the figure for scale.

Figure 5.1-16. Downriver view of large delta deposit likely associated with large flood event on Sand Creek.

The channel bed, which was dry during the reconnaissance, was dominated by coarse gravels, although the gradation became finer in the downstream direction (Table 5.1-24). The bar samples tended to be finer than the channel bed as the bars comprised mainly fine gravels. One exception was the medium to coarse sands in BM-10. It is likely that these finer size fractions are not represented farther down the delta because they can be washed away by the current in the mainstem.

Table 5.1-24. Summary particle size statistics of tributary delta deposits at Sand Creek.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Wolman Count	Station 0+00 – 0+50	89	34	14
BM-2	Volumetric	Station 0+45, bar sample, left side of channel	23	5.4	0.77
BM-3	Wolman Count	Station 0+50 – 1+50	65	30	12
BM-4	Volumetric	Station 1+10, bar sample, left side of channel	29	11	0.77
BM-5	Wolman Count	Station 1+50 – 3+00	43	21	12
BM-6	Volumetric	Station 3+00 – 4+00	27.0	10	1.2
BM-7	Volumetric	Station 4+00 – 5+75	0.31	0.13	0.036
BM-8	Volumetric	Station 4+00 – 5+75, subsurface	21	6.5	0.64
BM-9	Volumetric	Station 5+75 – 7+00	20	3.3	0.23
BM-10	Volumetric	Station 3+50, bar sample, 30-ft right of channel	0.96	0.35	0.19

Table 5.1-25 summarizes the measurements of surveyed thalweg surface slope and the visual determination of the Manning roughness coefficient at the two bed material load cross sections.

Table 5.1-25. Sand Creek bed material load calculation cross-section parameters.

Bed Load Cross Section	Measured Water Surface Slope (ft/ft)	Manning Roughness Coefficient
Sand BL-1	0.016[1]	0.040
Sand BL-2	0.016[1]	0.040

Notes:

1 Sand Creek was dry at the time of survey, so the thalweg slope was measured instead of the water surface slope.

5.2. Tributary Delta Sediment Processes

The Tributary Delta Sediment Processes study component will evaluate the effects of operations scenarios on the delta morphology of representative tributaries within the Pend Oreille River from Box Canyon Dam downstream to Boundary Dam. The study component will support the habitat modeling by determining if the tributary deltas will change over the 50-year term of the license. If a delta is determined to evolve under future conditions, the resulting changes will be estimated in this study component. The net change in the volume of sediment deposited on the tributary deltas will be estimated and potential zones of erosion and accumulation of sediment within the deltas will be delineated. It will also be determined if the delta evolution is sensitive to operations scenarios, which may then result in developing different future delta conditions for each operations scenario.

This effort uses results of work performed in the other two components of Study 8 to evaluate the future conditions of the tributary deltas. Other than refinement of the methods, work on this portion of Study 8 will be performed in 2008. Therefore, results are not provided in this report. Key information supplied from the delta habitat modeling effort will be the detailed characterization of the deltas, sediment sampling results, bed load calculation cross sections, and the evaluation of mainstem hydraulic conditions in from of the deltas. The primary information from the mainstem modeling effort that will be applied to this effort will be various components of the determination of sediment supply. This includes the estimation of the sediment supply to the deltas and the determination of the volume of deposition that has occurred at the deltas.

5.3. Mainstem Sediment Transport

The Mainstem Sediment Transport study effort will evaluate the effects of existing Project operations on channel morphology within the Pend Oreille River from Box Canyon Dam downstream to approximately Red Bird Creek. The evaluation will be conducted using a sediment routing model. The primary work conducted through early November 2007 involved the collection of the sediment samples to represent the bed material in the model and selection of the actual sediment routing model to be applied. The results of these two efforts are presented in this section. The development of the sediment routing model, its calibration, and its application will be performed in 2008.

5.3.1. Results of Mainstem Bed Material Sampling

Twenty-two bed material samples were collected along the mainstem of the Pend Oreille River between Box Canyon Dam and Metaline Falls. Figure 5.3-1 illustrates these sampling locations. More detailed figures of the sampling locations are presented in Appendix 5.

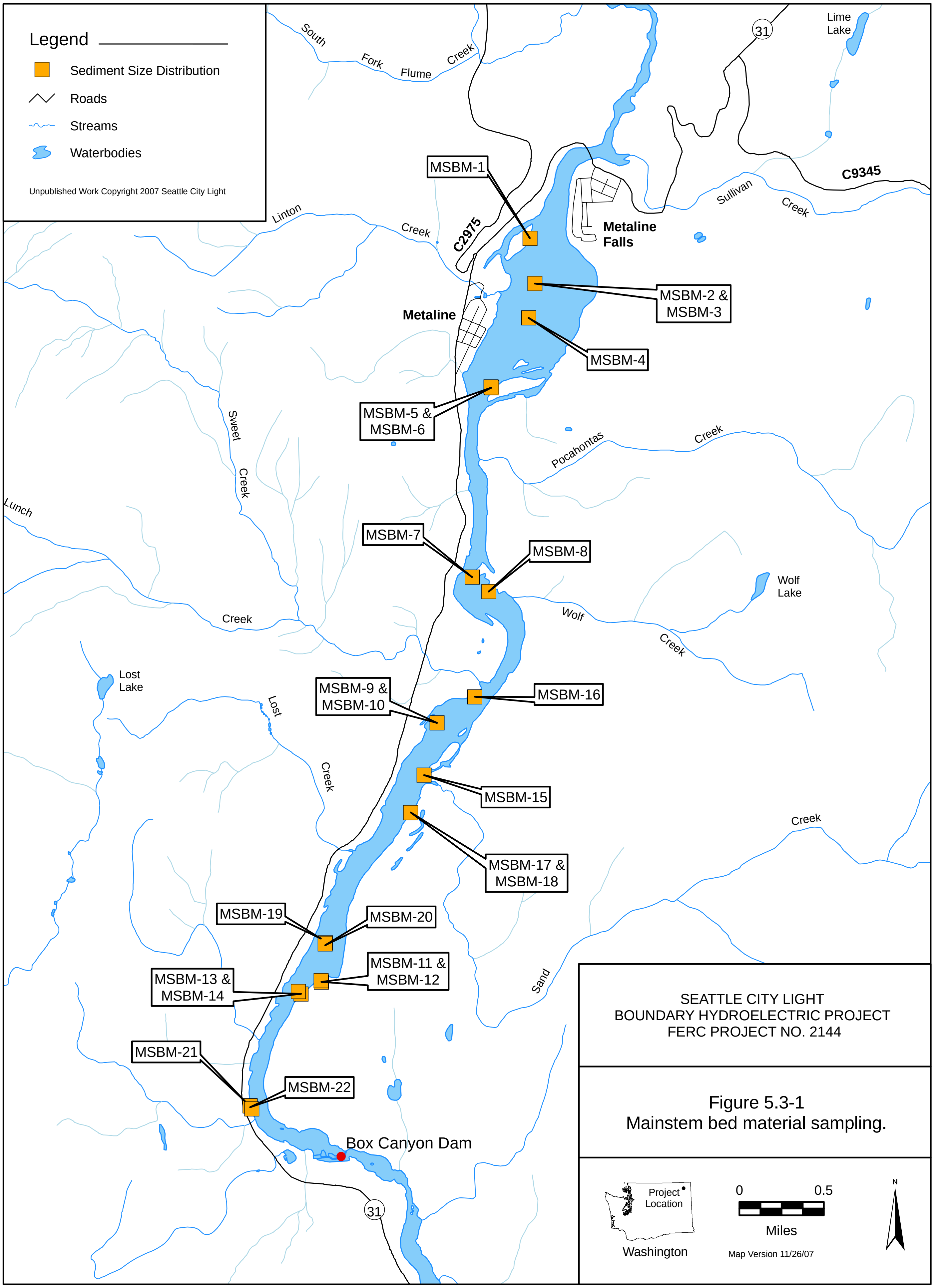

Figure 5.3-1
Mainstem bed material sampling.

Due to the significant depth of Boundary Reservoir downstream of Metaline Falls, no bed material mobilization is expected. The sediment samples were collected to quantify the particle size distribution of the bed material. The size distribution can be quantified using particle size diameter for which a standard percentage of the sample is finer (as measured by weight). Percent finer fractions selected for this study include d_{85}, d_{50}, and d_{15}. Summaries of the sediment samples and selected size fractions are presented in Table 5.3-1. An example particle size distribution is presented in Figure 5.1-2. Plots of the particle size distribution for each of these samples are presented in Appendix 5.

Table 5.3-1. Summary particle size statistics of bed material in the Pend Oreille River.

Sample Name	Sample Type	Notes	d_{85} (mm)	d_{50} (mm)	d_{15} (mm)
BM-1	Volumetric	Mainstem PRM 27.6	0.33	0.20	0.13
BM-2	Volumetric	Mainstem PRM 27.9, surface	13	4.1	0.51
BM-3	Volumetric	Mainstem PRM 27.9, subsurface	2.7	0.93	0.41
BM-4	Volumetric	Mainstem PRM 28.1	34	18	1.6
BM-5	Volumetric	Mainstem PRM 28.9	0.20	0.11	0.016
BM-6	Volumetric	Mainstem PRM 28.9	0.10	0.036	0.0042
BM-7	Wolman Count	Mainstem PRM 30.15	100	51	12
BM-8	Wolman Count	Mainstem PRM 30.25	110	66	26
BM-9	Volumetric	Mainstem PRM 31.4, surface	34	17	3.3
BM-10	Volumetric	Mainstem PRM 31.4, subsurface	20	4.2	0.36
BM-11	Volumetric	Mainstem PRM 33.0	0.19	0.12	0.069
BM-12	Volumetric	Mainstem PRM 33.0	0.13	0.057	0.011
BM-13	Wolman Count	Mainstem PRM 33.15	80	32	13
BM-14	Wolman Count	Mainstem PRM 33.15	110	42	20
BM-15	Wolman Count	Mainstem PRM 31.65	100	40	17
BM-16	Wolman Count	Mainstem PRM 31.0	130	100	51
BM-17	Volumetric	Mainstem PRM 31.9, subsurface	1.5	0.65	0.35
BM-18	Wolman Count	Mainstem PRM 31.9	80	34	12
BM-19	Volumetric	Mainstem PRM 32.8, subsurface	68	18	1.3
BM-20	Wolman Count	Mainstem PRM 32.8	100	51	18
BM-21	Volumetric	Mainstem PRM 33.8, subsurface	53	2.1	0.22
BM-22	Wolman Count	Mainstem PRM 33.8	102	91	50

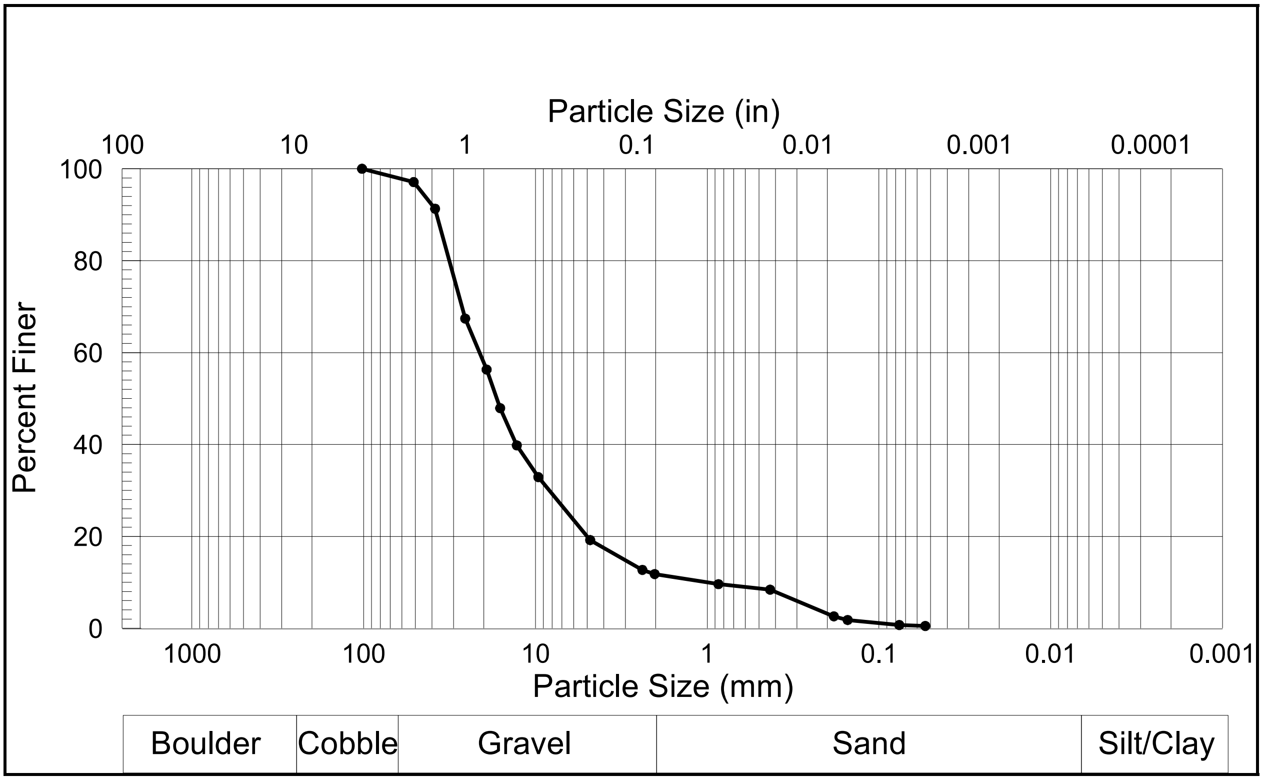

Figure 5.3-2. Particle size distribution for Pend Oreille River bed material sample BM-9.

5.3.2. Selection of Mainstem Sediment Transport Model

As indicated in Section 4.3.3.1, one-dimensional, public-domain sediment transport models were reviewed to determine the most appropriate model for evaluating the effects of operations scenarios on channel morphology within the Pend Oreille River. The following models were considered as candidates:

- HEC-6 – Scour and Deposition in Rivers and Reservoirs (USACE 1993)
- HEC-6T – Sedimentation in Stream Networks (MBH Software, Inc. 2002)
- EFDC1D – Environmental Fluid Dynamics Code – One Dimensional (Hamrick 2001)
- SRH-1D – Sedimentation and River Hydraulics – One Dimension (Huang and Greimann 2007)

5.3.2.1. Description of Candidate Models

The candidate models were reviewed to summarize their features and limitations. The characteristics for each candidate model are described in more detail in the following sections. Further details about features of each model are provided in Appendix 6.

5.3.2.2. Model Selection

The primary objective in selecting a mainstem sediment transport model was to pick the most efficient model that will meet the criteria set forth in Section 4.3.3.1. HEC-6T was selected as the model that will be applied to the Mainstem Sediment Transport component of Study 8. The following paragraphs document the factors considered in arriving at this selection.

In general, the hydraulic and sediment routing capabilities of the models were compared. All models can represent changing inflow rates, but EFDC1D is the only program reviewed that performs dynamic flow routing. Because the effects of operations scenarios on mainstem sediment transport are assumed to be minimal, hourly variations in reservoir pool level do not need to be represented in the model. Therefore, dynamic flow routing is not a needed feature and average daily flows and reservoir levels are sufficient to represent mainstem sediment transport conditions. The other hydraulic consideration compared was the ability to represent hydraulic structures, and all models have this capability. Concerning sediment routing capabilities, all models can route sediment by size fraction, all contain settling and consolidation routines, all allow for selection of different sediment transport regimes for different sediment size fractions, and all models are capable of representing the formation of an armor layer.

Given the many similarities across the capabilities of the available models, other factors such as compatibility with other relicensing studies were considered. The Tributary Delta Habitat Modeling component of Study 8 relies heavily on the HEC-RAS hydraulic model developed and calibrated in Study 7. HEC-6 and HEC-6T were evaluated more closely given the similarity of file structures and computation routines between the HEC models. Although both of these models allow for use of HEC-RAS data files, HEC-6T can directly import geometry files from HEC-RAS and it includes enhanced interfaces for compiling and editing input and output files. Further, the enhancements in HEC-6T over HEC-6 allow for greater flexibility in representing changes in channel morphology in response to erosion and sediment deposition. Thus, HEC-6T appears to be the more efficient model for application to this study component.

Prior to finalizing the selection of HEC-6T as the most efficient model for application to Study 8, SRH-1D and EFDC1D were directly compared to HEC-6T. SRH-1D is a model developed and primarily applied by the USBR. Due to its limited use outside of USBR projects, addressing model bugs and resolving troubleshooting issues may require periods of time too great to effectively meet the critical schedule associated with a relicensing project. EFDC1D is a robust model, but due to its development as a simplification of EFDC, which is a three-dimensional finite element water quality model, it requires considerable technical expertise in hydrodynamics to model effectively. If the mainstem sediment transport modeling criteria set forth exceeded the capabilities of HEC-6T, EFDC1D would be an appropriate model. However, in the interest of applying the most efficient model that meets the modeling criteria, the finalization of the selection of HEC-6T over EFDC1D was justified.

6 SUMMARY

A significant portion of the tasks associated with Study 8 has been performed to date, but a large portion of the effort remains to be performed in 2008. In general, the efforts associated with data collection were nearly completed in 2007. 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 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 crossover elements for each study component are also identified.

6.1. Tributary Delta Habitat Modeling

A summary of the efforts completed through December 2007 and the remaining work to be performed in 2008 is provided in Table 6.1-1. Data collection efforts have been completed except for the 2008 temperature monitoring. The majority of the analyses and modeling effort remain to be completed. The initial selection of tributary deltas to study has been completed and approved by the RPs. The proposed final selection of the tributary deltas has been completed and will be coordinated with the RPs in February/March 2008 for their approval. The Tributary Delta Habitat Modeling study approach has been coordinated with and agreed upon by the RPs at the June 7, 2007, Fish and Aquatics Workgroup meeting.

Table 6.1-1. Summary of work status for Tributary Delta Habitat Modeling component of Study 8.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort (Completed / *Remaining*)
1/ 4.1.1	Characterize tributary delta conditions	Effort has been completed / *No work remaining*
2/ 4.1.2	Tributary delta reconnaissance	Effort has been completed / *No work remaining*
3/ 4.1.3	Identify potential study streams	Initial screening was performed and approved by Relicensing Participants (RPs), final selection has been made / *Final selection will be presented to RPs in February/March for approval*
4/ 4.1.4	Delta water temperature monitoring	2007 effort has been completed / *Detailed monitoring of delta plumes portion of recommendations will be presented to RPs in Feb./Mar. for approval, 2008 monitoring needs to be performed*
5/ 4.1.5	Physical habitat modeling approach and data collection	Modification to modeling approach (use of HQR) has been presented to RPs and approved and data collection has been completed / *No work remaining*
6/ 4.1.6	Future tributary sediment supply	Effort was initiated with delineation of watershed, aerial photo analysis, and investigation of regional sediment supply, but completion delayed due to final bathymetry not being available / *Need to complete development of tributary sediment supply daily time series (Mainstem Sediment Transport modeling component RSP task 3/ISR section 4.1.3)*
7/ 4.1.7	Mainstem sediment transport capacity	Effort has not been initiated due to delays in the availability of final bathymetry / *Need to finalize HEC-RAS model (Study 7) and isolate hydraulics for delta areas, need to develop potential encroachment geometry at each study delta mouth*
8/ 4.1.8	Identify type 2 tributary deltas	Aerial photo analysis of each delta mouth performed / *Detailed evaluation of equilibrium conditions and future volume of sediment deposition needs to be performed*
9/ 4.1.9	Develop type 2 physical habitat models	Effort has not been initiated / *Requires RSP Task 8 : ISR section 4.1.8 for each delta, need to develop riverine and lacustrine area vs. pool elev. curves for each delta*
10/ 4.1.10	Identify Type 3 and 4 Tributaries	Aerial photo analysis of each delta mouth performed / *Detailed evaluation of equilibrium conditions and future volume of sediment deposition needs to be performed, will require scenarios be developed*
11/ 4.1.11	Develop type 3 physical habitat models	Effort has not been initiated / *Requires RSP Task 10 : ISR section 4.1.10 performed for each delta, need to develop riverine and lacustrine area versus pool elevation curves for each delta and each scenario, need scenarios*
12/ 4.1.12	Develop type 4 physical habitat models	Effort has not been initiated / *Requires RSP Task 10 : ISR section 4.1.10 performed for each delta; need to develop riverine and lacustrine area versus pool elevation curves for each delta each scenario, and three periods; need scenarios*
13/ 4.1.13	Develop type 3 physical habitat models	Effort has not been initiated */ Need to process hourly elevation results from the hydraulic routing model results for each scenario, apply tributary delta physical habitat models, post-process results of physical habitat modeling*

Notes:
RSP – Revised Study Plan

The remaining efforts involve performing analysis and developing information to support the Tributary Delta Habitat Modeling effort, developing the models, and applying the models. These efforts are in their initial phases. Work completed primarily involves refinement of methods and compilation of information to support analyses.

There are a variety of cross-over study elements in Study 8. These are listed and discussed below.

- Study 14 (Assessment of factors Affecting Aquatic Productivity in Tributary Habitats) addresses the tributaries beyond the delta areas. Studies 8 and 14 are being coordinated and are sharing information to both improve the studies and ensure consistency. The most significant item coordinated was recommendations for 2008 field efforts to support evaluation of physical conditions in Sullivan Creek. Additionally, the information characterizing the tributary deltas has been provided to Study 14.
- Study 7 provides information essential to performing the Tributary Delta Habitat Modeling component of Study 8. The habitat modeling effort will rely on water surface elevations from the Study 7 hydraulic routing model to evaluate reservoir pool levels at the deltas. Additionally, the calibrated hydraulic routing model will be utilized to determine hydraulic conditions as the deltas encroach into the mainstem. This information is required to determine the point at which the mainstem sediment transport conditions will prevent further advancement of the deltas into the mainstem. Close coordination will be facilitated because both studies have the same lead and several of the study staff are participating in both efforts.
- Study 9 has several elements that are important to Study 8. Study 9 will provide refinement to the periodicity table that will help guide application of the tributary delta habitat model. The CART tag information to be collected in 2008 as part of Study 9 may help in the evaluation of the thermal refugia aspect of the tributary deltas. This could include identifying periods when fish use the delta areas, and the depth and temperature of the water they utilize.
- To provide information for Study 24 during the tributary delta reconnaissance, each delta was surveyed for the presence of fire-cracked rock and fire-cracked rock clusters. The apparent absence of these features has been communicated to the cultural resource lead.

6.2. Tributary Delta Sediment Processes

Efforts on the delta sediment processes component of Study 8 performed in 2007 have been limited to refinement of the study plan and compilation of information. The technical efforts associated with this study component will be performed in 2008. These efforts are listed in Table 6.2-1 and consist of determining the delta evolution for operations scenarios. The first steps in this effort involve determining whether the deltas will change under future conditions and whether the change will depend on the nature of the operations scenario. The next step will be determining the nature of the change and the representation of the delta geometry under future conditions.

Table 6.2-1. Summary of work status for Tributary Delta Sediment Processes component of Study 8.

RSP Task / ISR Section	Task Name	Status of Work Effort
1/ 4.2.1	Phase 1, Evaluate Potential Delta Change	Technical efforts have not been initiated; efforts to date have involved refinement of the study plan and compilation of information / *Requires Tributary Delta Habitat Modeling RSP task No. 6 and 7/ISR section 4.1.6 and 4.1.7, need to perform equilibrium slope analysis and volume of sediment deposition analyses for each study delta, identify future geometry for each delta*
2/ 4.2.2	Phase 2, Predict Delta Change Common to All Scenarios	Technical efforts have not been initiated; efforts to date have involved refinement of the study plan and compilation of information / *Requires Tributary Delta Habitat Modeling RSP task No. 6 and 7/ISR section 4.1.6 and 4.1.7, requires scenarios to be identified and evaluated by hydraulic routing model (Study 7), need to perform equilibrium slope analysis and volume of sediment deposition analyses for each study delta, identify future geometry for each delta*
3/ 4.2.3	Phase 3, Predict Delta Change Associated with Specific Scenarios	Technical efforts have not been initiated; efforts to date have involved refinement of the study plan and compilation of information / *Requires Tributary Delta Habitat Modeling RSP task No. 6 and 7/ISR section 4.1.6 and 4.1.7, requires scenarios to be identified and evaluated by hydraulic routing model (Study 7), need to perform equilibrium slope analysis and volume of sediment deposition analyses for each study delta, identify future geometry for each delta and for initial, middle and final periods of 50-year license term*

This effort supports the Tributary Delta Habitat Modeling effort. There are no cross-over elements beyond internal transfer of information between the components of Study 8. This study component provides the essential information on the future development of the tributary delta morphology for development of the habitat models. The Mainstem Sediment Transport study provides information essential to this study on the rate of sediment supply to the tributary deltas.

6.3. Mainstem Sediment Transport

Table 6.3-1 summarizes the work completed and the remaining efforts to be performed in the Mainstem Sediment Transport component of Study 8. Efforts conducted in 2007 for this study component have primarily involved data collection and compilation of information. Field efforts have included a reconnaissance trip and collection of bed material samples. Technical work completed has included selection of HEC-6 as the sediment routing model, delineation of watersheds and review of regional sediment yield relationships to support determination of tributary sediment supply, review of aerial photographs to identify delta deposits, and initial review of historic mapping to identify areas of erosion and sediment accumulation.

Table 6.3-1. Summary of work status for Mainstem Sediment Transport component of Study 8.

RSP Task / Interim Study Report Section	Task Name	Status of Work Effort
1/ 4.1.1	Delineate zones of erosion and accumulation of sediment from 1967 to 2006	Analysis of aerial photographs has been initiated, obtained historic bathymetry in DTM form, initiated visual review of mapping / *Initiation of effort was delayed due to final bathymetry being delivered early Dec 2007, need to overlay current and pre-reservoir mapping, review initially identified areas of potential deposition and erosion, determine volumes associated with identified areas of change*
2/ 4.1.2	Characterize sediment supply	Effort was initiated with delineation of watershed, aerial photo analysis, and investigation of regional sediment supply, obtain mainstem USGS sediment records, but completion delayed due to final bathymetry not being available / *Need to complete development of tributary sediment supply daily time series, need to develop mainstem sediment supply rating curves*
3/ 4.1.3	Develop and calibrate sediment transport model	Selection of sediment routing model completed (HEC-6), bed material samples collected and reconnaissance of main stem between Boundary Dam and Box Canyon have been performed / *Need to convert HEC-RAS geometry to HEC-6, develop bed material input, develop mainstem and tributary sediment supply input, perform reconnaissance of tailrace reach to Salmo River, develop calibration conditions from RSP task 1 : ISR section 4.1.3, perform calibration*
4/ 4.1.4	Predict future patterns of erosion and accumulation	Effort has not been initiated / *Need to develop future conditions input and perform 50 year model run, interpret results as to potential changes in channel morphology and influences on physical habitat*

The only field effort associated with the Mainstem Sediment Transport study to be performed in 2008 will be the reconnaissance of the tailrace reach including the U.S. and Canadian portions. The majority of the analysis and modeling effort remains to be completed in 2008. This effort includes determination of areas of historic erosion and deposition, development of daily time series of sediment inflow and sediment supply rating curves, development and calibration of the HEC-6 model to historic information, and application of the sediment routing model to estimate future mainstem sediment deposition and erosion under the existing Project operations for the 50-year term of the license. The results of the future sediment routing effort will be utilized to evaluate whether the morphology of the channel may change and influence future aquatic habitat conditions.

The following is a list of cross-over study elements for Mainstem Sediment Transport study.

- Study 7 will provide basic model geometry and calibration of hydraulic parameters for development of sediment transport model in Study 8. Coordination between these two studies is facilitated by sharing the same study lead and many of the staff performing the modeling.

- Results of the sediment routing model need to be shared with Study 4 (Toxics Assessment: Evaluation of Contaminant Pathways) because there is the need to understand potential locations of sediment accumulation and scour in evaluating issues associated with Study 4. The toxics study team and the team performing the hydraulics and sediment transport modeling effort have been working together since early 2007 when the hydraulics team developed a steady flow hydraulic model to estimate depositional potential in the area between Box Canyon and Boundary Dams.
- The estimation of the size and rate of shoreline erosion sites performed in Study 1 (Erosion) will provide one component of the sediment supply for the sediment routing model. Coordination of these study efforts is facilitated by sharing the same study lead. Staff involved in the sediment transport study also assisted in performing the erosion study field work.

7 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

This section presents and discusses both variances from the FERC-approved RSP and proposed modifications. Variances include both changes in methods to conduct the studies and changes in the approved study schedules presented in the RSP. Proposed modifications are changes to elements of the study that are not part of the RSP. In general, proposed modifications are additions to the study effort to address study needs that have been identified by either the study team or the relicensing participants. For both types of changes, a brief description is provided of why the deviations have been made and how the relicensing participants were, or will be involved in the process.

7.1. Variances from FERC-Approved Study Plan

Variances from the FERC-approved study plan for Study 8 components consist of minor changes to the schedule and minor changes to field and analysis methods. Schedule-related variances from the RSP are the result of final bathymetric mapping not being available until early December 2007.

7.1.1. Tributary Delta Habitat Modeling

The variances from the FERC-approved RSP methods in the Tributary Delta Habitat Modeling study component involve the procedure to perform the physical habitat modeling and the data collection effort to provide the information necessary to describe the physical habitat.

7.1.1.1. Physical Habitat Data Collection and Modeling Procedure

The details of the methods for evaluating the tributary delta habitats in Boundary Reservoir were altered in the study refinement process, but build upon the concepts presented in the RSP. The new approach proposed for evaluating the tributary delta habitats is more straightforward, relies on readily available and proven riverine and lacustrine fish habitat suitability index models, and simplifies post-data collection analyses techniques. The details of the tributary delta habitat evaluation contained in this current study plan were presented to and approved by the relicensing participants during the June 2007 Fish and Aquatic Workgroup meeting in Spokane, Washington. The coordination effort with the relicensing participants included documentation of the methods for the effort in Tetra Tech and TRPA (2007).

The procedure for modeling the major tributary deltas presented in the RSP involved application of methods analogous to the mainstem aquatic habitat model in which a transect-based hydraulic model and HSI information would be used to translate changes in depth, velocity, substrate, and cover to indices of habitat suitability. The FERC-approved tributary delta habitat modeling procedure is presented in tasks 8 through 13 of the RSP (SCL 2007). The data collection effort to support the modeling methods in the RSP is transect-based and described in Task 5 of the RSP.

After reviewing the procedure in the RSP, available information, and site conditions, it was proposed that the procedure presented in the RSP was not consistent with available information to support the effort as well as the resolution of predicting future channel conditions within the deltas. In terms of available information, actual long-term hydrologic records are only available for Sullivan Creek. Consequently, all flow information to support a hydraulic-based modeling procedure for the other major tributaries would need to be synthesized from other locations and could deviate from actual conditions. Under the hydraulic transect-based procedures proposed in the RSP, to reflect potential changes in habitat conditions under future conditions, the changes in delta morphology would need to be translated into changes in cross-sectional geometry. In the highly dynamic environment of the tributary deltas, any such predictions would be rather coarse and open to considerable debate.

Considering the above limitations, a procedure the study team identified as being more consistent with these limitations was developed. The result was the HQR methodology presented in Section 4.1.5.

The quantification of physical habitat using the HQR procedure relies on field evaluation of existing habitat conditions for the two habitat types, riverine and lacustrine, and identification of the surface areas associated with each habitat type. It does not require estimation of flow in the tributaries or of future depth and velocity conditions through hydraulic modeling of transects as the delta evolves over the 50-year term of the license[4]. It does require identification of hourly fluctuations in reservoir elevations to determine areas associated with the lacustrine (inundated portions of the delta) and riverine (free-flowing portion of the delta). The hourly reservoir level fluctuations at each major delta are readily available from the hydraulic routing model developed in Study 7. The HQR procedure also requires estimation of the potential evolution of the delta over the relicense term. However, rather than requiring estimation of future transect conditions, the HQR procedure requires an estimation of the area occupied by the delta. Estimation of the future delta area can be reasonably performed utilizing historic information on delta evolution and growth, modeling of potential hydraulic interaction with the mainstem flow, and knowledge

[4] HQR for Sullivan Creek will be performed for two periods, high flow and low flow. To support the HQR determination, physical habitat data were collected both in September 2007 and November 2007 on Sullivan Creek. All other tributaries had habitat characterization data collected during the September low flow condition and will have HQRs determined based on these conditions. This aspect of the procedure was developed and approved through interaction with the RPs at the June 7, 2007, Fish and Aquatics Workgroup meeting in Spokane.

of reservoir elevations during key periods of the year for delta growth for each operations scenario.

The refinement of the delta habitat modeling effort to incorporate the HQR procedure required changes in the methods for collection of information to describe the physical habitat conditions. The original data collection effort was described in the RSP under Task 5. The new methods for the physical habitat data collection associated with the HQR procedure are presented in Section 4.1.5 of this report. Though the application of the HQR physical habitat data collection did not require survey of the 8 to 14 transects as described in the RSP, the data collected did include macrohabitat determination, substrate, fish cover and fry habitat, characterization of pools, fine sediment, LWD, channel geometry (width and depth), flow, and water quality parameters (temperature, pH, and dissolved oxygen). The new data collection methods were presented to and approved by the RPs at the June 7, 2007, Fish and Aquatics Workgroup meeting in Spokane, Washington.

7.1.1.2. Schedule

Changes to the schedule for conducting the Tributary Delta Habitat Modeling portion of Study 8 have been made due to final bathymetry for Boundary Reservoir not being available until early December 2007. Under the schedules presented in the RSP, final bathymetry had been assumed to be available in the first quarter (Q1) of 2007. Development of the sediment supply to the tributary deltas requires the final bathymetry be available. This effort had originally been scheduled for late 2007. It is now being performed in early 2008. As a result of this schedule modification, the actual model development efforts for the tributary deltas have been shifted from early 2008 to the middle of 2008. The actual modeling of the tributary delta habitat will still be performed in Q4 of 2008 as originally indicated in the RSP.

7.1.2. Tributary Delta Sediment Processes

There are no variances from the FERC-approved study plan for either the methods or the schedule.

7.1.3. Mainstem Sediment Transport

There are no variances proposed in the methods associated with the Mainstem Sediment Transport component of Study 8. However, due to delays in the availability of the final bathymetry, the schedule has been adjusted. The adjusted schedule still meets the goal of completing the Mainstem Sediment Transport modeling effort in Q4 of 2008. The revised schedule has been developed to meet the requirement of being able to complete prediction of future patterns of mainstem sediment erosion and accumulation in Q4 of 2008. The determination of historical sediment erosion and accumulation and estimation of the sediment supply time series has been shifted from 2007 into early 2008. This requires shifting the model development and calibration task from early 2008 into the middle of 2008. The prediction of future patterns of sediment erosions and accumulation will be completed by the end of Q3 2008.

7.2. Recommendations for Study Modifications

Study recommendations are modifications to the effort that do not involve changes to the FERC-approved study plan. In general, recommended modifications are additions to the study effort to address study needs that have been identified by either the study team or the RPs. The only recommended modifications in Study 8 involve temperature monitoring for the tributary deltas and are part of the Tributary Delta Habitat Modeling study component. These recommendations are described in the following two subsections and are divided into temperature monitoring efforts for 2007 and temperature monitoring efforts for 2008.

7.2.1. 2007 Temperature Monitoring

Two types of temperature measurements are being collected to characterize conditions at the tributary deltas. The first involves installing water temperature recorders in the mainstem channel, in the delta channel thalweg within the varial zone, and in the tributary channel upstream of the reservoir influence. This portion of the 2007 temperature monitoring effort was described in the RSP and was performed per the RSP description in Task 4. The second set of measurements collected were several data sets taken at specific pool levels to identify whether thermal plumes of low temperature water occur across the delta thalweg beyond the channel thalweg. This second set of measurements was not originally included in the RSP, but was conducted in response to RP requests after presentation of the tributary delta study methods at the June 7, 2007, RP meeting. The initial findings were used to develop the proposed recommendations for the 2008 temperature monitoring plan.

During the June 7, 2007, Fish and Aquatics Workgroup meeting, RPs brought up concerns about the need for additional delta temperature monitoring outside of the longitudinal thalweg profile and also in the vertical. The impetus behind the additional monitoring was development of a better understanding of the lateral and vertical extent of the lower temperature plume that could develop in the summer and early fall when tributary inflows may be substantially cooler than the mainstem. A July 17, 2007, conference call between SCL and the RPs was held to further discuss additional temperature monitoring at the tributary deltas. As a result of this call, SCL developed a proposed 2007 monitoring plan for the tributary delta thermal plumes and presented the plan to the RPs at the July 24, 2007, Fish and Aquatics Workgroup meeting. The 2007 data collection was planned mainly to gather general information about temperature patterns at the tributary deltas and based on the results, additional data collection could be proposed to be undertaken in 2008 to address questions that arose as a result of the 2007 data. The Fish and Aquatics Workgroup members agreed that the proposed approach for monitoring temperature in tributary deltas in 2007 was acceptable.

The methods to conduct the detailed spatial monitoring of the tributary delta temperature plumes are provided in Section 4.1.4.2.1. Three tributary deltas were selected for the 2007 study based on either the observation of fish holding at the tributary confluence, or the relative size and configuration of the delta and its tributary making it most likely to develop a thermal plume. The three tributaries selected were Slate, Sullivan, and Sweet creeks. The latter two creeks were selected because of their physical characteristics whereas Sweet Creek was selected because of observations of fish at its mouth. Each tributary was evaluated in August at two or three pool levels during a period of relatively low and stable inflow from Box Canyon Dam.

The monitoring was performed in August 2007 and the results presented in Section 5.1.4.2. General observations from the 2007 effort were:

- A cool water thermal plume existed at the tributary deltas selected for monitoring.
- The size of the plumes varied.
- The size and behavior of the plumes was influenced by the delta morphology.

Observations from the 2007 monitoring effort were used to help develop the 2008 monitoring plan for the thermal plumes.

7.2.2. 2008 Temperature Monitoring

Recommendations for modifications to tributary delta monitoring in 2008 involve both the continuous water temperature monitoring component and the monitoring of the tributary delta temperature plume.

7.2.2.1. Continuous Tributary Delta Water Temperature Monitoring

The continuous monitoring of water temperature at the tributary deltas is changed only slightly from 2007. The changes are based on reviewing the results from 2007 and are intended to enhance the information collected in 2007. The proposed 2008 effort is described in Section 4.1.4.1.2. The changes involve relocating several thermographs to better represent the range of longitudinal conditions in the varial zone, relocating several of the mainstem buoys to ensure that they record mainstem temperatures and not thermal plume temperatures during low reservoir pool levels, lowering the thermographs on the mainstem buoys to be at a depth of 6 feet rather than 3 feet, and deploying the thermographs by June 15, 2008.

Continuous temperature monitoring will be conducted in 2008 on all seven of the tributary deltas. This will include attempting to collect data on Pocahontas and Sand creeks in 2008, though they were dry for much of the 2007 summer period. Deployment of the thermographs in mid-June is primarily being performed to have a higher likelihood of obtaining some data on Pocahontas and Sand creeks prior to these streams going dry.

7.2.2.2. Monitoring of Spatial Distribution of Tributary Delta Temperature Plumes

The proposed detailed monitoring of the thermal plumes in the tributary deltas for 2008 is presented in Section 4.1.4.2.2. This proposed plan was coordinated with the RPs with the distribution of this Interim Study Report and a presentation in Spokane, Washington, in February/March 2008. The monitoring for 2008 is proposed because the efforts conducted in 2007 indicated that thermal plumes existed, over a range of water surface level fluctuations, during warm summer months at the three tributaries studied. The monitoring also indicated the thermal plumes may be influenced by interaction with the mainstem current and topography of the delta. In addition, results of Study 9 (Fish Distribution, Timing, and Abundance Study Interim Report [SCL 2008b]), as well as informal observations during field trips, have indicated fish congregated at the mouths of these tributaries during periods of high reservoir water temperatures. The 2008 monitoring is being proposed to better understand the extent and behavior of thermal plumes in order to incorporate their presence in the habitat evaluation for the tributary deltas.

The proposed delta thermal plume monitoring program for 2008 has been developed to address two primary goals. The first goal is to monitor all major Boundary Reservoir tributaries that have high potential for the existence of a cool water plume being utilized as thermal refugia. The second goal is to define thermal plume response to changes in reservoir levels resulting from the combination of forebay water surface elevations and upstream inflows. The 2008 monitoring effort described in Section 4.1.4.2.2 provides the details on achieving these goals.

The information recommended for collection in 2008, along with the data collected in 2007, will be used to draw conclusions about the general behavior of the thermal plumes at the major tributaries in which they may exist on the tributary deltas. This information will be used to support the evaluation of habitat conditions at each of the major tributaries and may be incorporated into the HQR modeling for the tributary deltas.

The recommended 2008 monitoring will support the determination of whether cold water plumes at the individual deltas exhibit a “transitional” reservoir water surface elevation response. The transitional response would be associated with a more rapid reduction in the size of the thermal plume as the water surface elevation drops below the transitional level. A transitional elevation for a thermal plume may occur when the combination of delta topography, forebay water surface elevation, and mainstem flow results in the mainstem flow interacting with the tributary outflow to reduce the size and constancy of the thermal plume.

Based on the information collected in 2007, it appears that the thermal plumes do not exhibit large variations in size at the tributary deltas until the water surface elevation adjacent to the tributary delta drops below a transitional elevation. When the mainstem reservoir water surface elevation drops below a certain level, the mainstem flow appears to start interacting with the plume and transports the cold tributary outflow downstream. Until the water surface elevation is drawn down to the transitional elevation, the reservoir water surface elevation fluctuations result in the plume migrating up and down the delta surface while maintaining a relatively consistent size. Within this range of water surface elevation fluctuations, from the highest elevation down to the transitional elevation, the thermal plume is protected from direct influence from mainstem flows by the embayment in which the delta is located. However, as the water surface elevation drops, the downstream edge of the thermal plume may be drawn sufficiently close to the mainstem channel that it interacts with the downstream flow of the mainstem channel or the circulating flow caused by eddies generated from the mainstem current. At this transitional elevation, the size of the thermal plume may decrease more rapidly with variation in water surface elevation, because the edge of the mainstem channel or circulating eddy tends to limit the downstream extent of the thermal plume.

In some cases, the geometry of the tributary delta embayment and the flow conditions in the mainstem may result in the size of the thermal plume being rather stable over the range of reservoir water surface elevations. This appears to be the case with Slate Creek, as is likely the case with other tributary deltas below Metaline Falls, where the mainstem flows do not expose the tributary delta to mainstem currents during summer low flow periods. At water surface elevations where tributary thermal plumes do not appear responsive to fluctuating reservoir levels, the habitat represented by the thermal refugia will not vary greatly under each operations scenario.

If evaluation of the data collected in 2007 and 2008 indicates consistent behavior in the extent (area) of the thermal plumes at individual tributary deltas, it is anticipated that the area of the thermal refugia will be incorporated into the HSI and HQR determinations for the lacustrine habitat at the tributary deltas. If the review of the information indicates that tributary thermal plumes at delta mouths are dynamic on an hourly basis, results of the thermal plume monitoring will not be incorporated into the HSI and HQR determination for that tributary delta. Instead, the frequency and duration at which the mainstem elevation falls below the transitional reservoir water surface elevation at the tributary delta will be determined for each operations scenario.

The evaluation of the thermal refugia at the major tributary deltas may be aided in 2008 by efforts in Study 9. Data that can be collected from fish implanted with CART tags that are observed near stream mouths with monitoring equipment will indicate the temperature and depth these fish are occupying during warm water periods. The monitoring plan calls for this type of information to be continuously recorded during the warm water months. This information may assist in indicating how fish behave in the tributary delta areas during changing mainstem water temperature, river flow, and reservoir water surface elevation over a range of summertime Project operations and flow conditions. The information could potentially identify fish behavioral responses such as location (based on its change in depth plus or minus approximately 2 feet), what temperature range fish may select, and how that selection changes with the changes in other physical factors noted above.

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Appendix 1. Tributary Delta Topography, Aerial Photographs, and Photographs

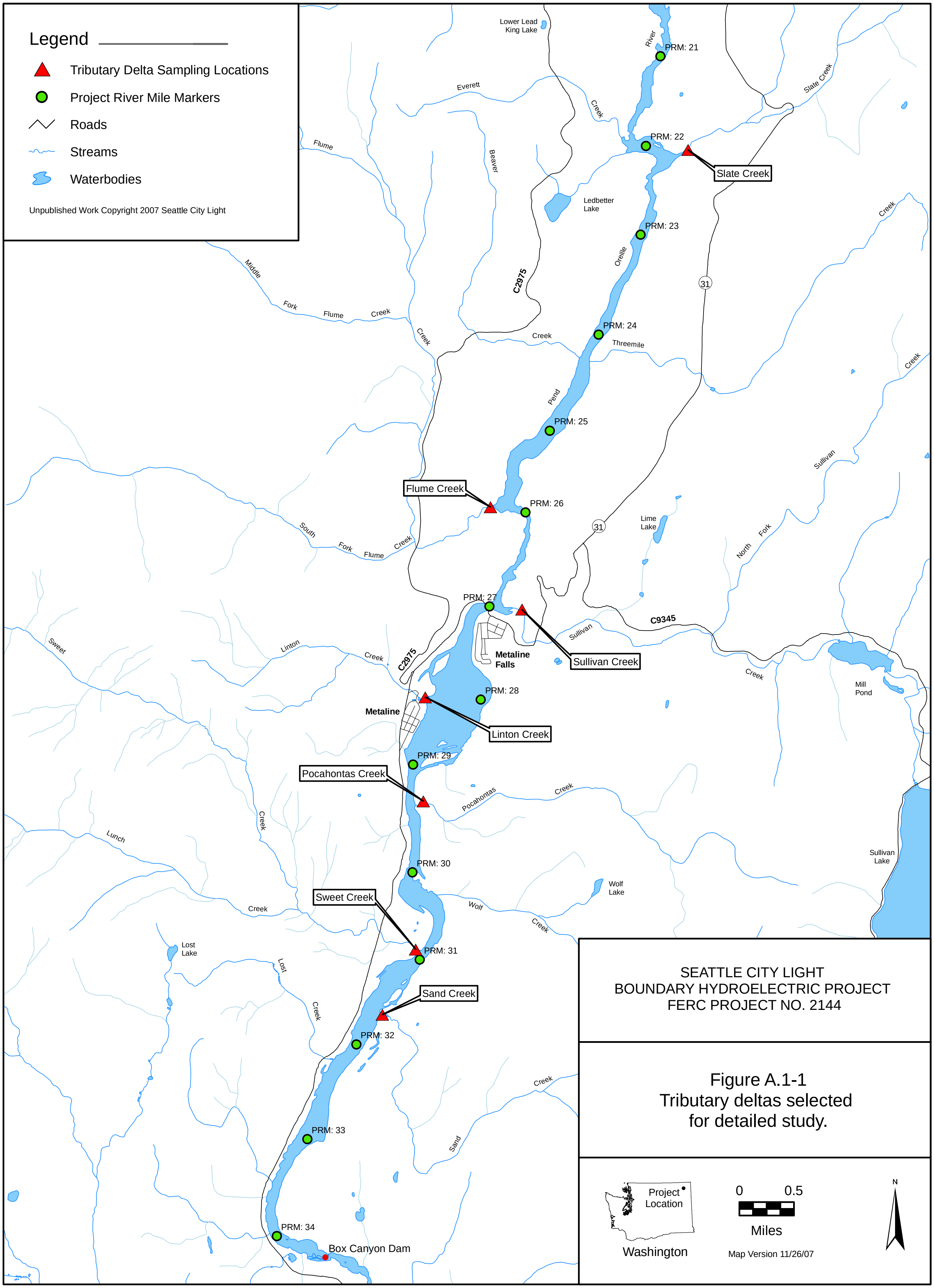
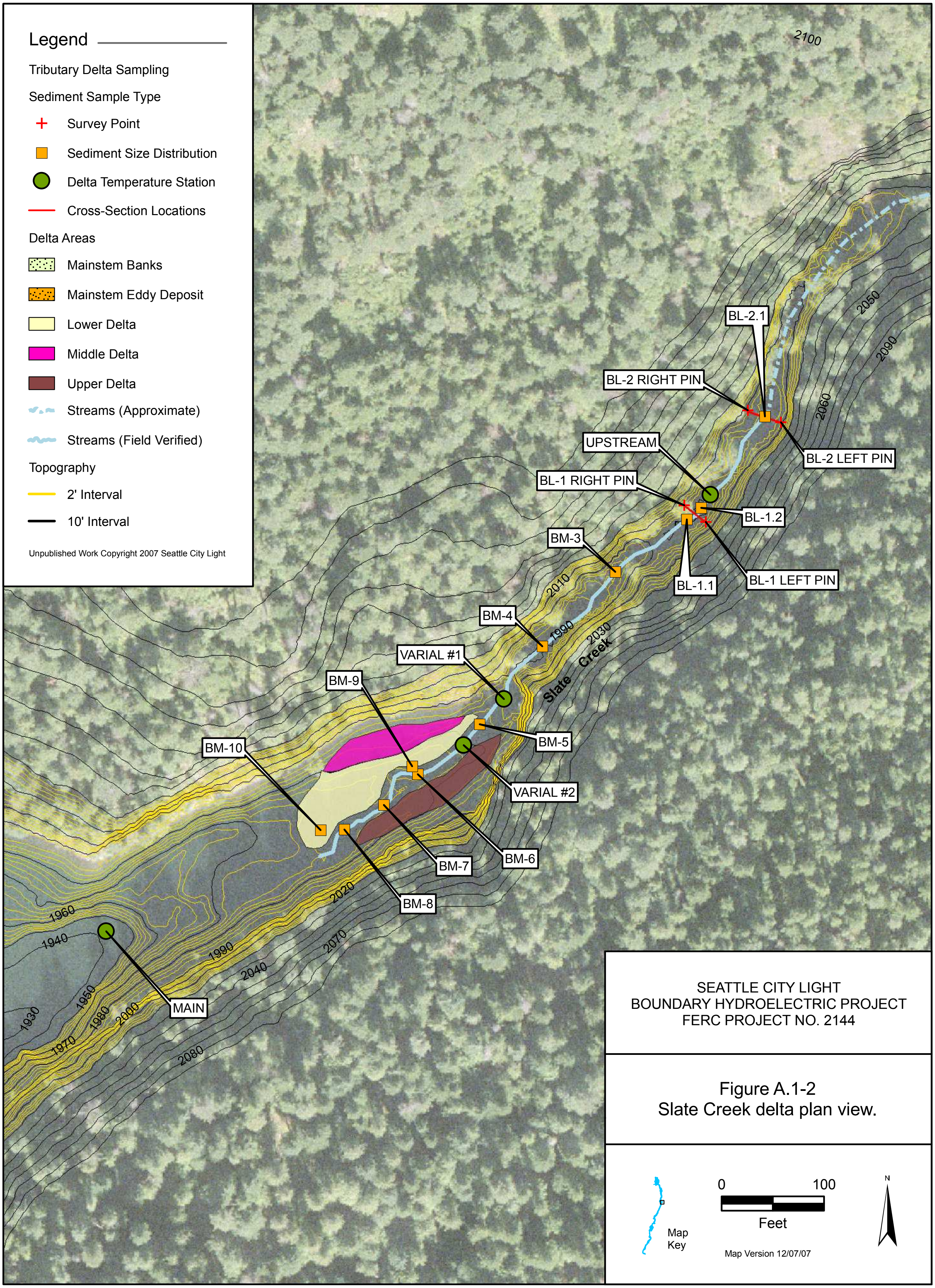


Figure A.1-1
Tributary deltas selected for detailed study.



SEATTLE CITY LIGHT
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FERC PROJECT NO. 2144

Figure A.1-2
Slate Creek delta plan view.

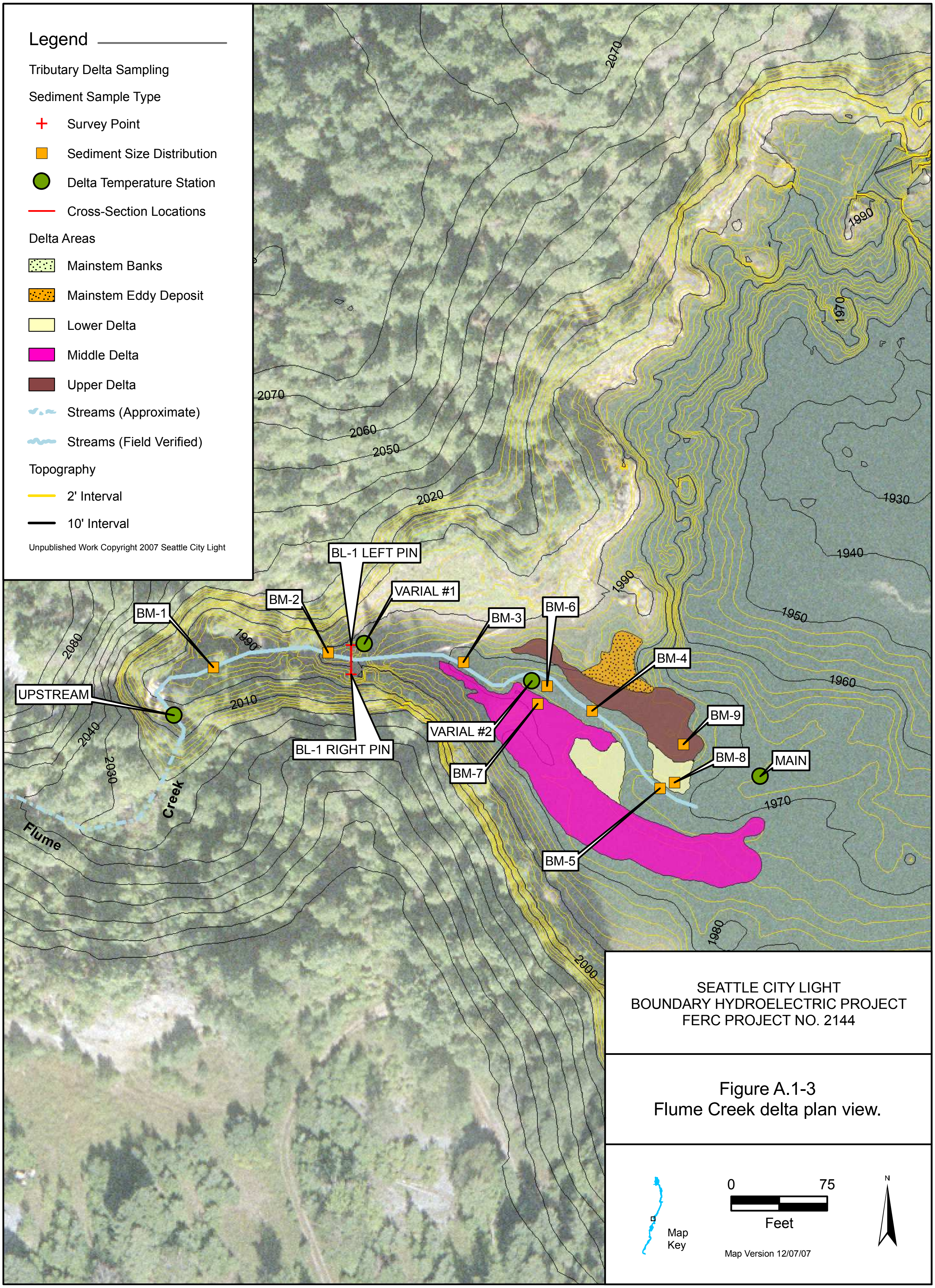

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Figure A.1-3
Flume Creek delta plan view.

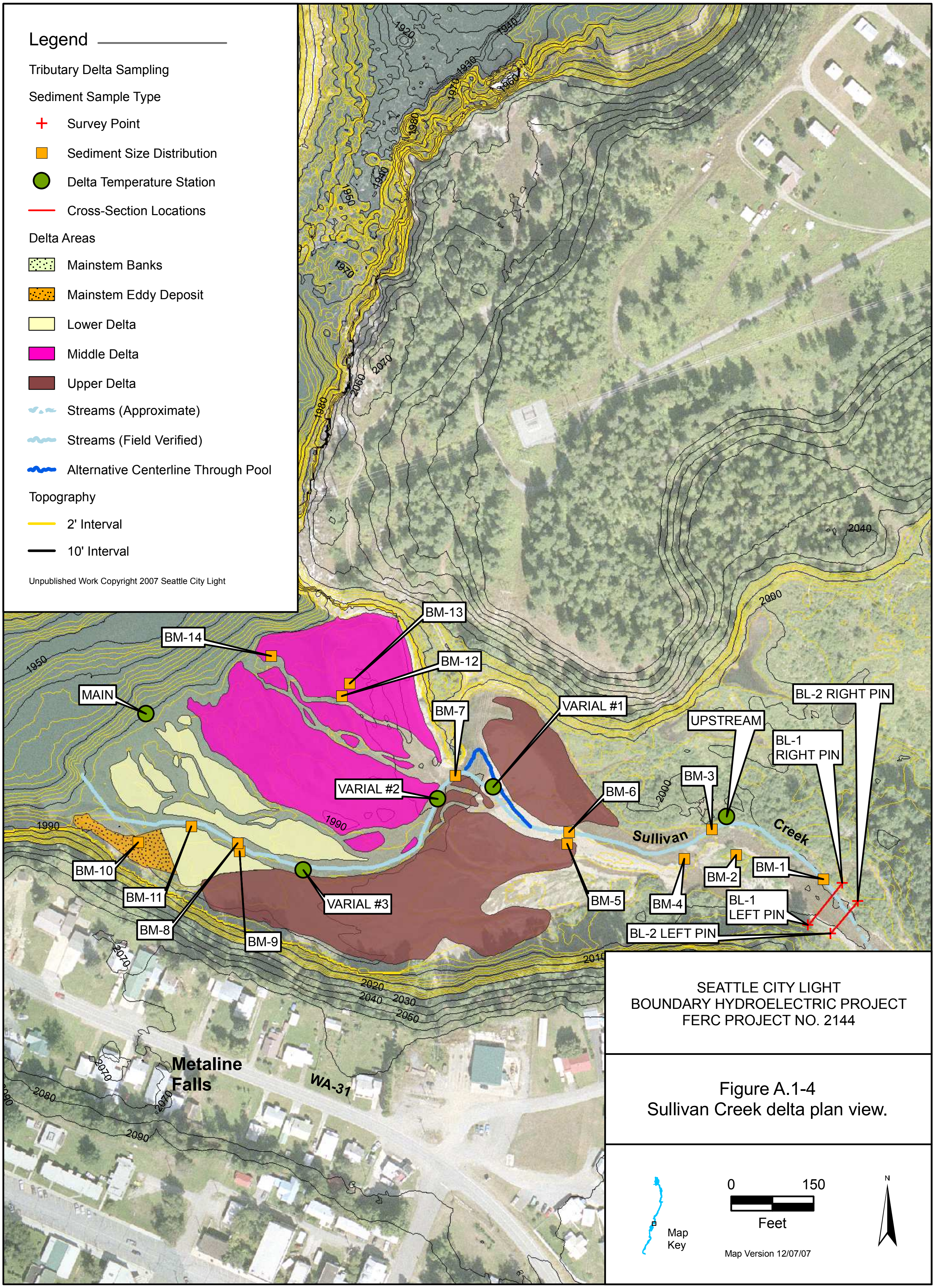


Figure A.1-4
Sullivan Creek delta plan view.

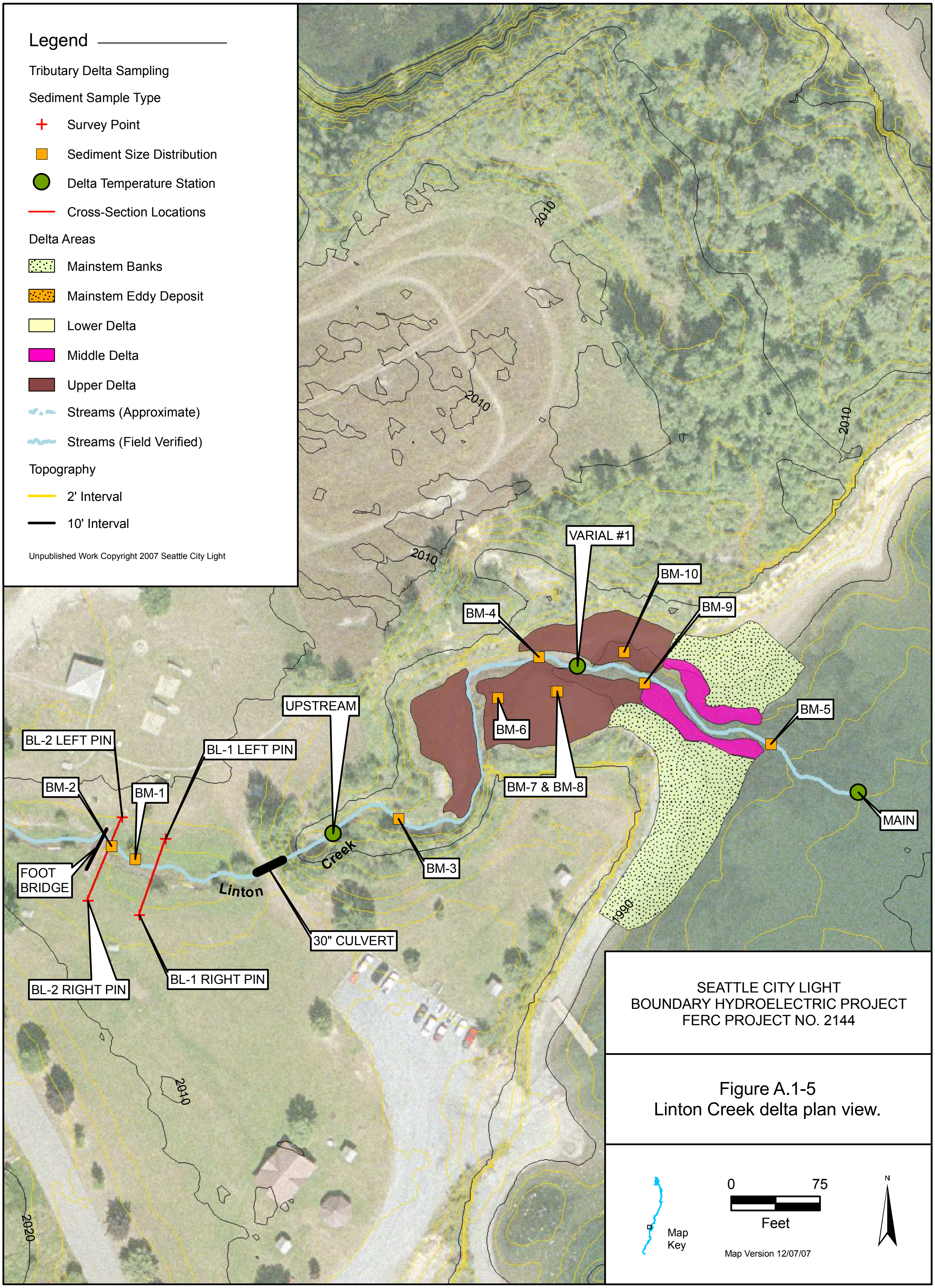
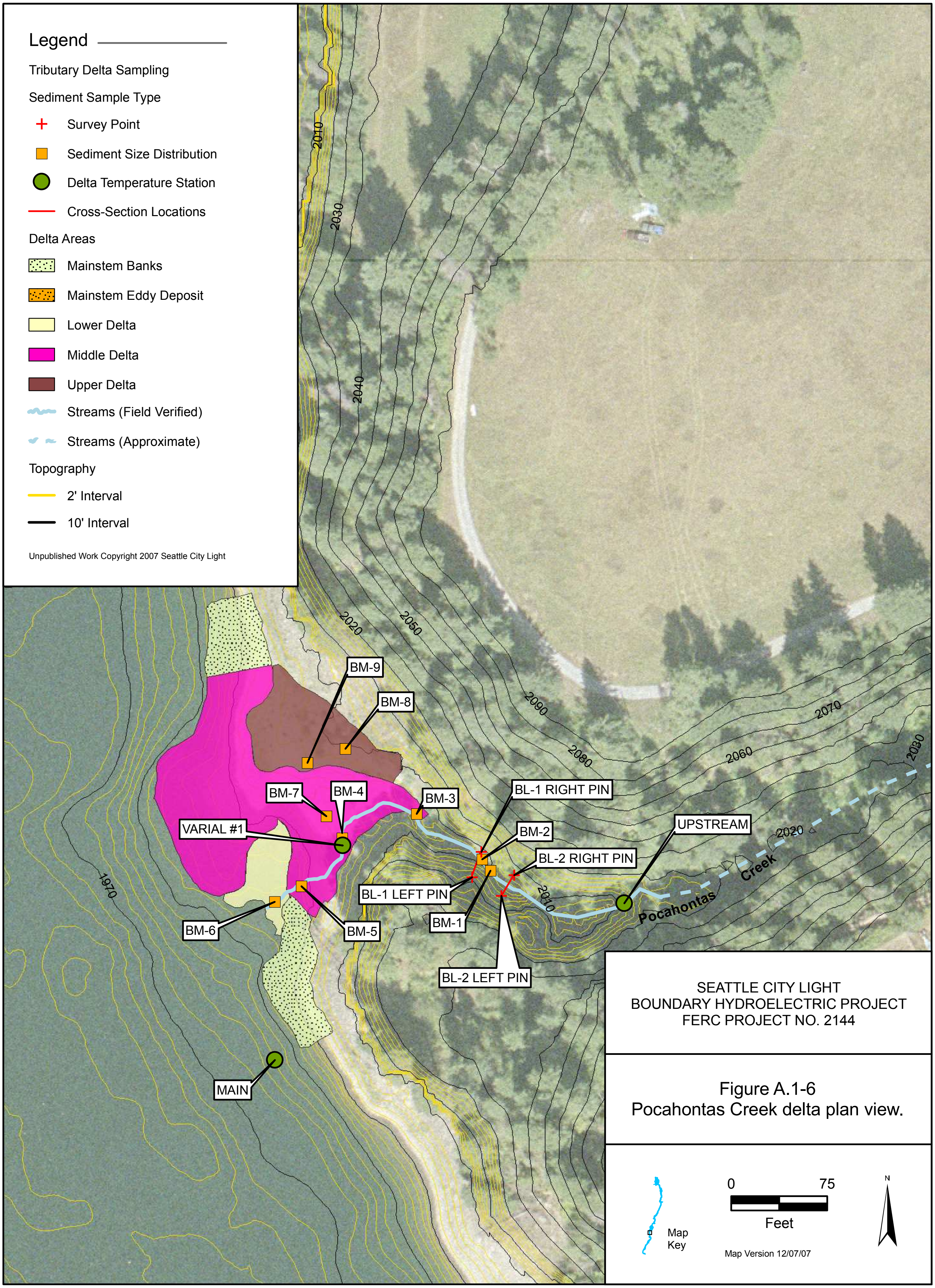


Figure A.1-5
Linton Creek delta plan view.



Legend
Tributary Delta Sampling
Sediment Sample Type
Survey Point
Sediment Size Distribution
Delta Temperature Station
Cross-Section Locations
Delta Areas
Mainstem Banks
Mainstem Eddy Deposit
Lower Delta
Middle Delta
Upper Delta
Streams (Field Verified)
Streams (Approximate)
Topography
2' Interval
10' Interval
Unpublished Work Copyright 2007 Seattle City Light
2010
2030
2040
2020
2050
2090
2080
2070
2060
2030
2020
2010
1970
BM-9
BM-8
BM-7
BM-4
BM-3
VARIAL #1
BL-1 RIGHT PIN
BM-2
BL-2 RIGHT PIN
UPSTREAM
BL-1 LEFT PIN
BM-1
BM-6
BM-5
BL-2 LEFT PIN
Pocahontas Creek
MAIN
SEATTLE CITY LIGHT
BOUNDARY HYDROELECTRIC PROJECT
FERC PROJECT NO. 2144
Figure A.1-6
Pocahontas Creek delta plan view.
0
75
Feet
Map Key
Map Version 12/07/07
N

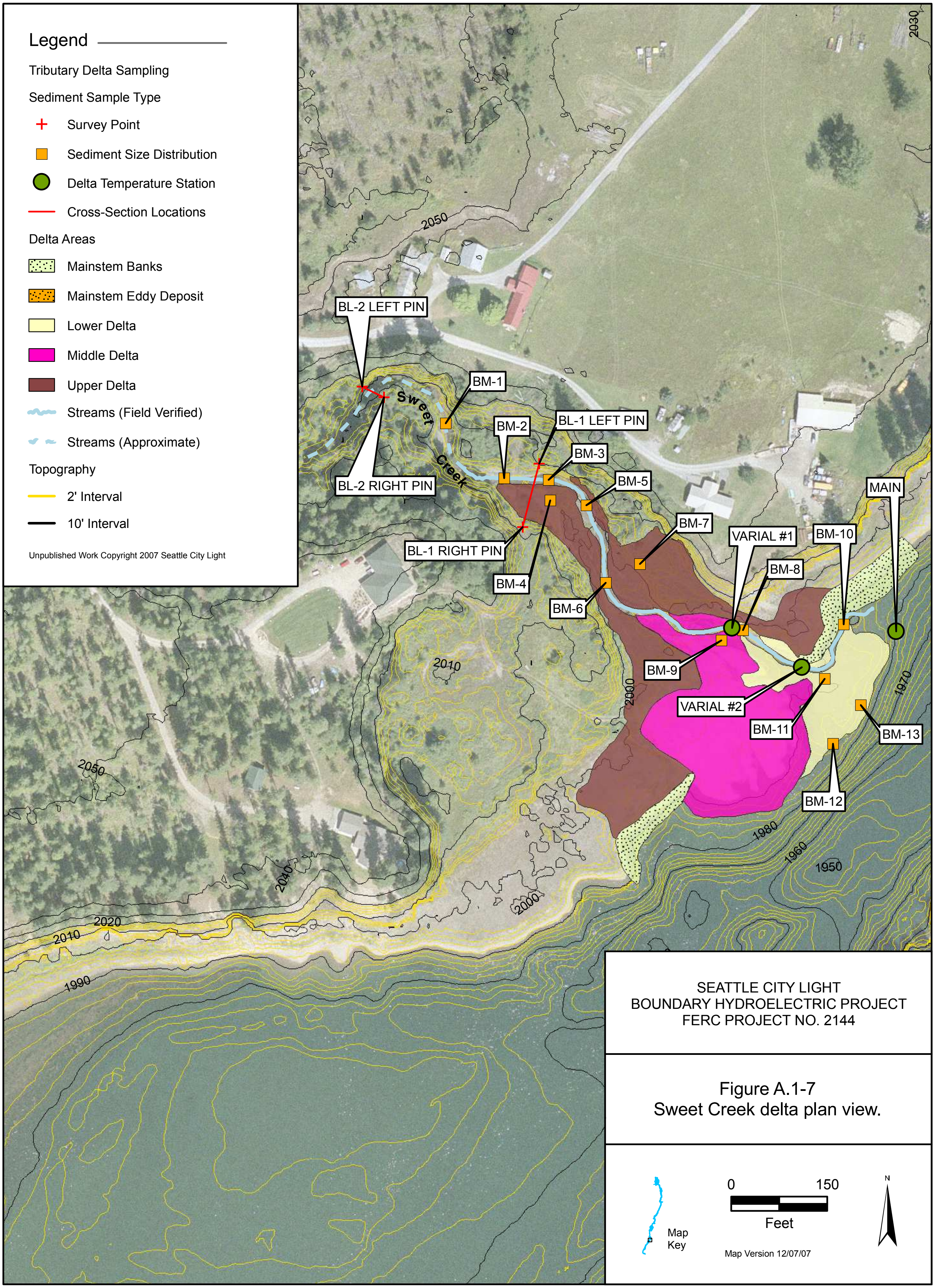


Figure A.1-7
Sweet Creek delta plan view.

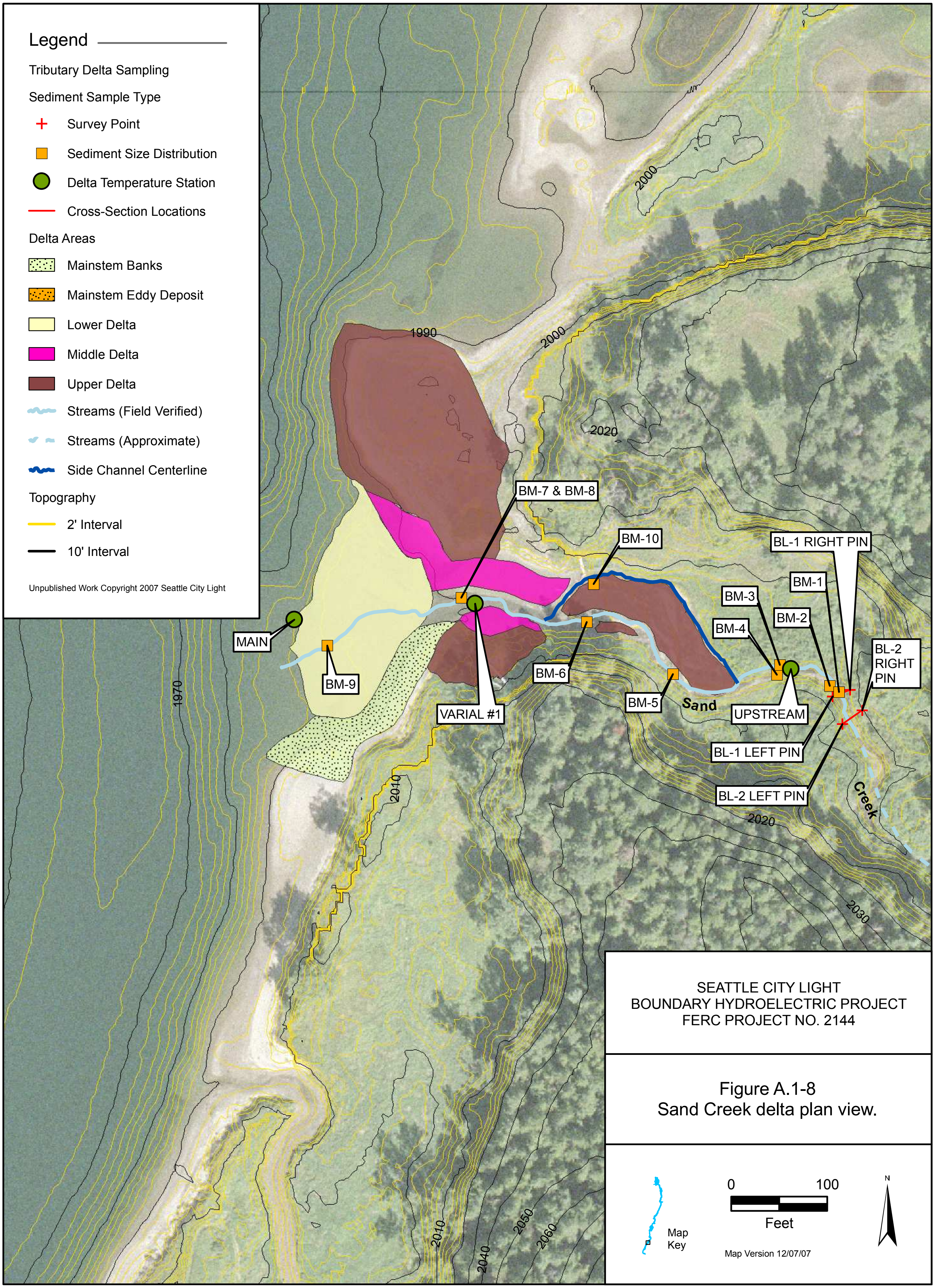


Figure A.1-8
Sand Creek delta plan view.

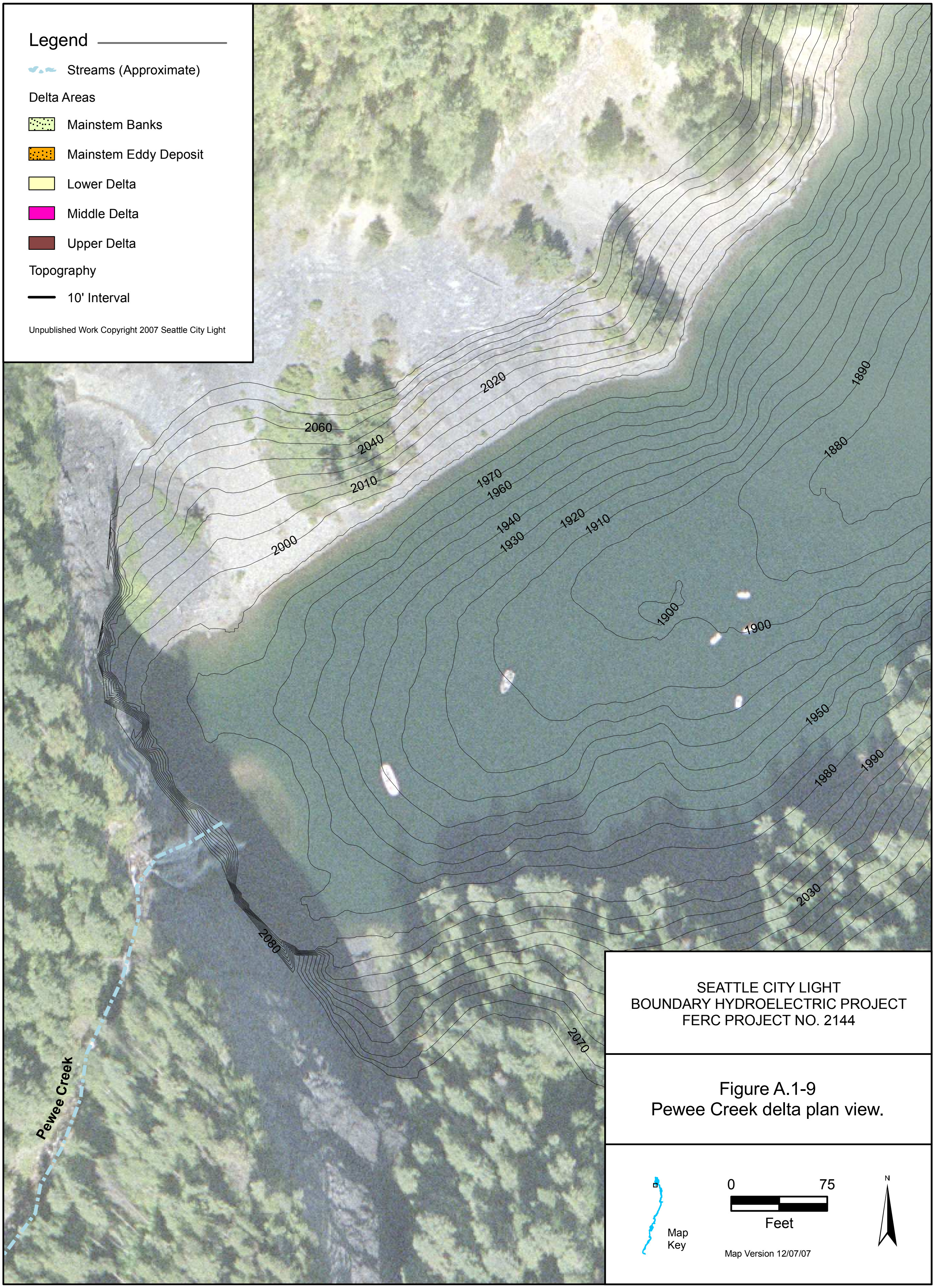


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Figure A.1-9
Pewee Creek delta plan view.

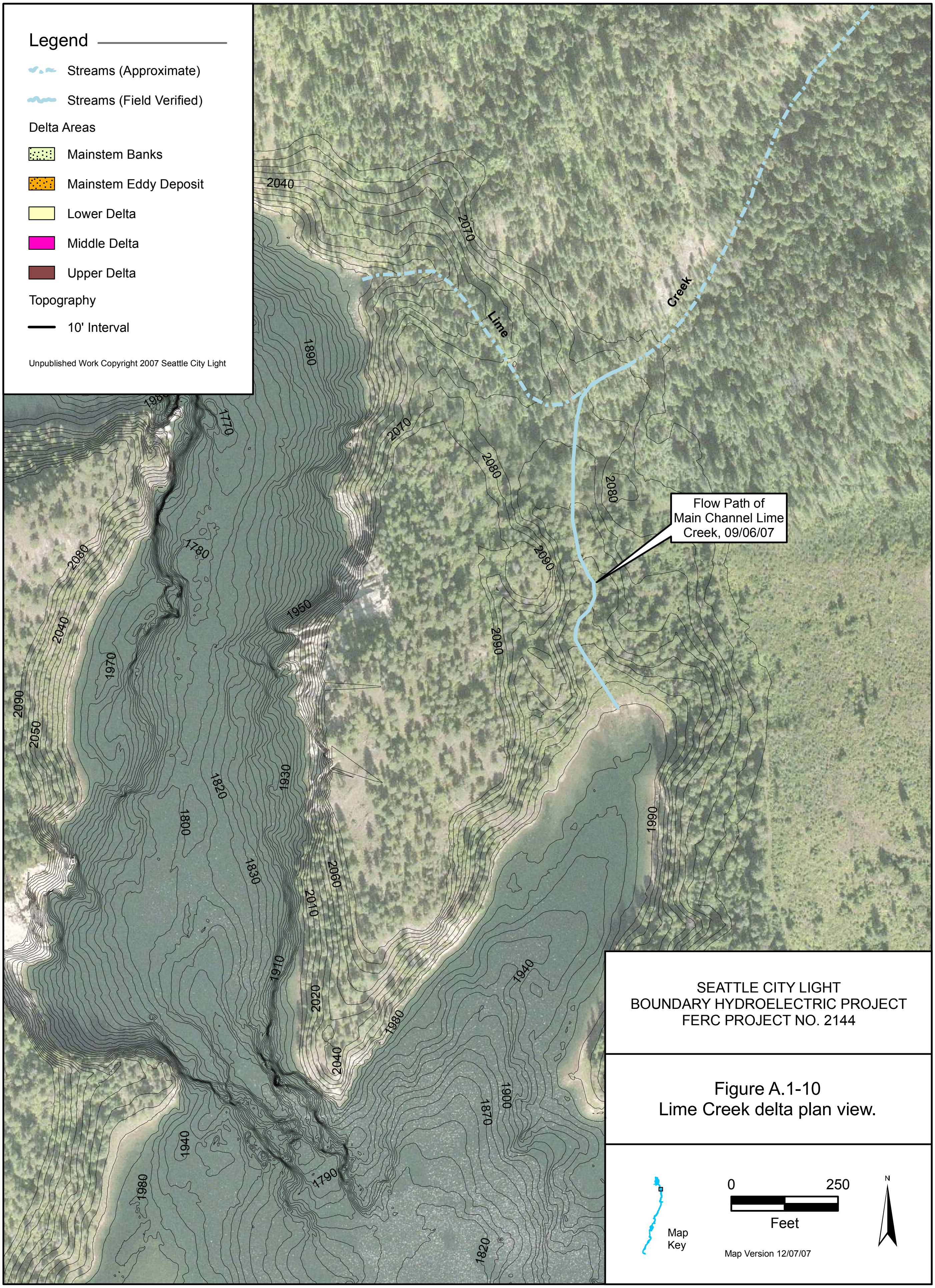

Figure A.1-10
Lime Creek delta plan view.

Appendix 2. Tributary Delta Temperature Monitoring Results for July 2007 through Early October 2007

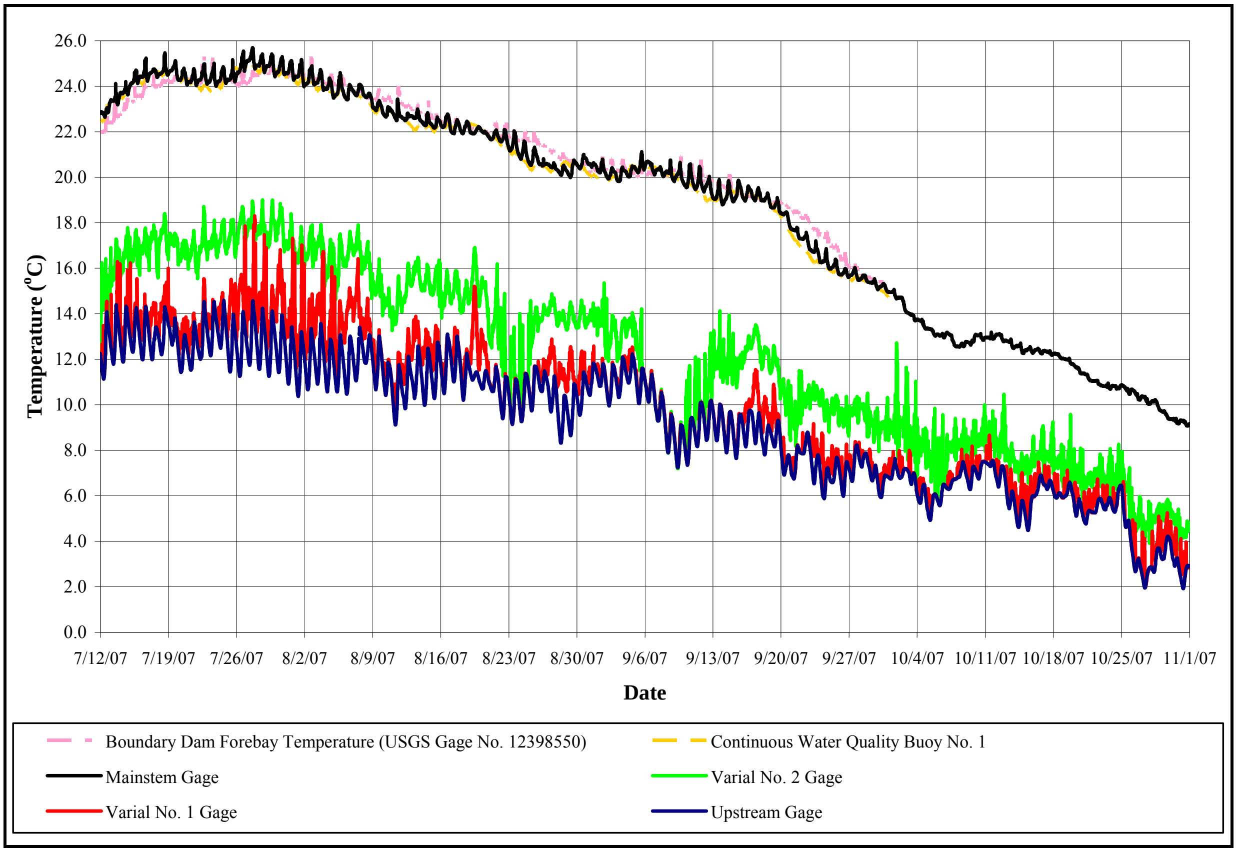

Figure A.2-1. Slate Creek continuous temperature data from September 12 through October 31, 2007.

NOTE: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report.

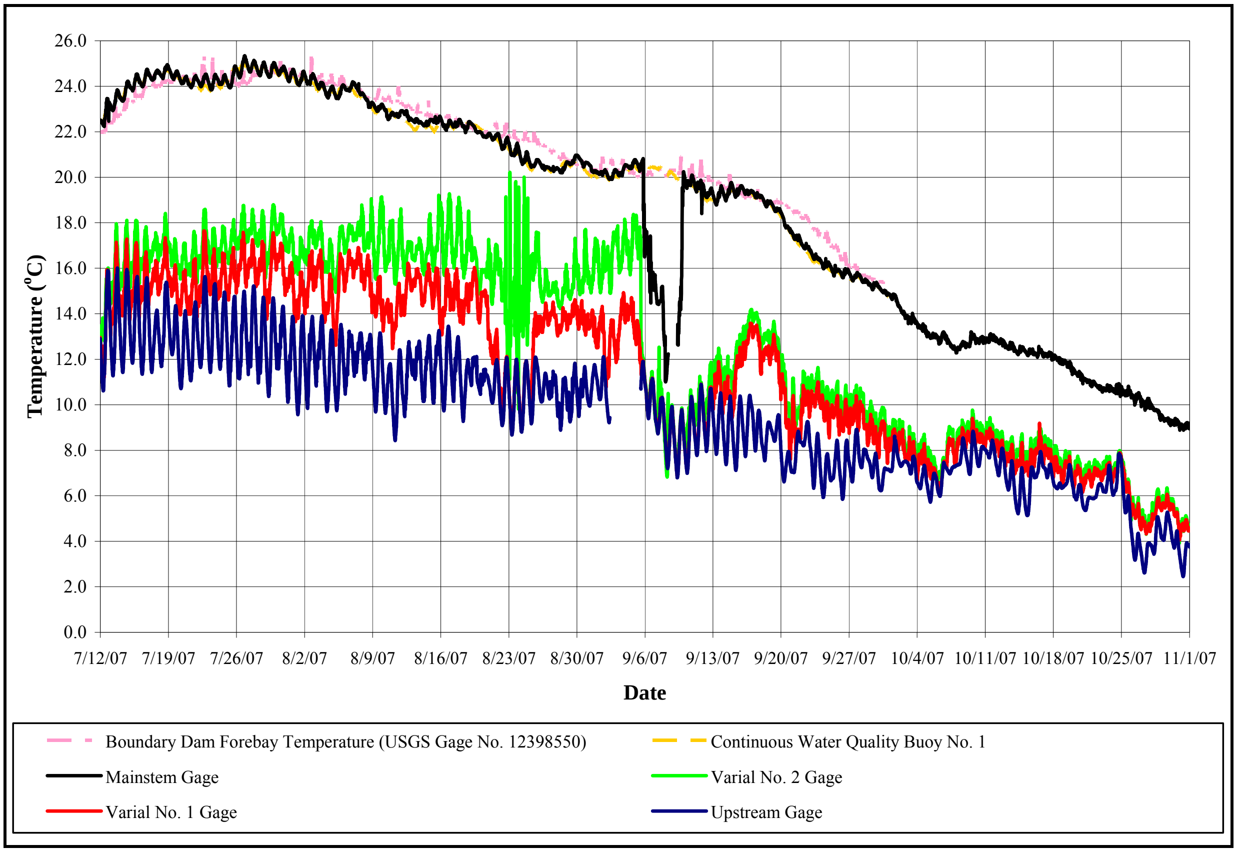

Figure A.2-2. Flume Creek continuous temperature data from September 12 through October 31, 2007.

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report**.**

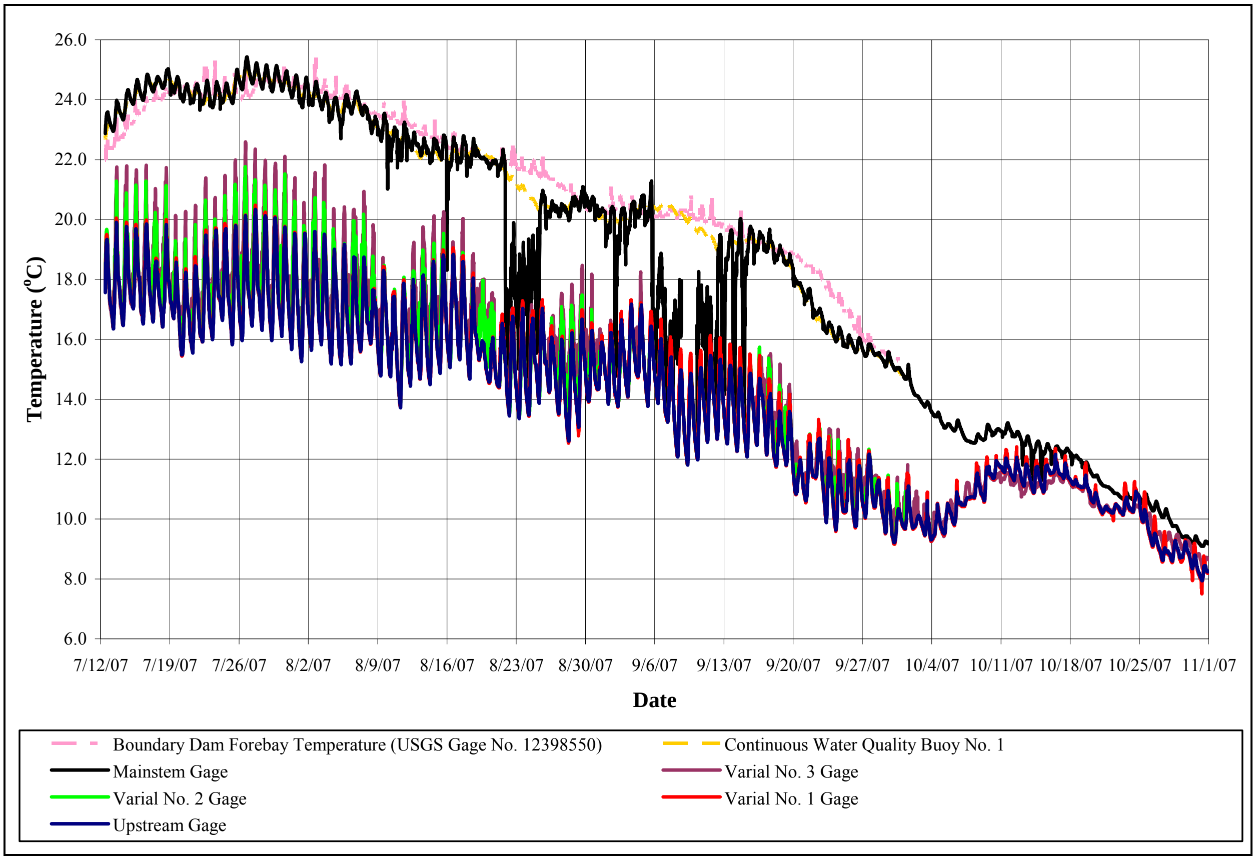

Figure A.2-3. Sullivan Creek continuous temperature data from September 12 through October 31, 2007.

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report.

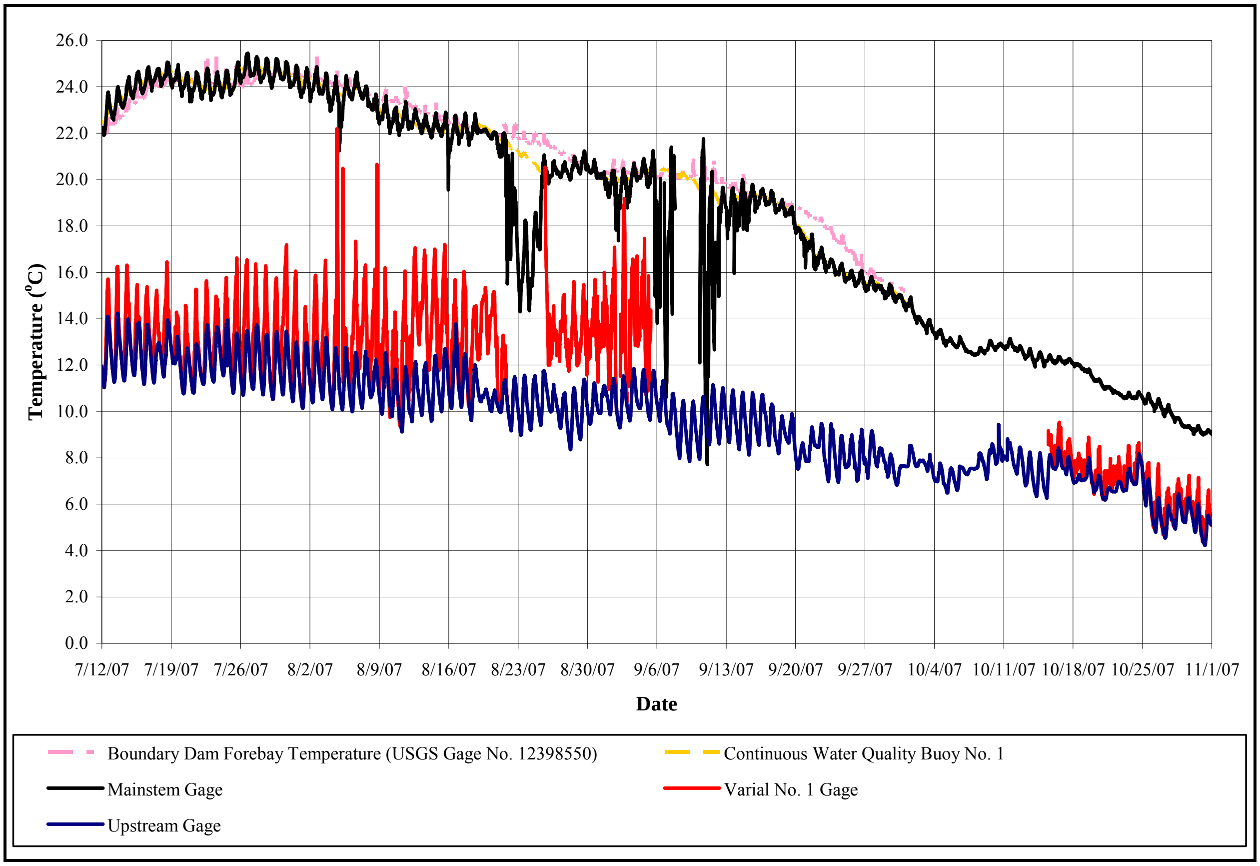

Figure A.2-4. Linton Creek continuous temperature data from September 12 through October 31, 2007.

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1-31, 2007 at the time of this report.

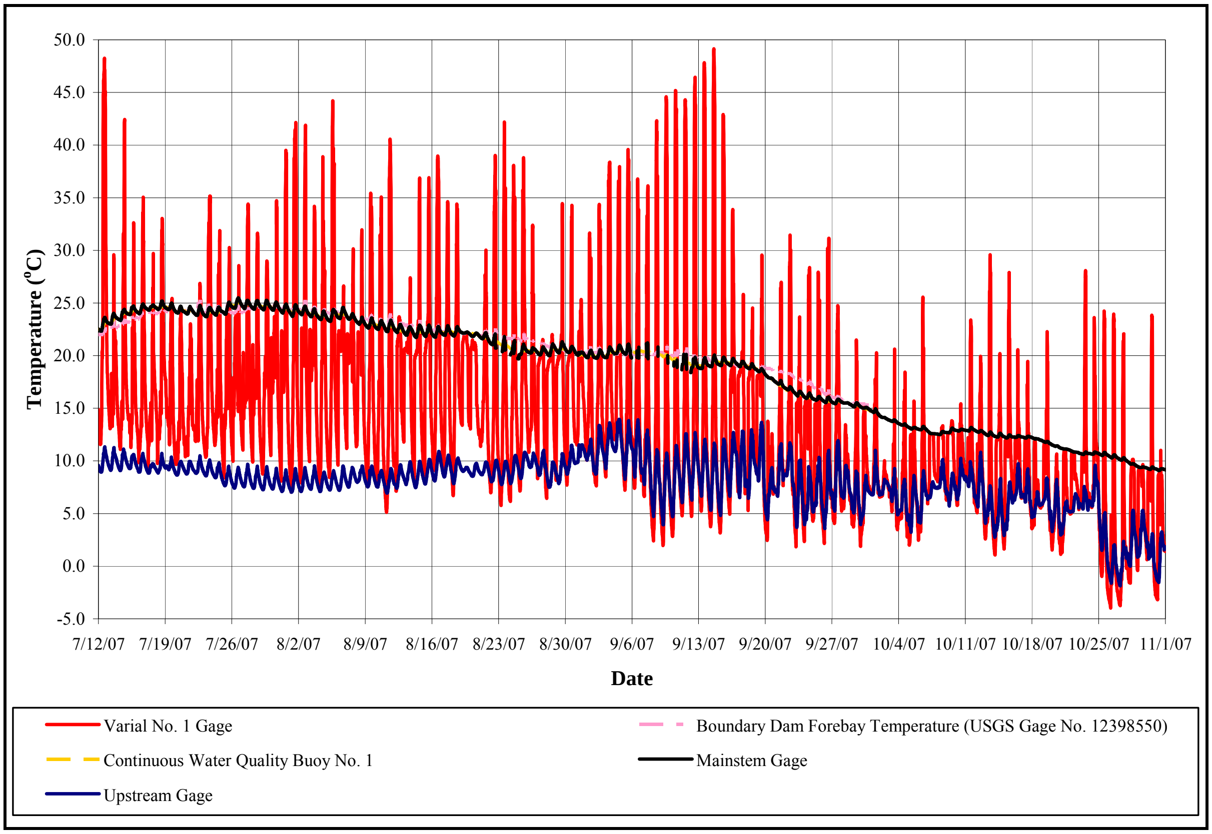

Figure A.2-5. Pocahontas Creek continuous temperature data from September 12 through October 31, 2007.

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report.

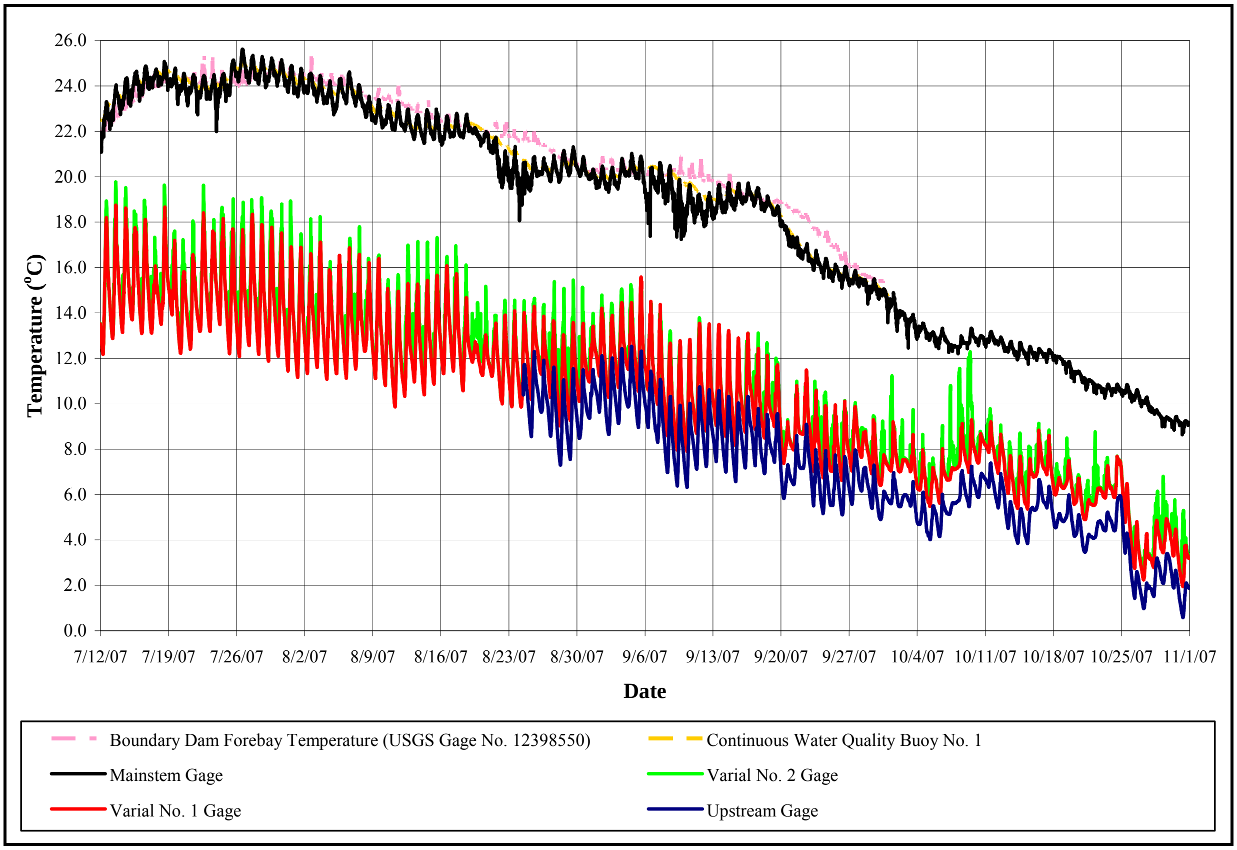

Figure A.2-6. Sweet Creek continuous temperature data from September 12 through October 31, 2007.

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report.

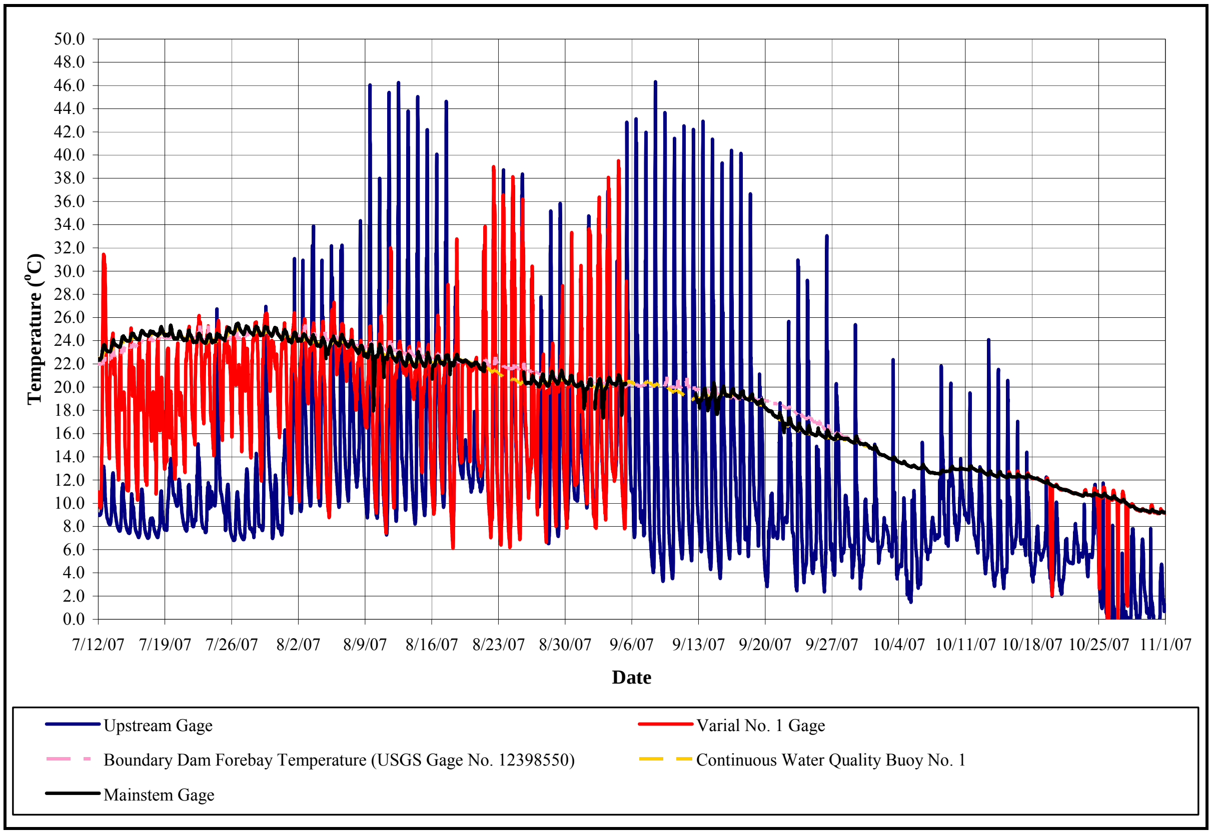

Figure A.2-7. Sand Creek continuous temperature data from September 12 through October 31, 2007

Note: Data from USGS 12398550 and Continuous Water Quality Buoy No. 1 were not available from October 1 to 31, 2007, at the time of this report.

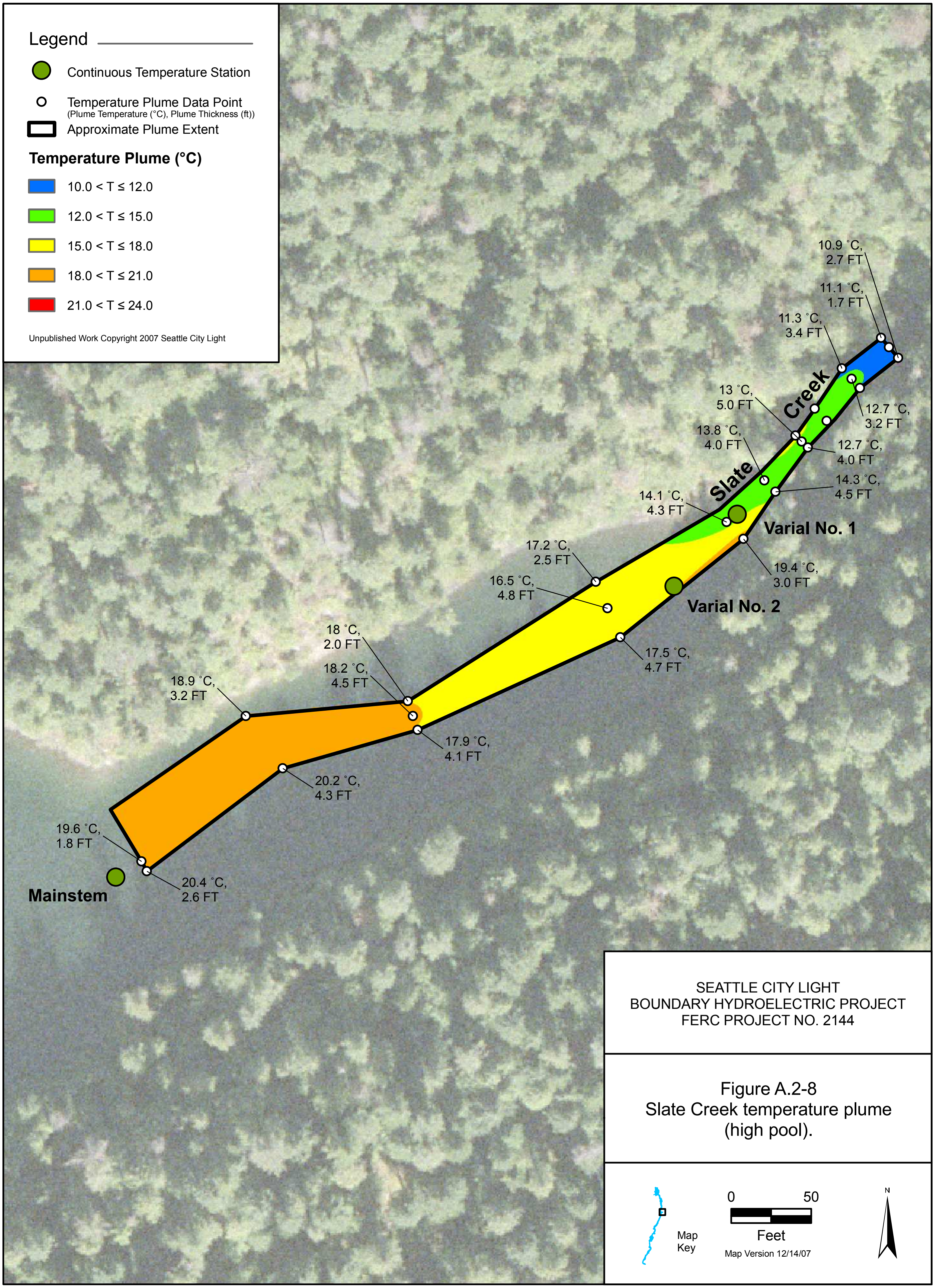

Figure A.2-8
Slate Creek temperature plume
(high pool).

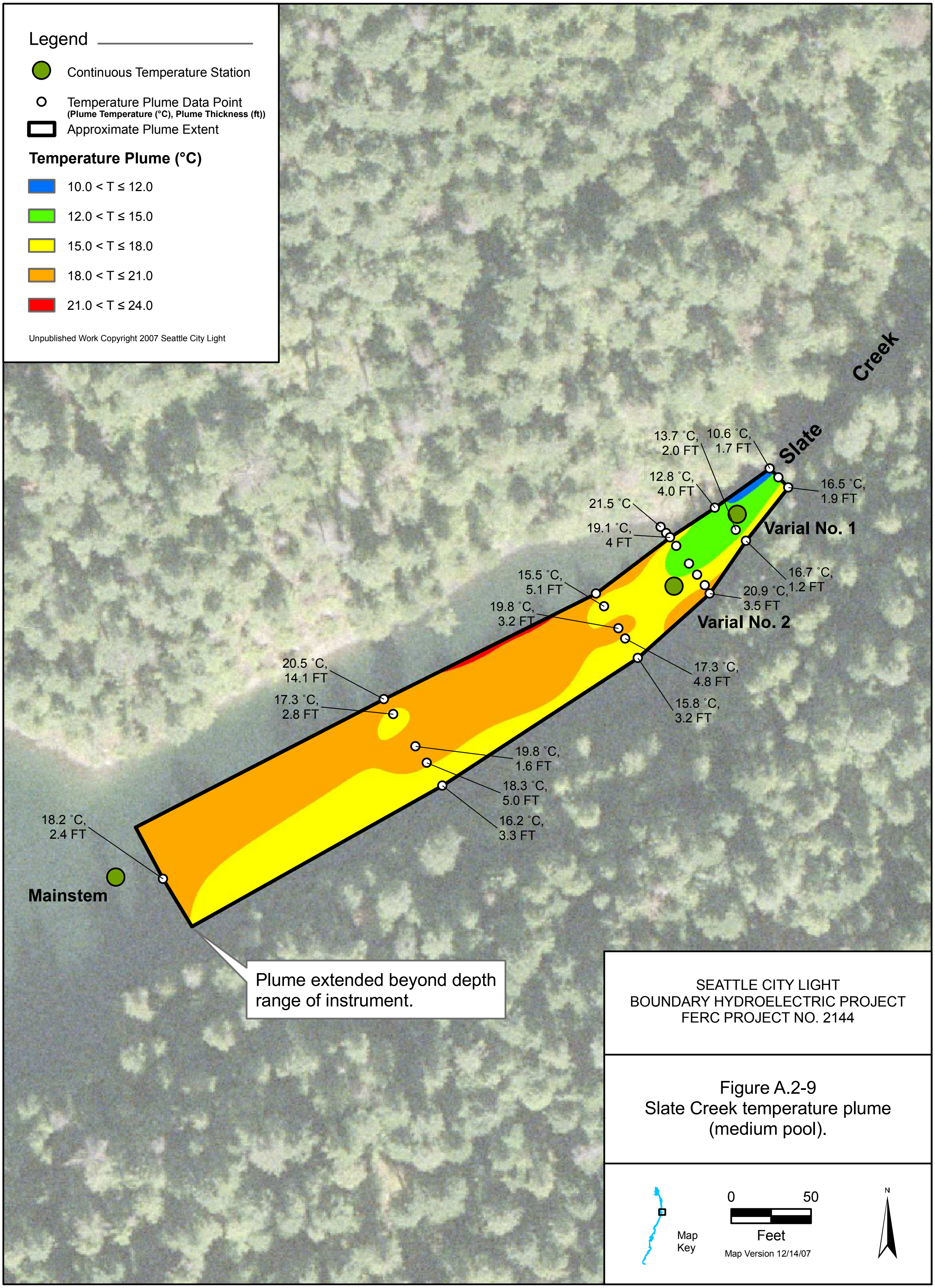

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Figure A.2-9
Slate Creek temperature plume (medium pool).

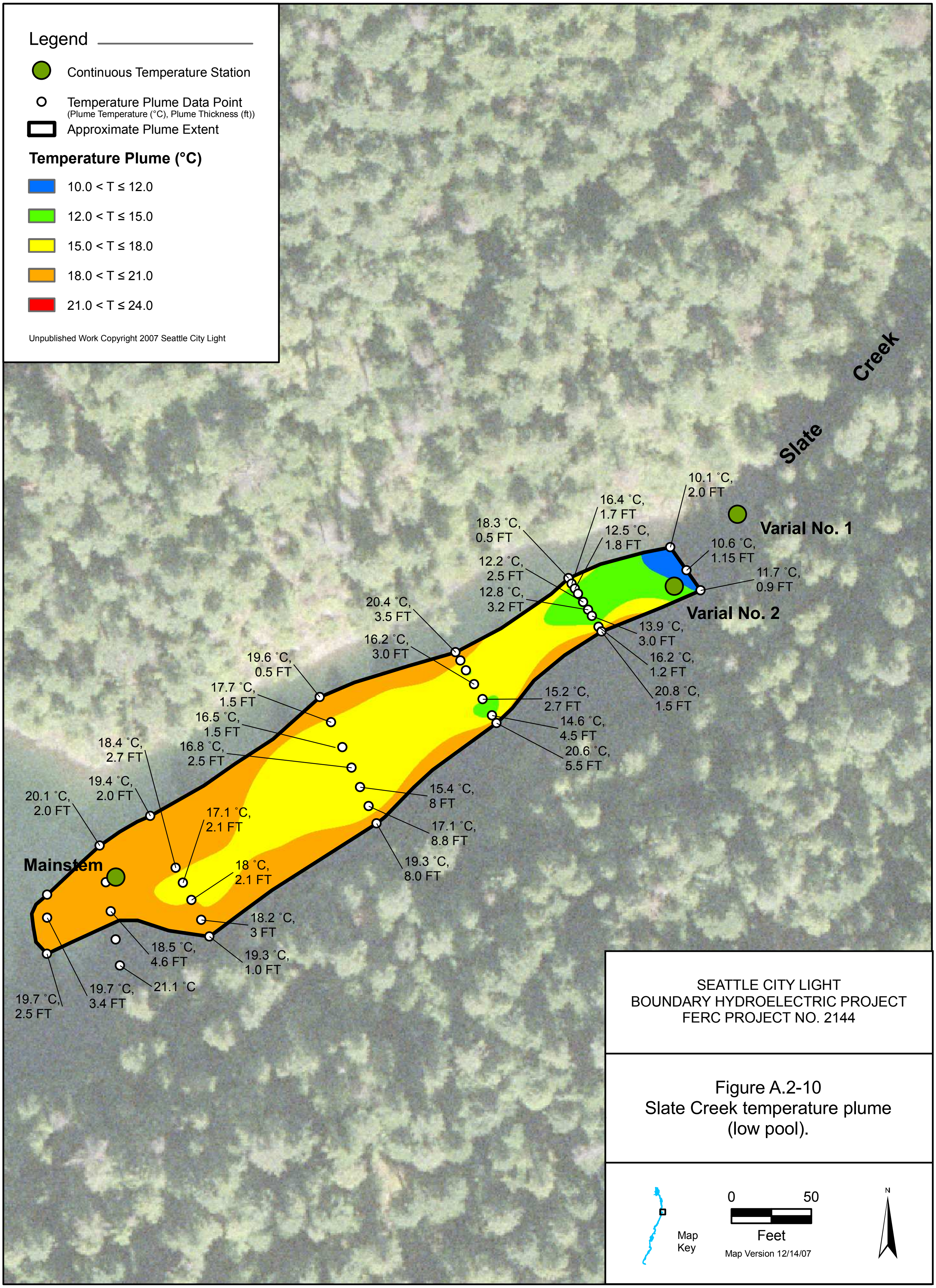
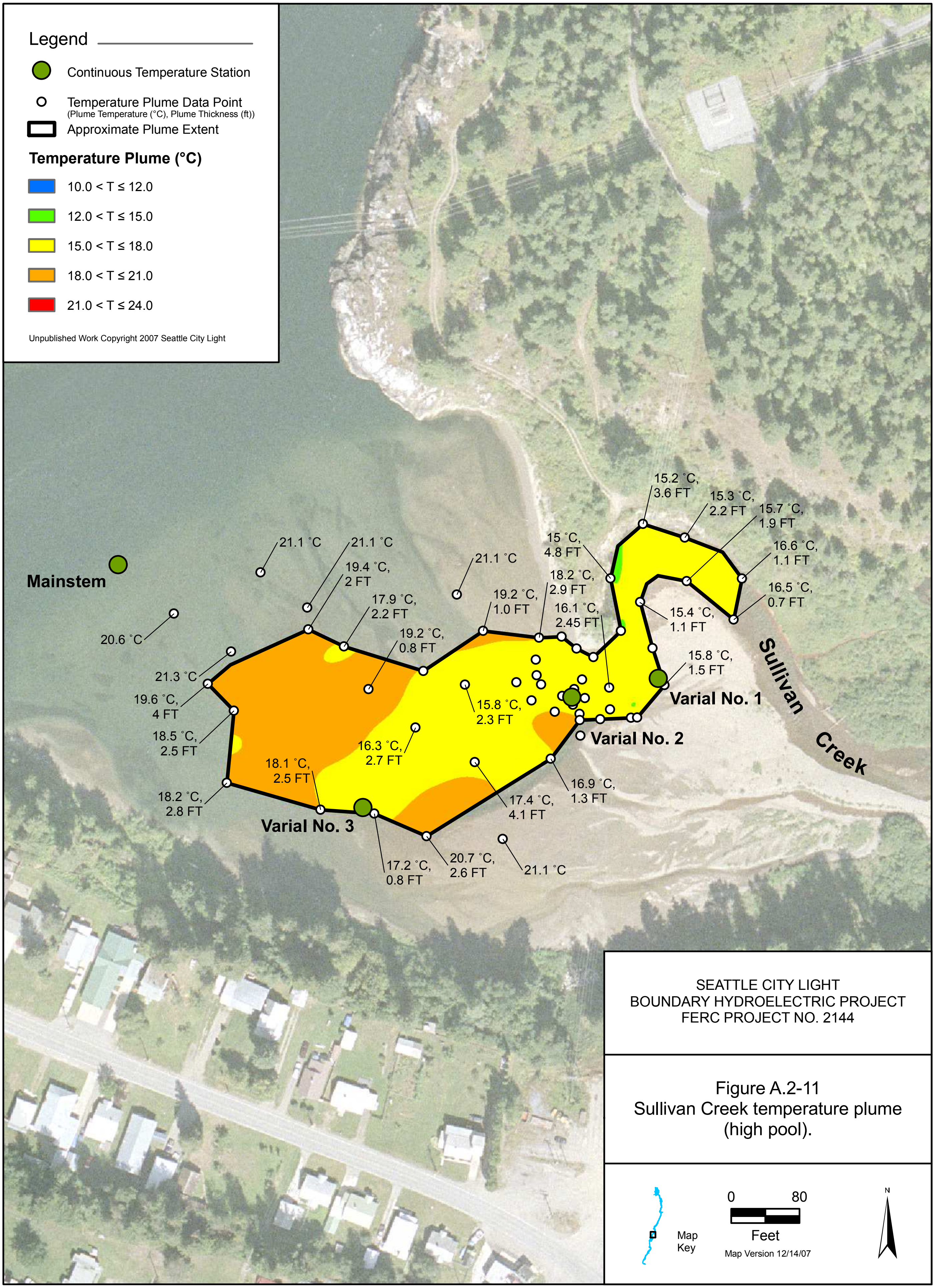


Figure A.2-10
Slate Creek temperature plume
(low pool).



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FERC PROJECT NO. 2144

Figure A.2-11
Sullivan Creek temperature plume (high pool).

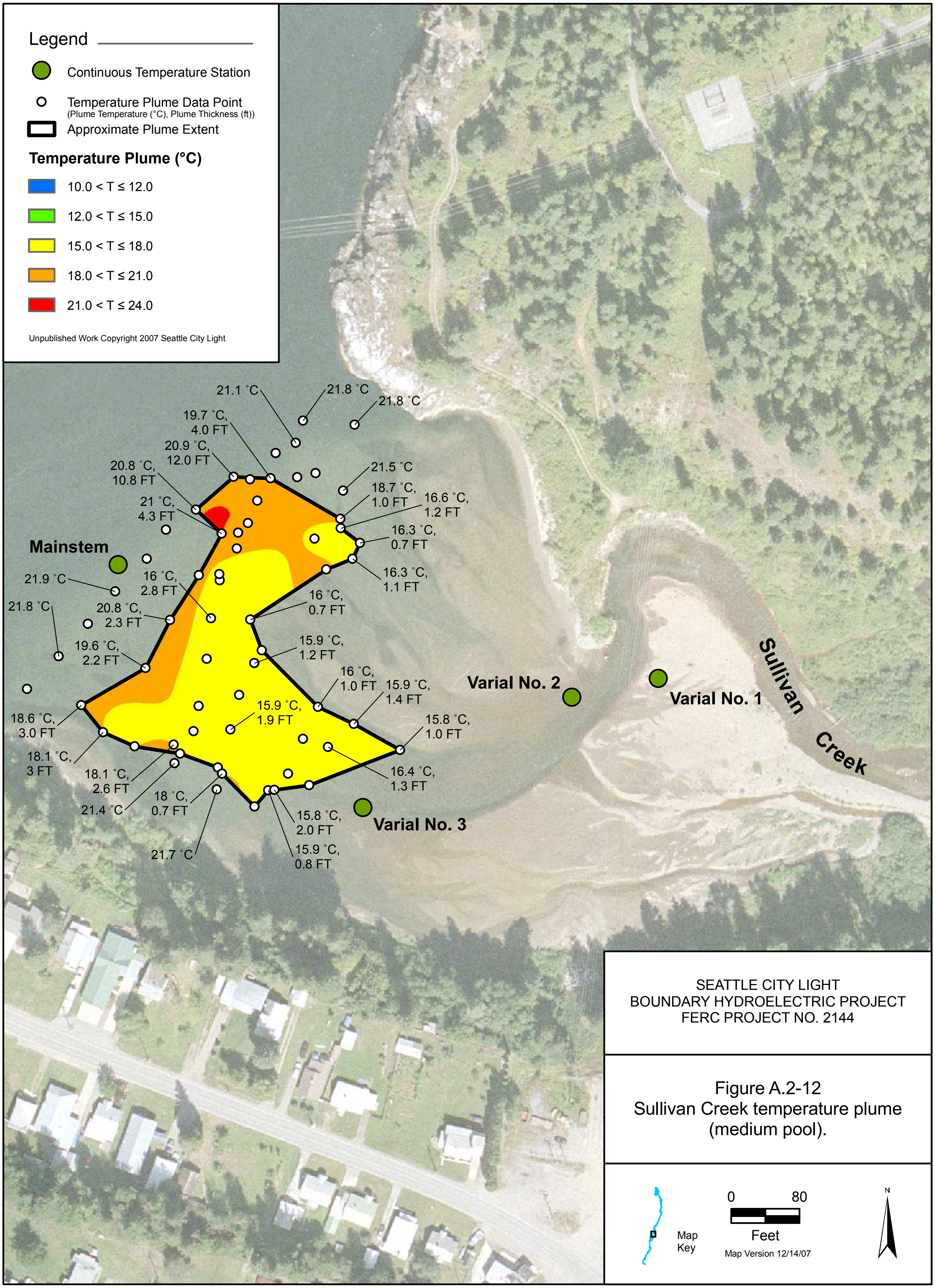

Figure A.2-12
Sullivan Creek temperature plume (medium pool).

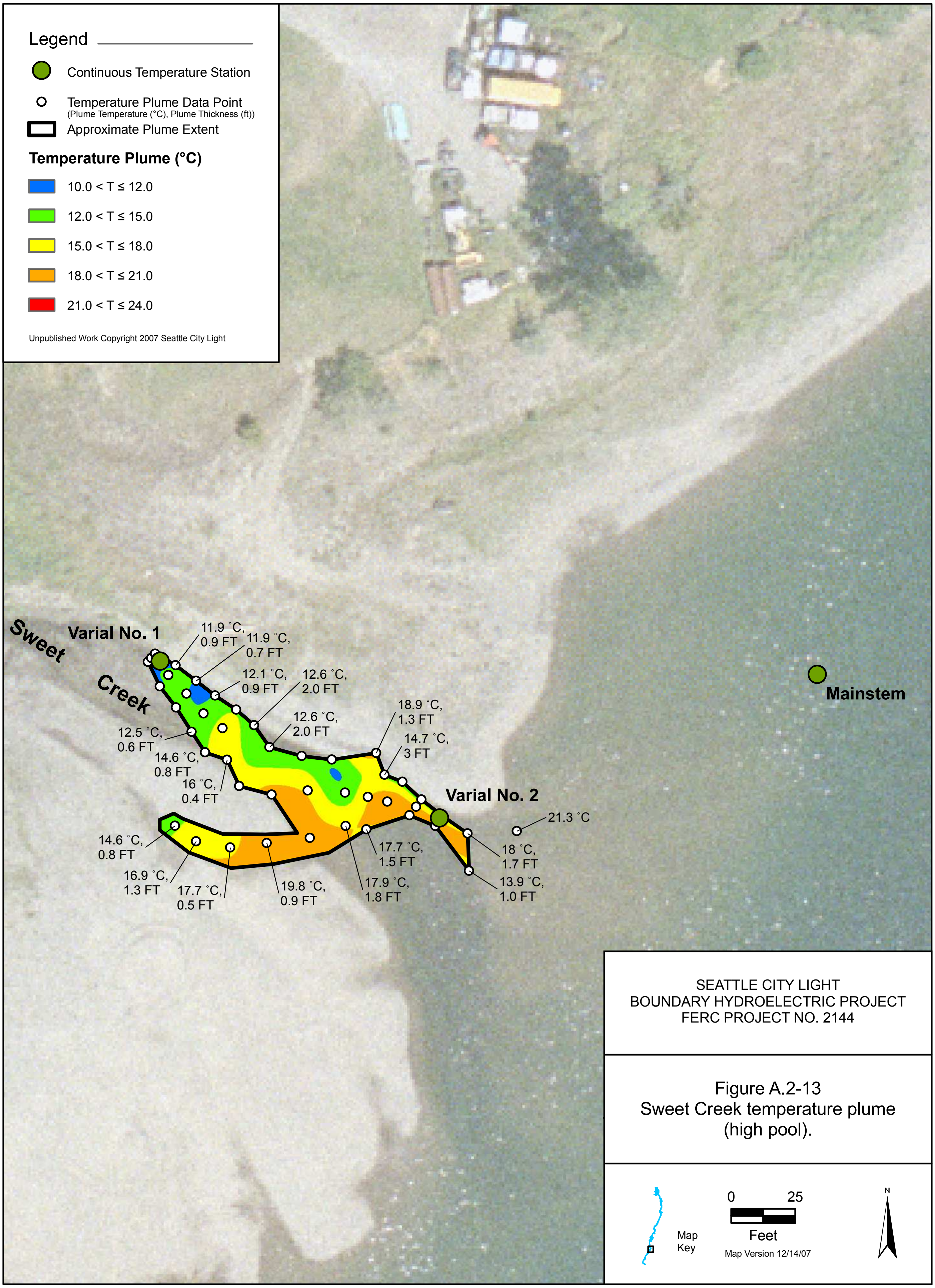

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Figure A.2-13
Sweet Creek temperature plume (high pool).

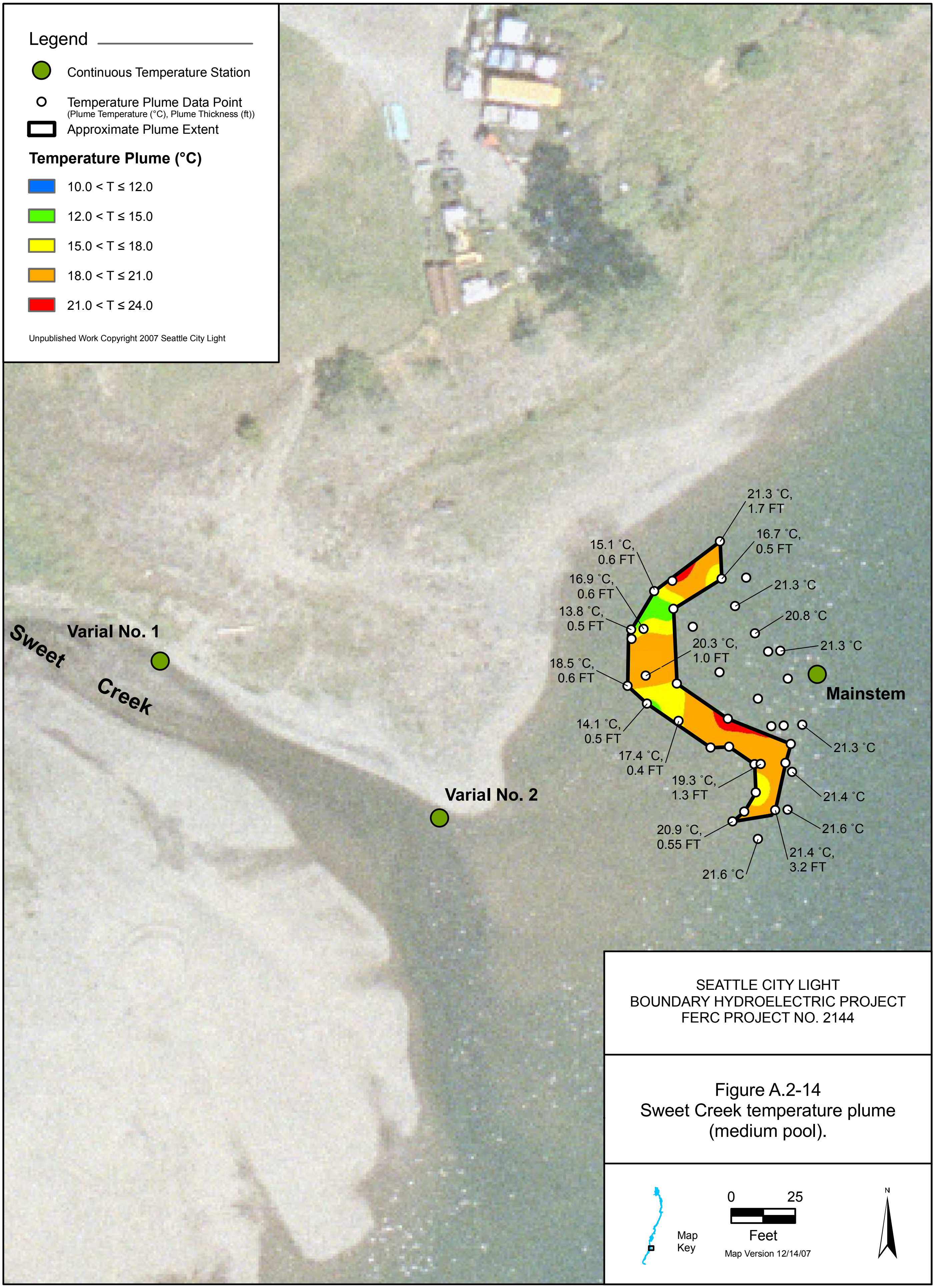


Figure A.2-14
Sweet Creek temperature plume (medium pool).

Appendix 3. Tributary Delta Bed Material Sampling Results

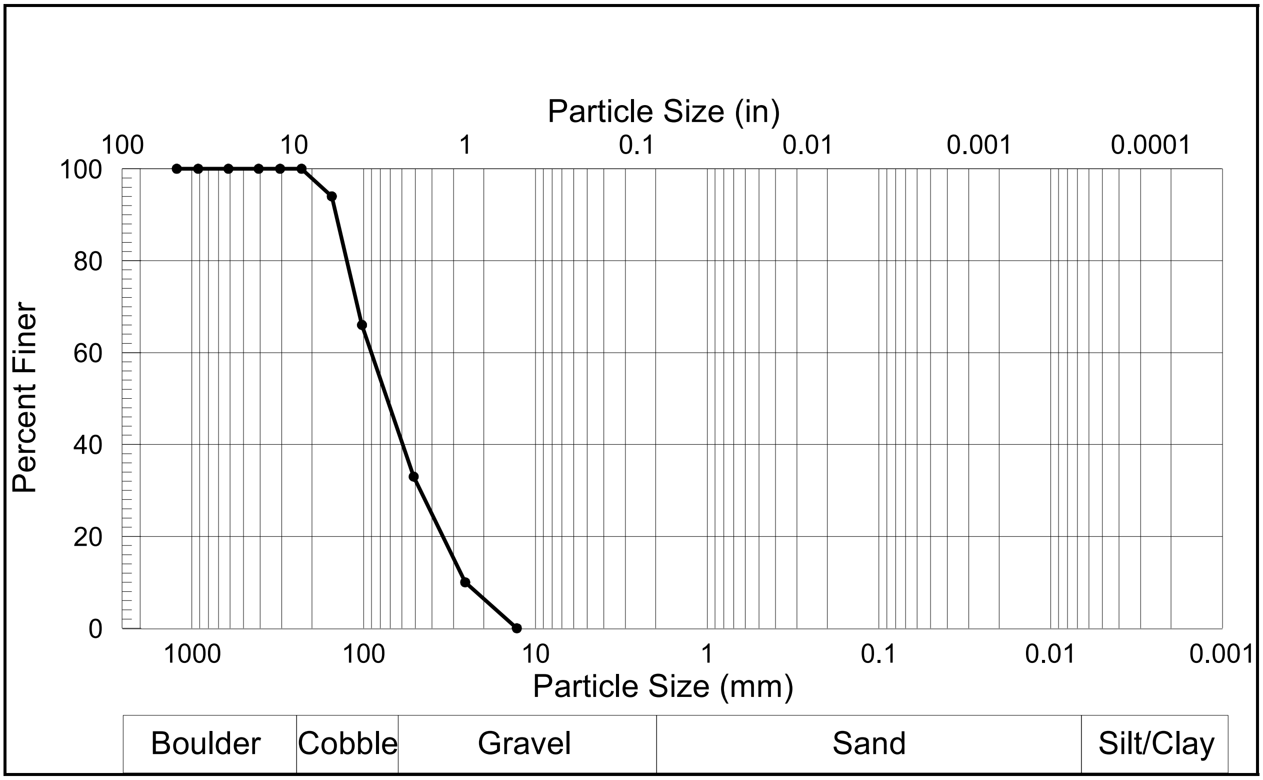


Figure A.3-1. Particle size distribution for Slate Creek sample BL-1.1.

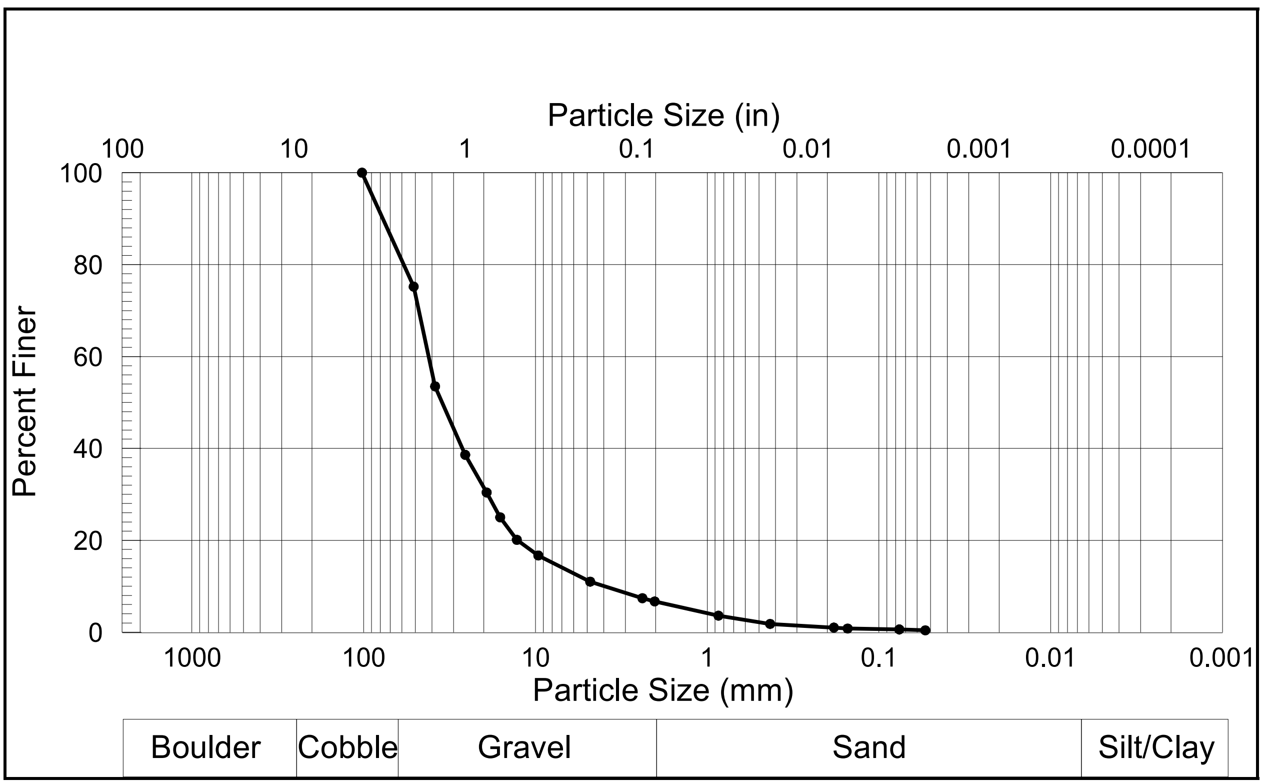


Figure A.3-2. Particle size distribution for Slate Creek sample BL-1.2.

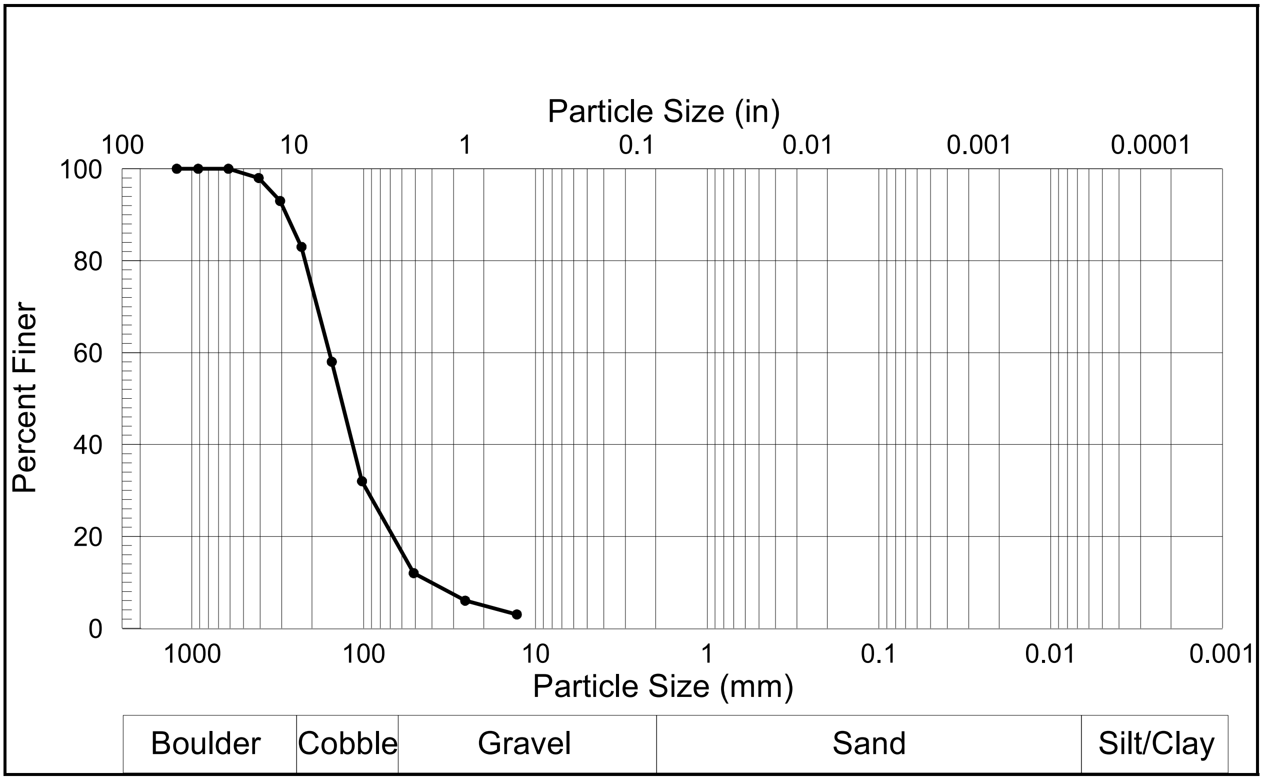


Figure A.3-3. Particle size distribution for Slate Creek sample BL-2.

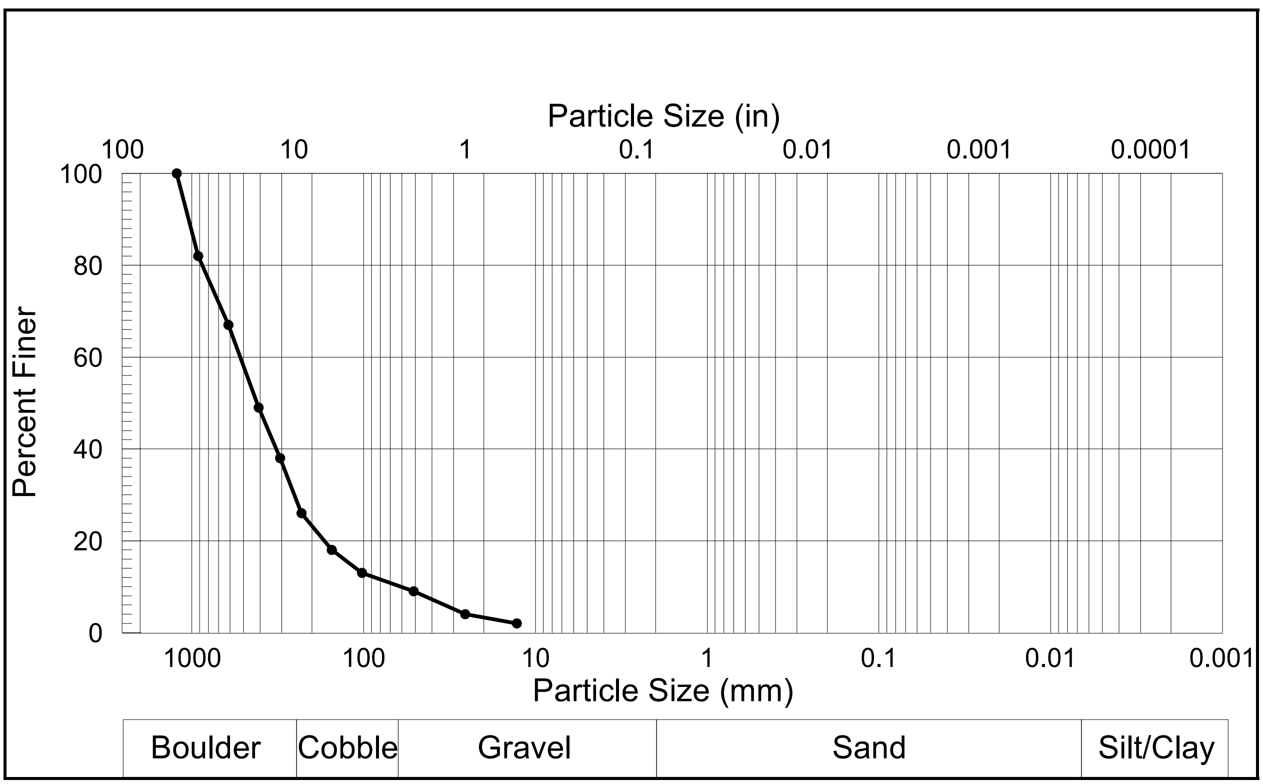


Figure A.3-4. Particle size distribution for Slate Creek sample BM-3.

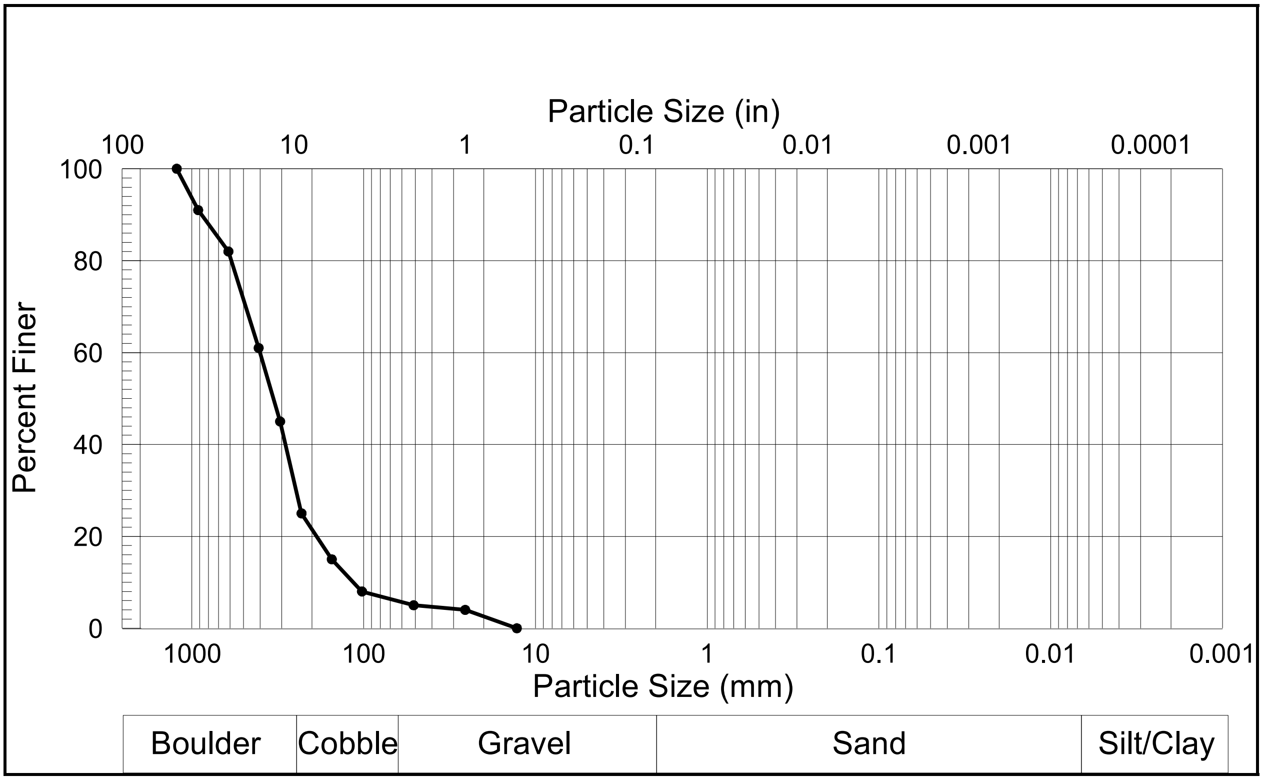


Figure A.3-5. Particle size distribution for Slate Creek sample BM-4.

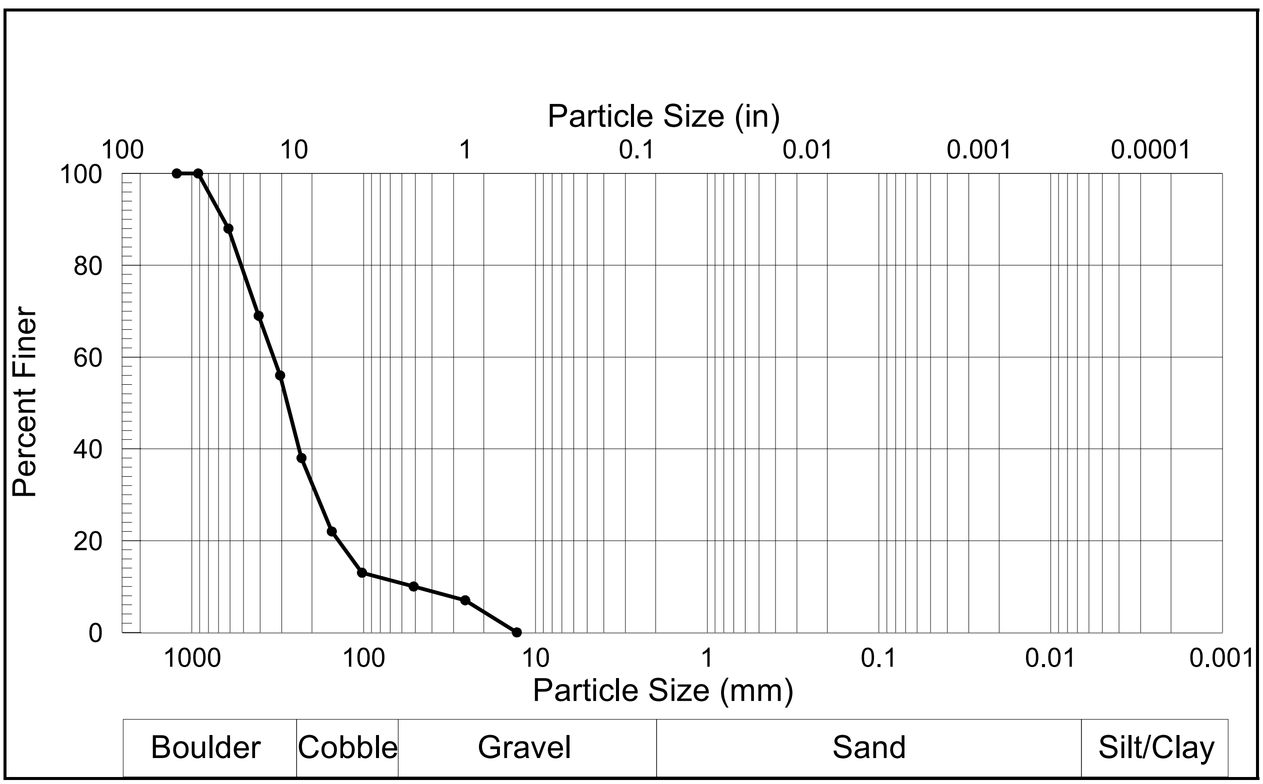


Figure A.3-6. Particle size distribution for Slate Creek sample BM-5.

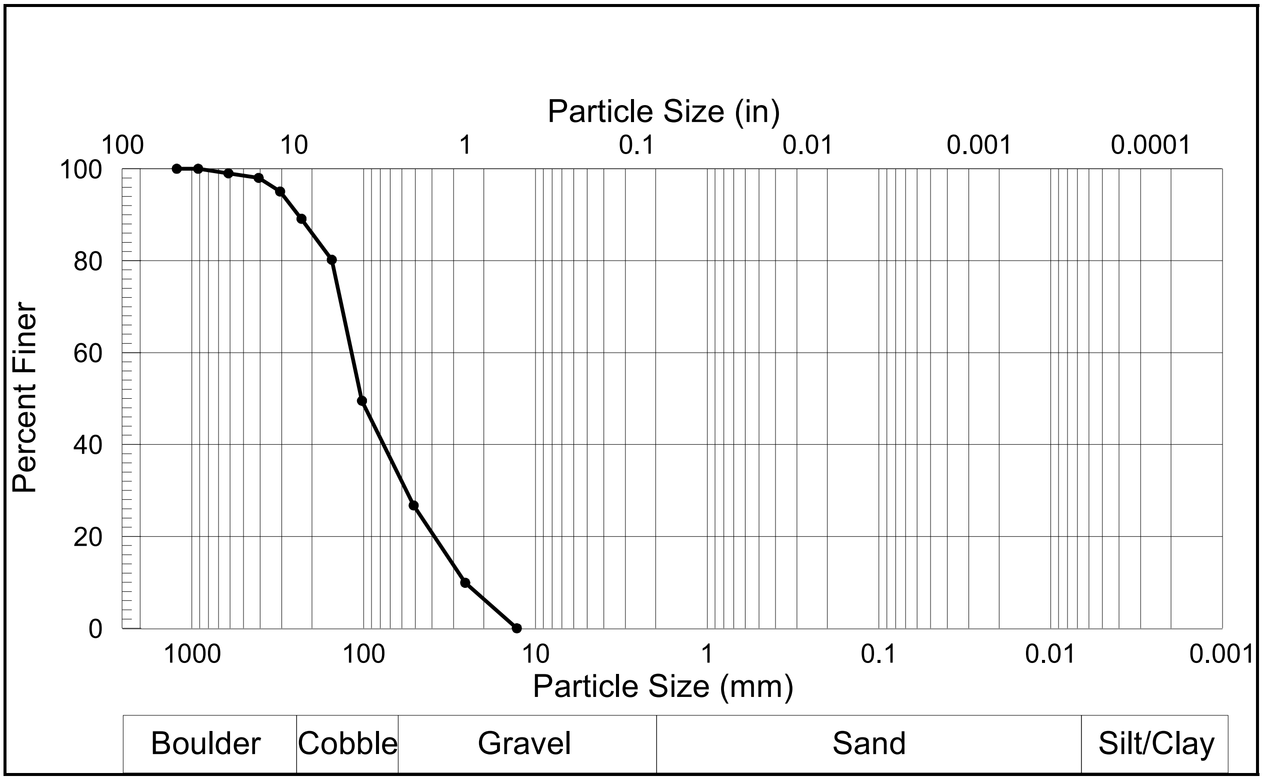


Figure A.3-7. Particle size distribution for Slate Creek sample BM-6.

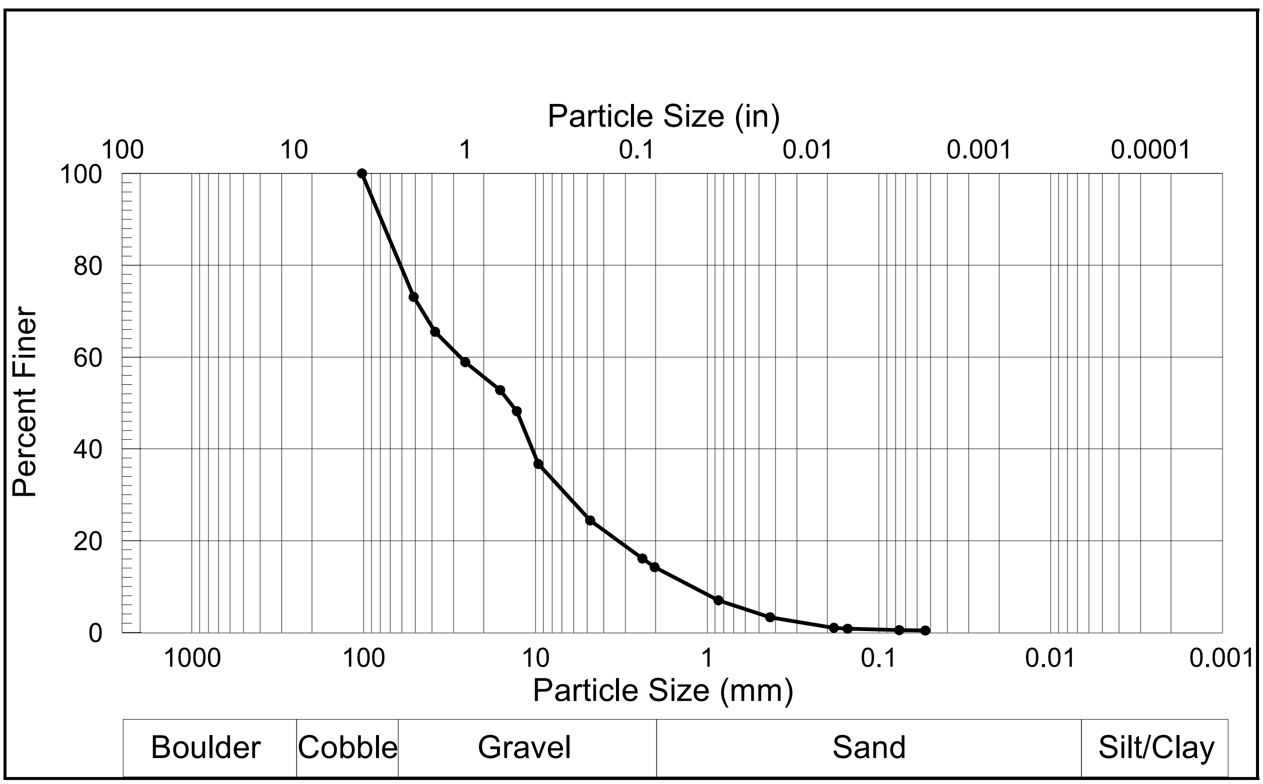


Figure A.3-8. Particle size distribution for Slate Creek sample BM-7.

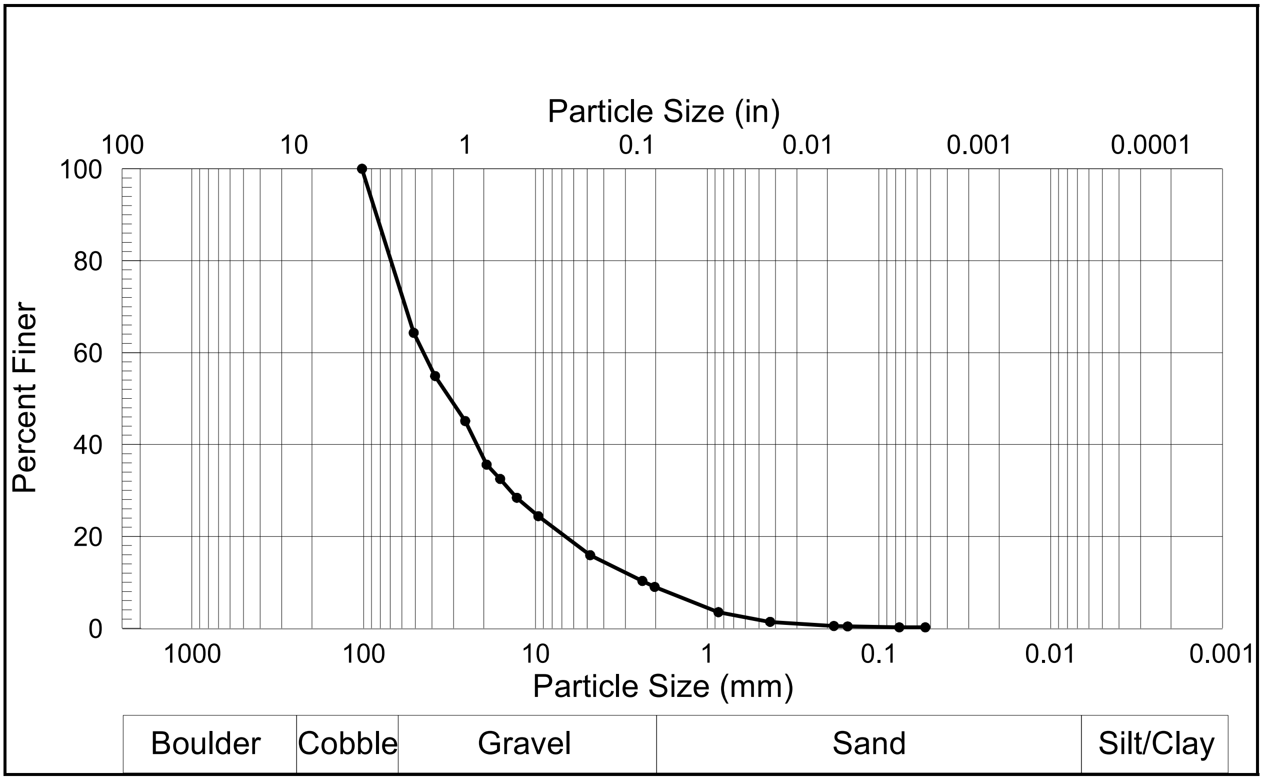


Figure A.3-9. Particle size distribution for Slate Creek sample BM-8.

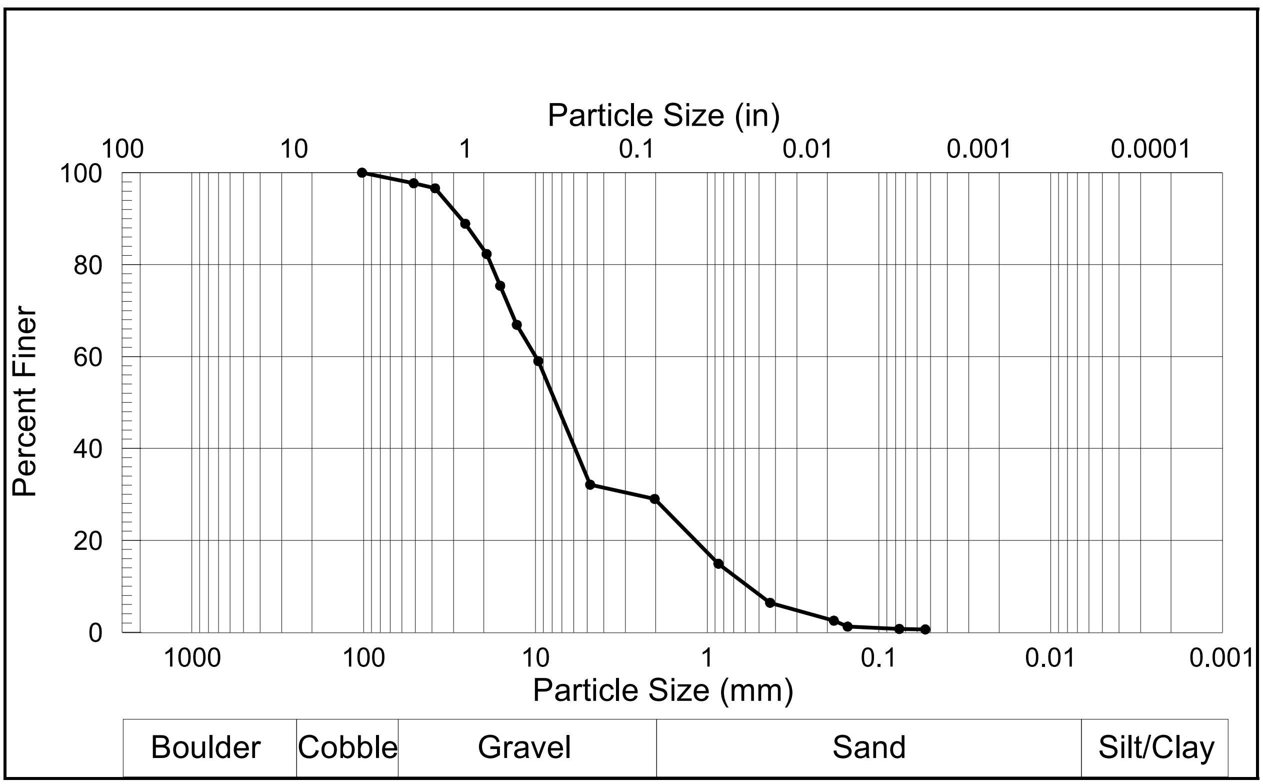


Figure A.3-10. Particle size distribution for Slate Creek sample BM-9.

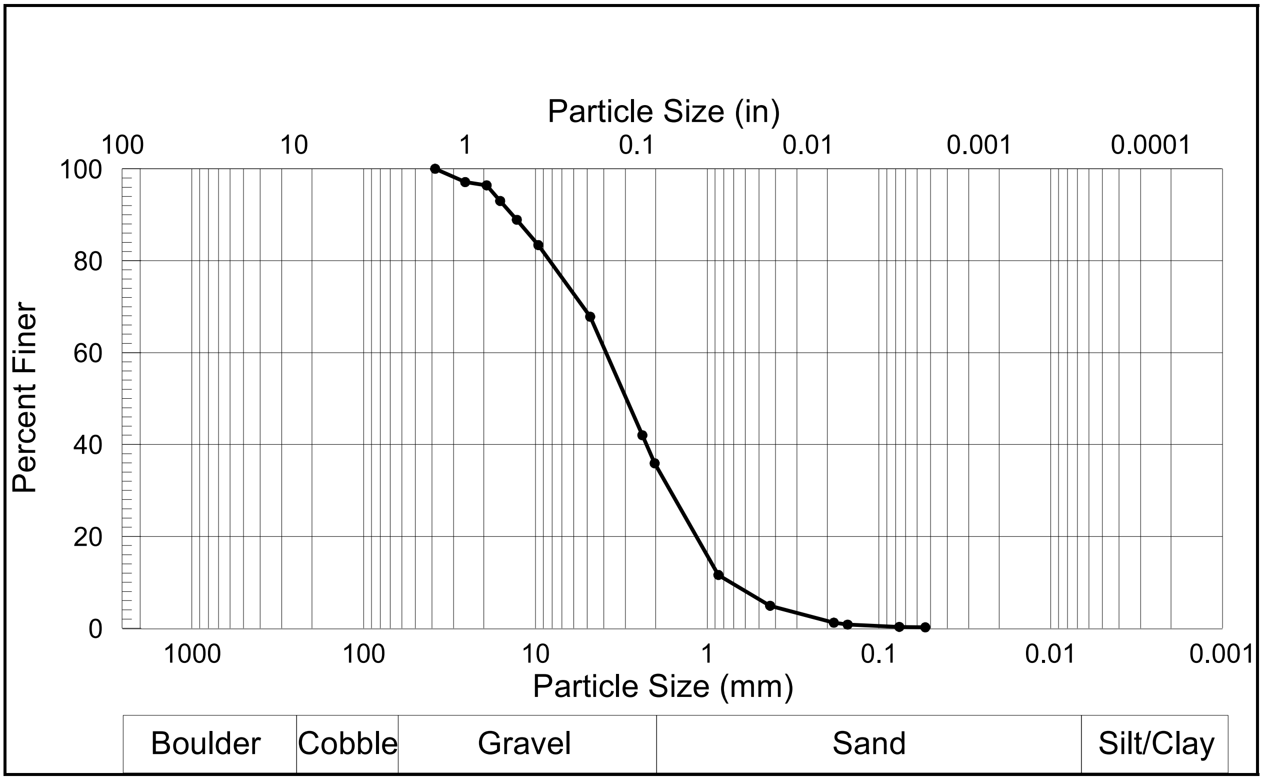


Figure A.3-11. Particle size distribution for Slate Creek sample BM-10.

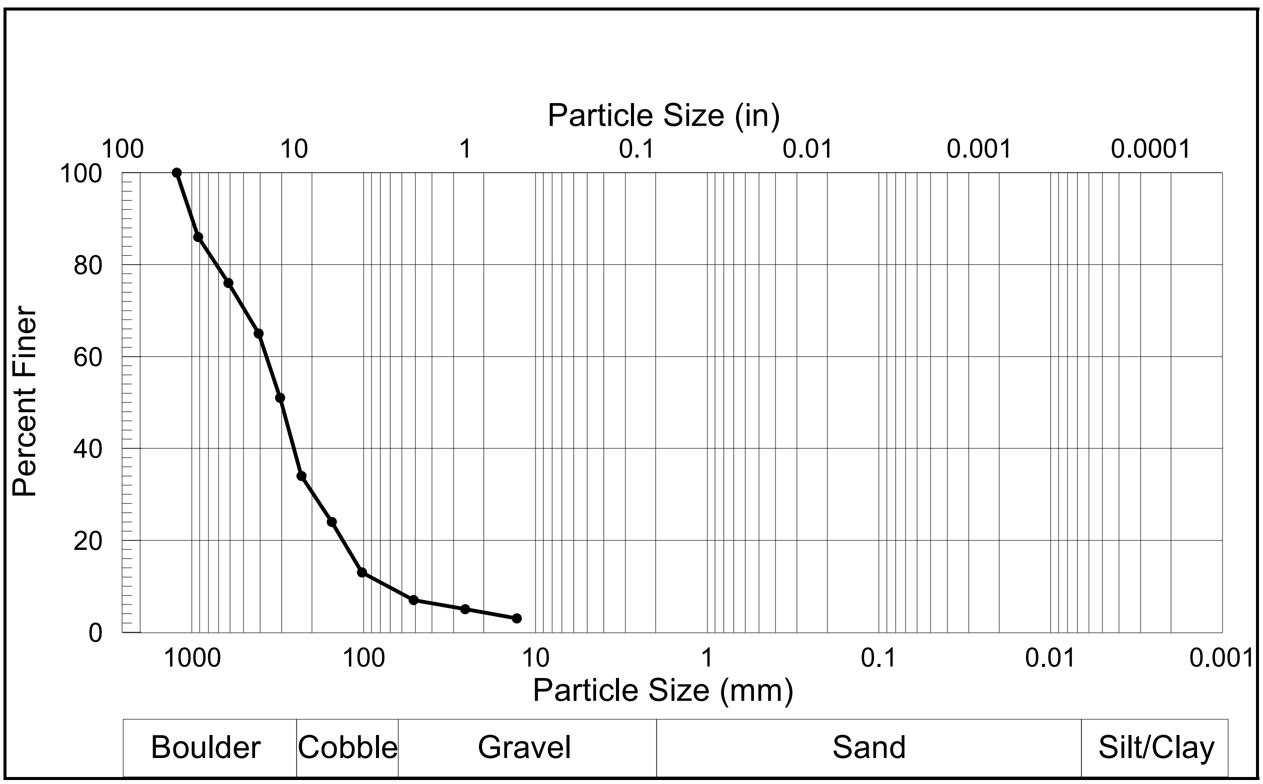


Figure A.3-12. Particle size distribution for Flume Creek sample BM-1.

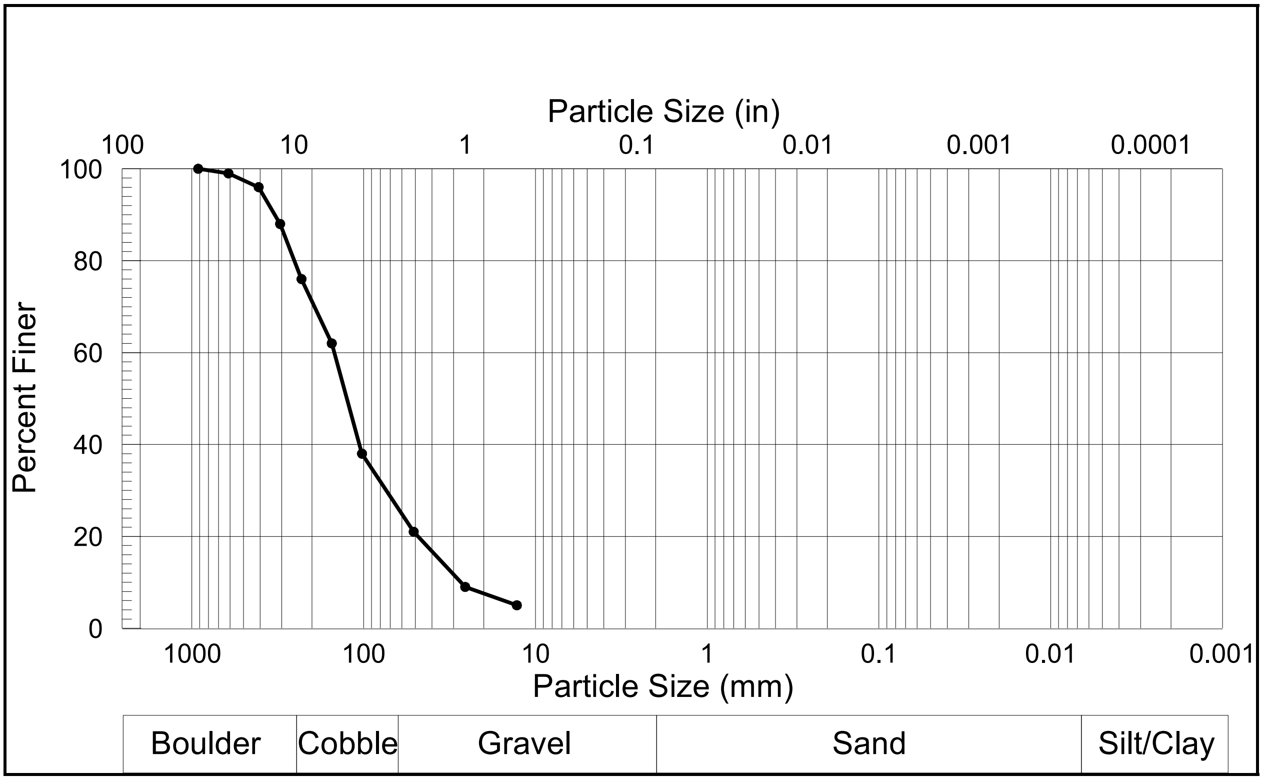


Figure A.3-13. Particle size distribution for Flume Creek sample BM-2.

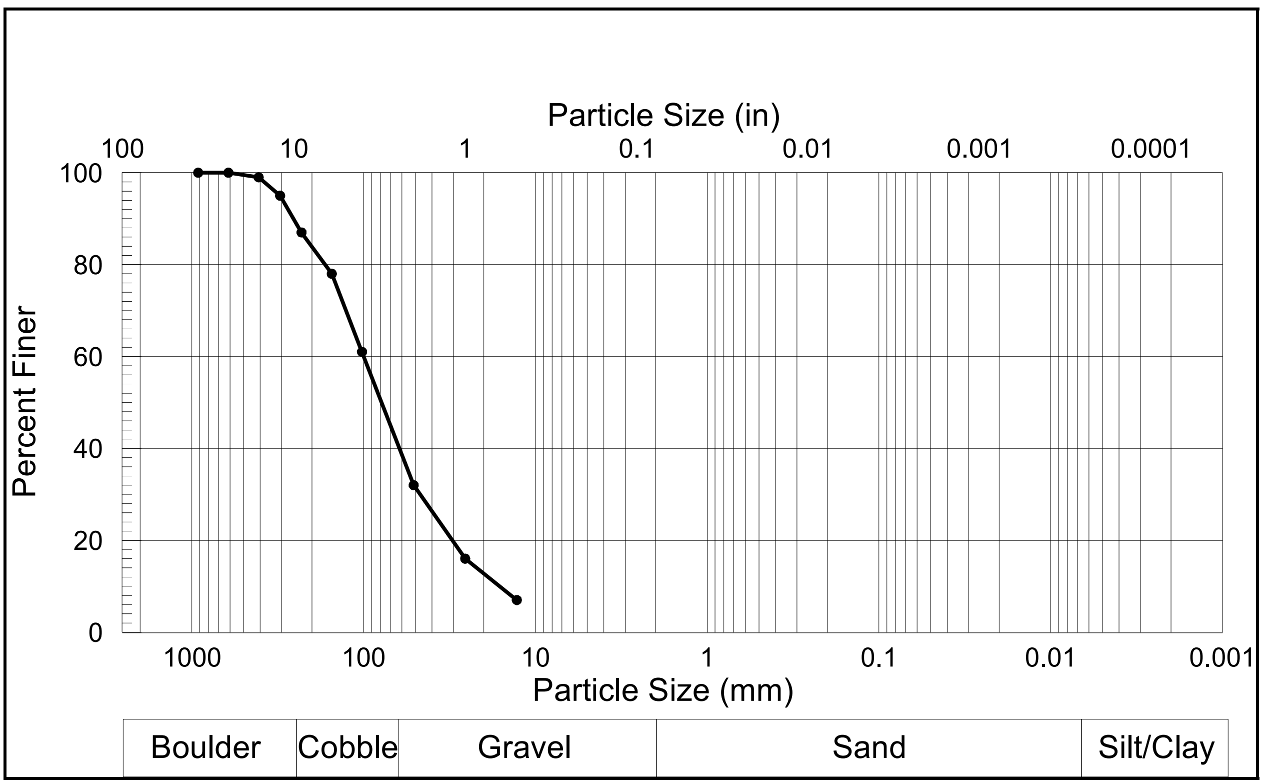


Figure A.3-14. Particle size distribution for Flume Creek sample BM-3.

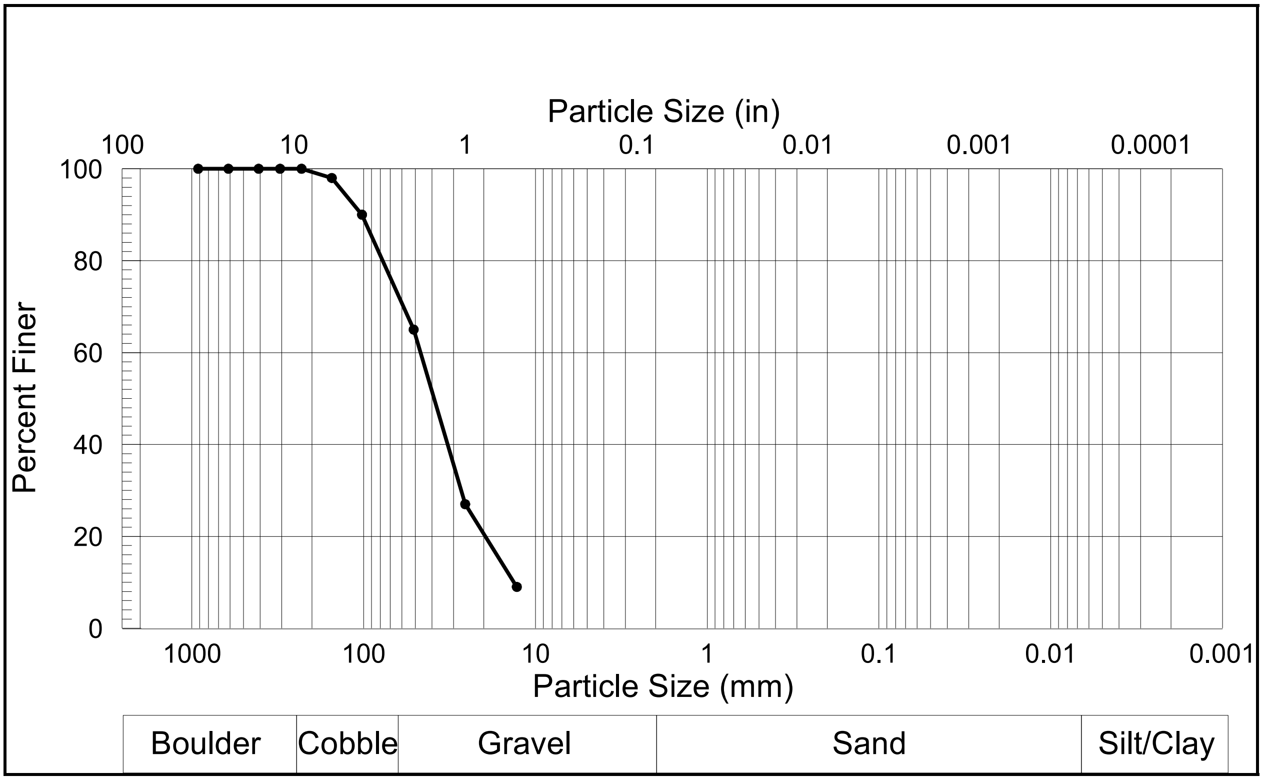


Figure A.3-15. Particle size distribution for Flume Creek sample BM-4.

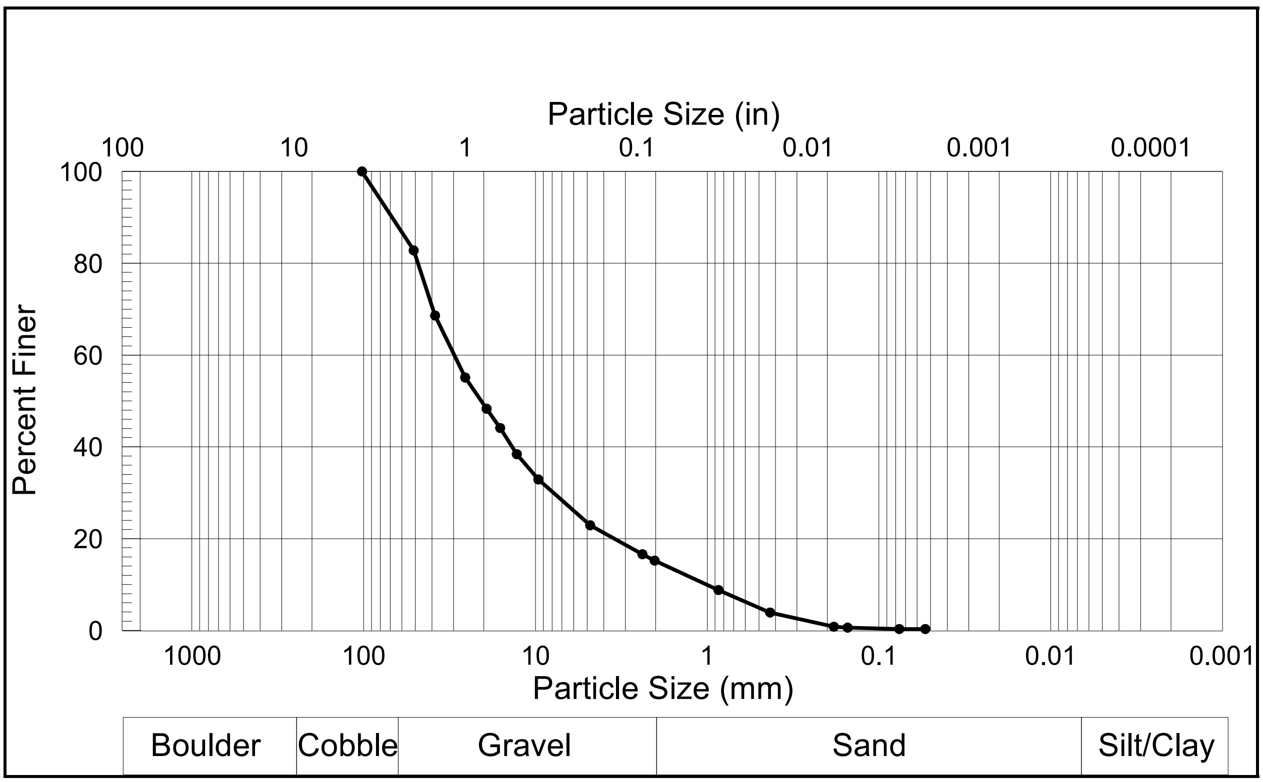


Figure A.3-16. Particle size distribution for Flume Creek sample BM-5.

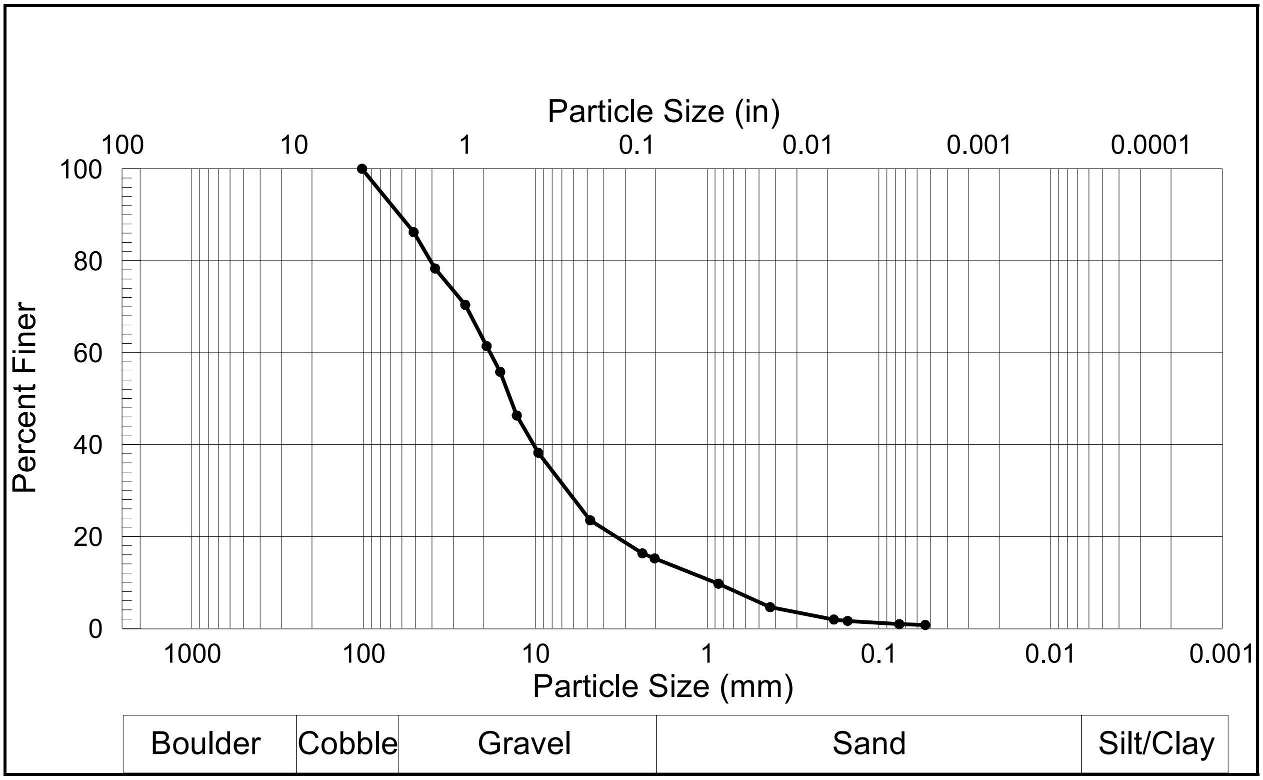


Figure A.3-17. Particle size distribution for Flume Creek sample BM-6.

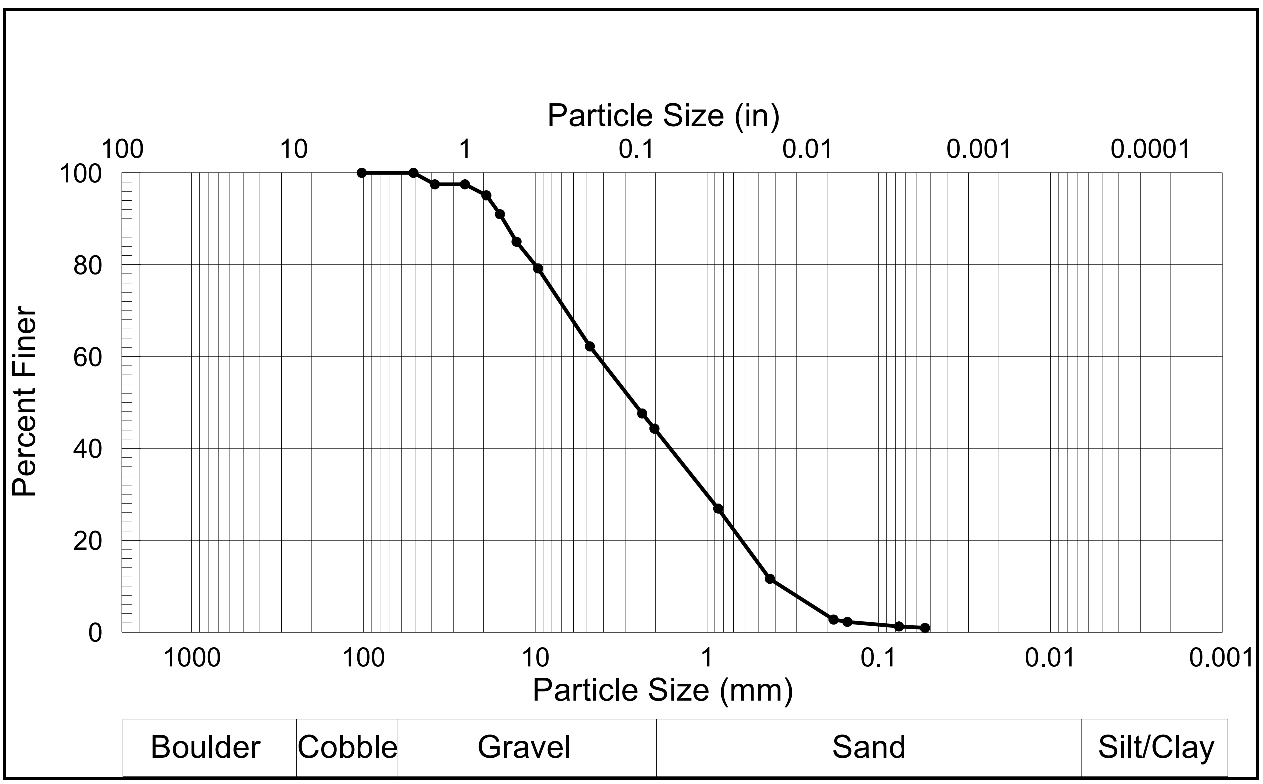


Figure A.3-18. Particle size distribution for Flume Creek sample BM-7.

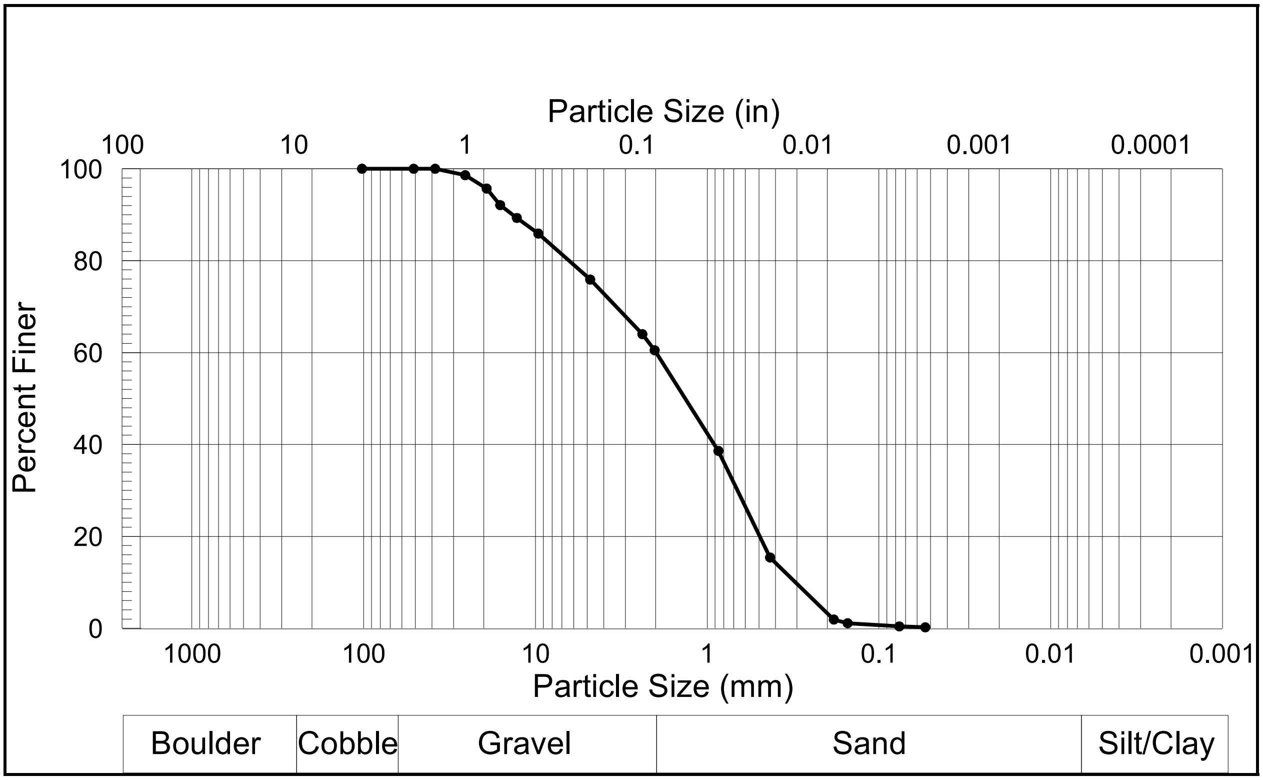


Figure A.3-19. Particle size distribution for Flume Creek sample BM-8.

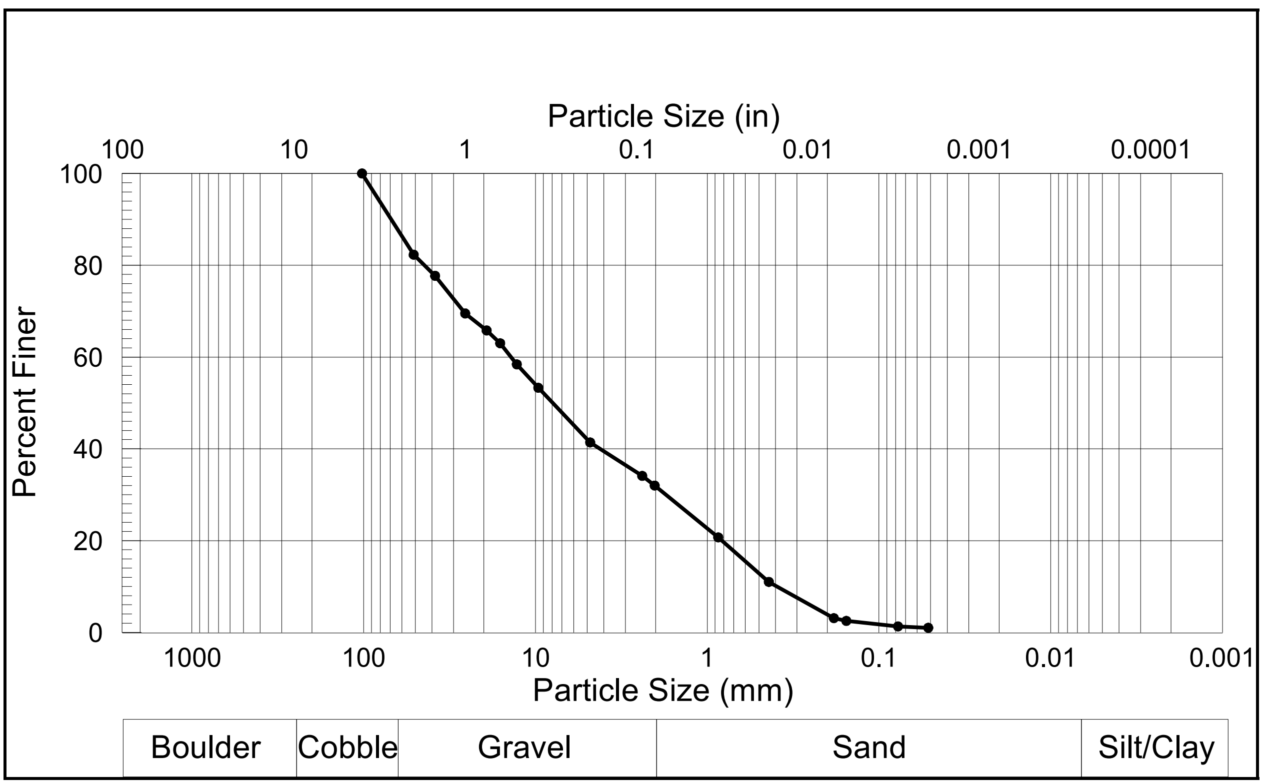


Figure A.3-20. Particle size distribution for Flume Creek sample BM-9.

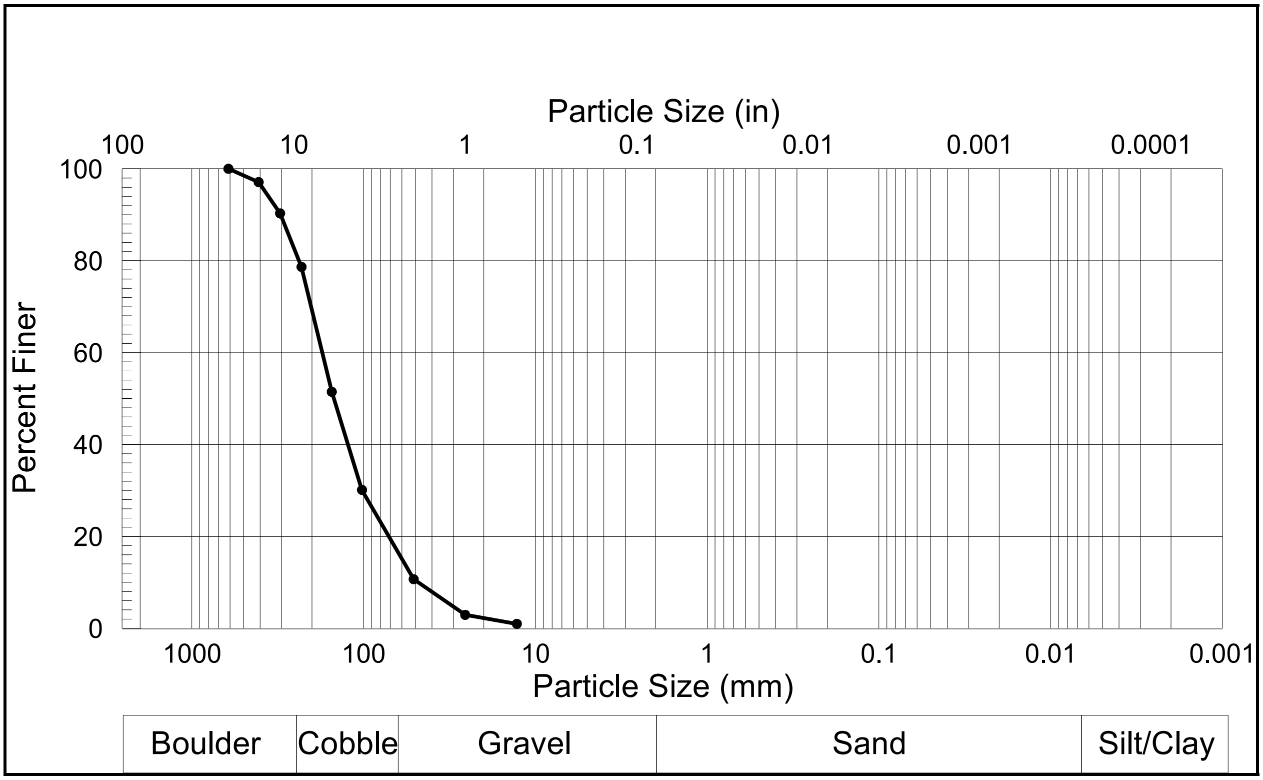


Figure A.3-21. Particle size distribution for Sullivan Creek sample BM-1.

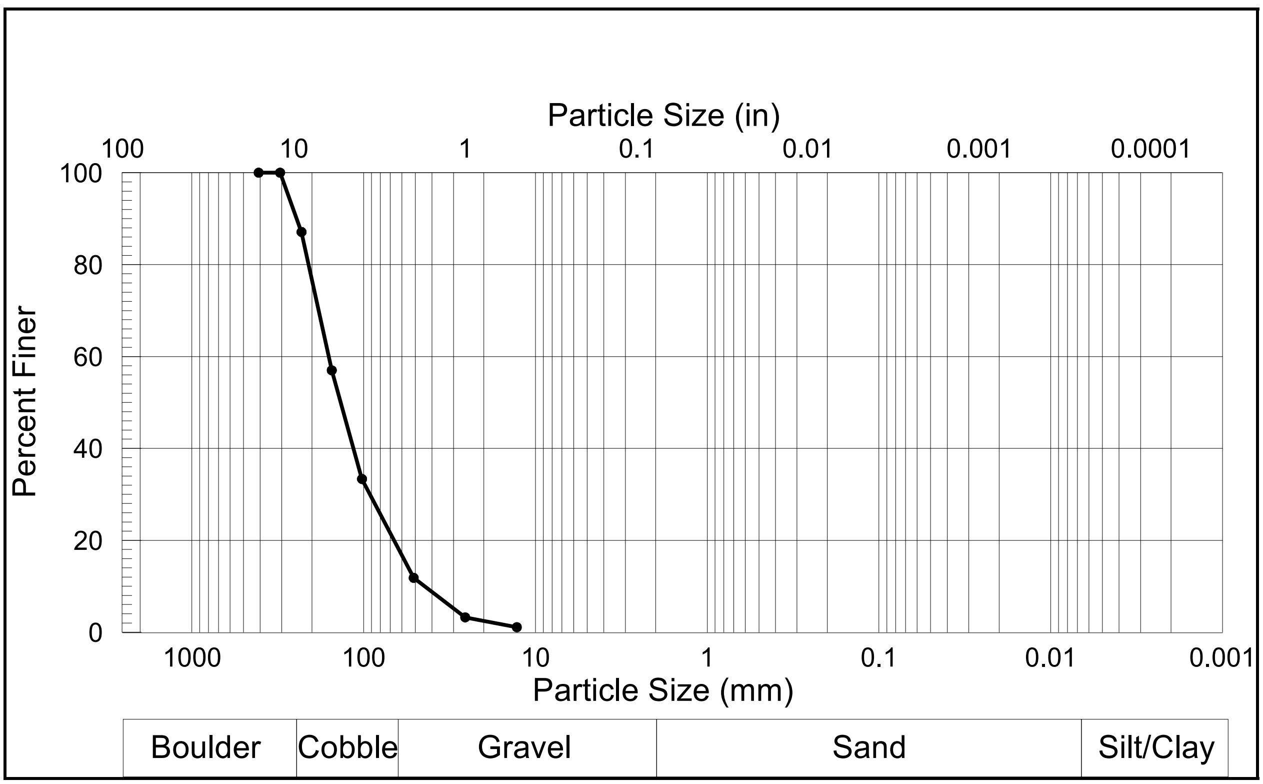


Figure A.3-22. Particle size distribution for Sullivan Creek sample BM-2.

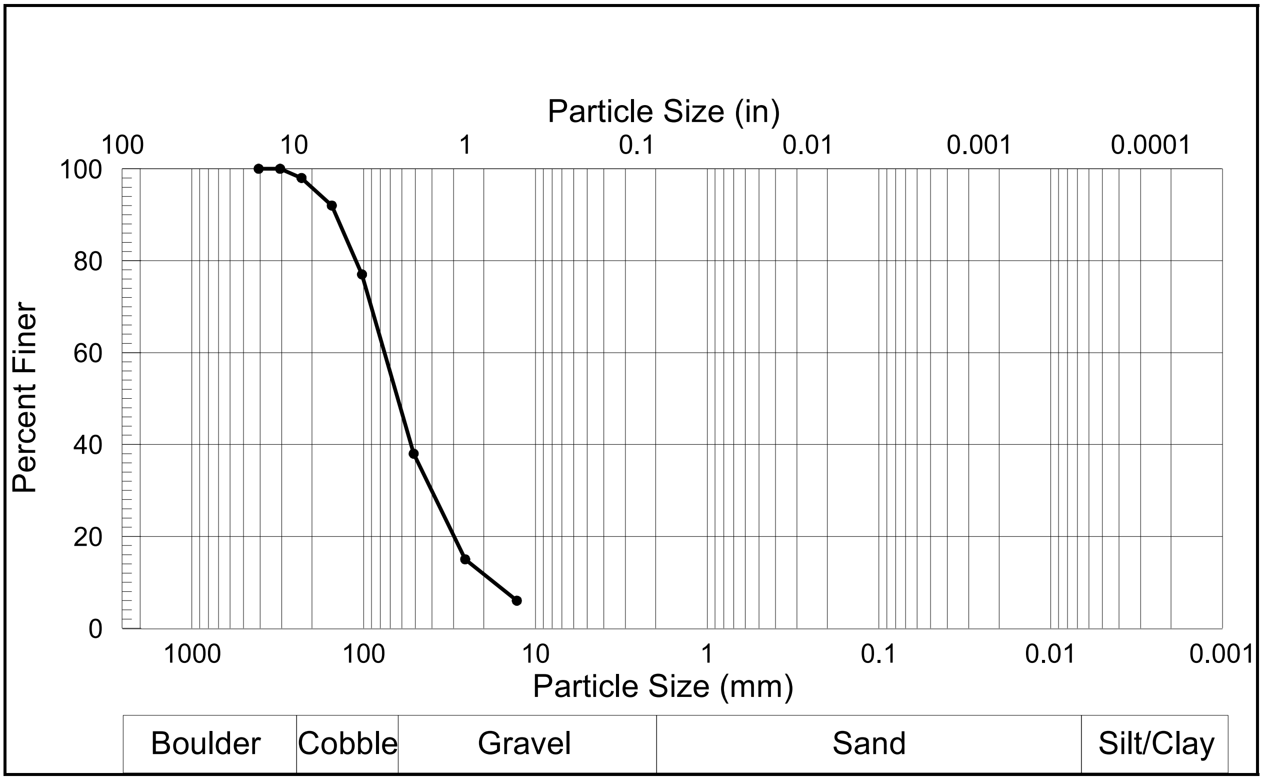


Figure A.3-23. Particle size distribution for Sullivan Creek sample BM-3.

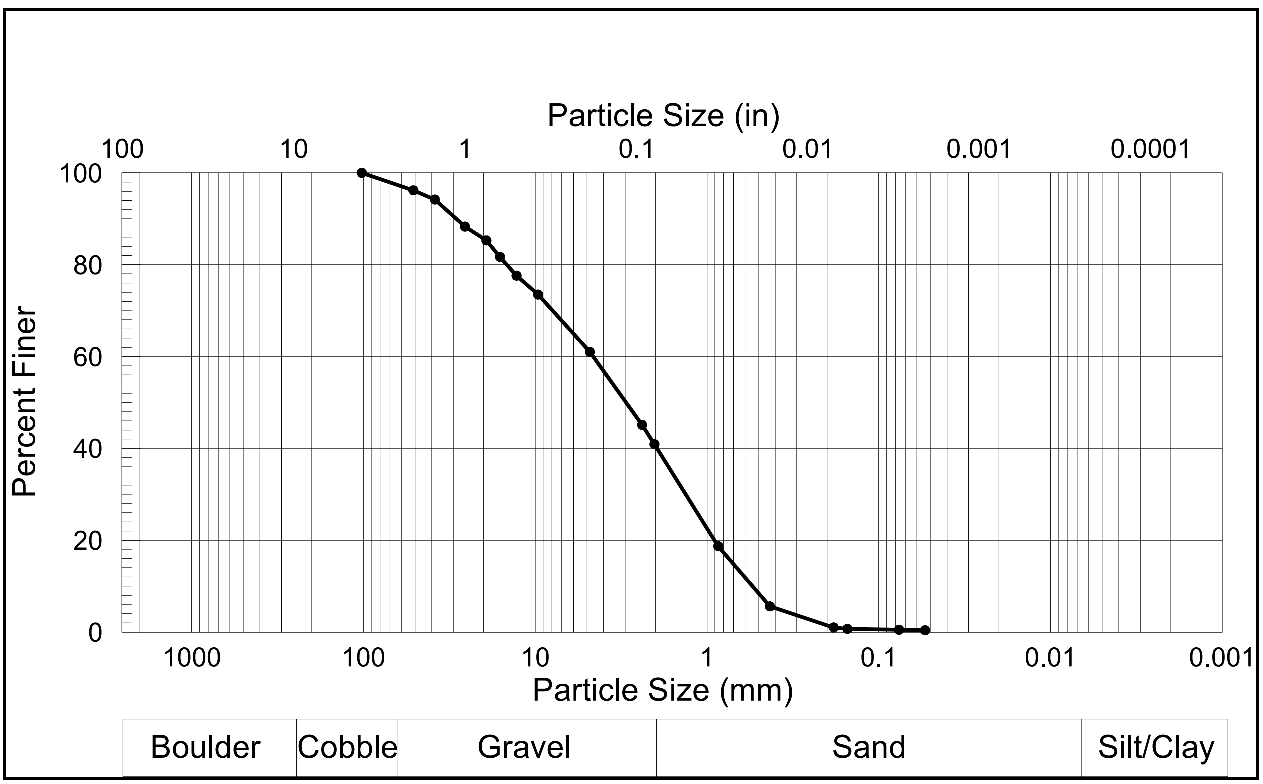


Figure A.3-24. Particle size distribution for Sullivan Creek sample BM-4.

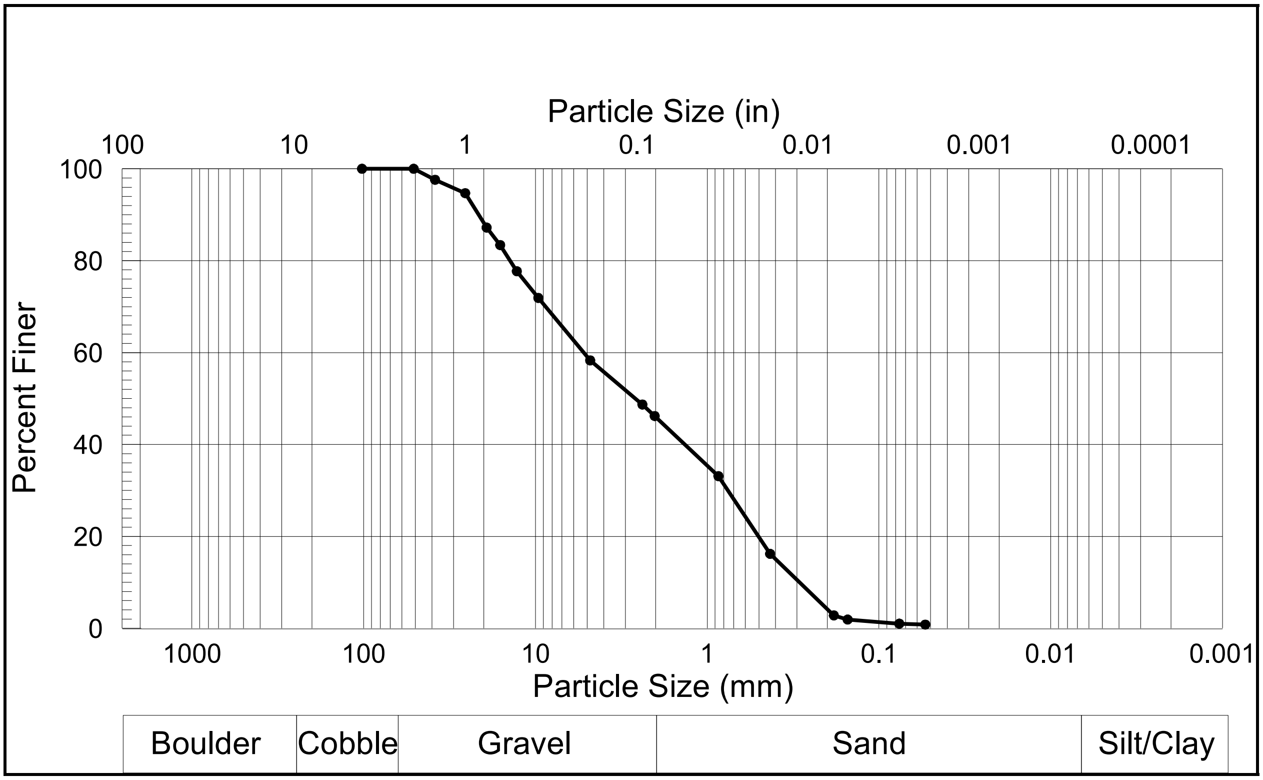


Figure A.3-25. Particle size distribution for Sullivan Creek sample BM-5.

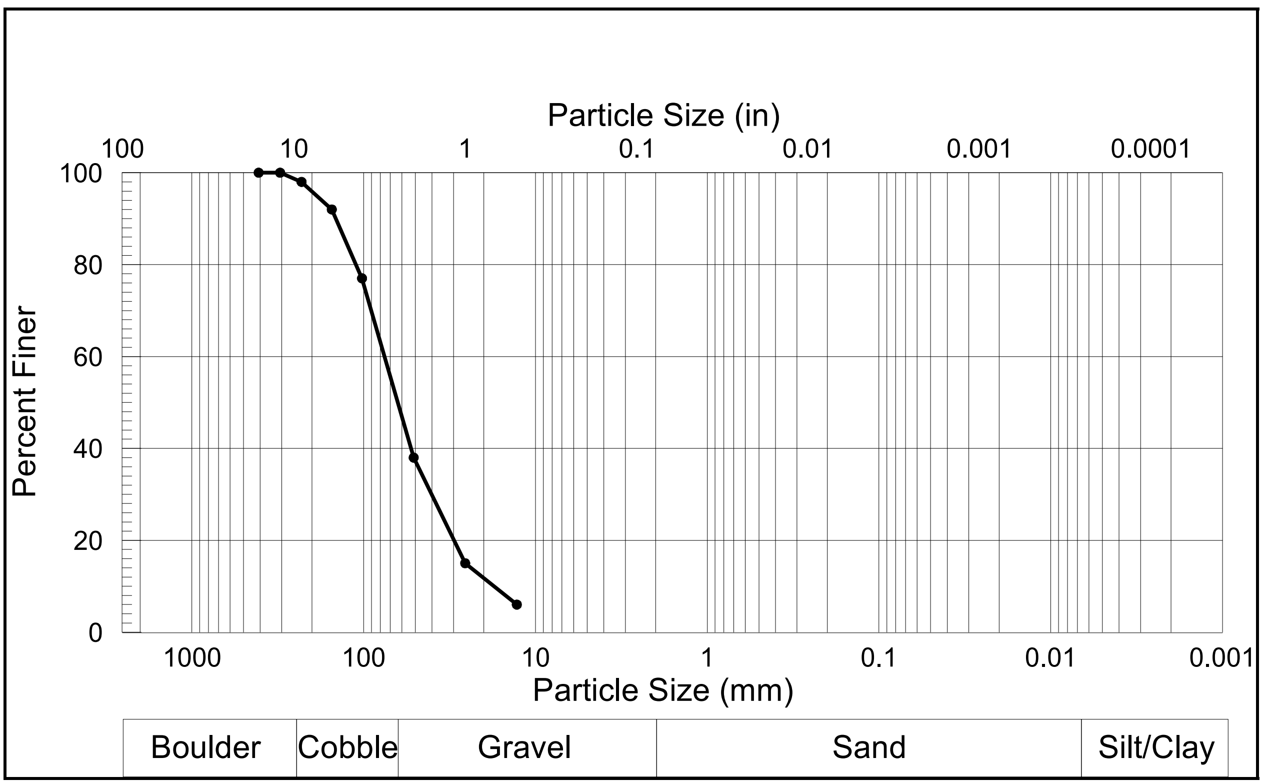


Figure A.3-26. Particle size distribution for Sullivan Creek sample BM-6.

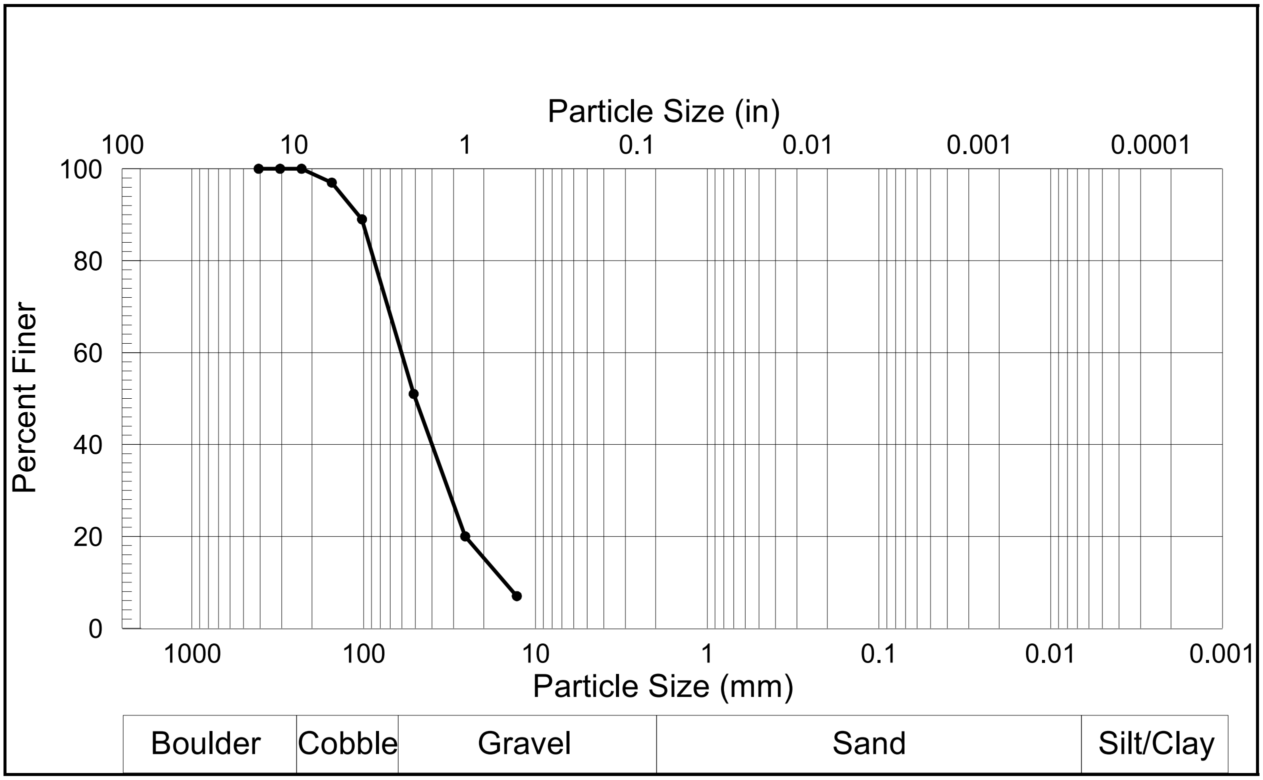


Figure A.3-27. Particle size distribution for Sullivan Creek sample BM-7.

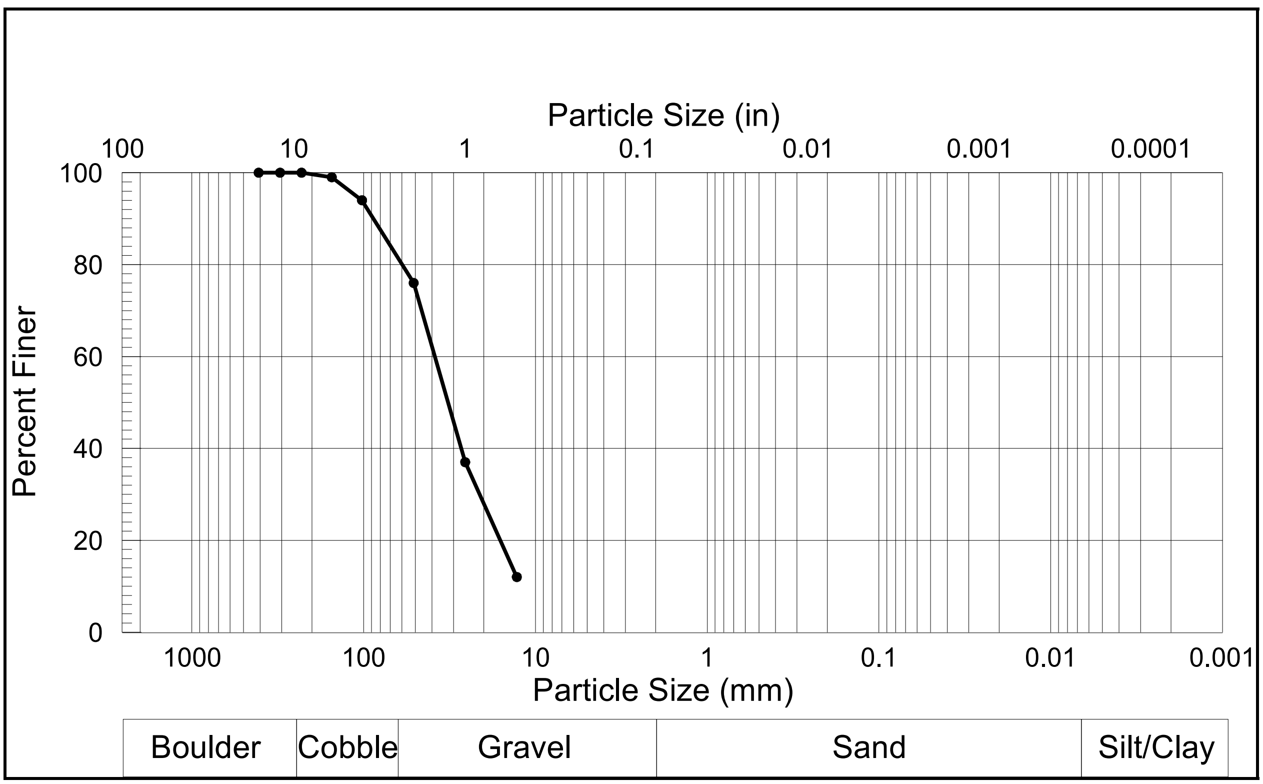


Figure A.3-28. Particle size distribution for Sullivan Creek sample BM-8.

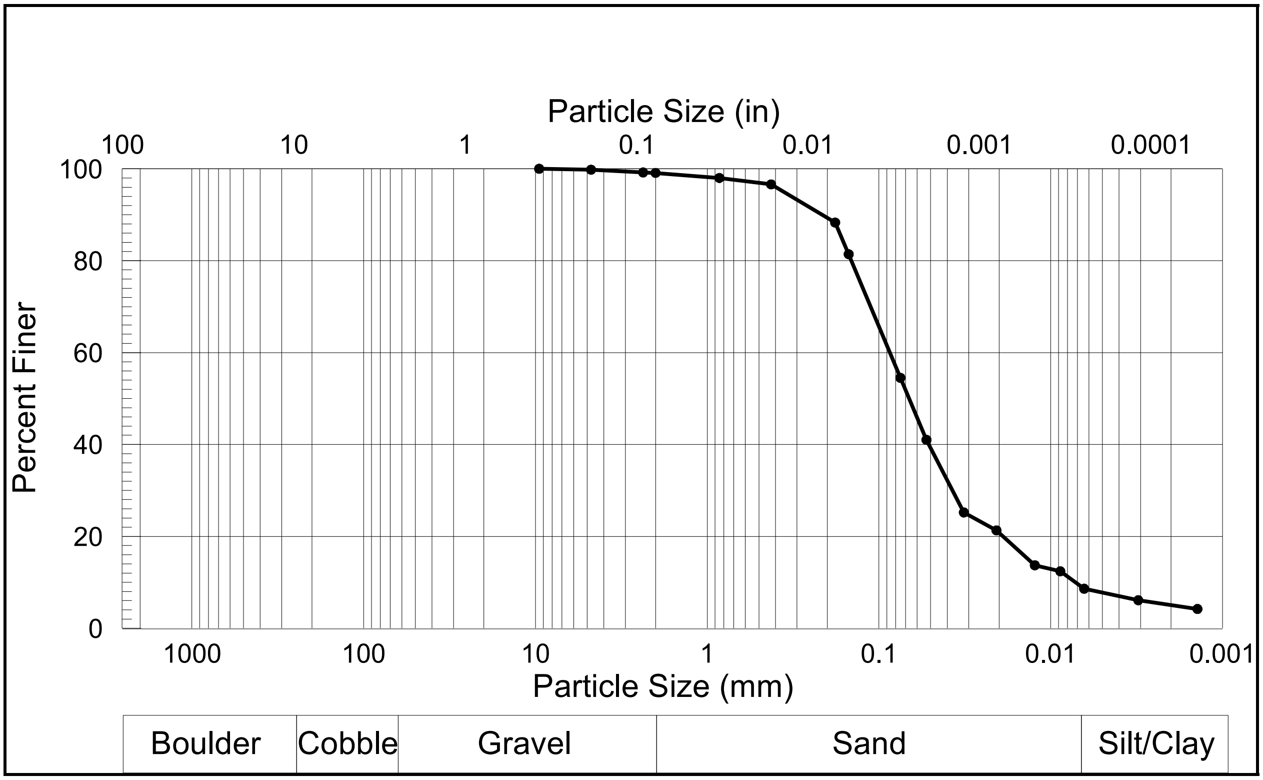


Figure A.3-29. Particle size distribution for Sullivan Creek sample BM-9.

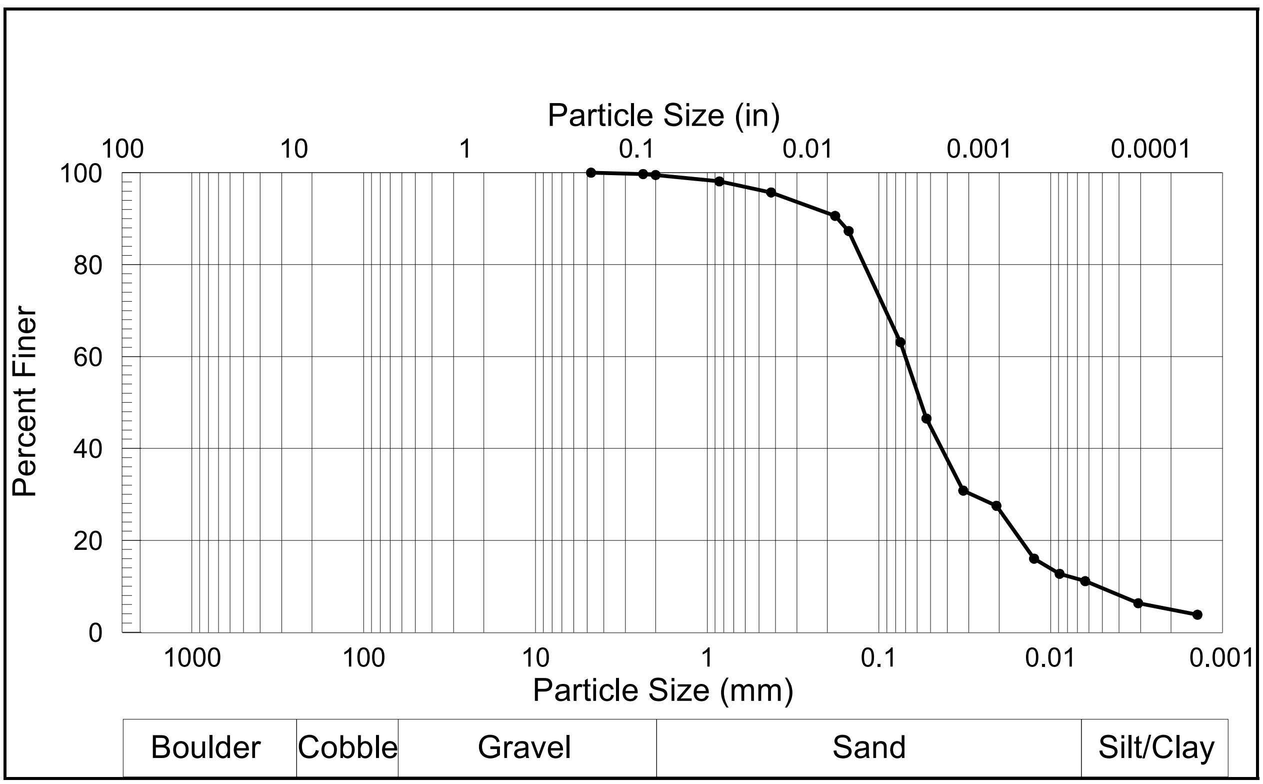


Figure A.3-30. Particle size distribution for Sullivan Creek sample BM-10.

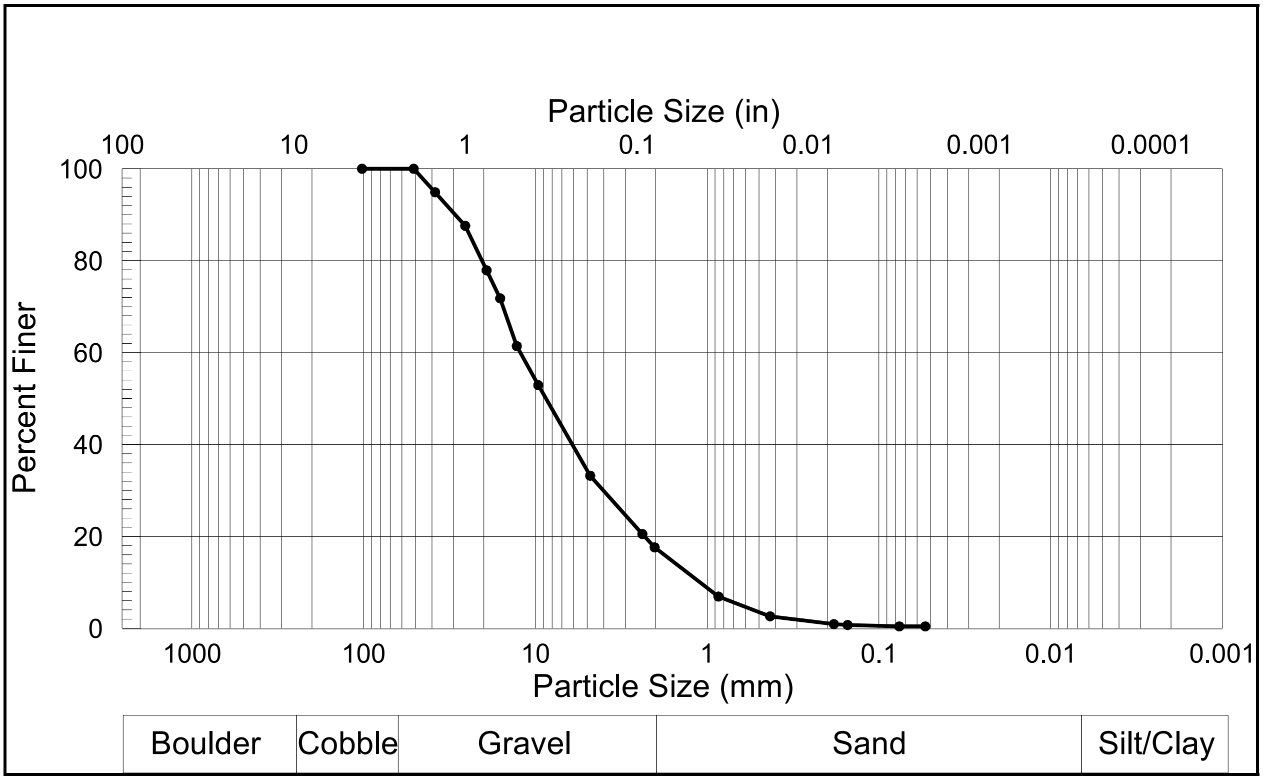


Figure A.3-31. Particle size distribution for Sullivan Creek sample BM-11.

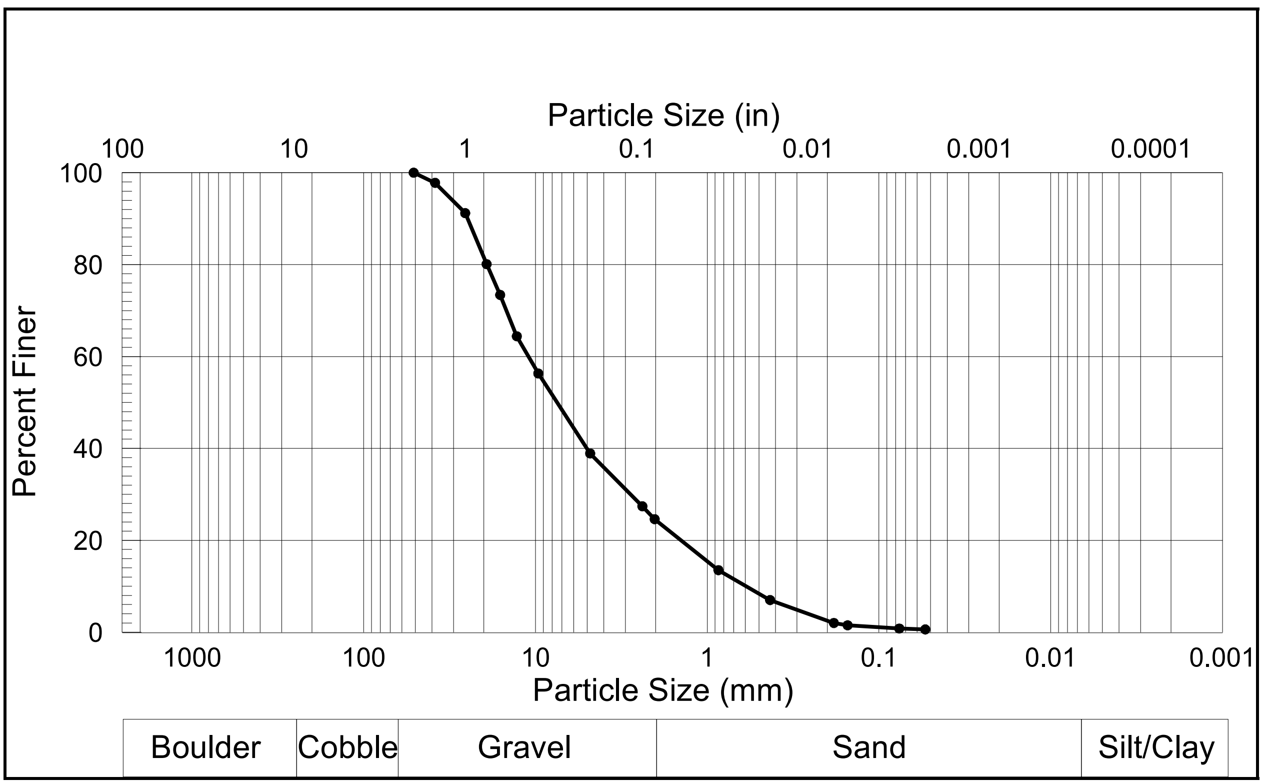


Figure A.3-32. Particle size distribution for Sullivan Creek sample BM-12.

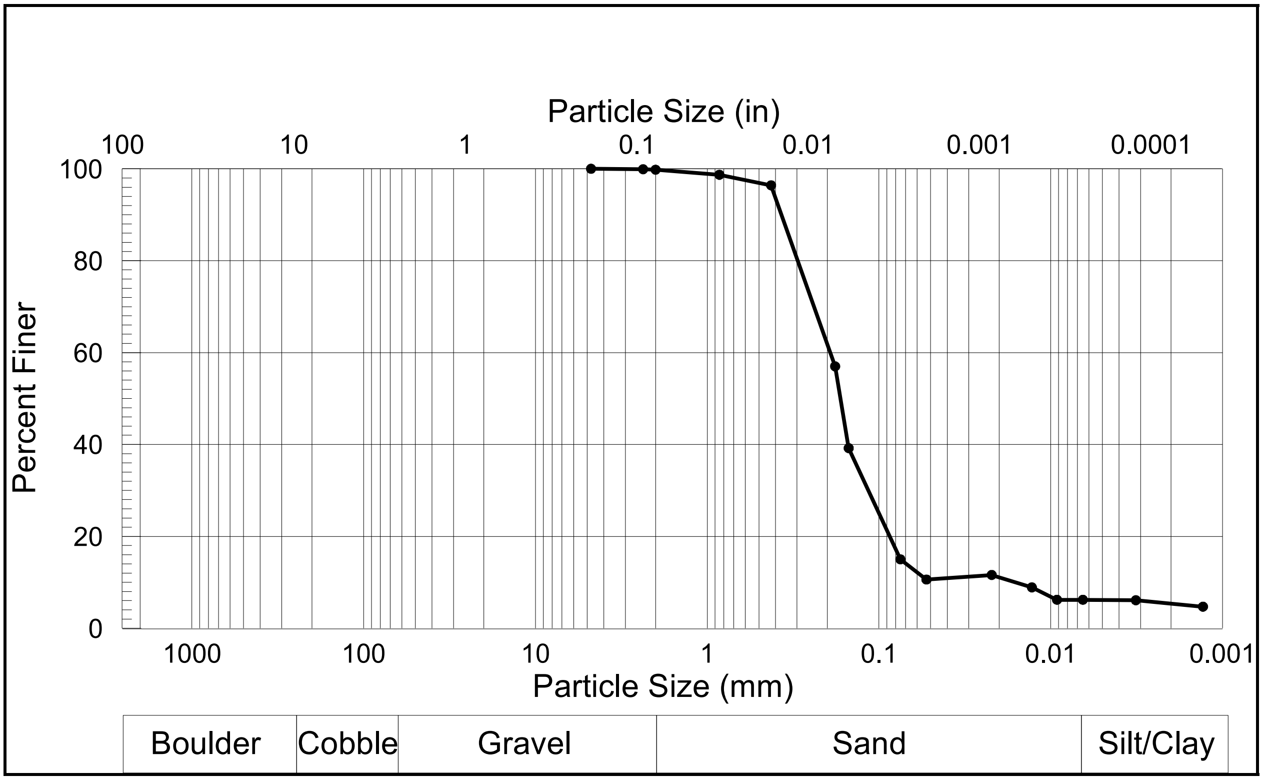


Figure A.3-33. Particle size distribution for Sullivan Creek sample BM-13.

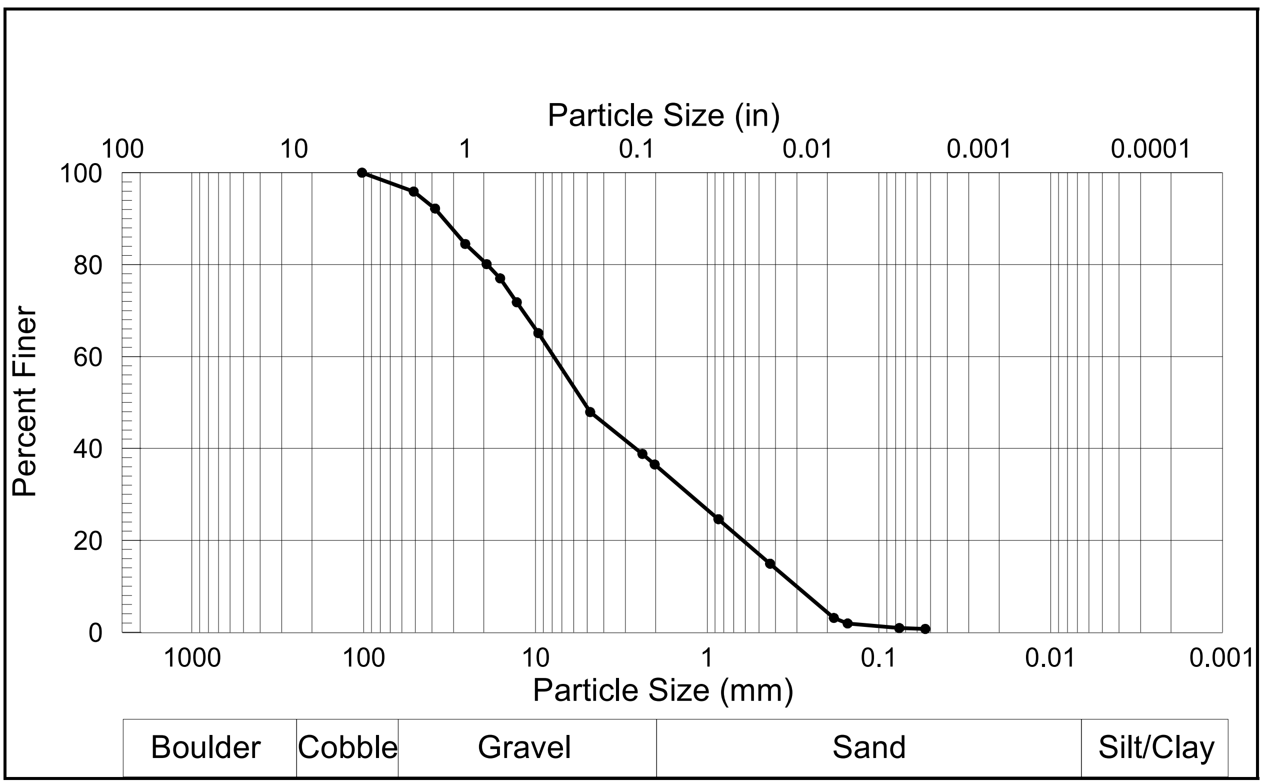


Figure A.3-34. Particle size distribution for Sullivan Creek sample BM-14.

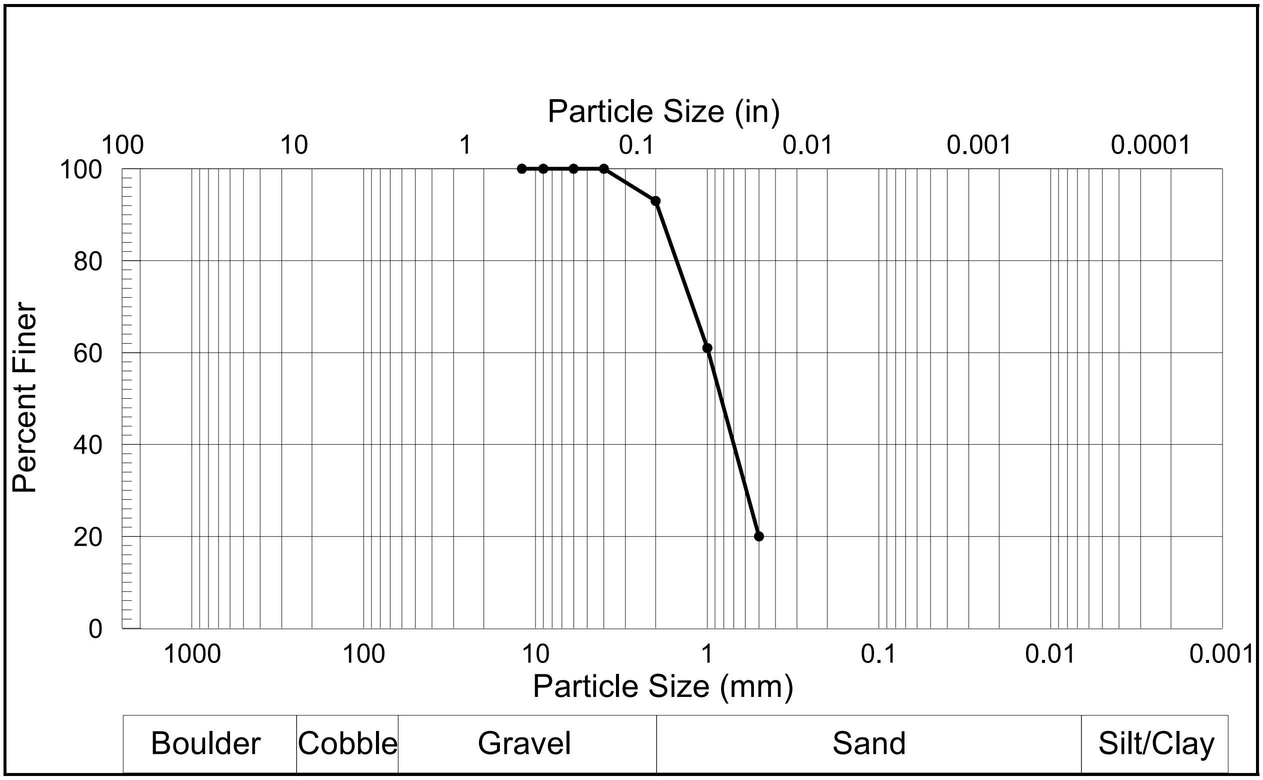


Figure A.3-35. Particle size distribution for Linton Creek sample BM-1.

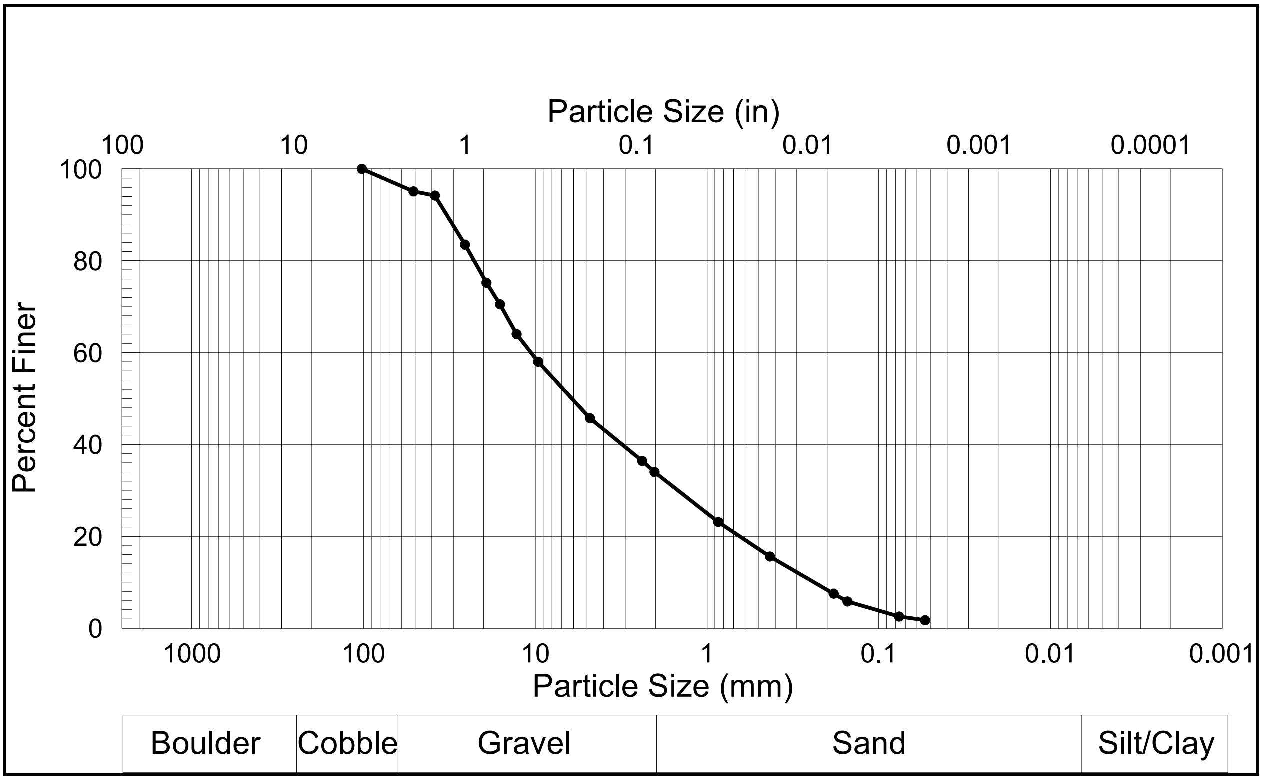


Figure A.3-36. Particle size distribution for Linton Creek sample BM-2.

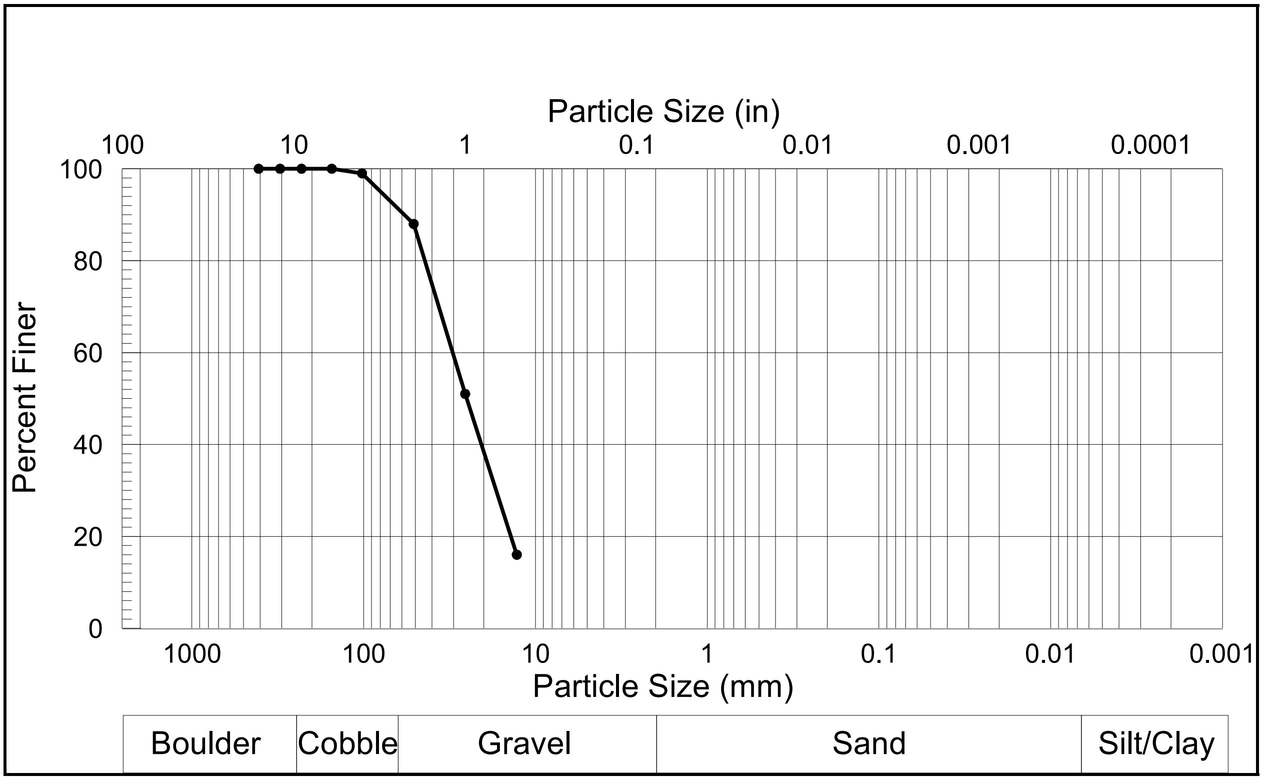


Figure A.3-37. Particle size distribution for Linton Creek sample BM-3.

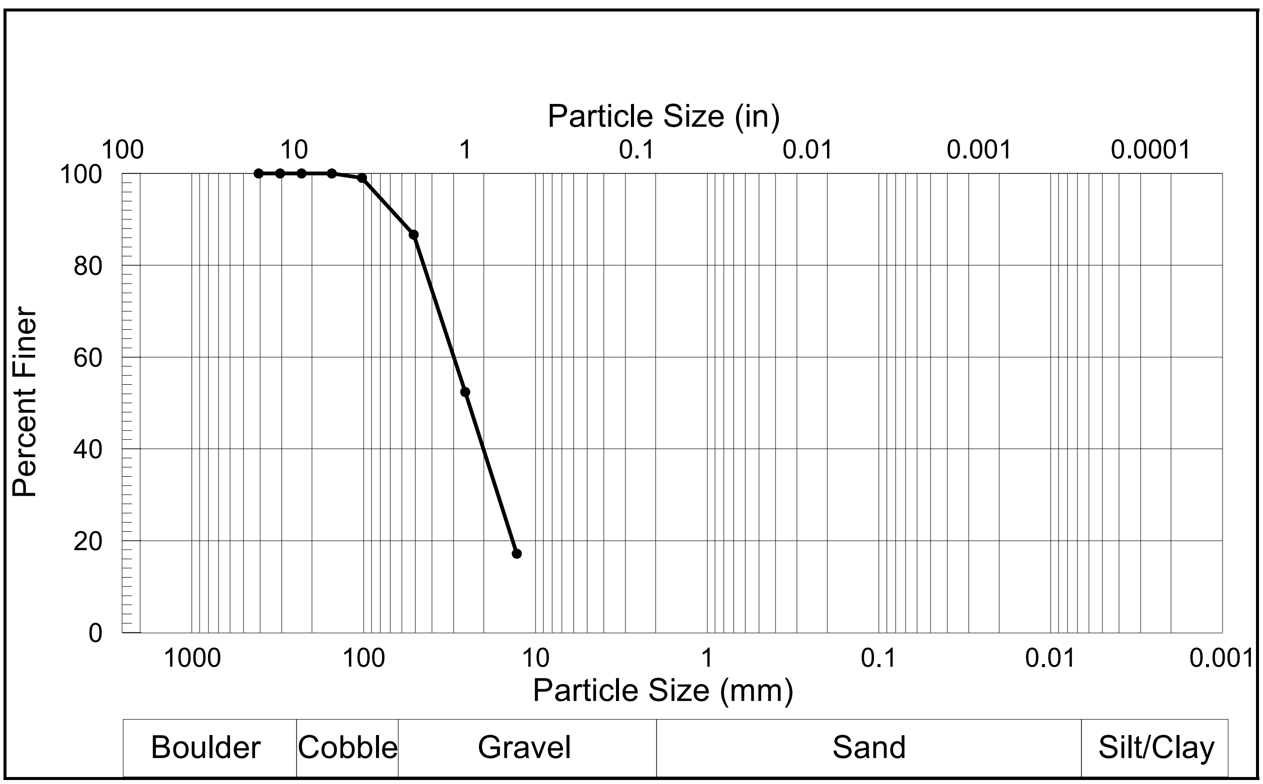


Figure A.3-38. Particle size distribution for Linton Creek sample BM-4.

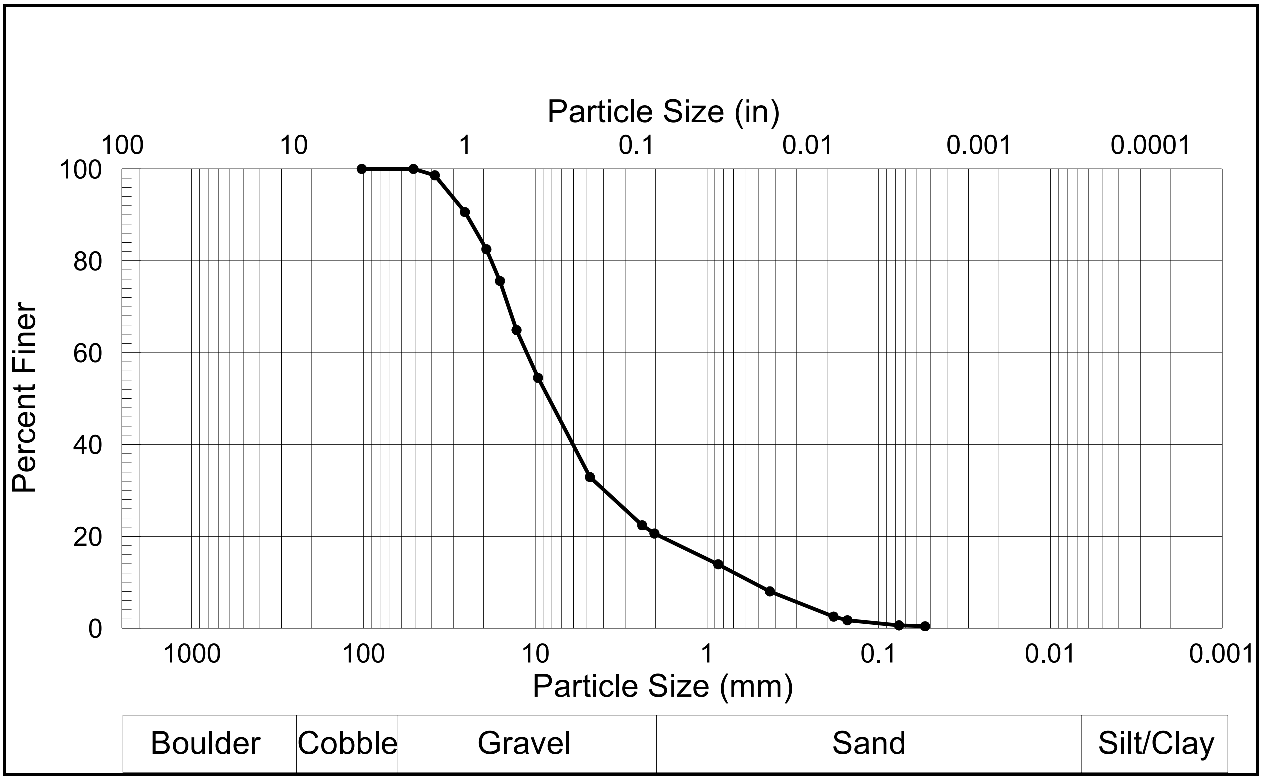


Figure A.3-39. Particle size distribution for Linton Creek sample BM-5.

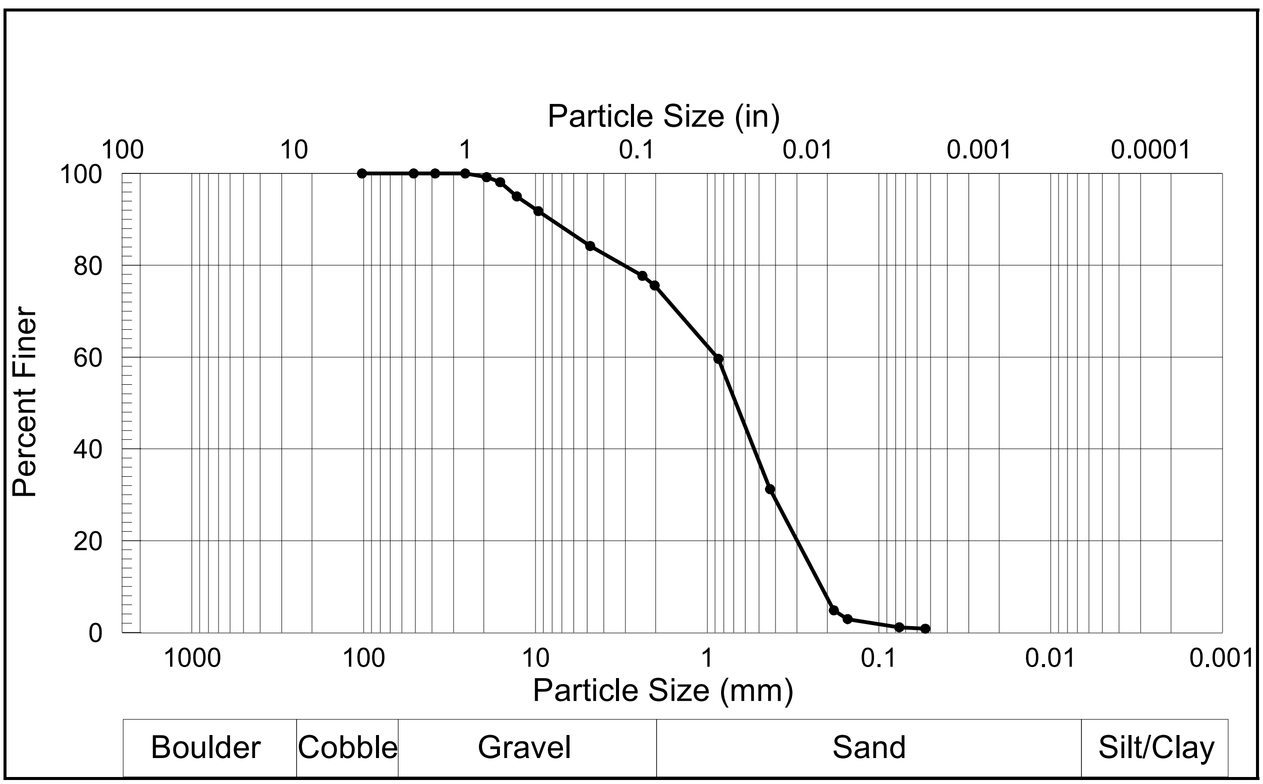


Figure A.3-40. Particle size distribution for Linton Creek sample BM-6.

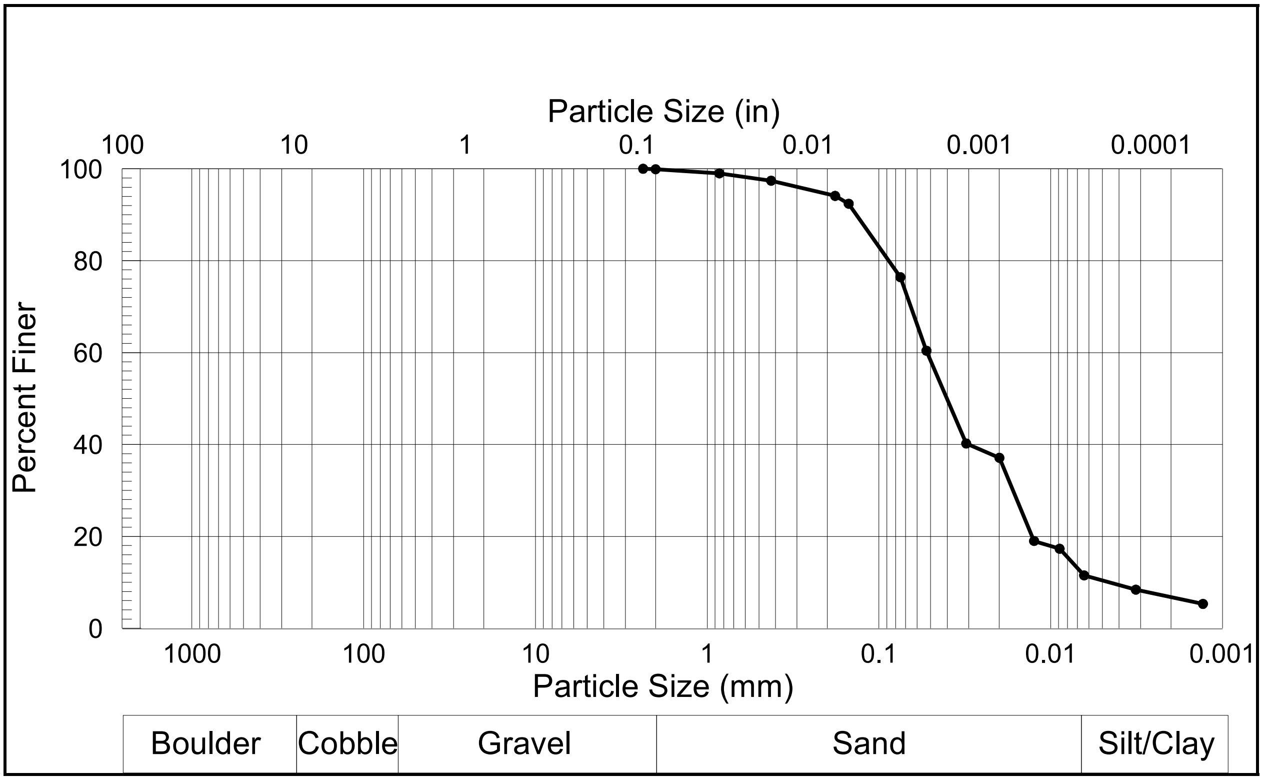


Figure A.3-41. Particle size distribution for Linton Creek sample BM-7.

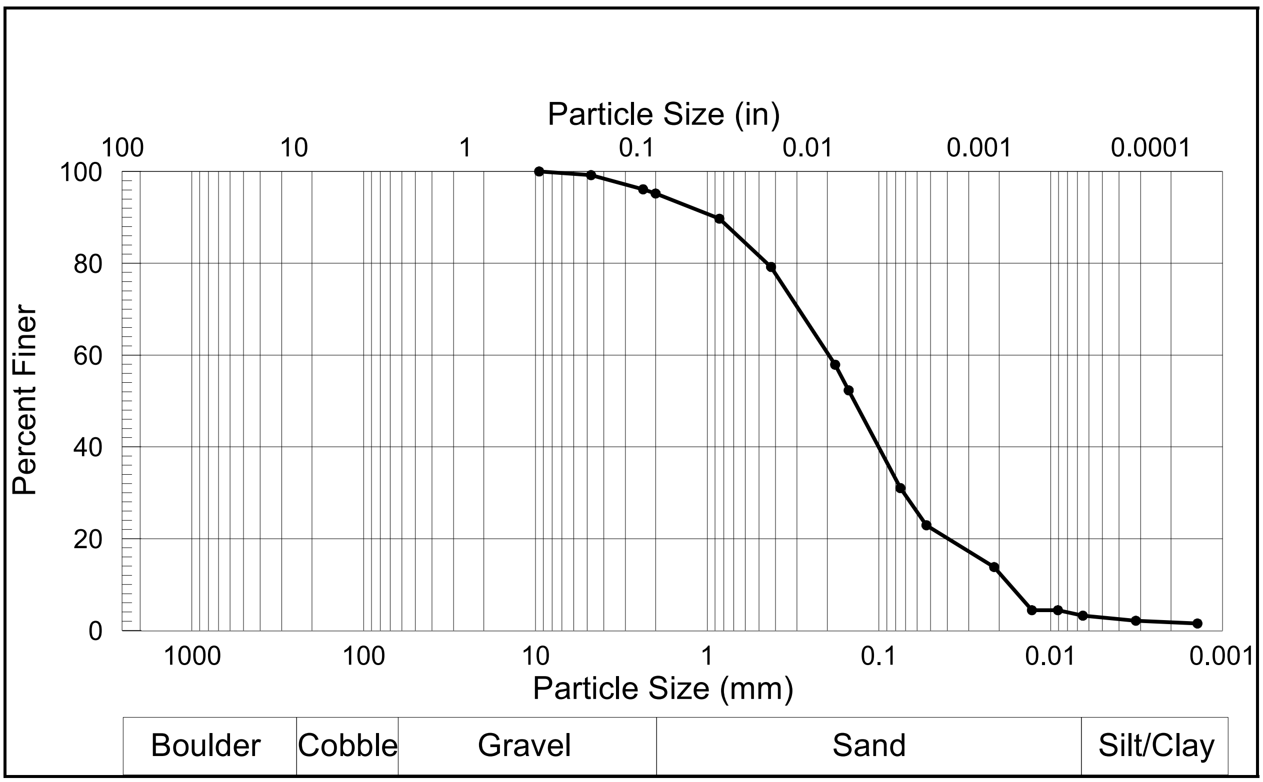


Figure A.3-42. Particle size distribution for Linton Creek sample BM-8.

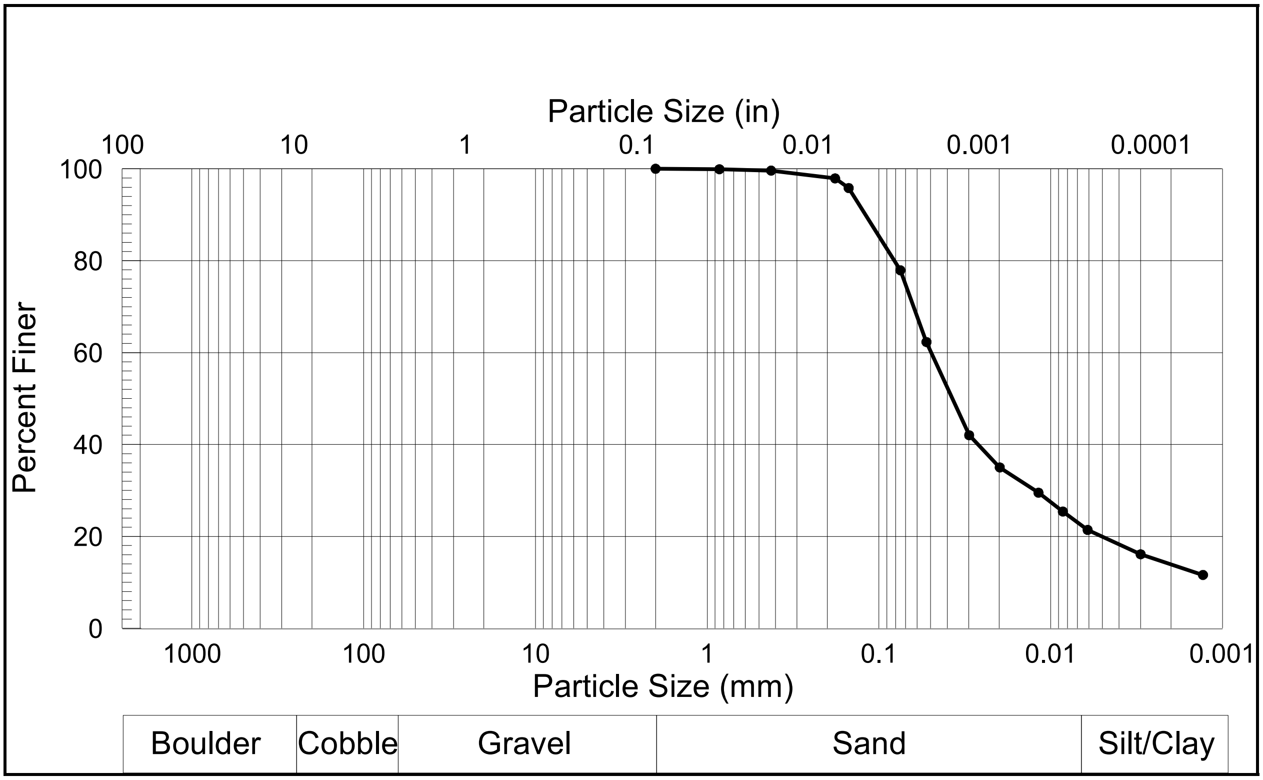


Figure A.3-43. Particle size distribution for Linton Creek sample BM-9.

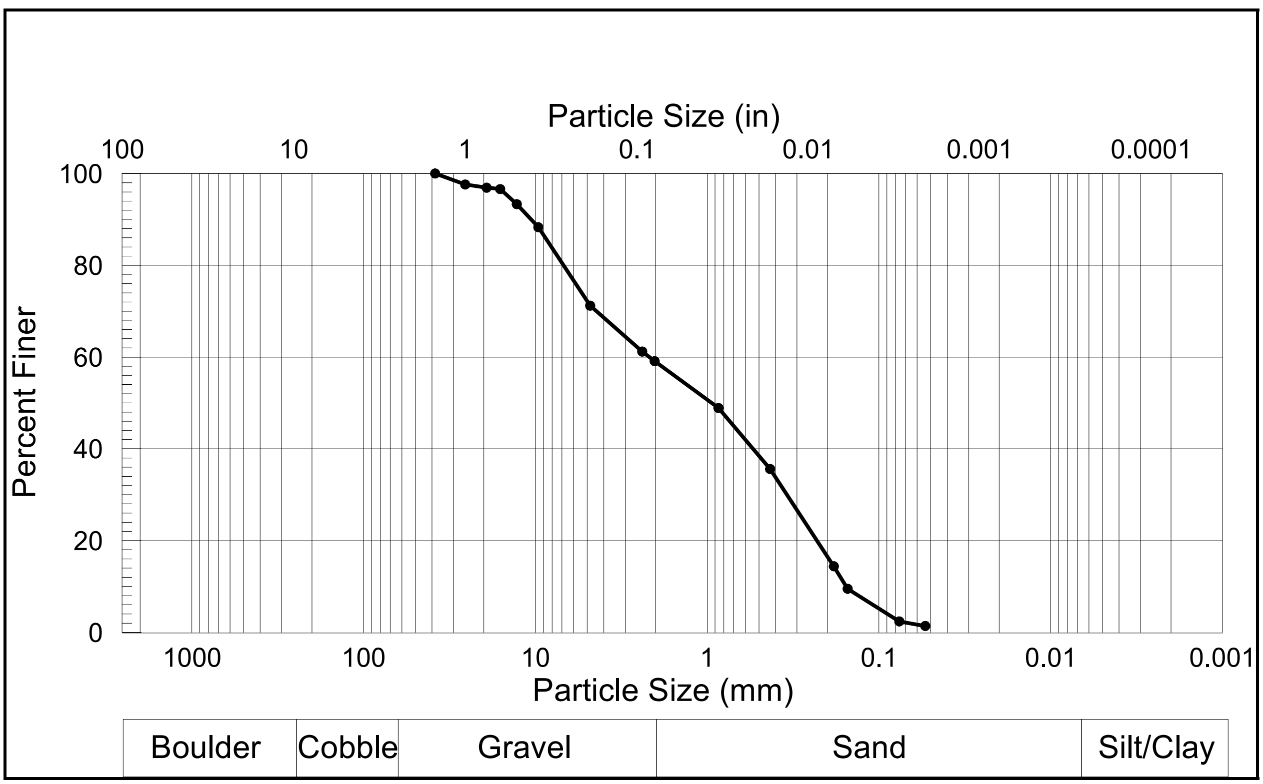


Figure A.3-44. Particle size distribution for Linton Creek sample BM-10.

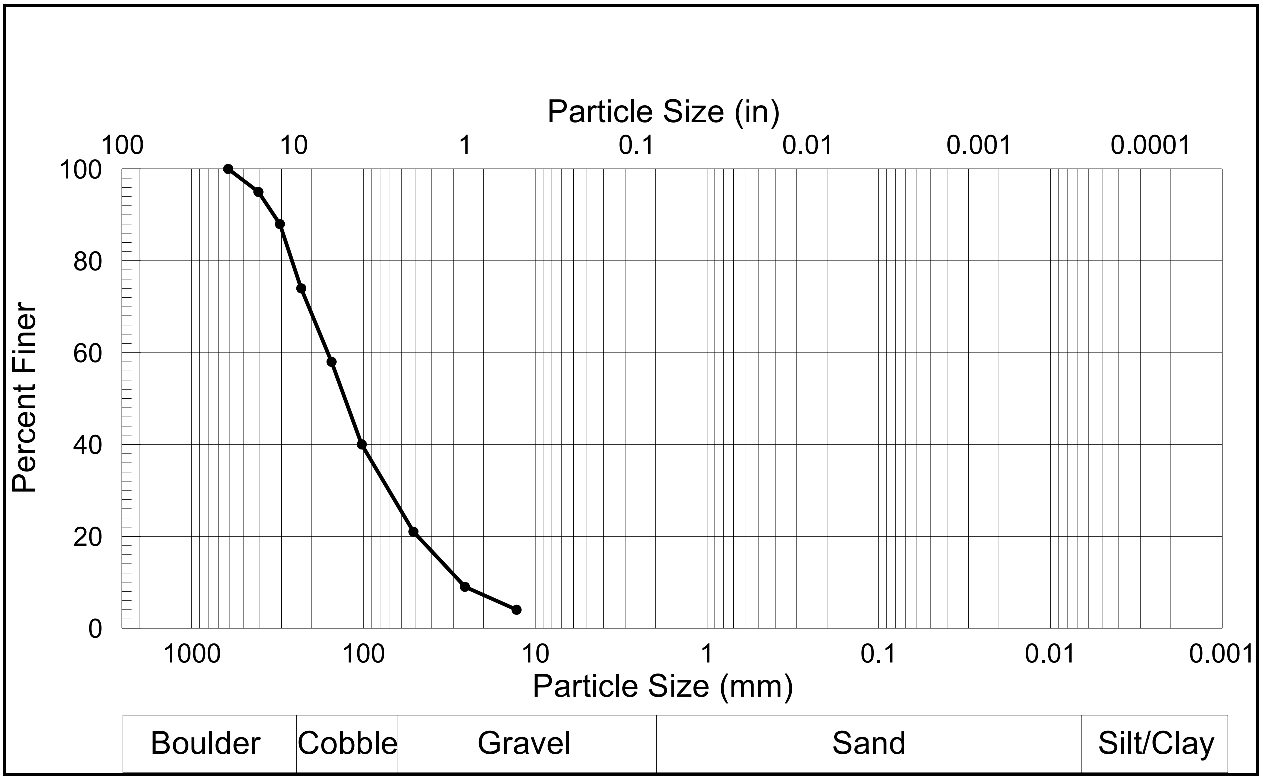


Figure A.3-45. Particle size distribution for Pocahontas Creek sample BM-1.

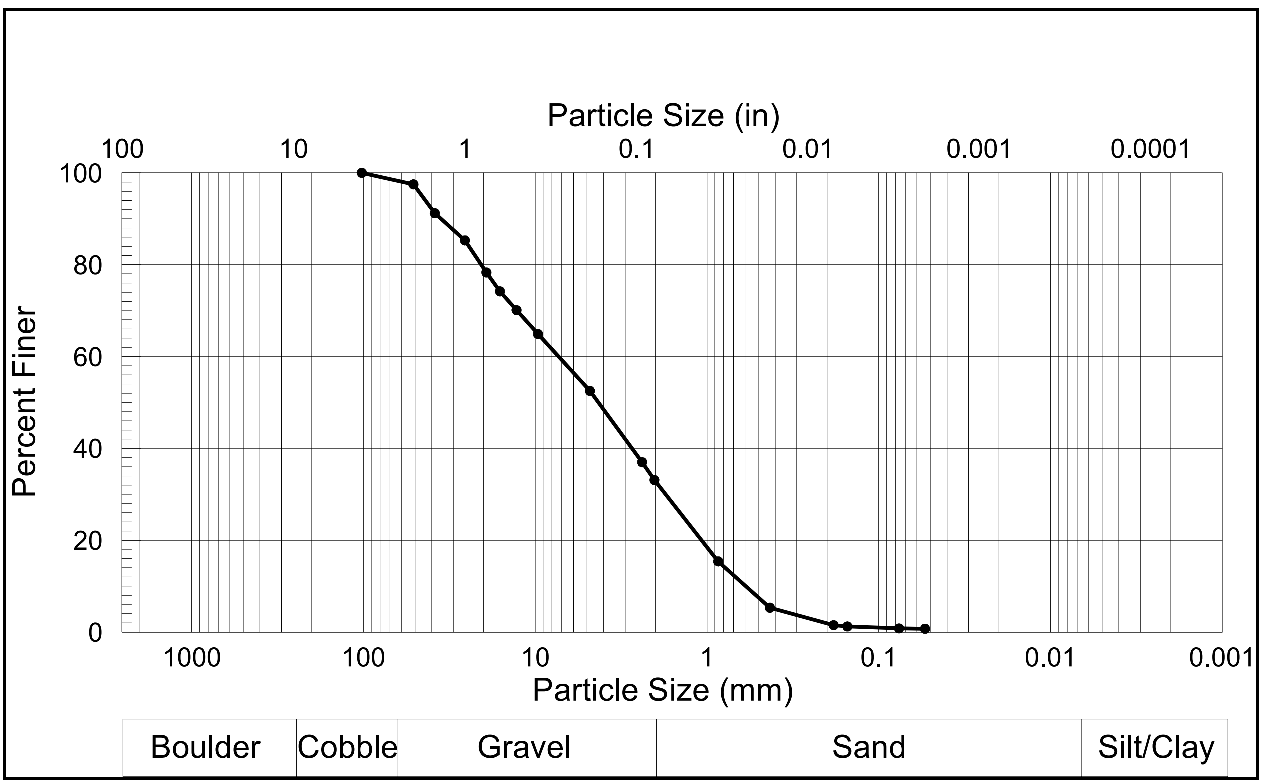


Figure A.3-46. Particle size distribution for Pocahontas Creek sample BM-2.

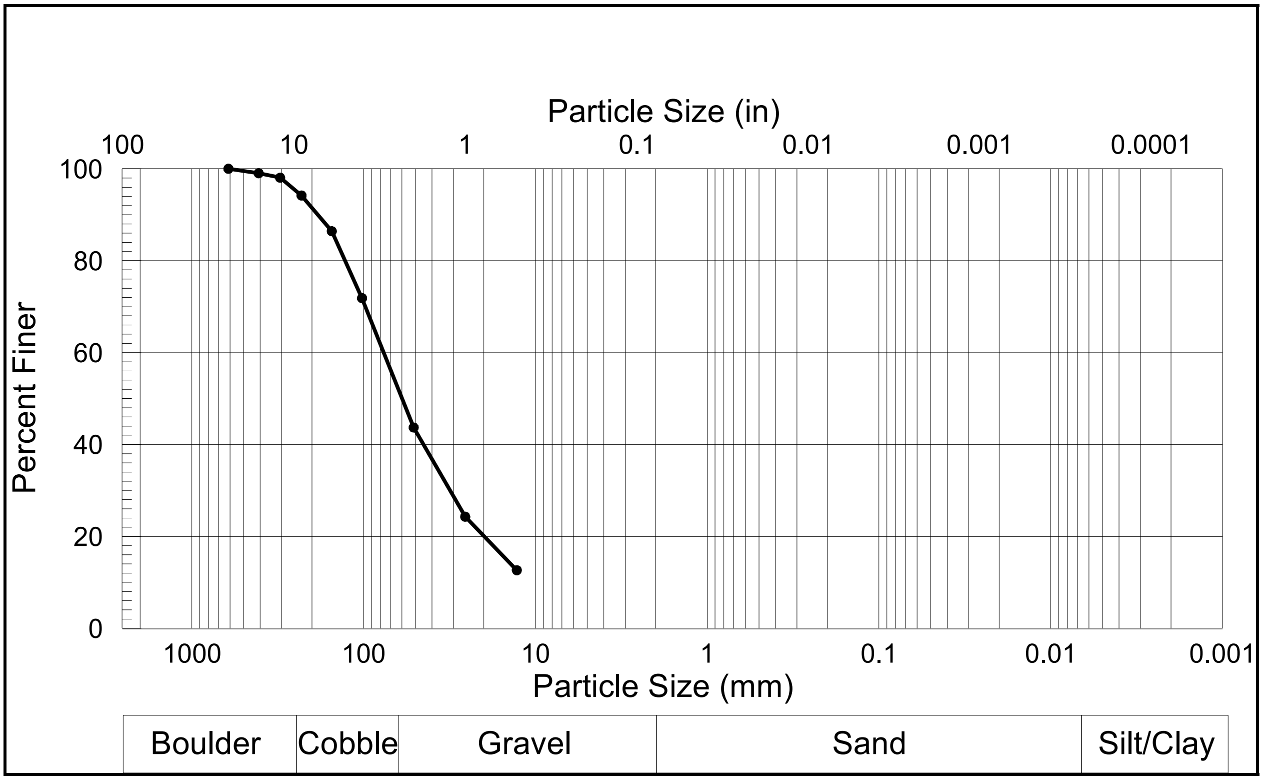


Figure A.3-47. Particle size distribution for Pocahontas Creek sample BM-3.

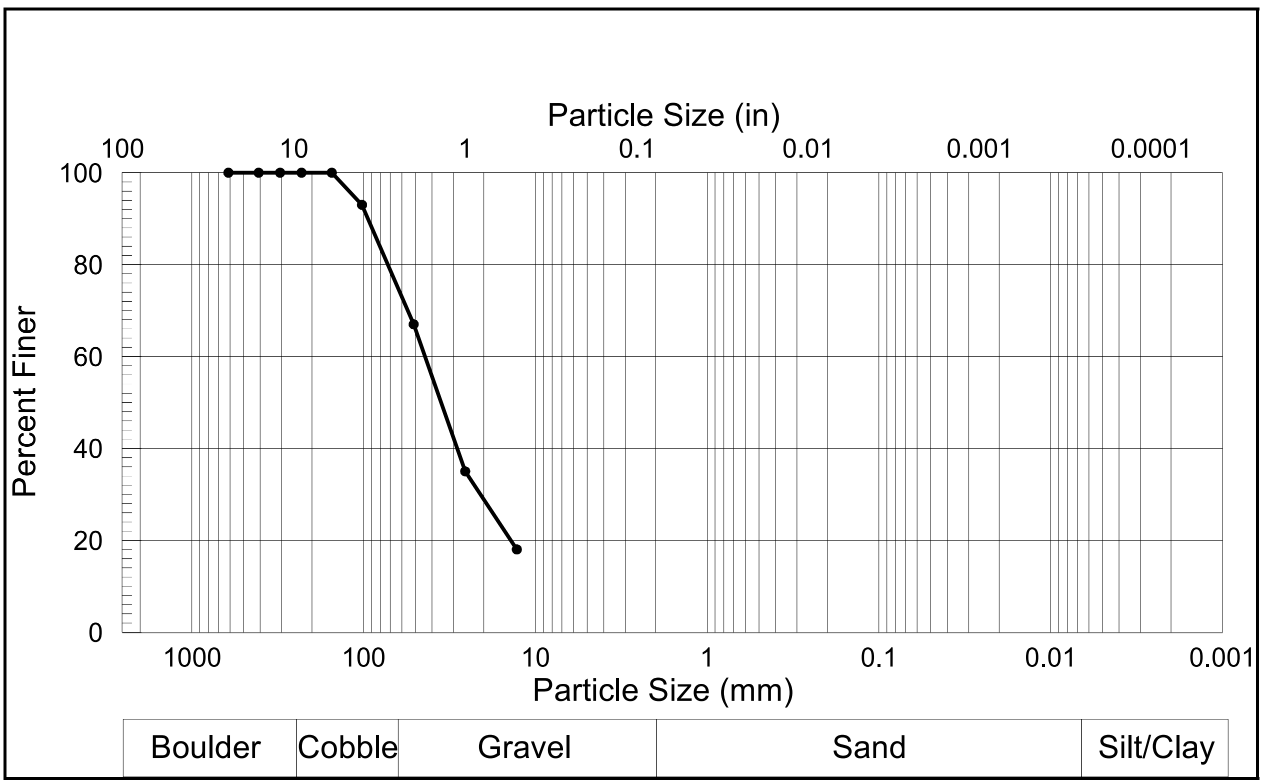


Figure A.3-48. Particle size distribution for Pocahontas Creek sample BM-4.

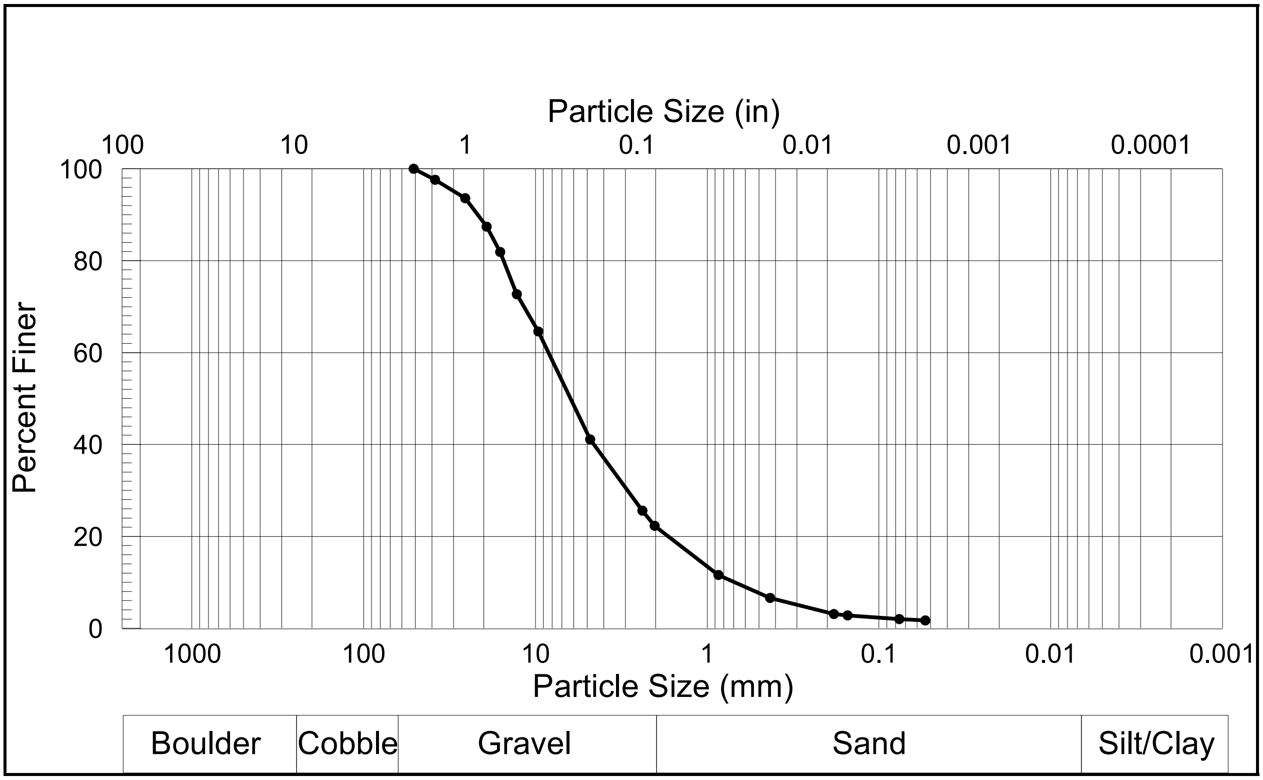


Figure A.3-49. Particle size distribution for Pocahontas Creek sample BM-5.

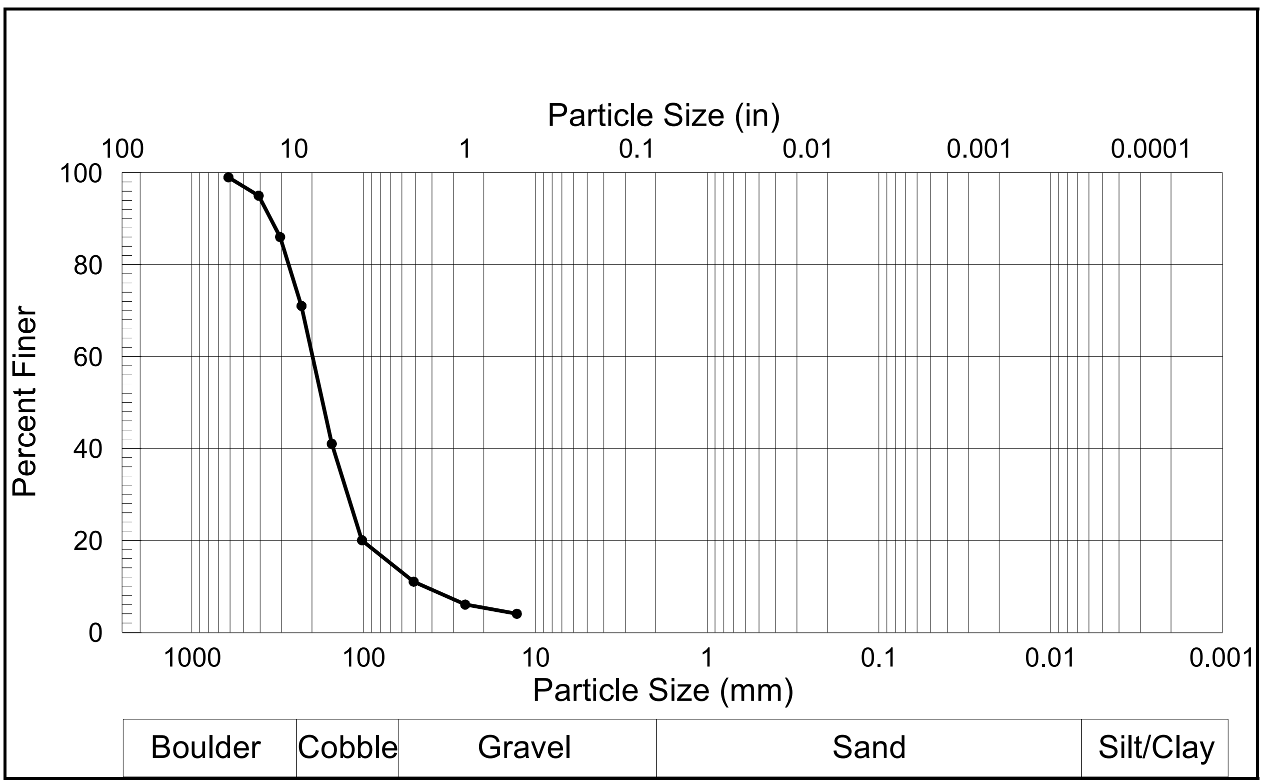


Figure A.3-50. Particle size distribution for Pocahontas Creek sample BM-6.

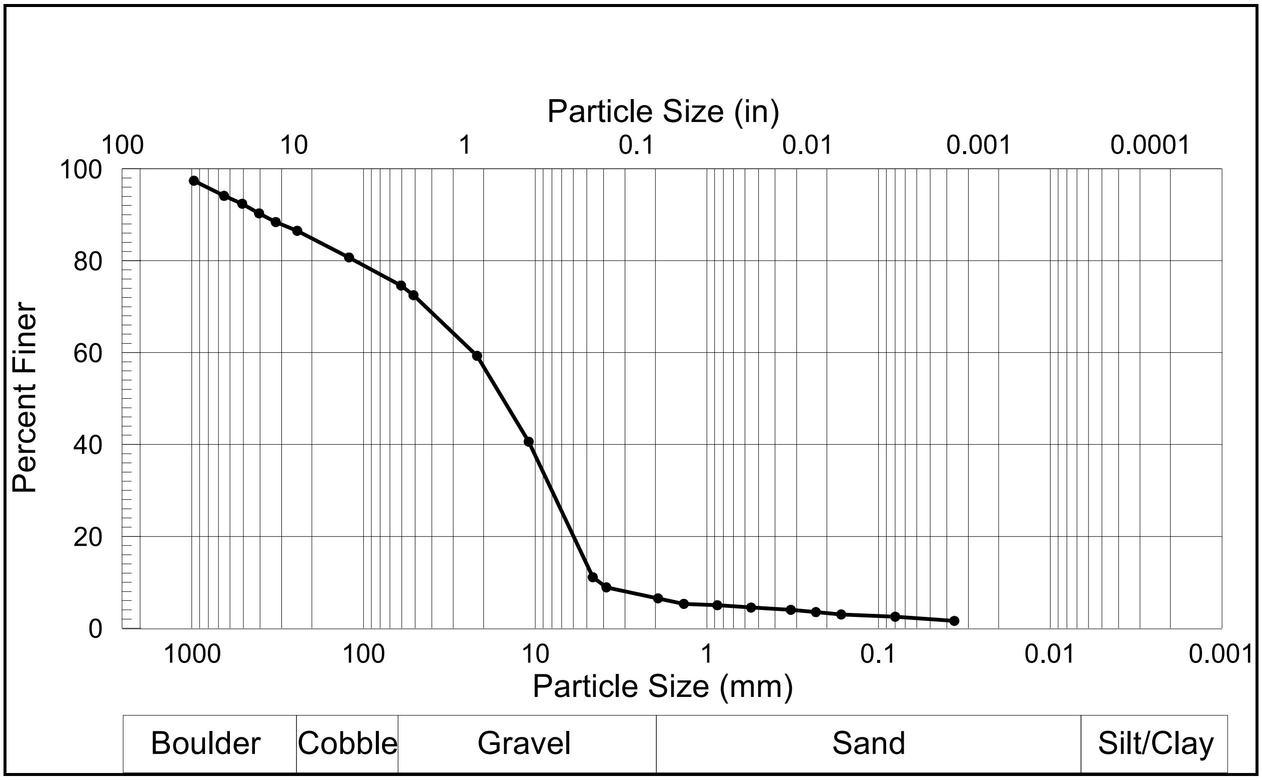


Figure A.3-51. Particle size distribution for Pocahontas Creek sample BM-7.

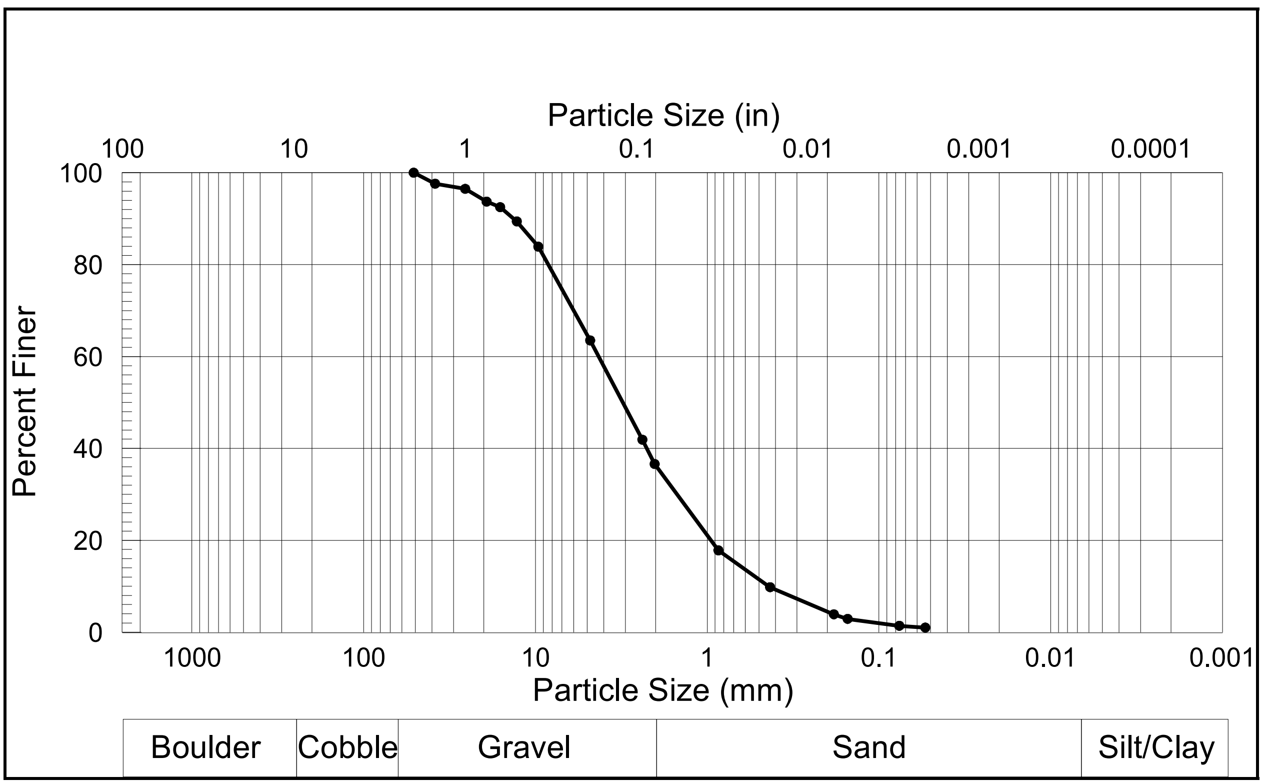


Figure A.3-52. Particle size distribution for Pocahontas Creek sample BM-8.

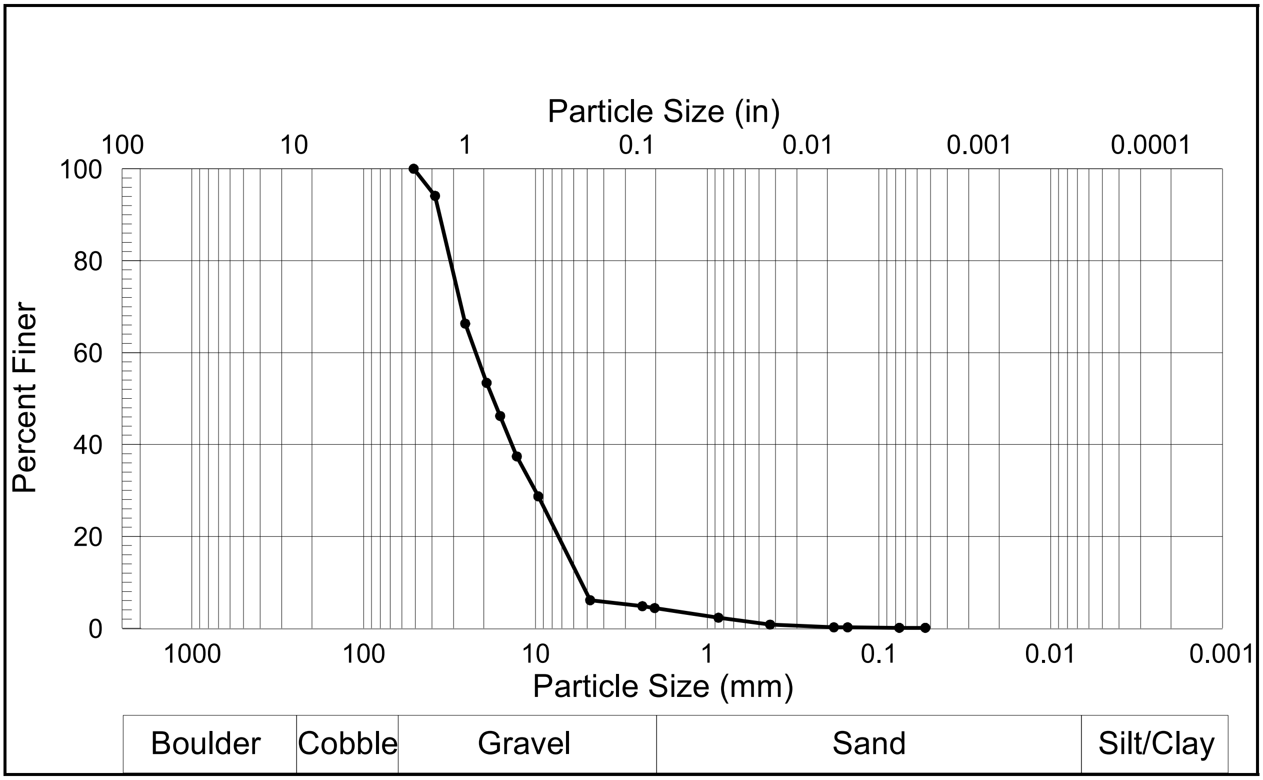


Figure A.3-53. Particle size distribution for Pocahontas Creek sample BM-9.

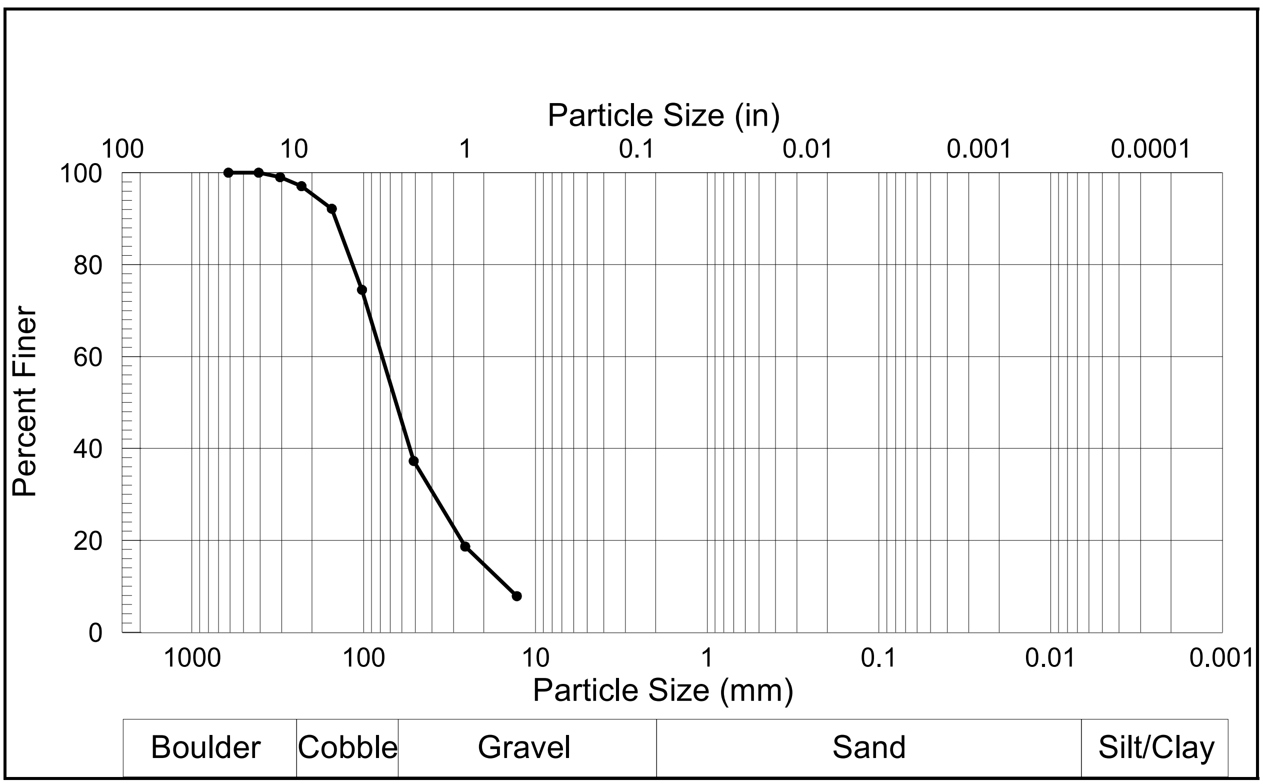


Figure A.3-54. Particle size distribution for Sweet Creek sample BM-1.

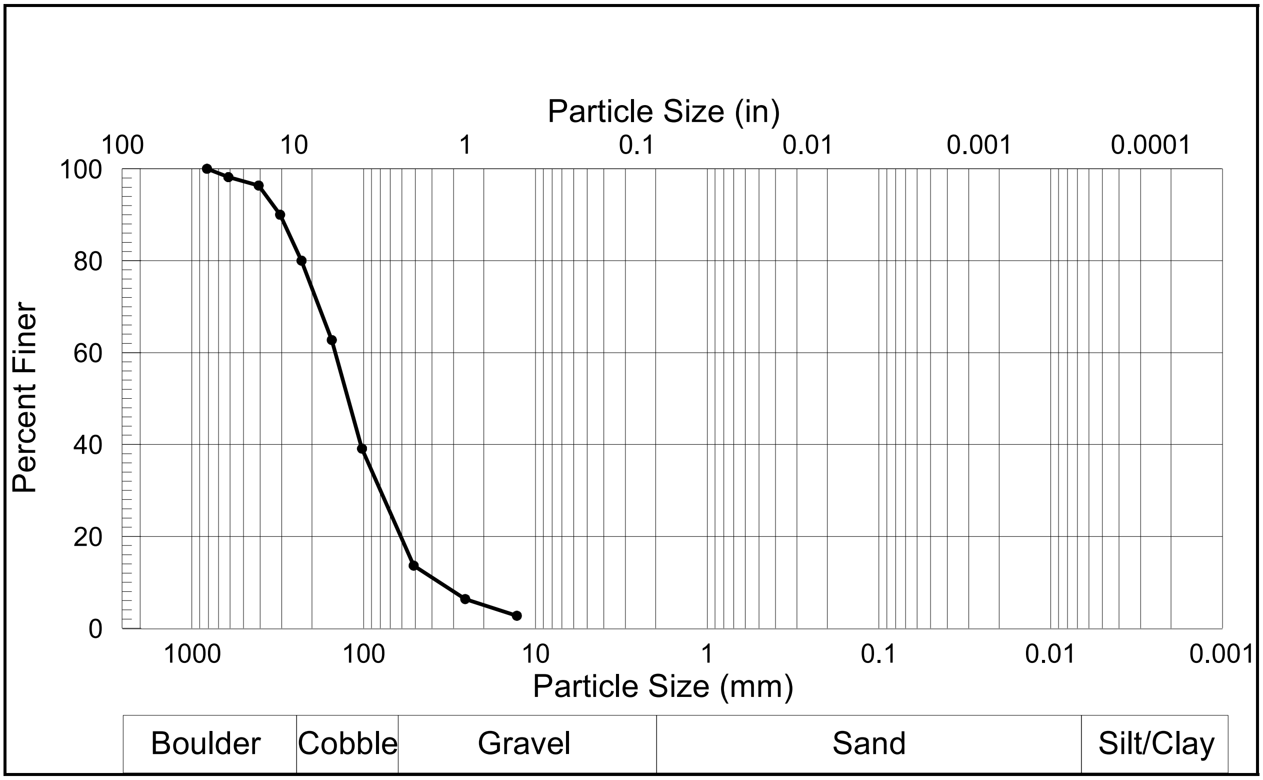


Figure A.3-55. Particle size distribution for Sweet Creek sample BM-2.

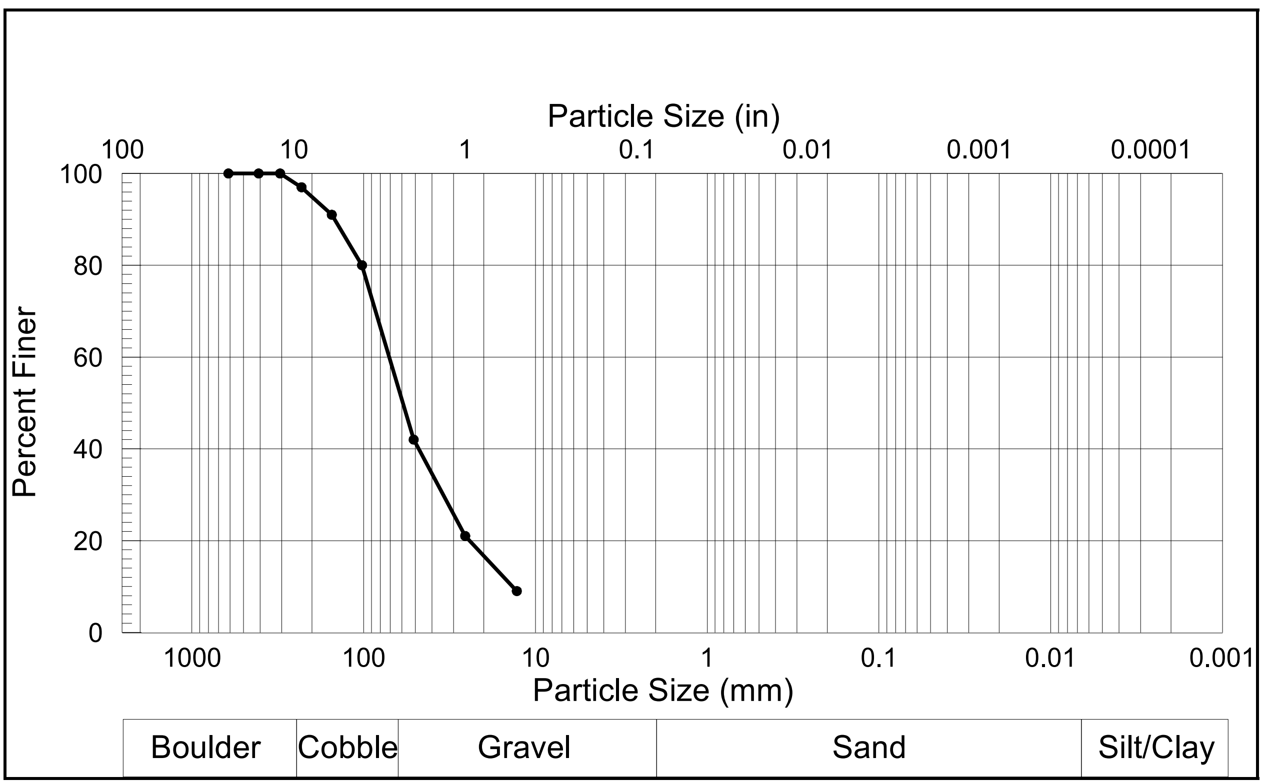


Figure A.3-56. Particle size distribution for Sweet Creek sample BM-3.

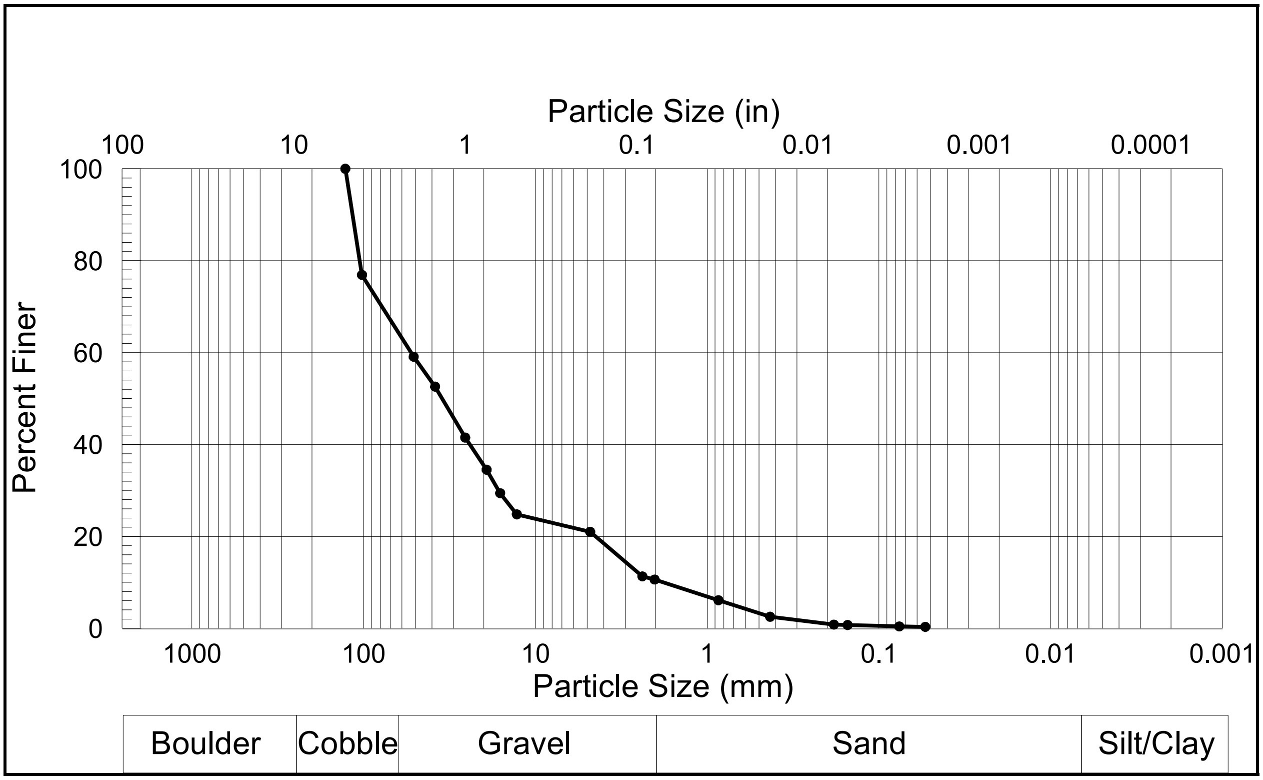


Figure A.3-57. Particle size distribution for Sweet Creek sample BM-4.

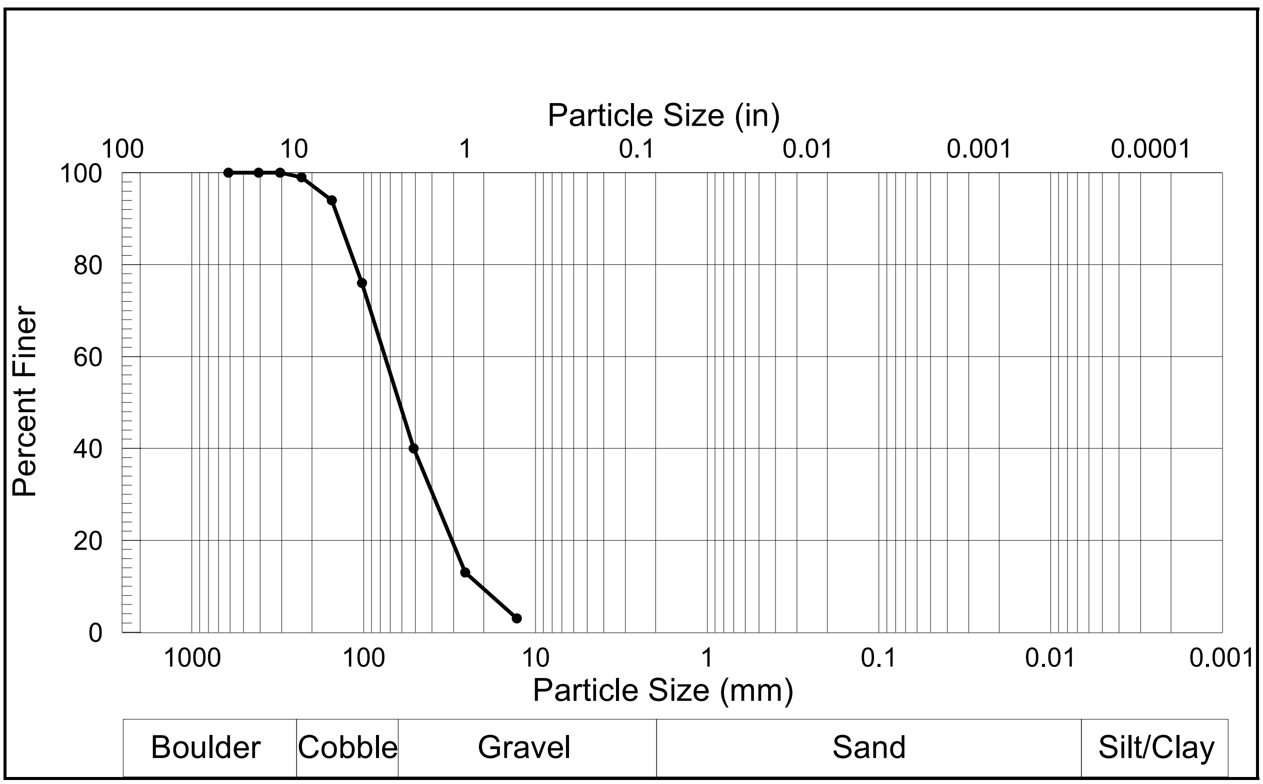
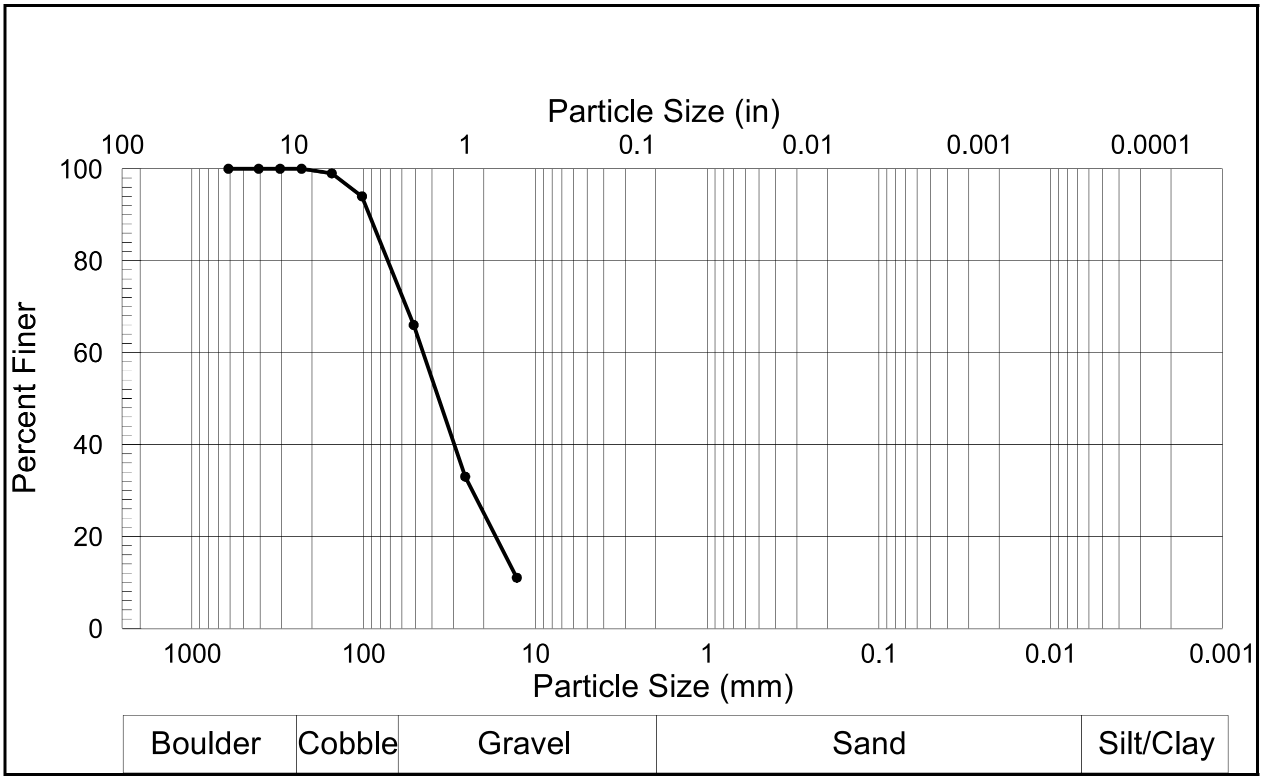


Figure A.3-58. Particle size distribution for Sweet Creek sample BM-5.



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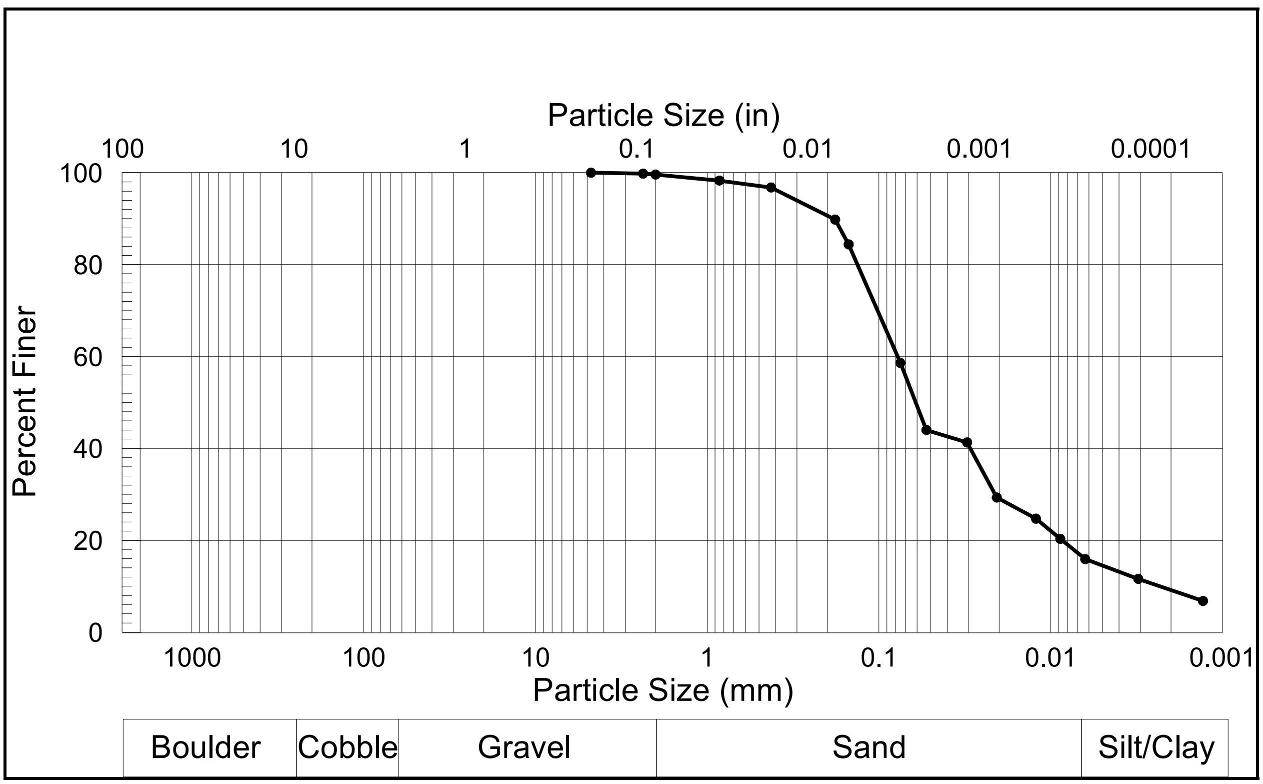

Figure A.3-60. Particle size distribution for Sweet Creek sample BM-7.

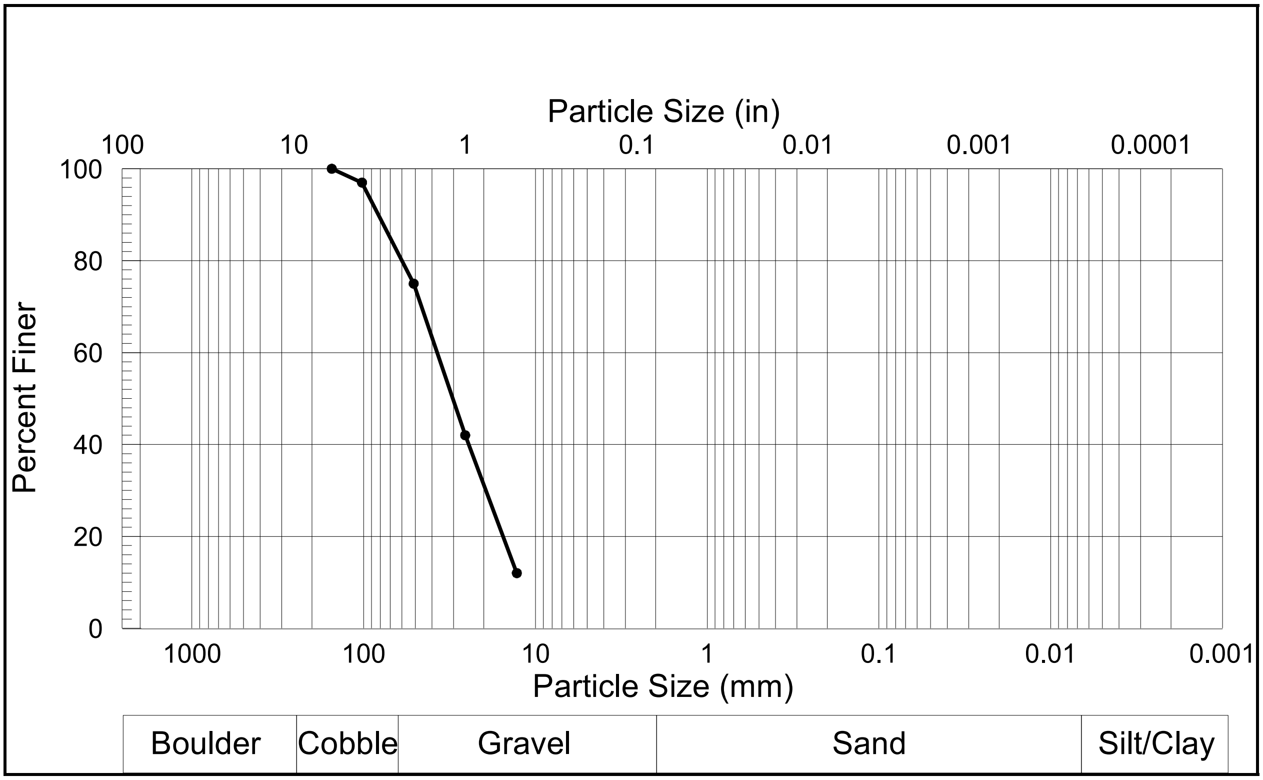

Figure A.3-61. Particle size distribution for Sweet Creek sample BM-8.

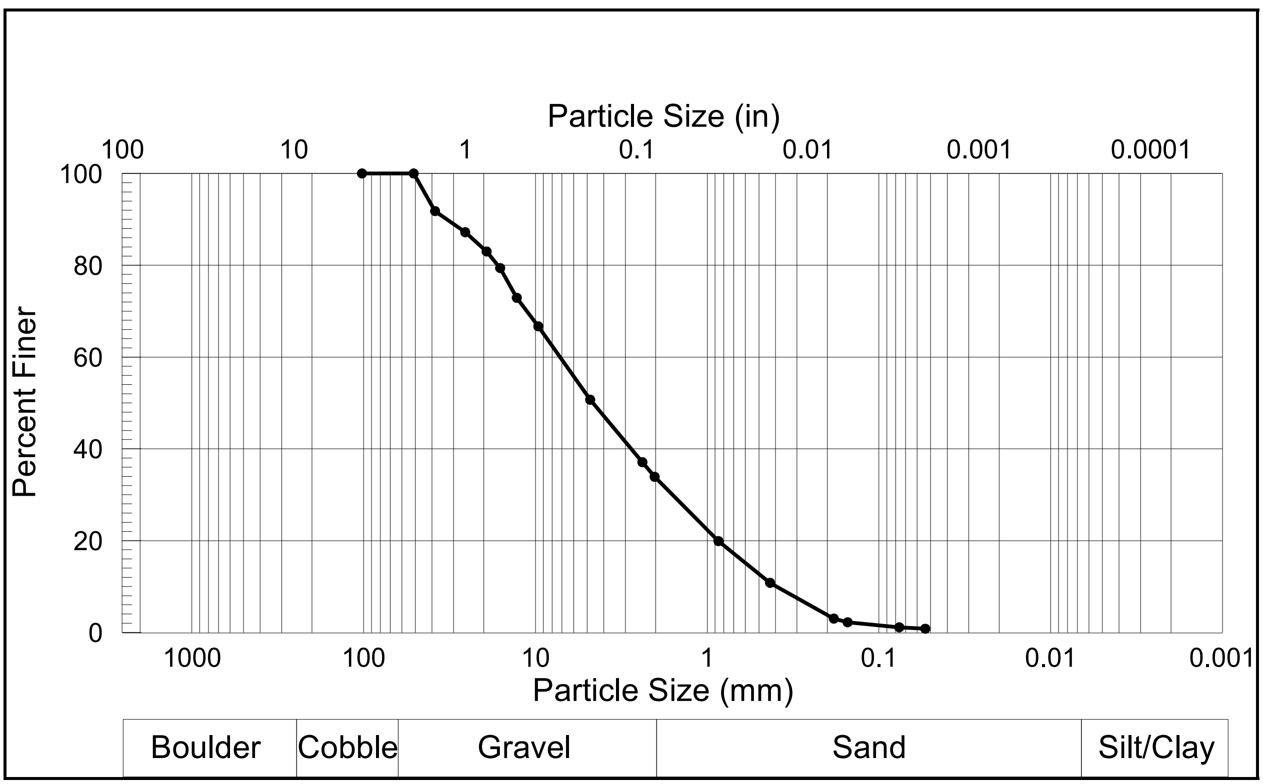

Figure A.3-62. Particle size distribution for Sweet Creek sample BM-9.

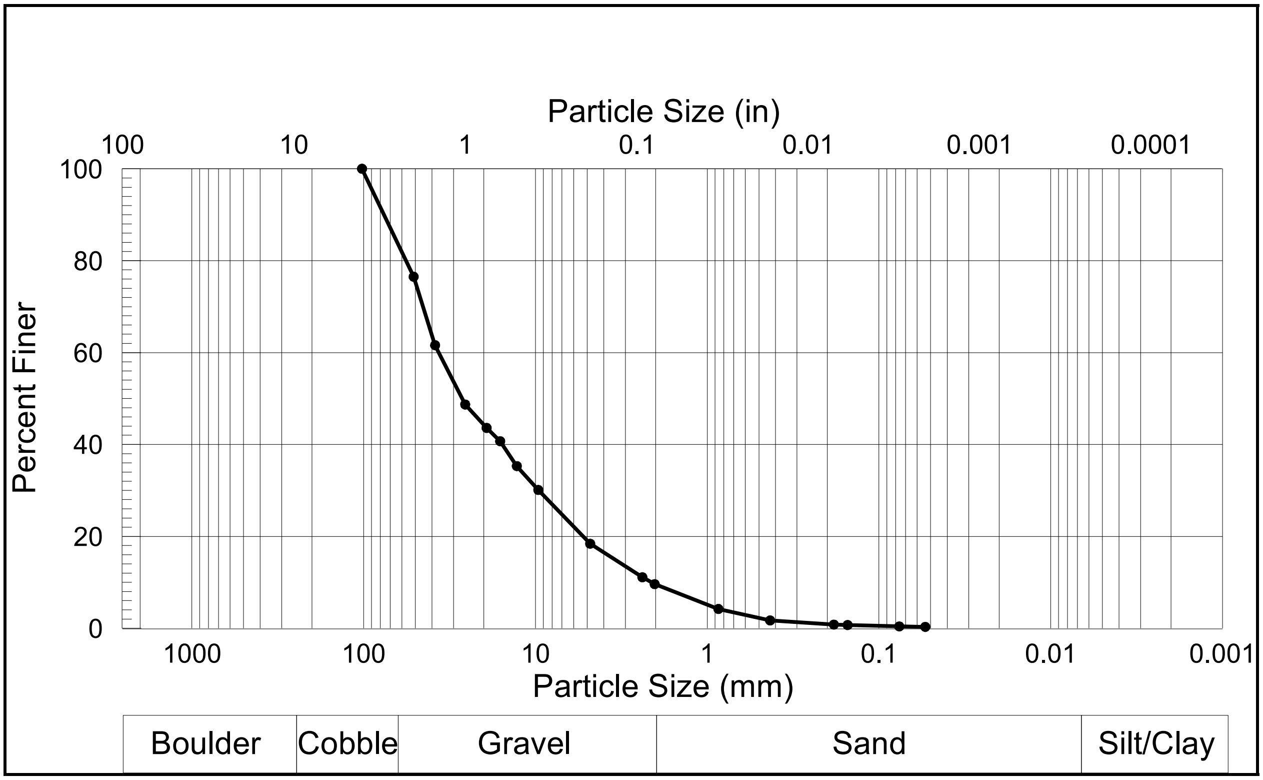

Figure A.3-63. Particle size distribution for Sweet Creek sample BM-10.

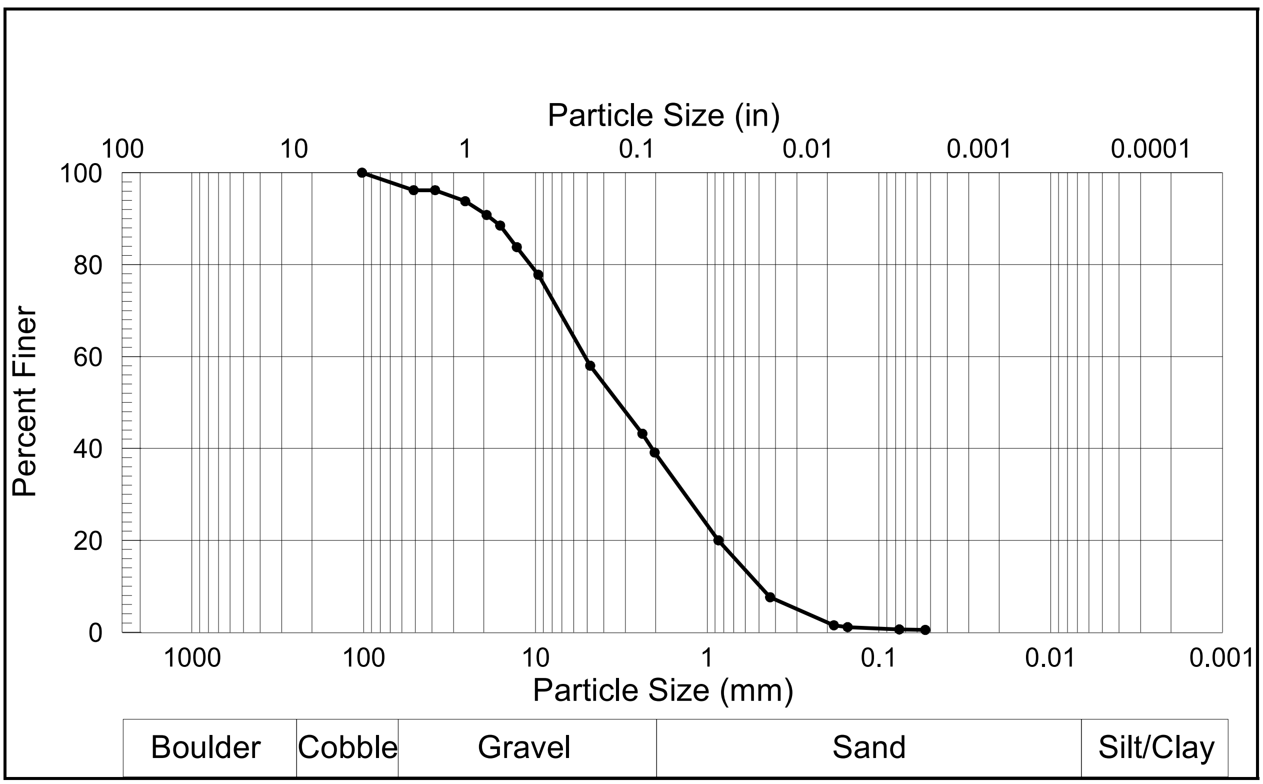

Figure A.3-64. Particle size distribution for Sweet Creek sample BM-11.

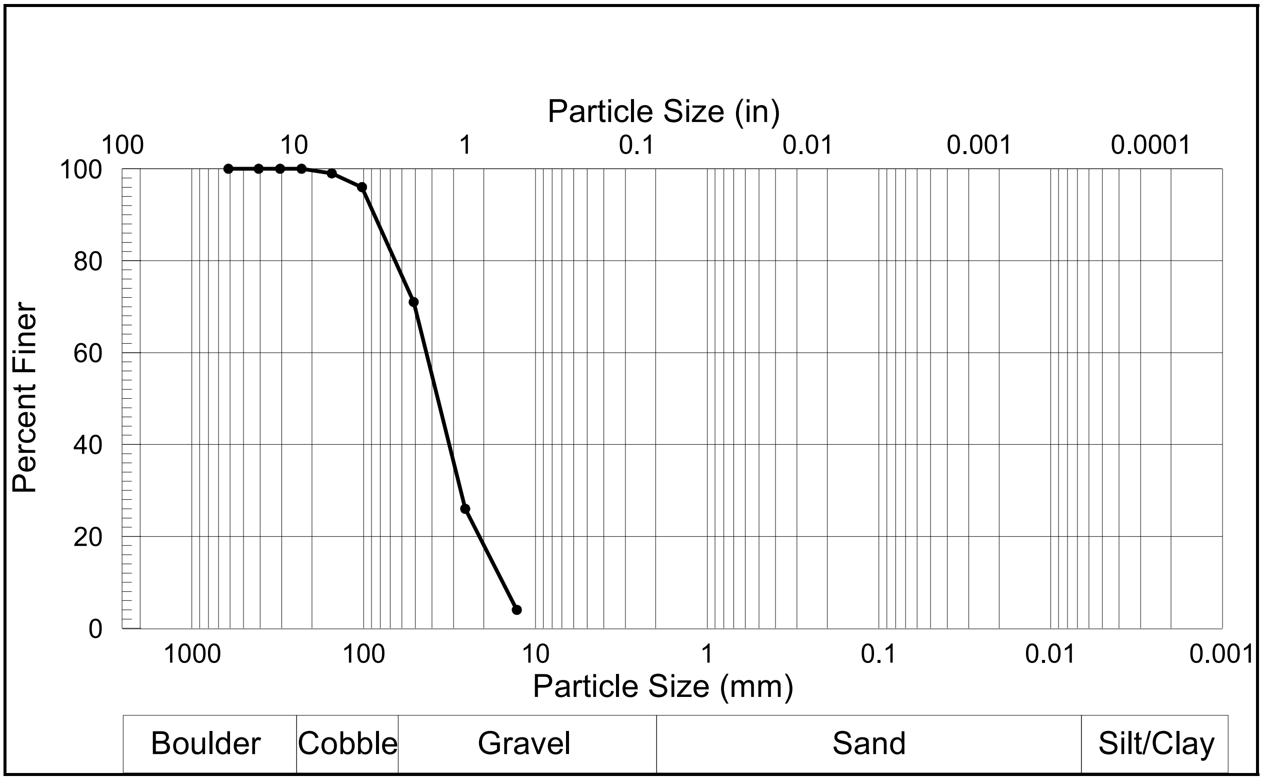

Figure A.3-65. Particle size distribution for Sweet Creek sample BM-12.

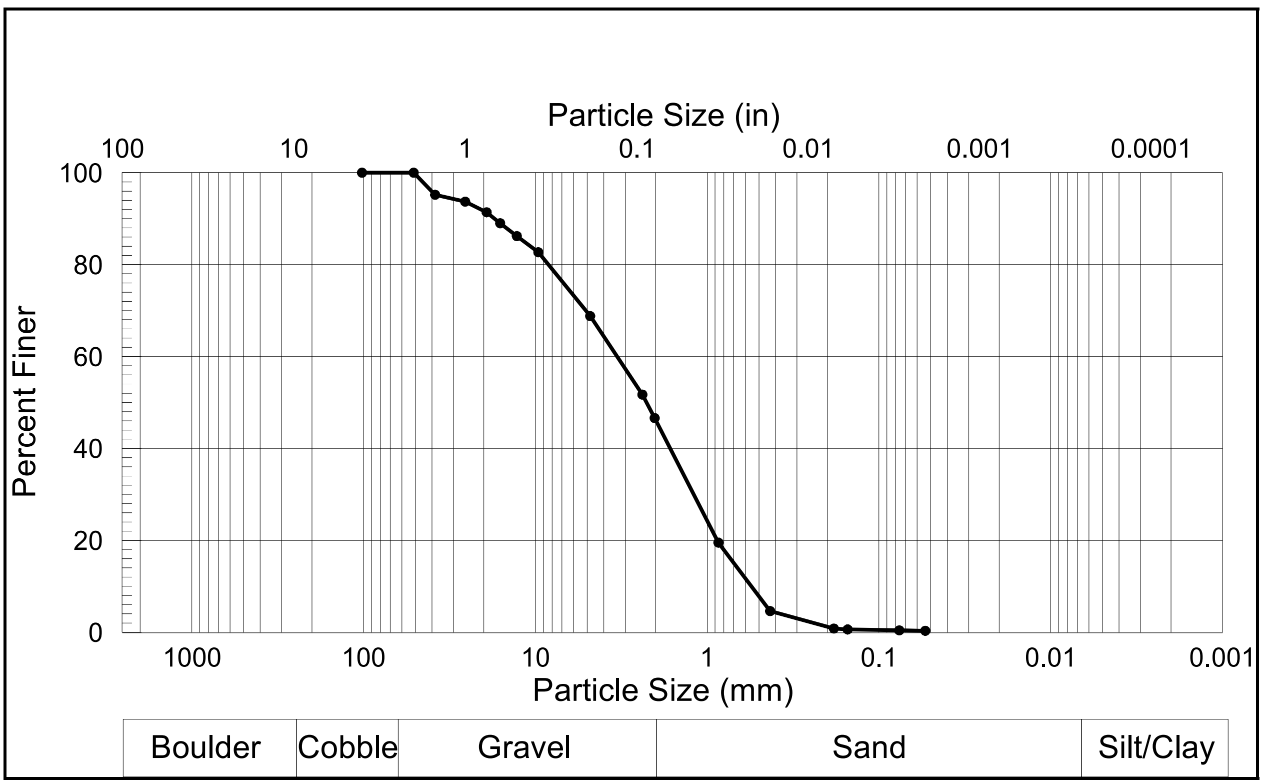

Figure A.3-66. Particle size distribution for Sweet Creek sample BM-13.

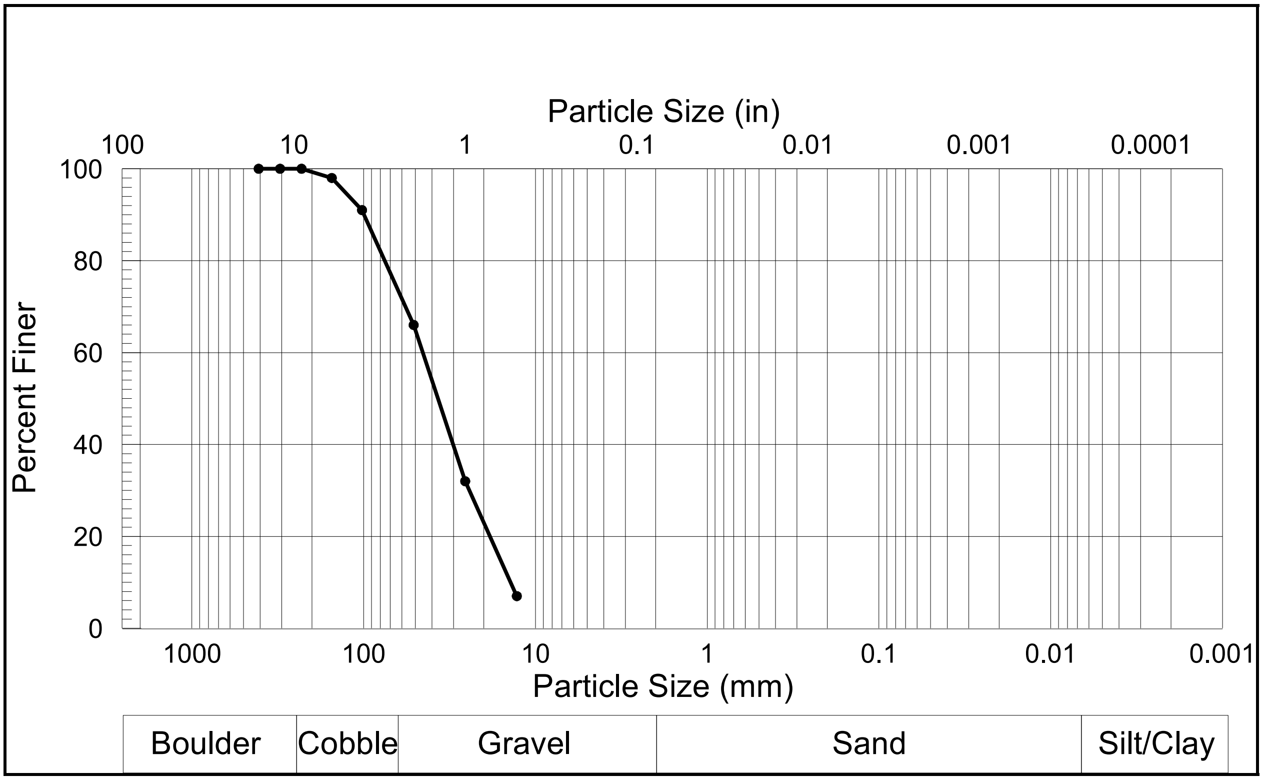

Figure A.3-67. Particle size distribution for Sand Creek sample BM-1.

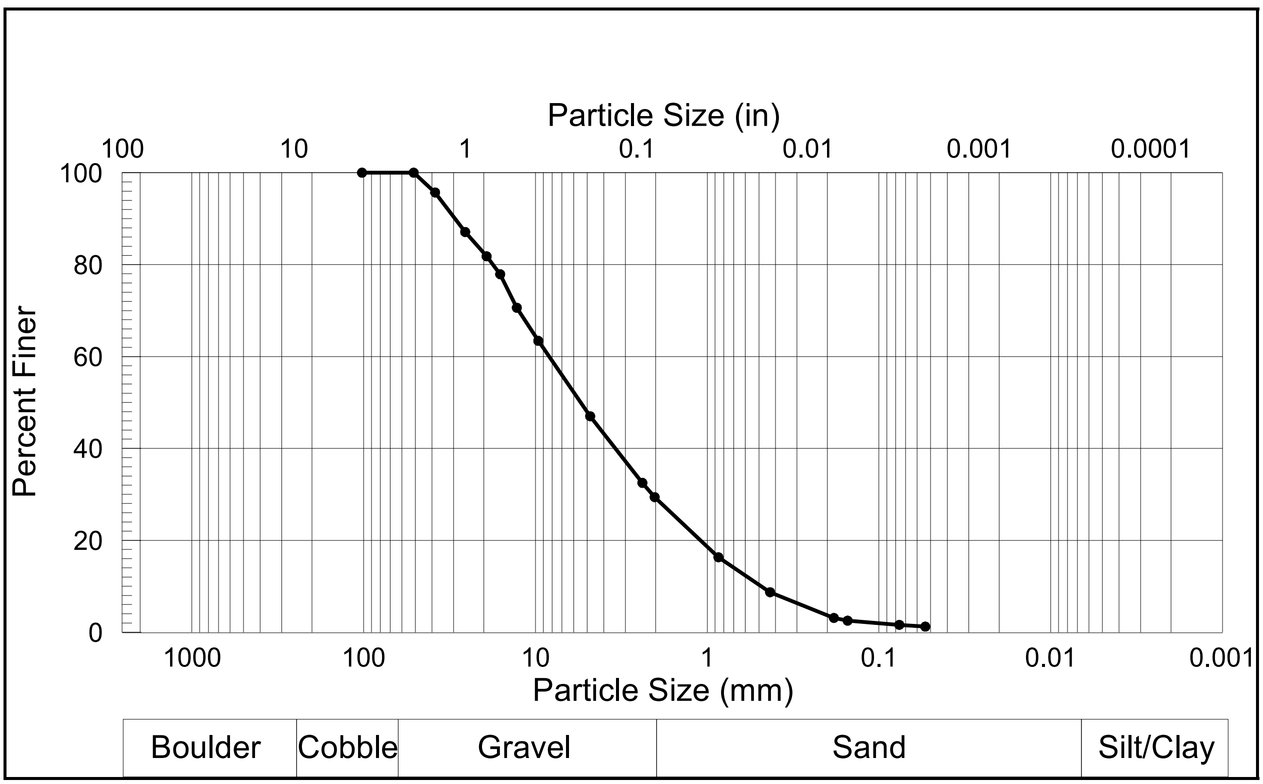

Figure A.3-68. Particle size distribution for Sand Creek sample BM-2.

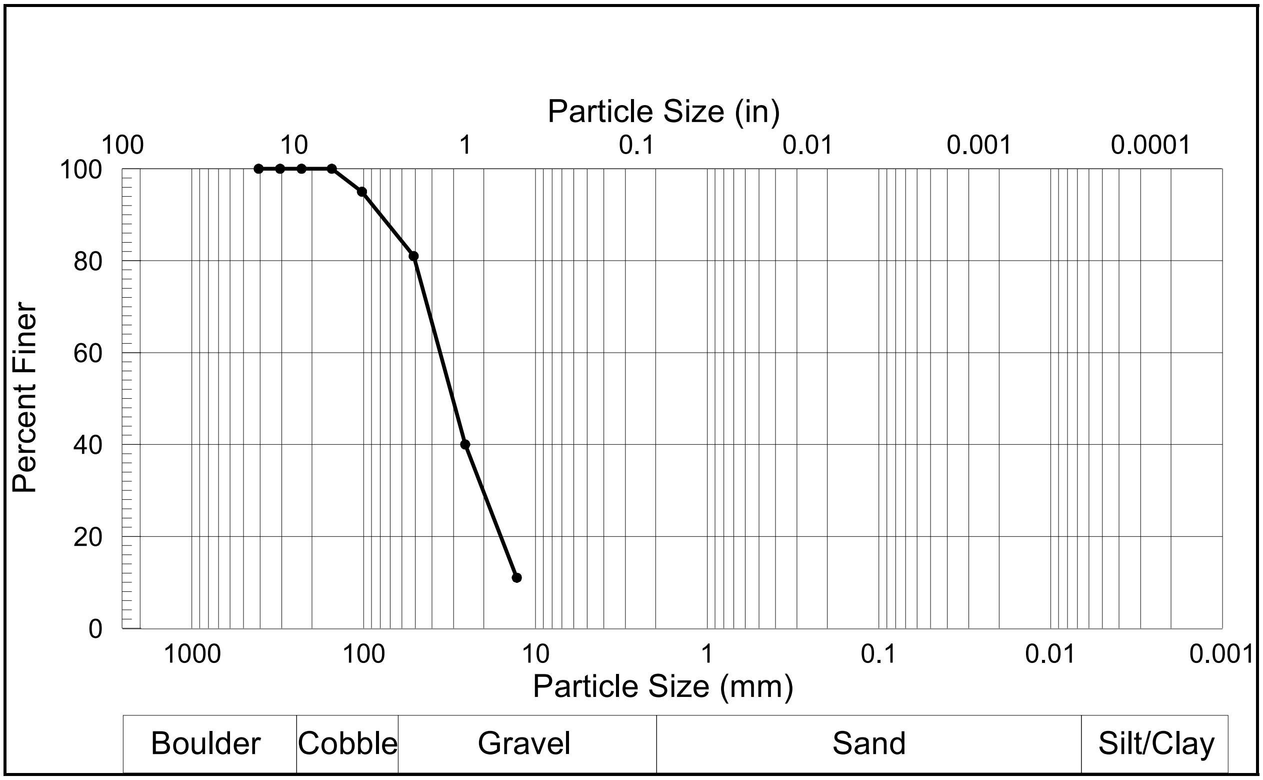

Figure A.3-69. Particle size distribution for Sand Creek sample BM-3.

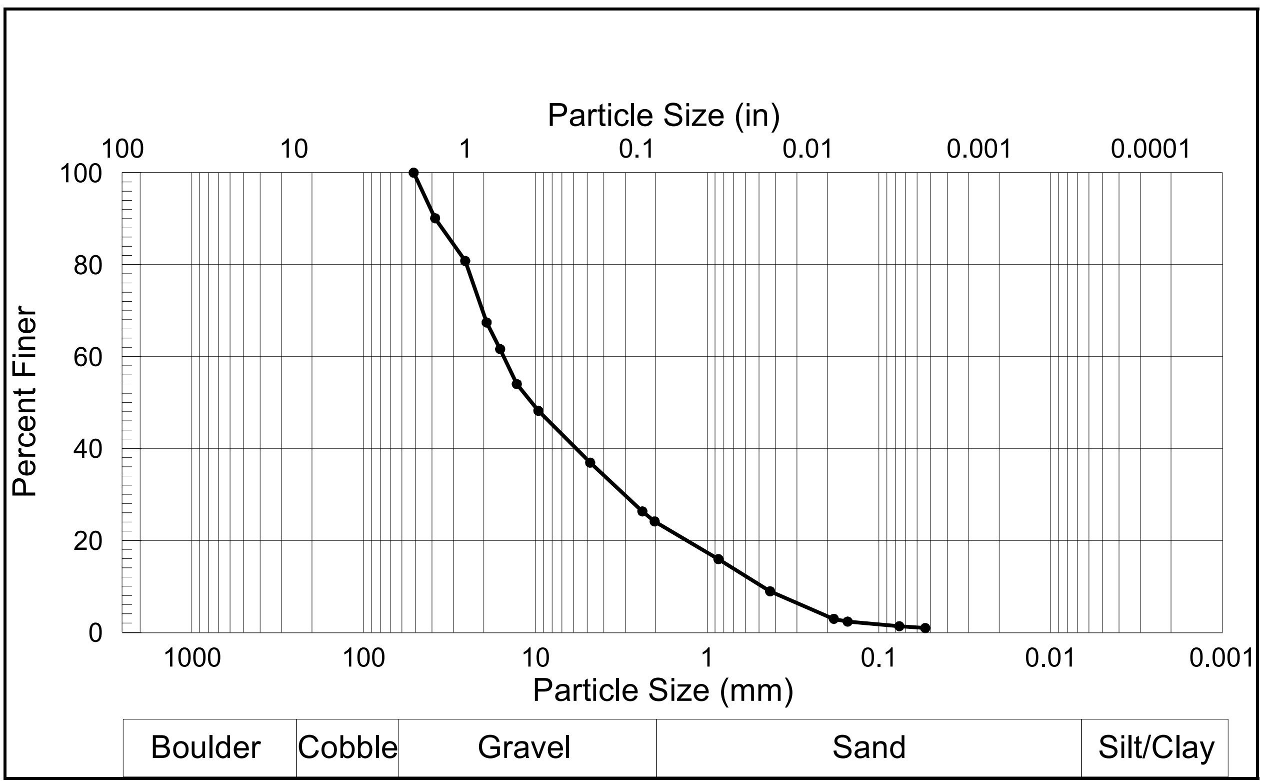

Figure A.3-70. Particle size distribution for Sand Creek sample BM-4.

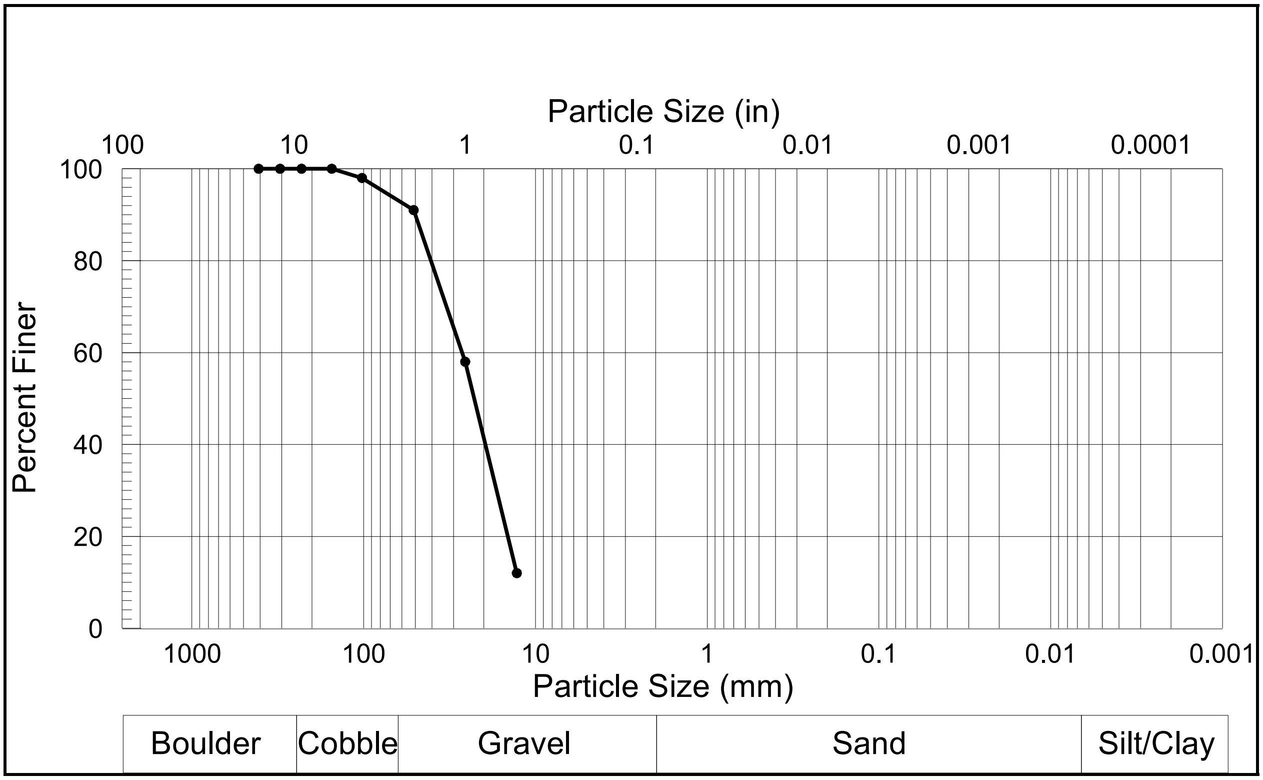

Figure A.3-71. Particle size distribution for Sand Creek sample BM-5.

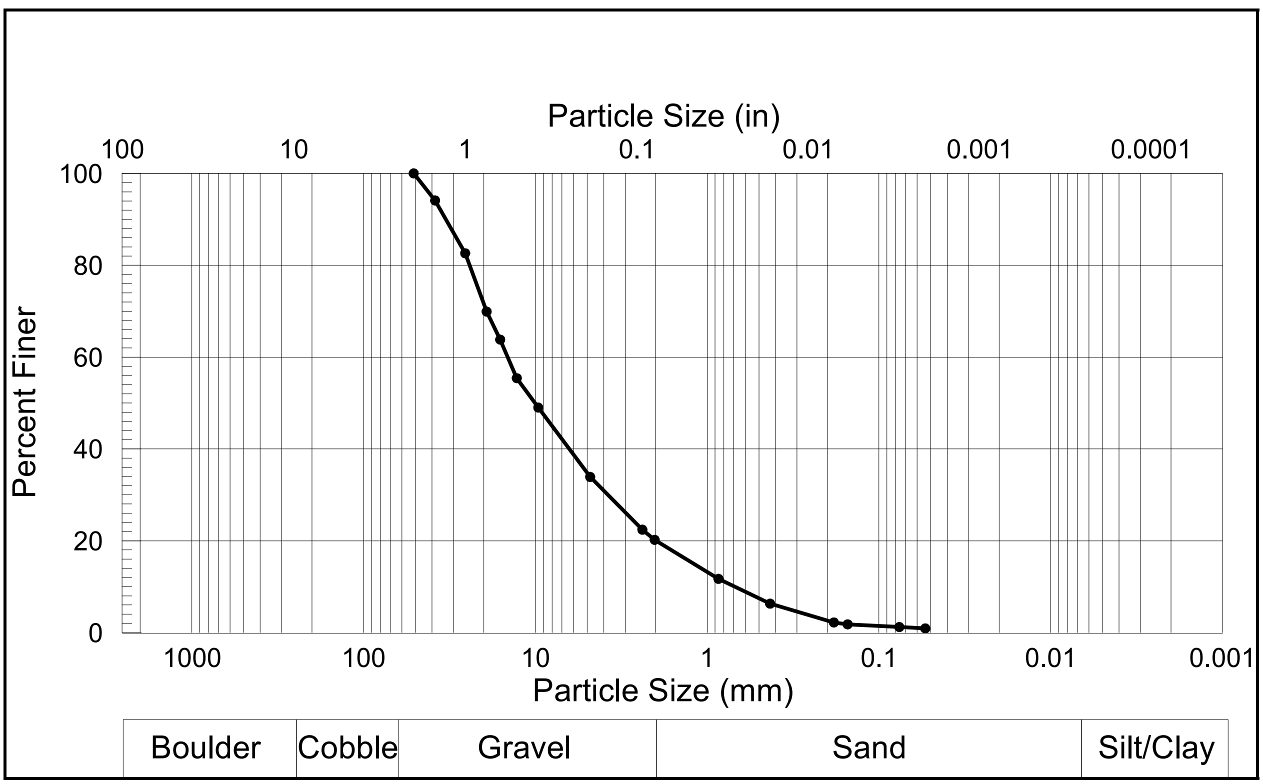

Figure A.3-72. Particle size distribution for Sand Creek sample BM-6.

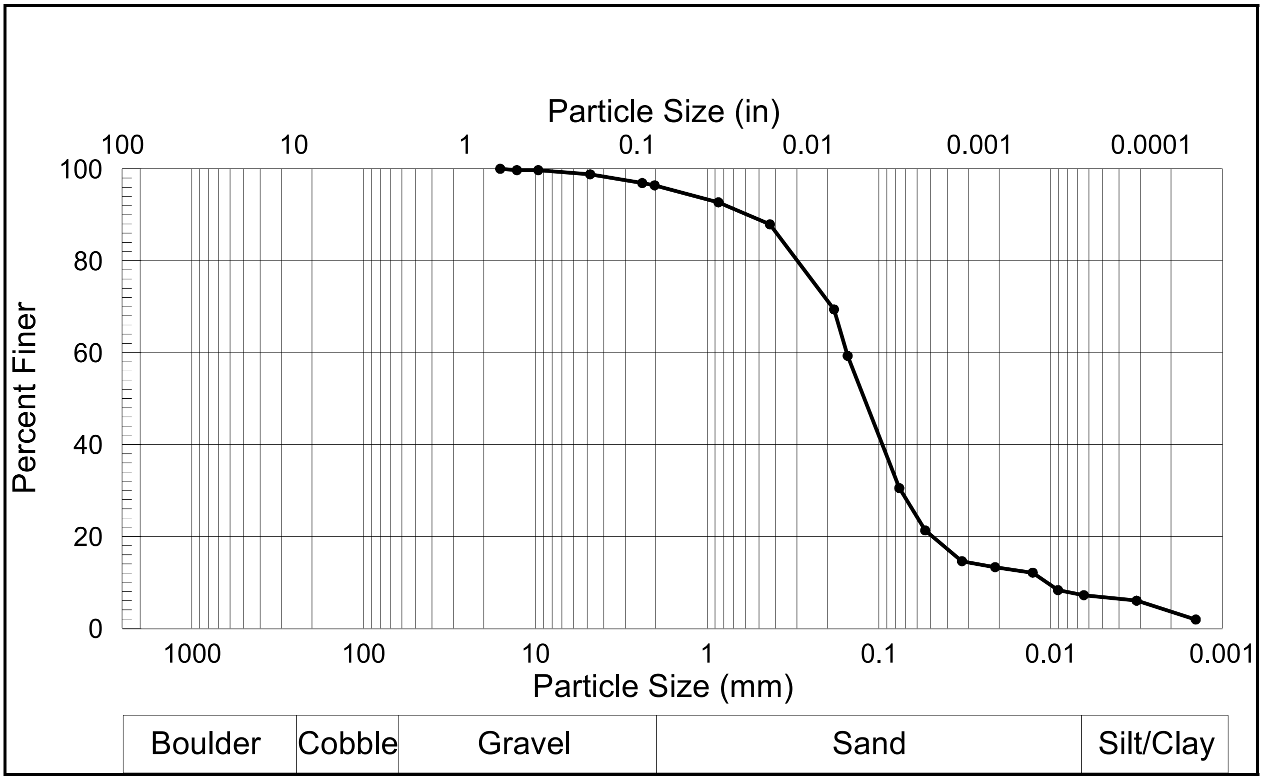

Figure A.3-73. Particle size distribution for Sand Creek sample BM-7.

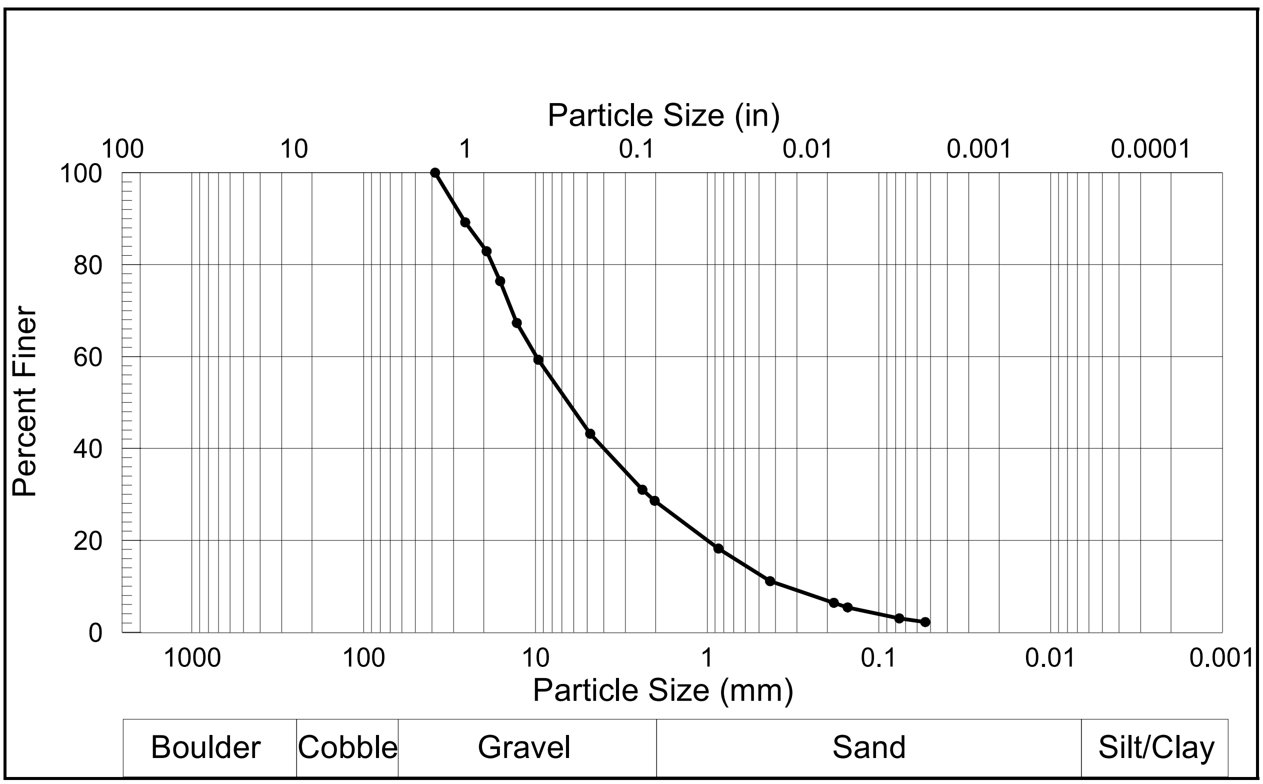

Figure A.3-74. Particle size distribution for Sand Creek sample BM-8.

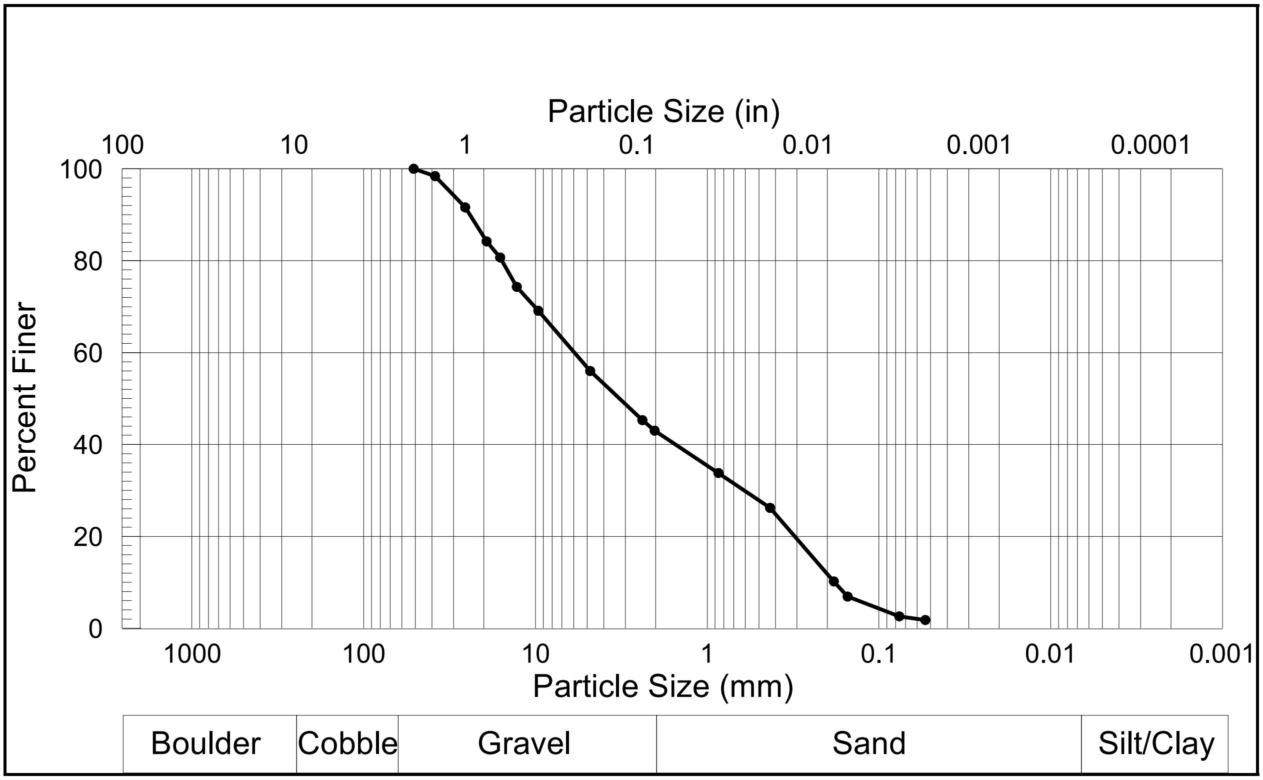

Figure A.3-75. Particle size distribution for Sand Creek sample BM-9.

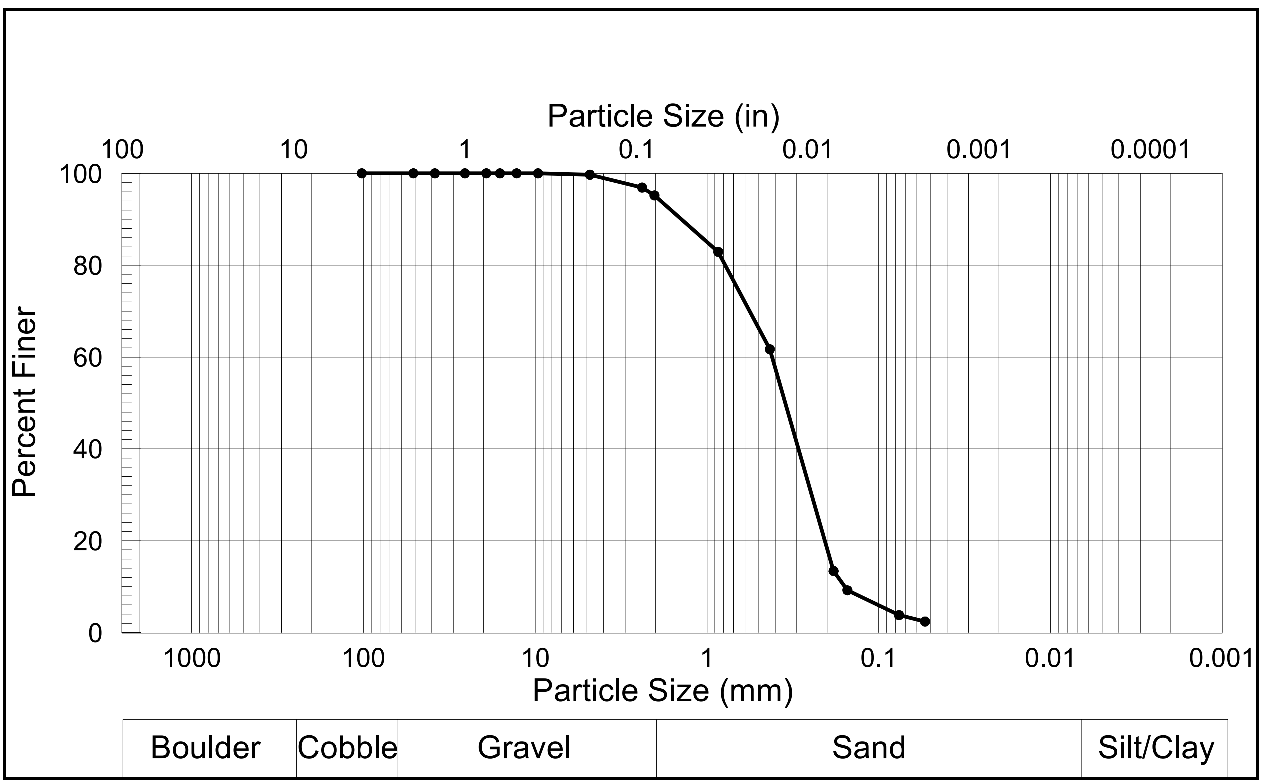

Figure A.3-76. Particle size distribution for Sand Creek sample BM-10.

Appendix 4. Tributary Delta Cross Sections for Bed Load Calculations

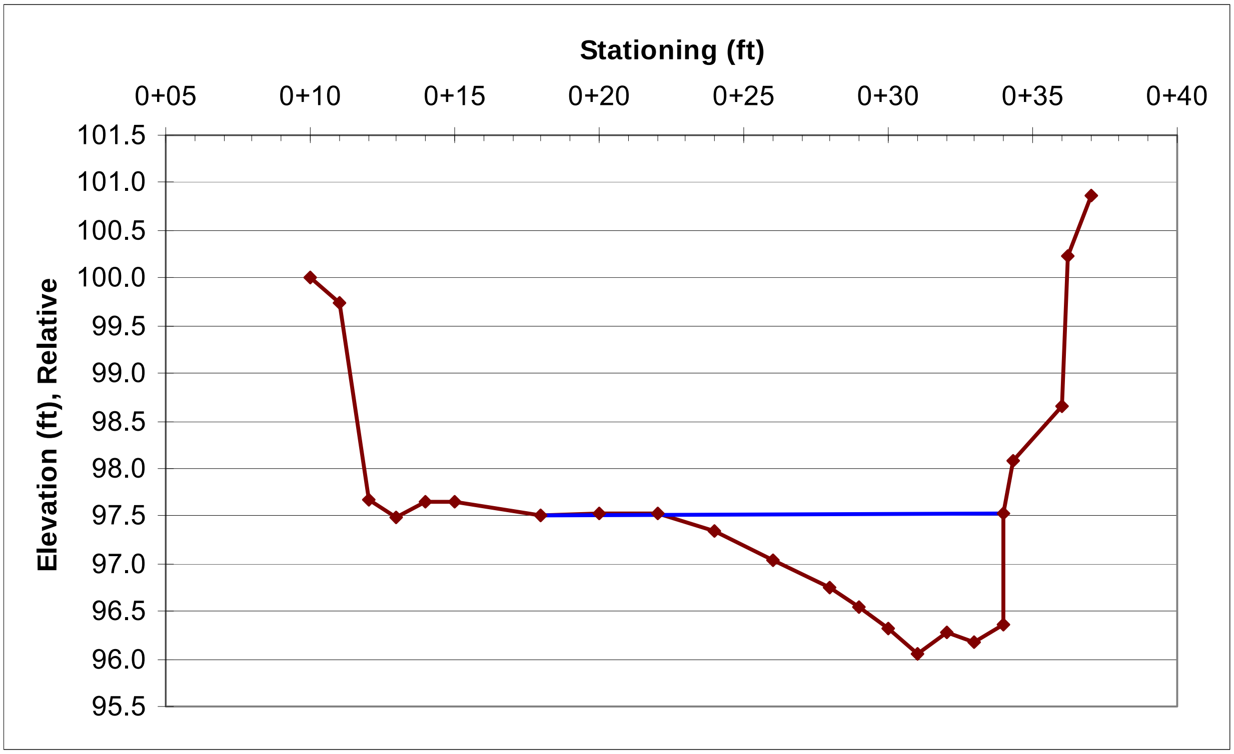

Figure A.4-1. Downstream view of Slate Creek cross-section BL-1.

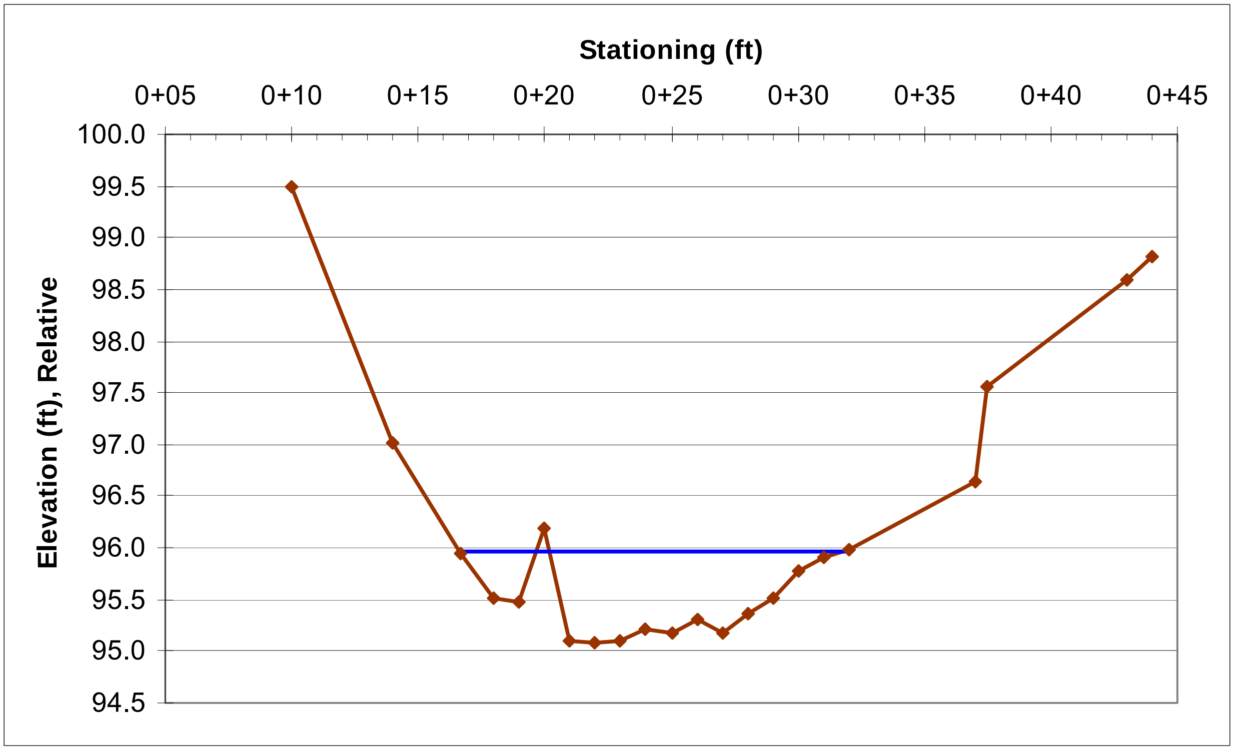

Figure A.4-2. Downstream view of Slate Creek cross-section BL-2.

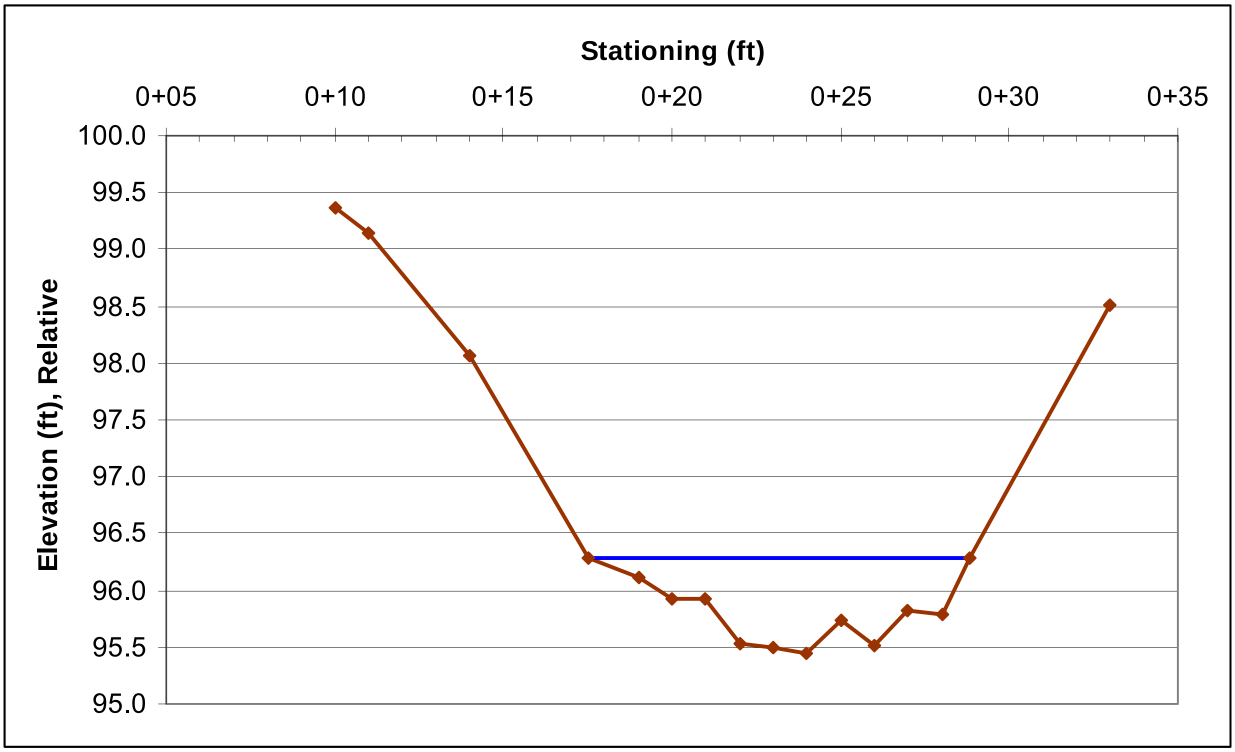

Figure A.4-3. Downstream view of Flume Creek cross-section BL-1.

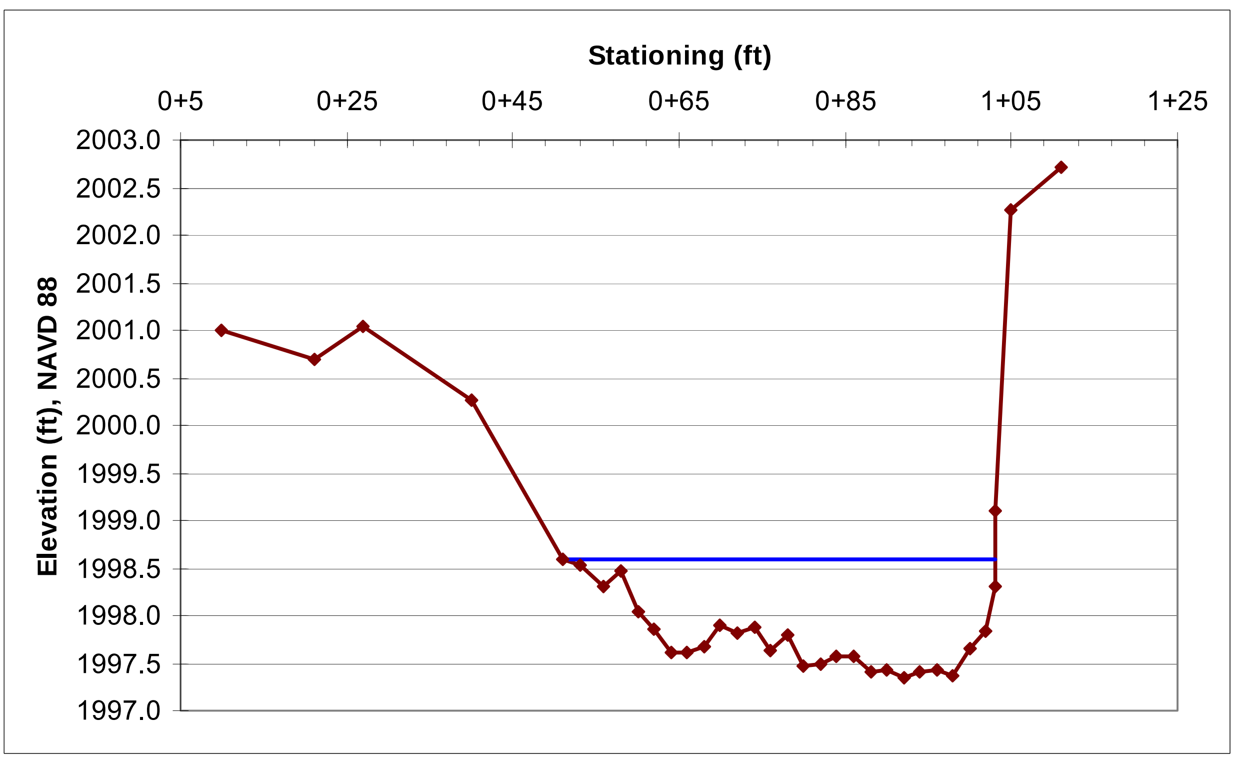

Figure A.4-4. Downstream view of Sullivan Creek cross-section BL-1.

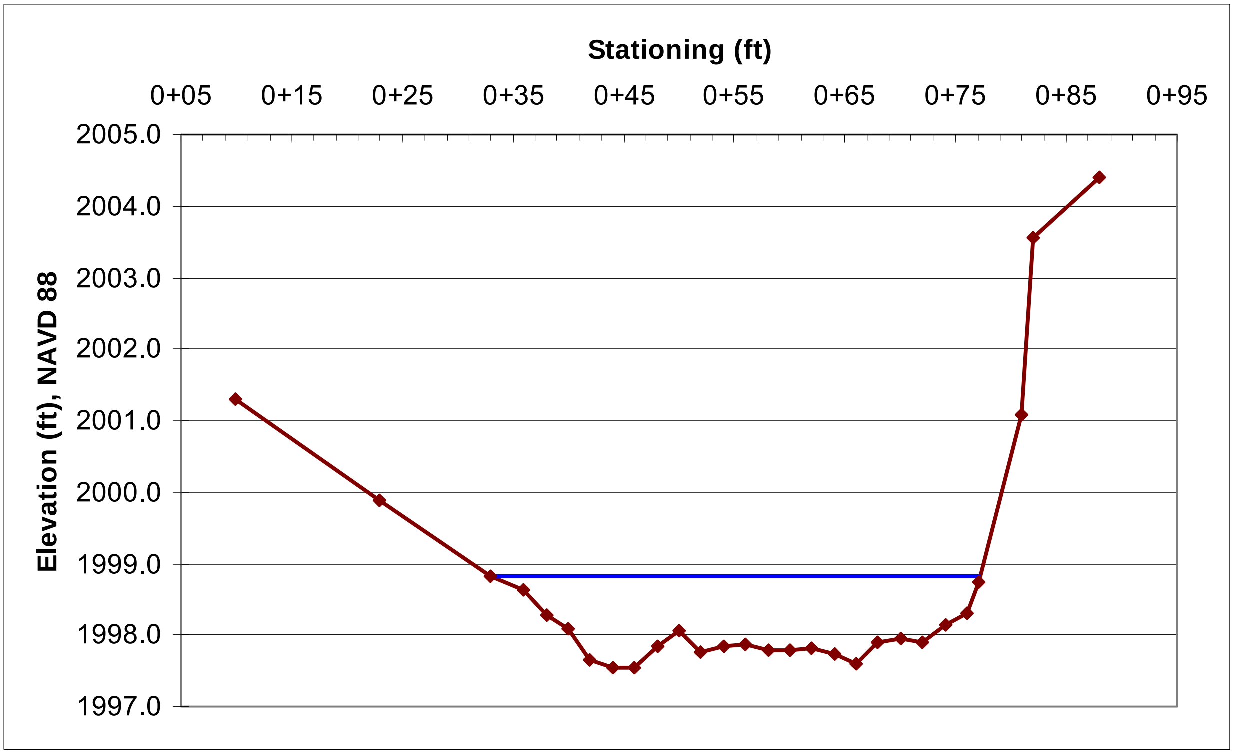

Figure A.4-5. Downstream view of Sullivan Creek cross-section BL-2.

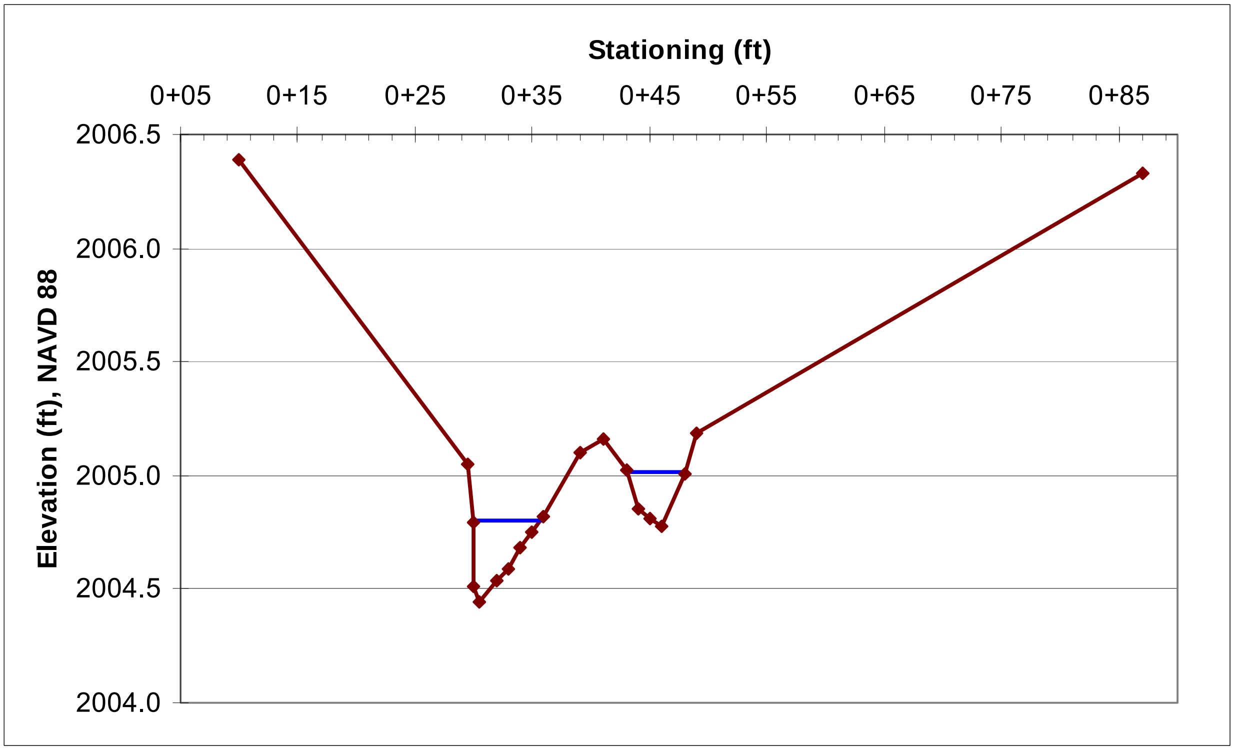

Figure A.4-6. Downstream view of Linton Creek cross-section BL-1.

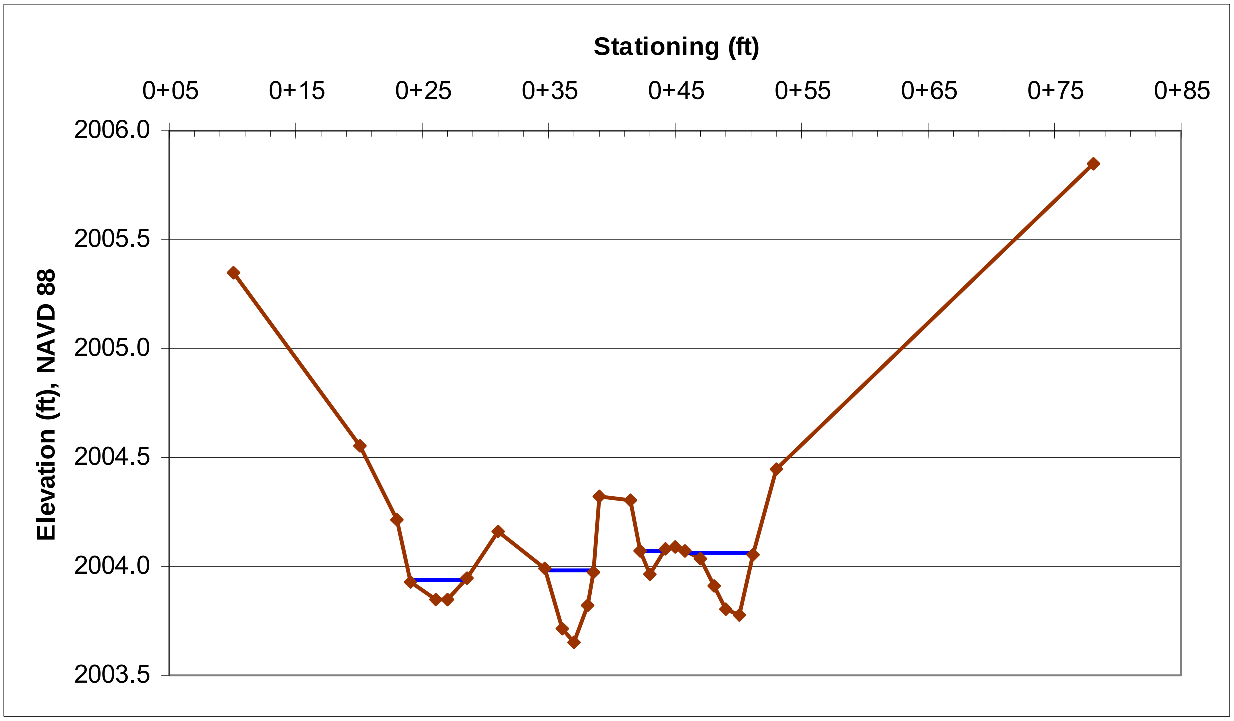

Figure A.4-7. Downstream view of Linton Creek cross-section BL-2.

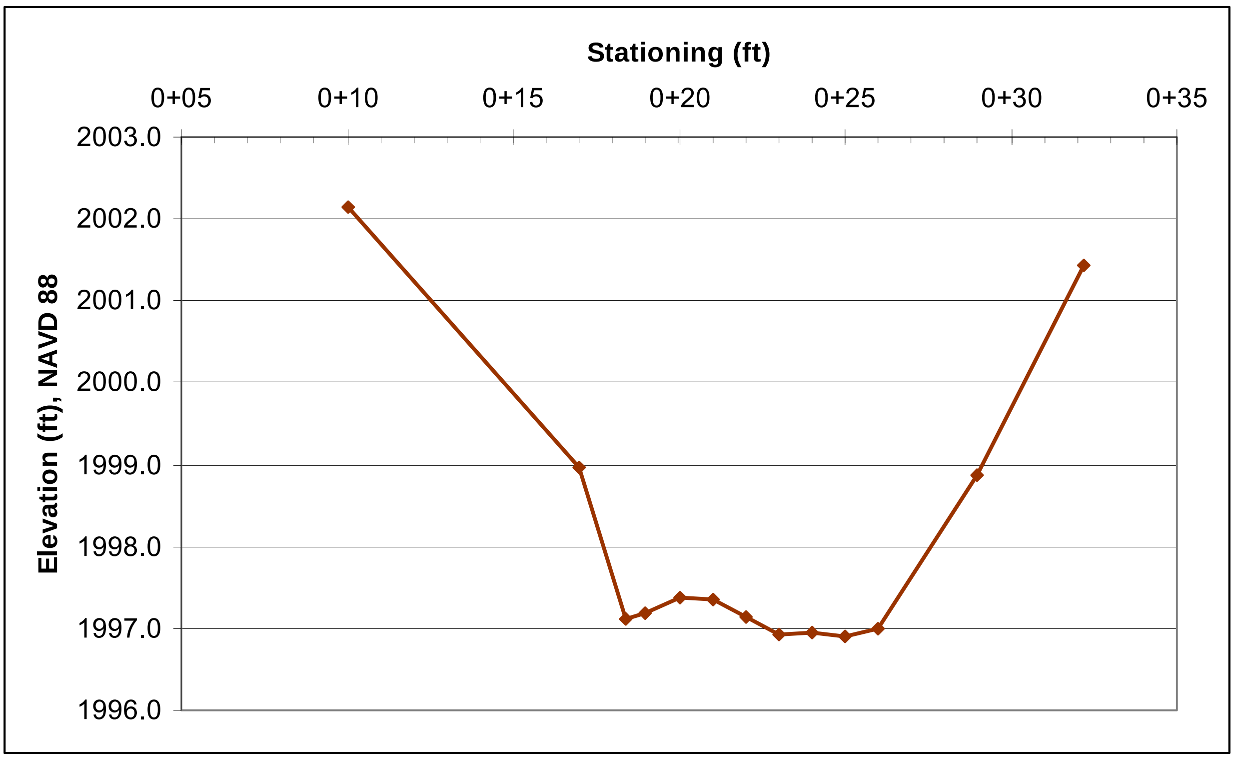

Figure A.4-8. Downstream view of Pocahontas Creek cross-section BL-1.

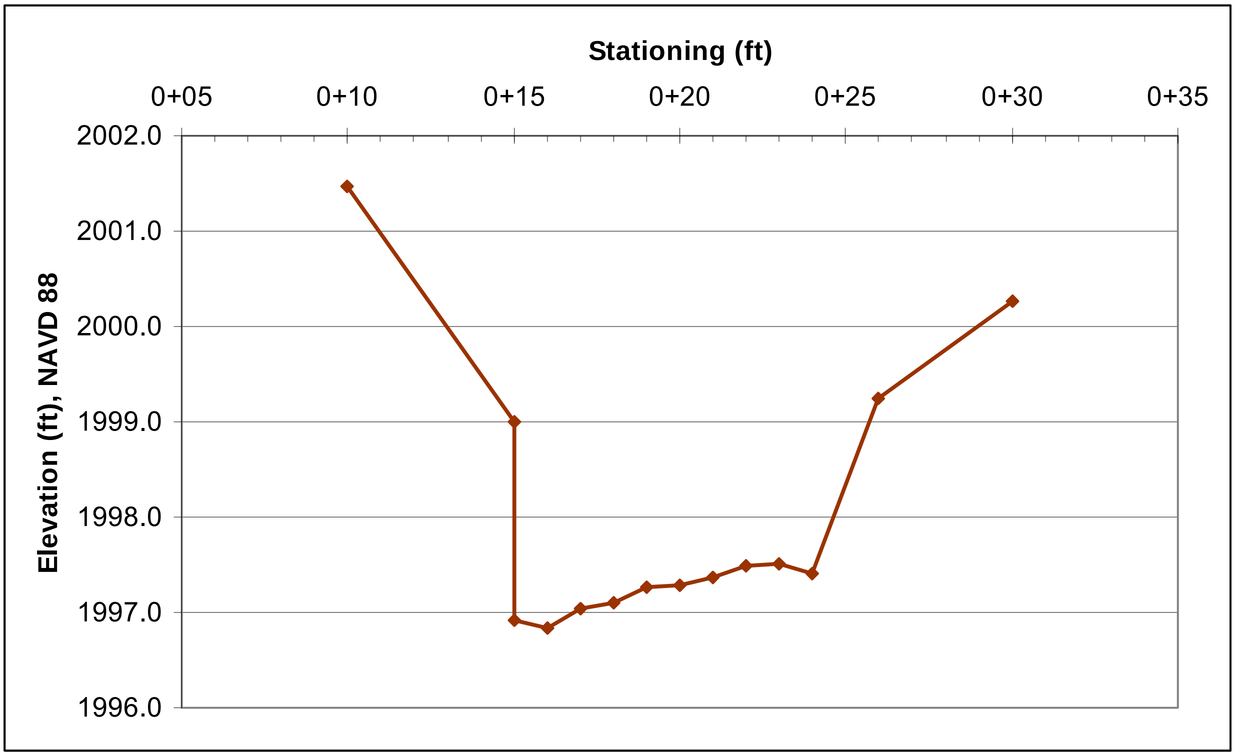

Figure A.4-9. Downstream view of Pocahontas Creek cross-section BL-2.

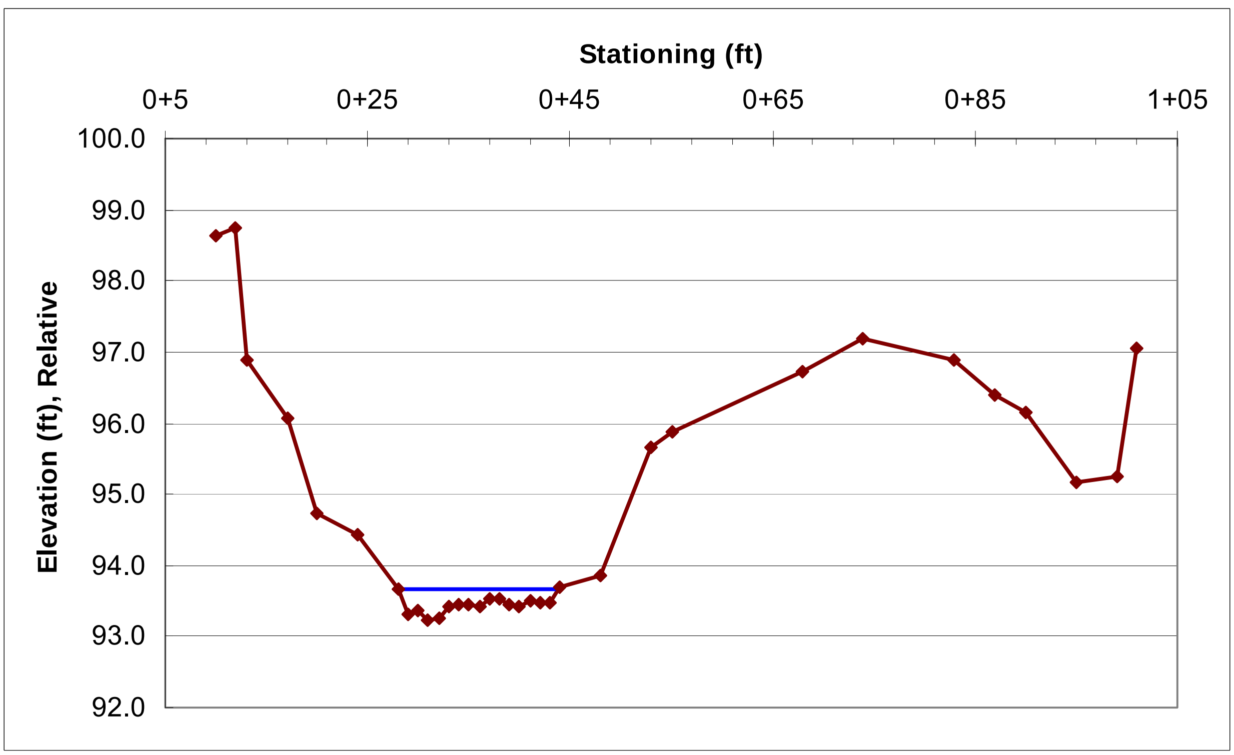

Figure A.4-10. Downstream view of Sweet Creek cross-section BL-1.

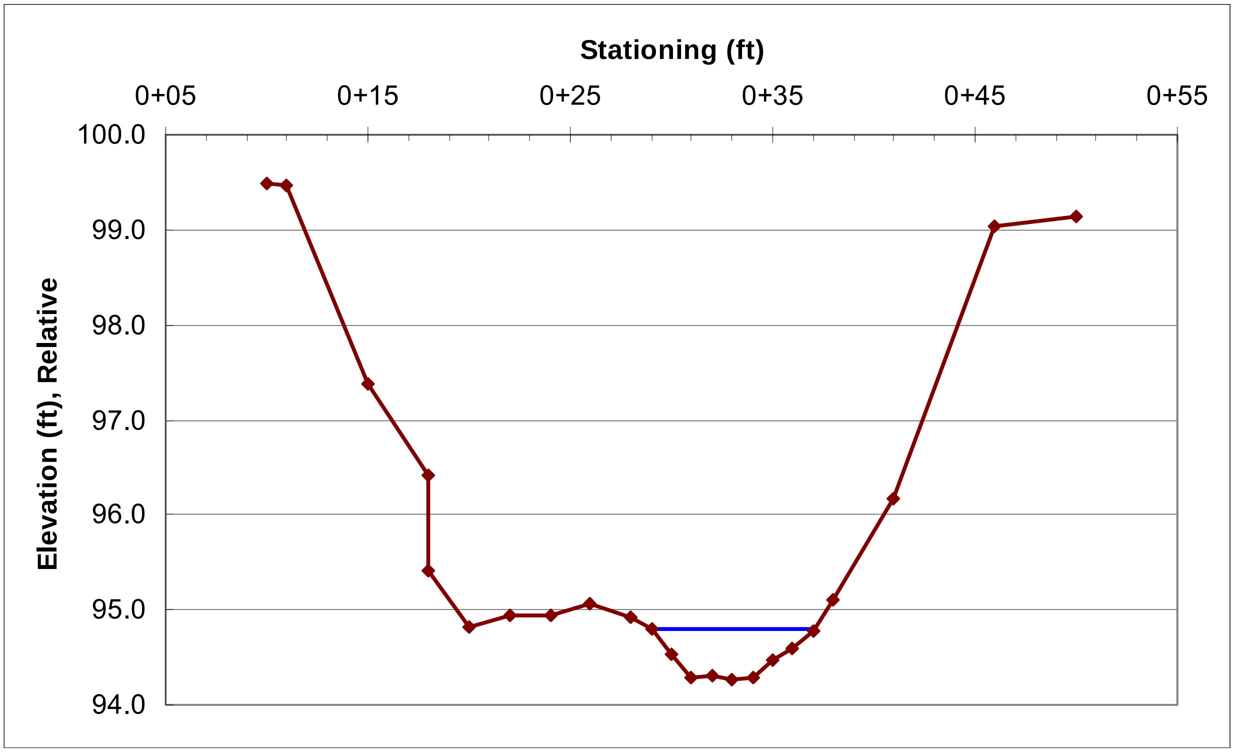

Figure A.4-11. Downstream view of Sweet Creek cross-section BL-2.

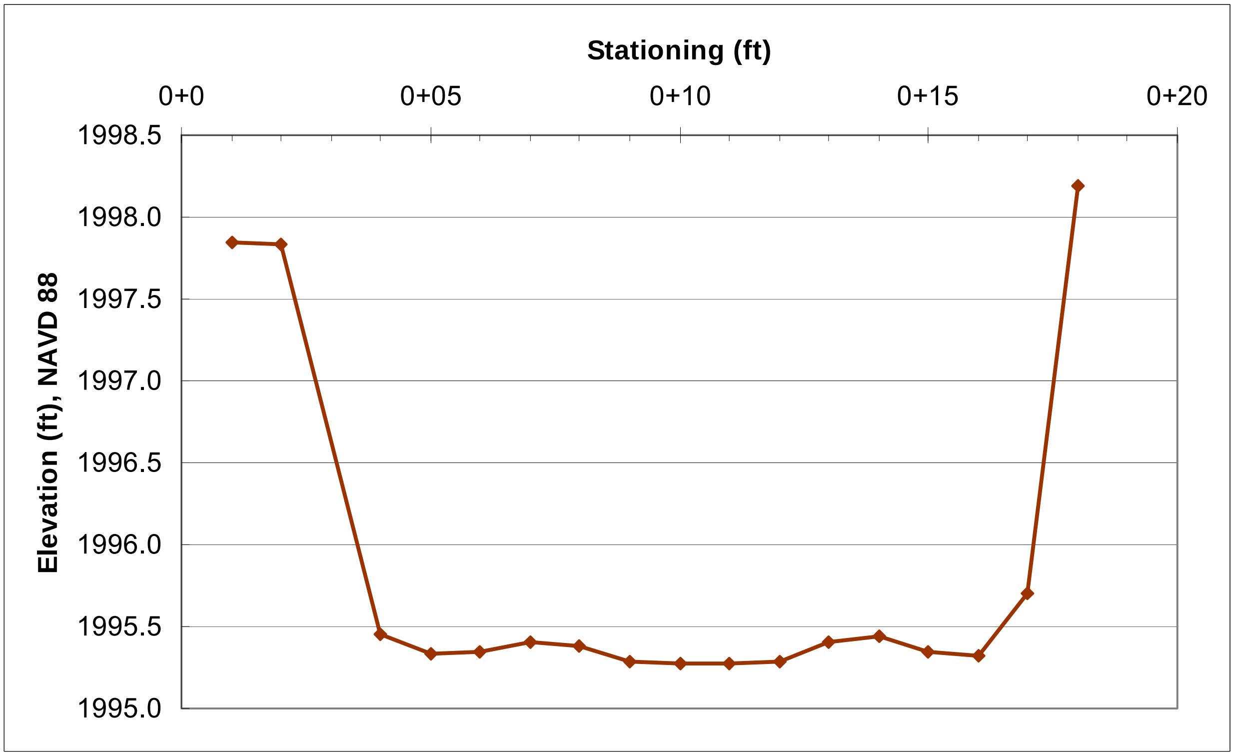

Figure A.4-12. Downstream view of Sand Creek cross-section BL-1.

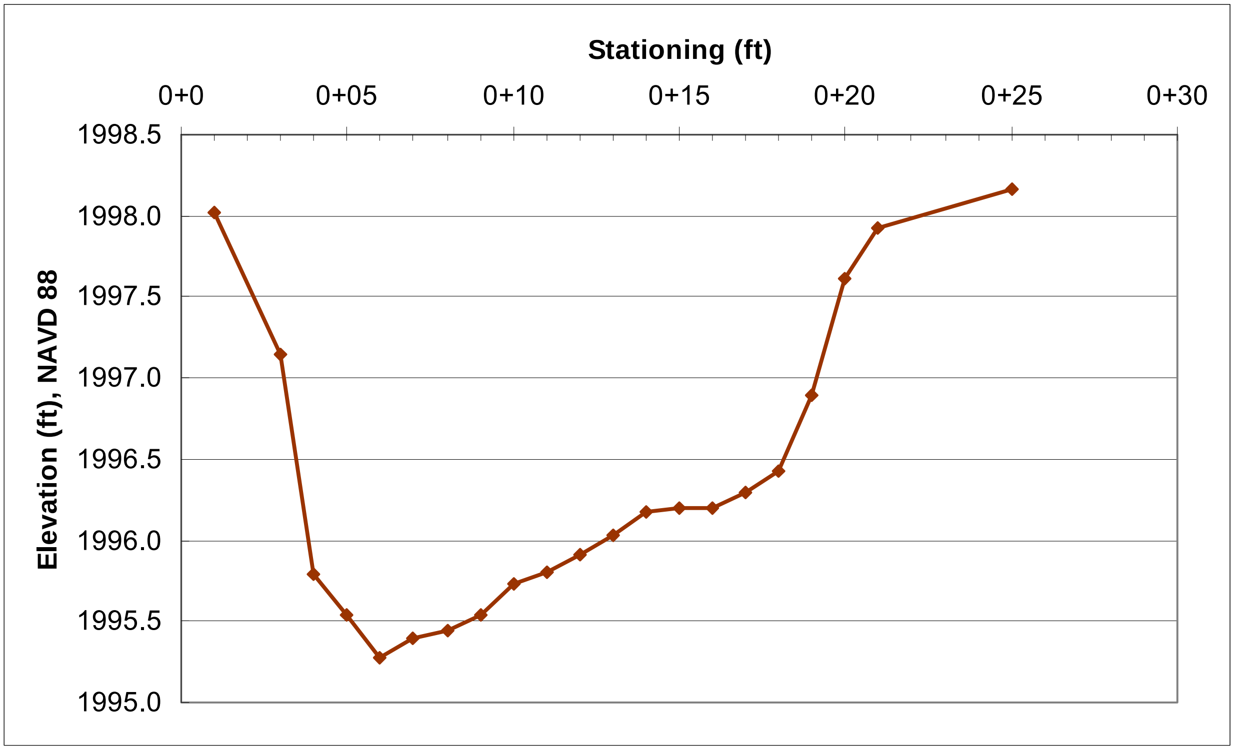

Figure A.4-13. Downstream view of Sand Creek cross-section BL-2.

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Appendix 5. Mainstem Bed Material Sampling Results

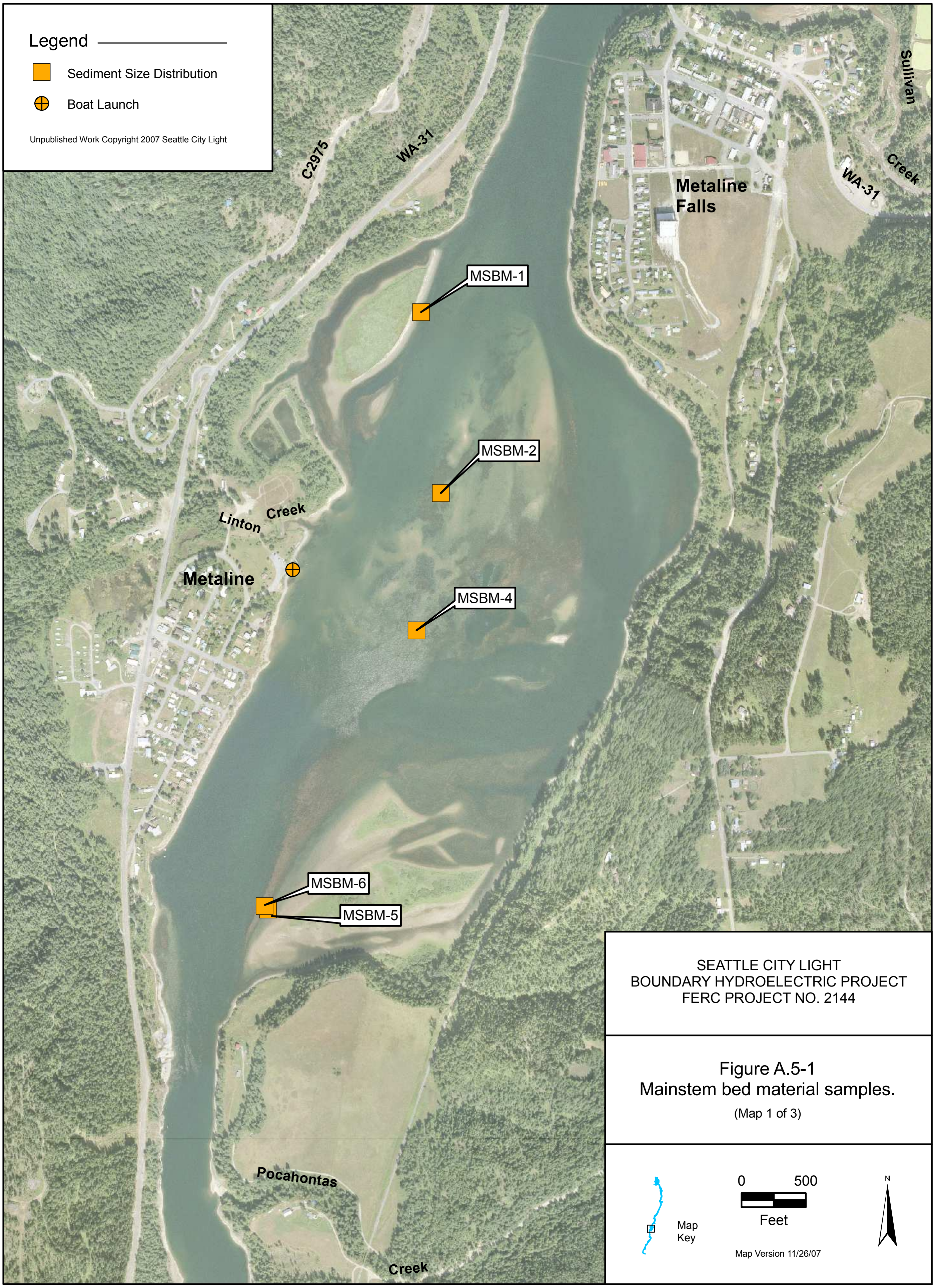

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Figure A.5-1
Mainstem bed material samples.
(Map 1 of 3)

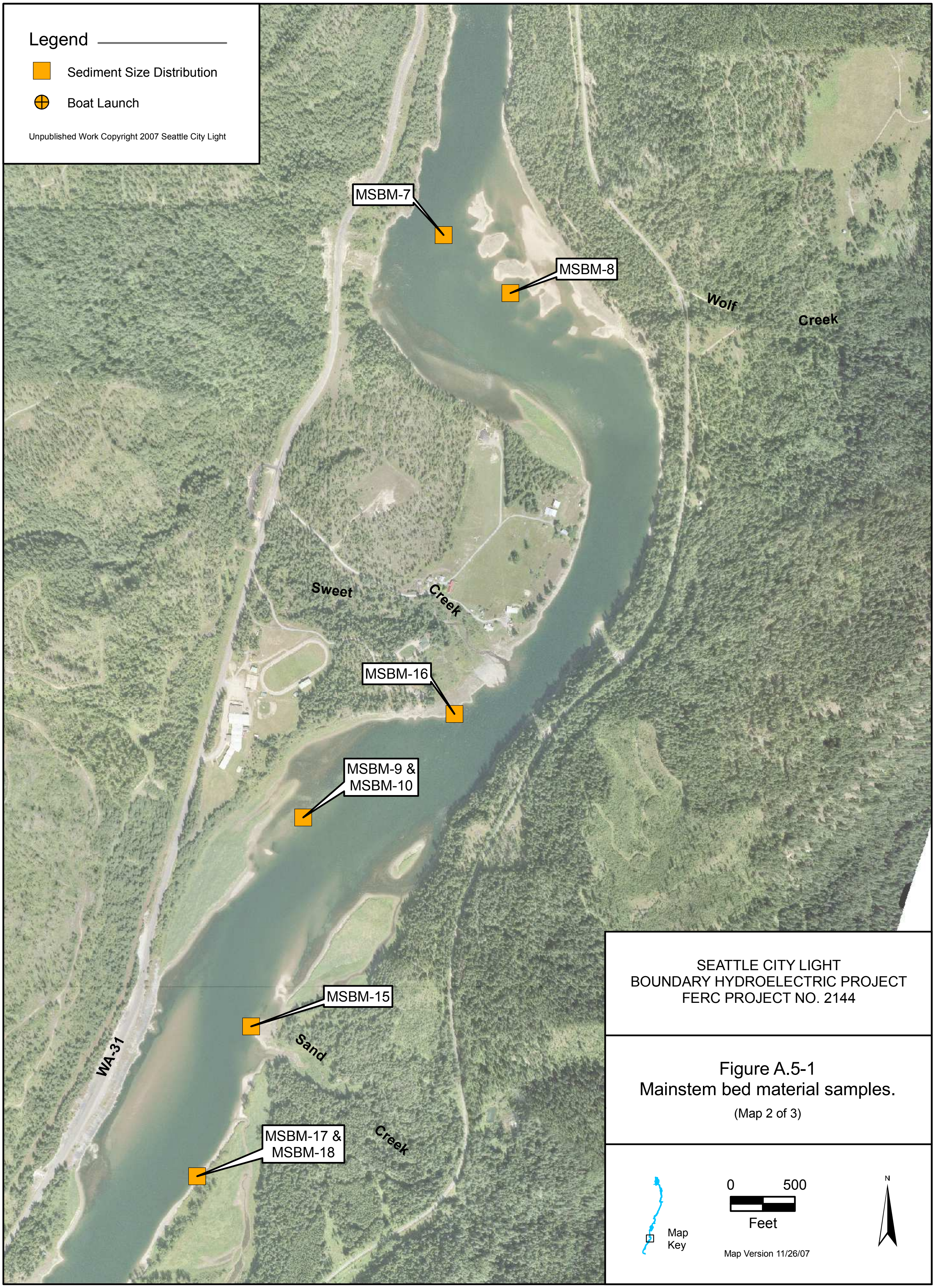

Figure A.5-1
Mainstem bed material samples.
(Map 2 of 3)

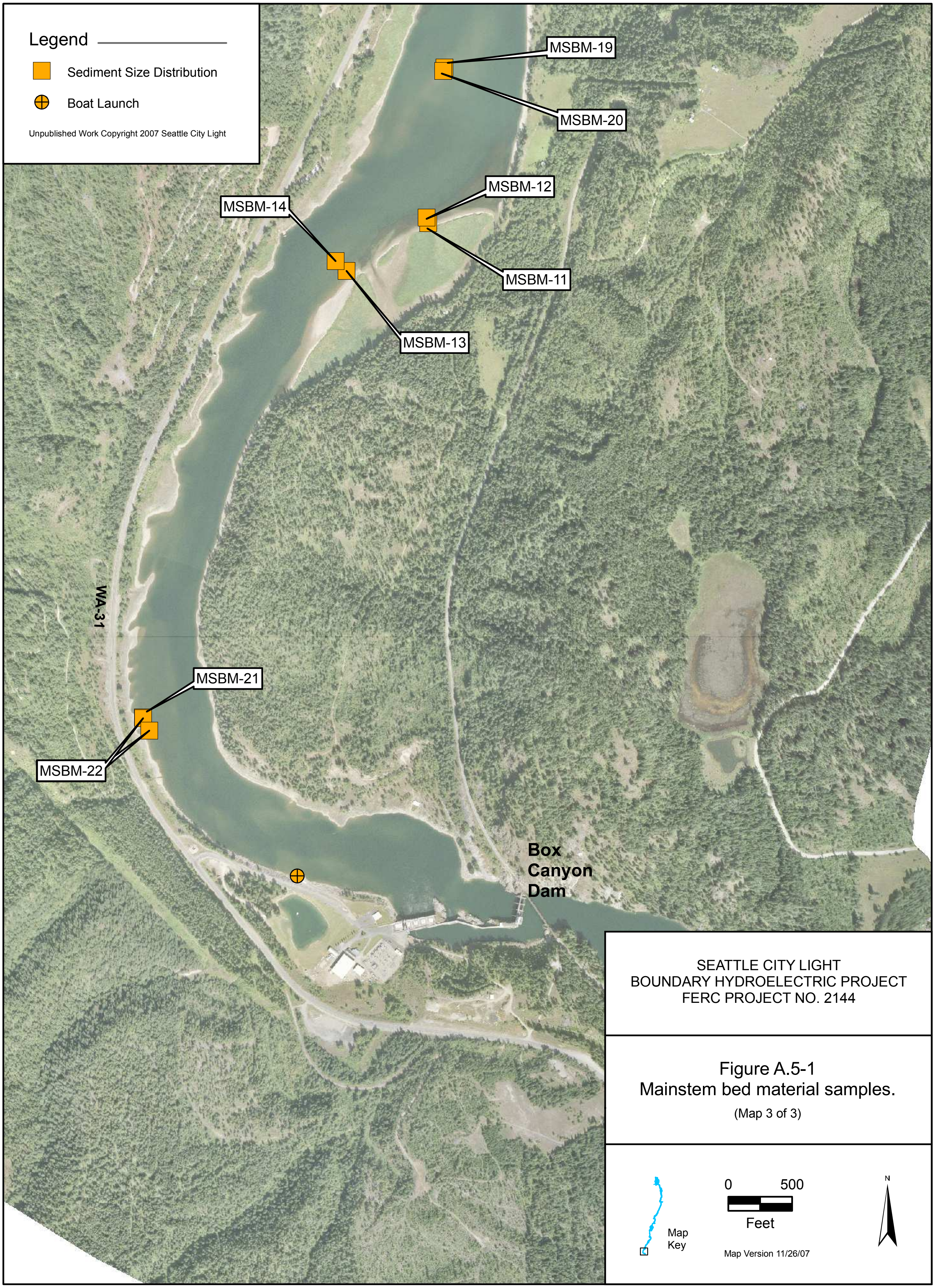

Figure A.5-1
Mainstem bed material samples.
(Map 3 of 3)

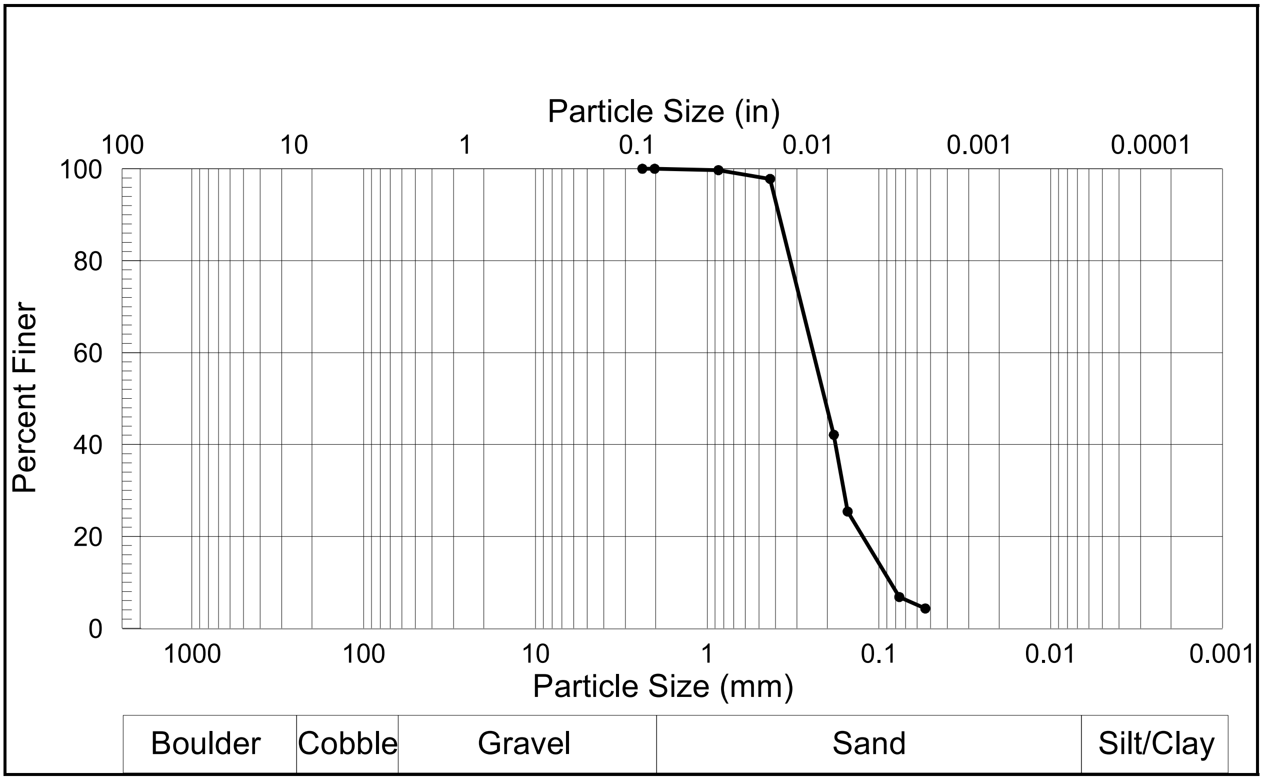

Figure A.5-2. Particle size distribution for mainstem sample BM-1.

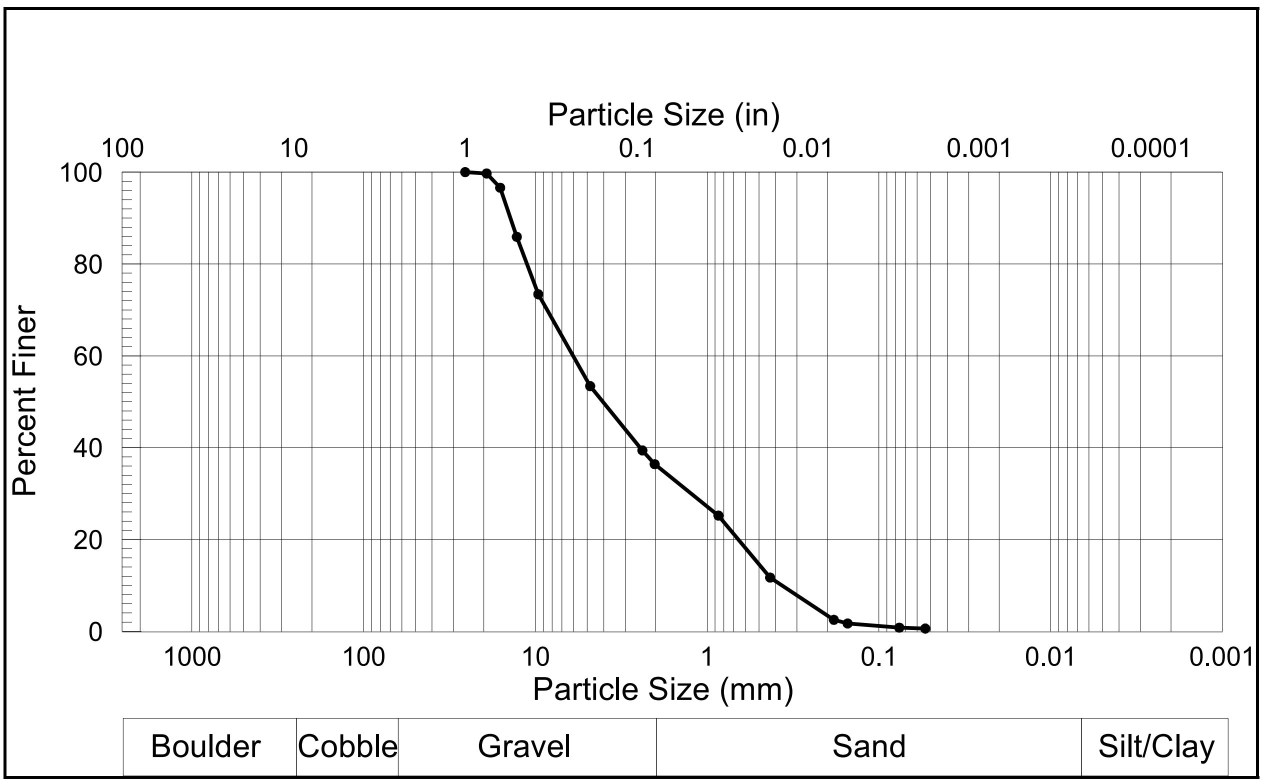

Figure A.5-3. Particle size distribution for mainstem sample BM-2.

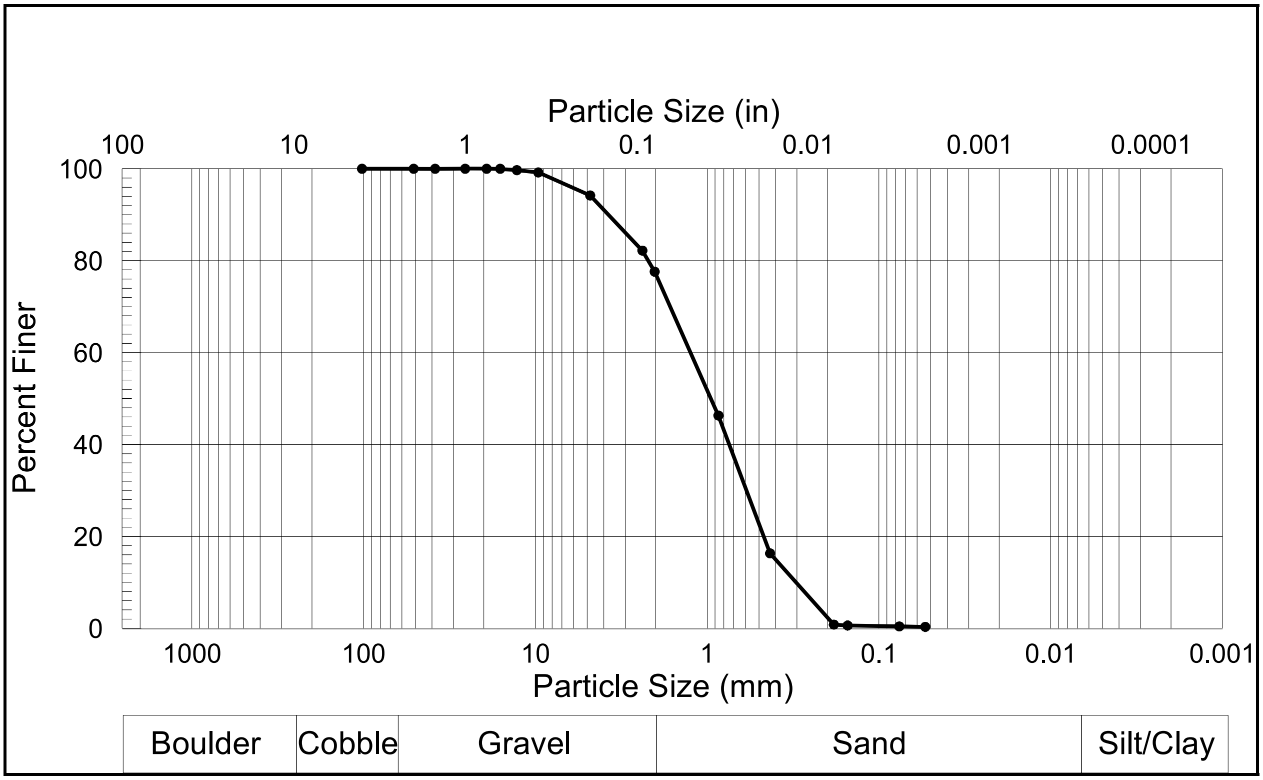

Figure A.5-4. Particle size distribution for mainstem sample BM-3.

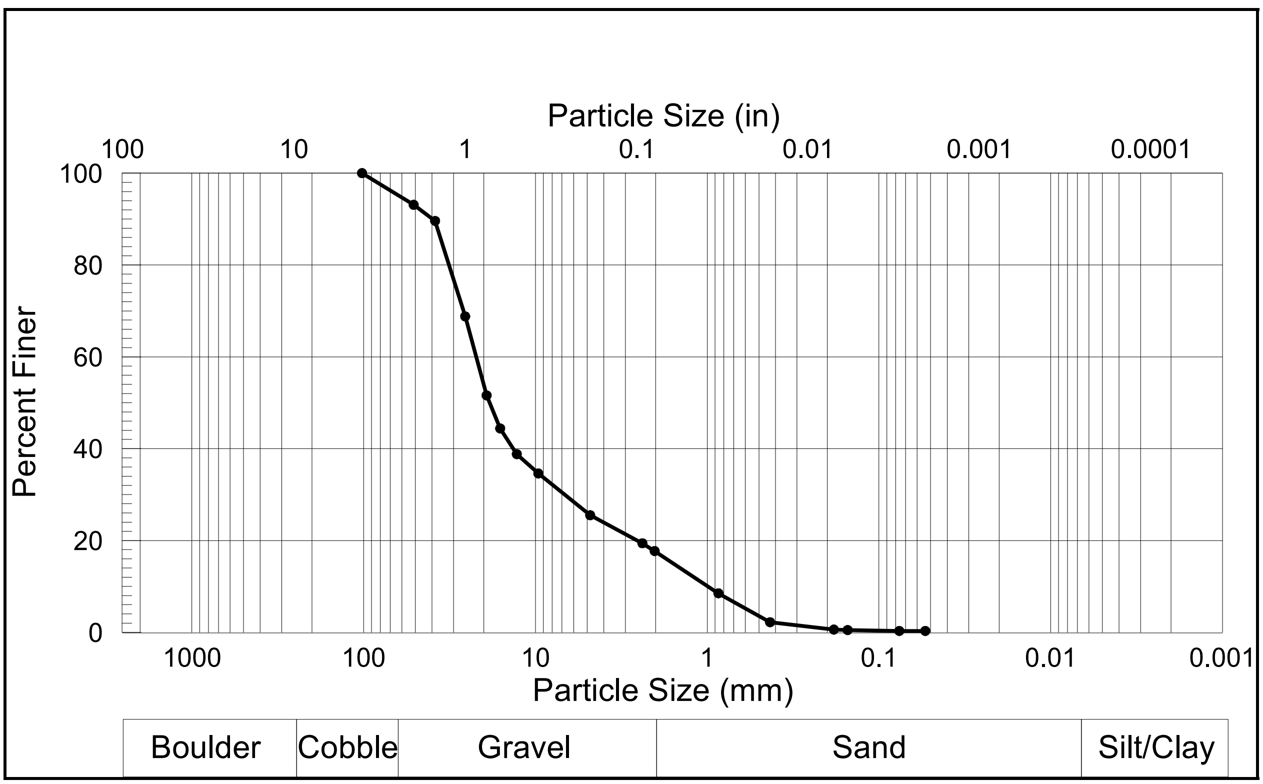

Figure A.5-5. Particle size distribution for mainstem sample BM-4.

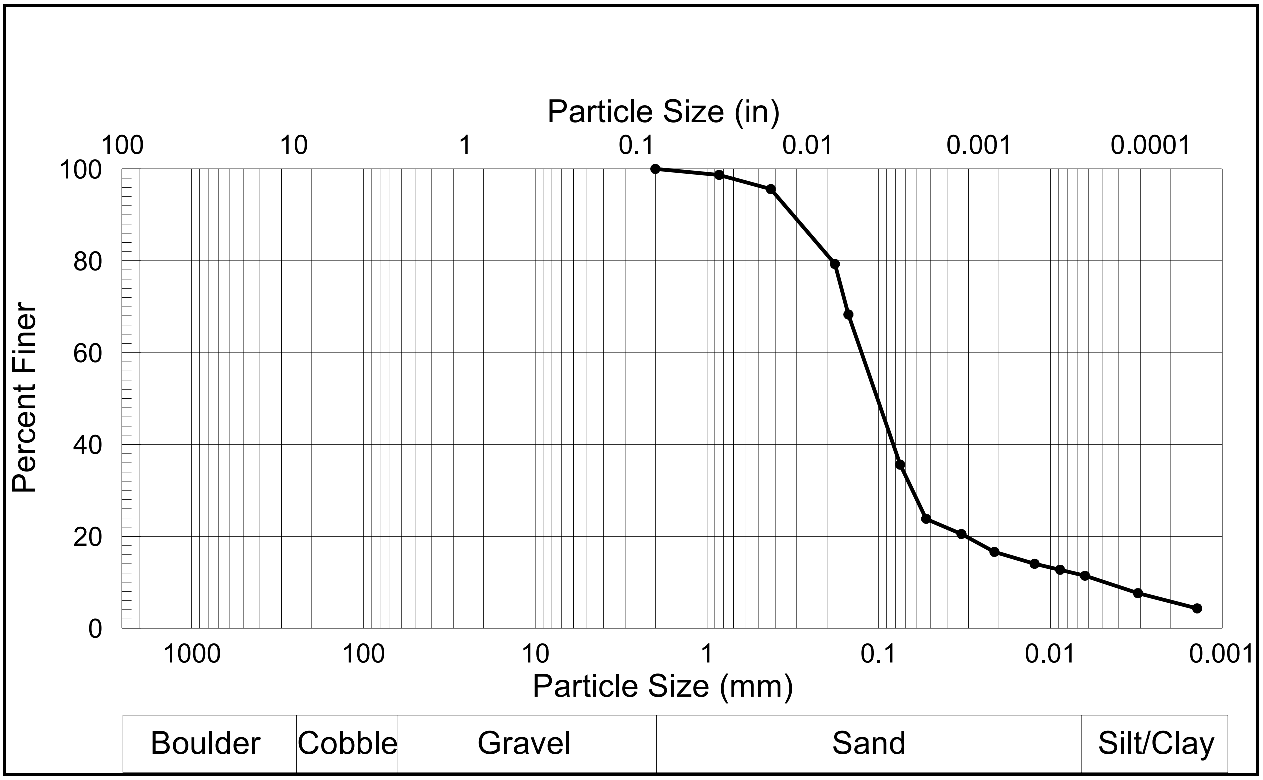

Figure A.5-6. Particle size distribution for mainstem sample BM-5.

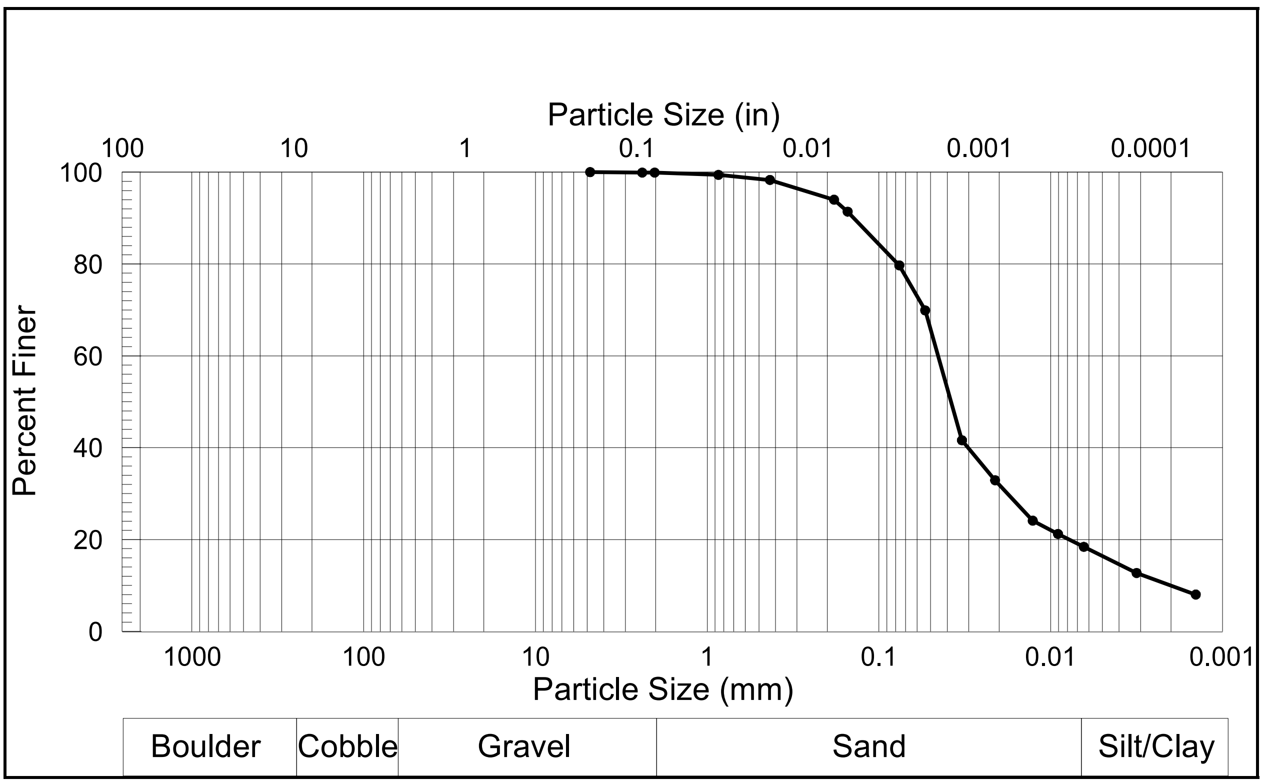

Figure A.5-7. Particle size distribution for mainstem sample BM-6.

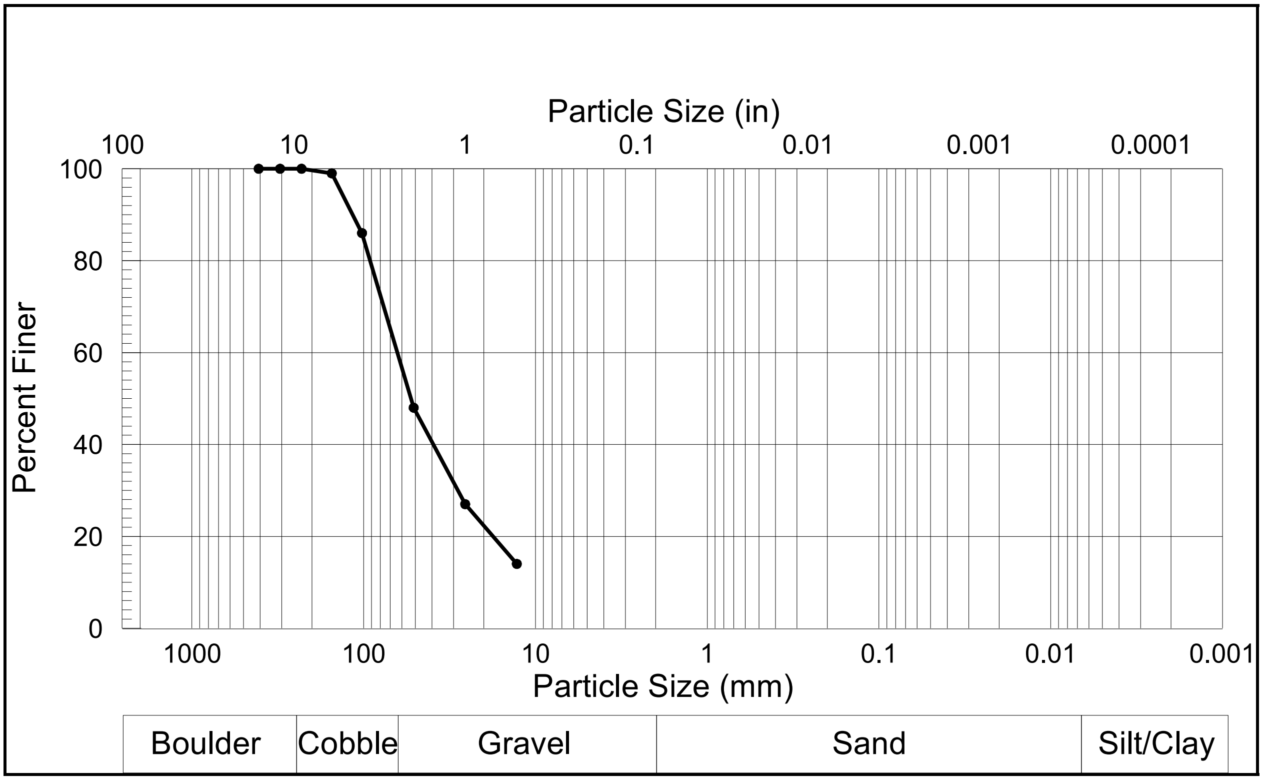

Figure A.5-8. Particle size distribution for mainstem sample BM-7.

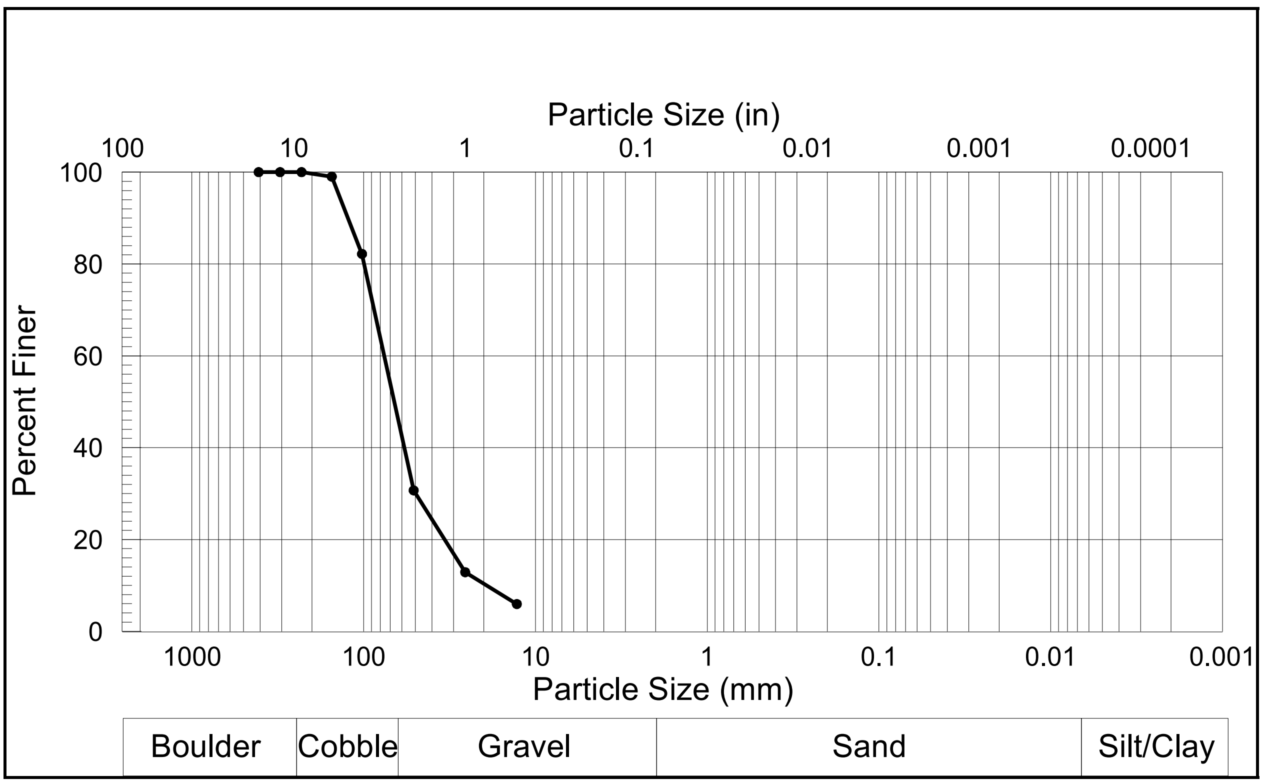

Figure A.5-9. Particle size distribution for mainstem sample BM-8.

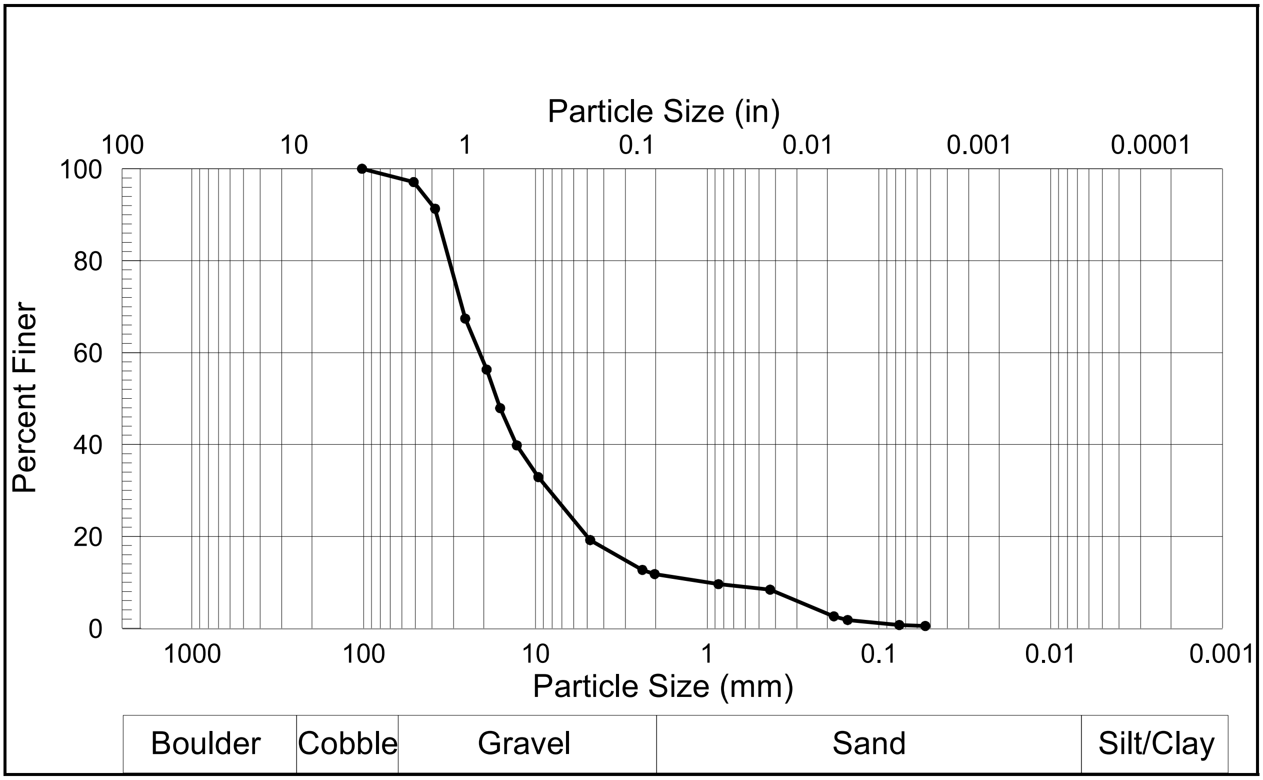

Figure A.5-10. Particle size distribution for mainstem sample BM-9.

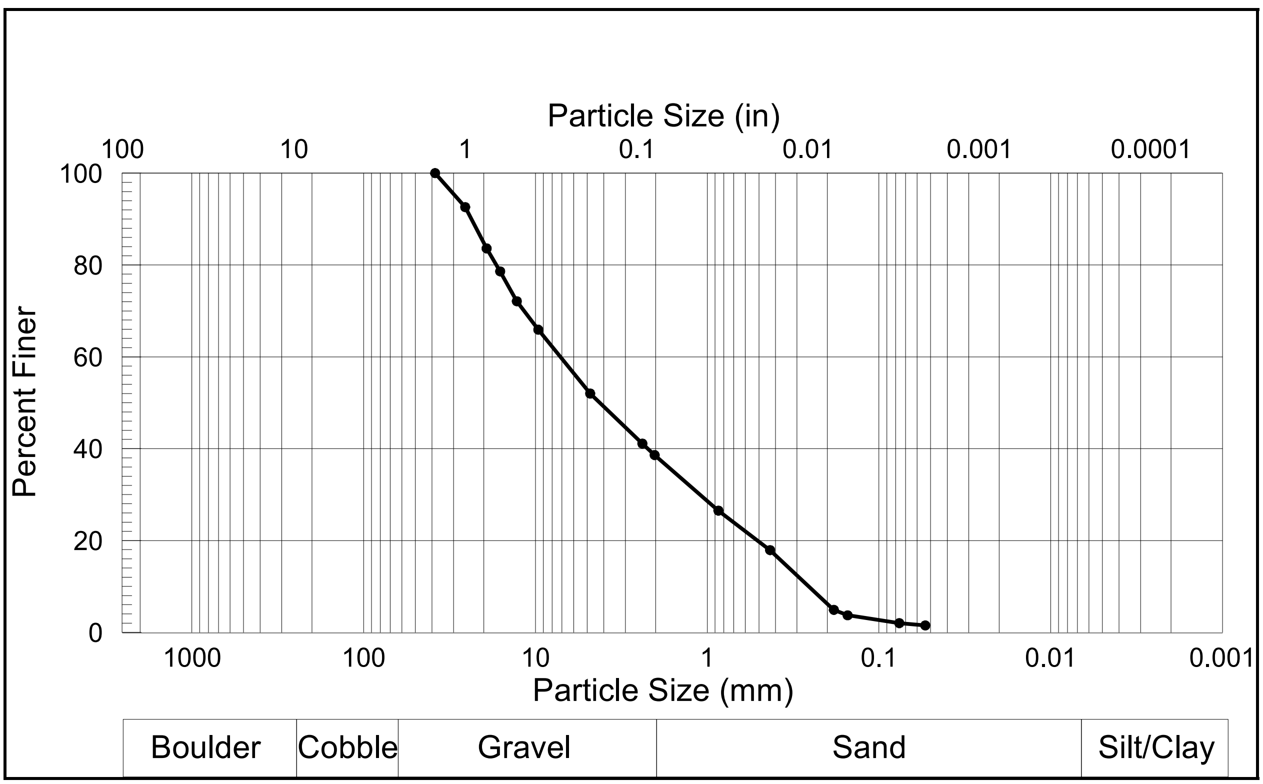

Figure A.5-11. Particle size distribution for mainstem sample BM-10.

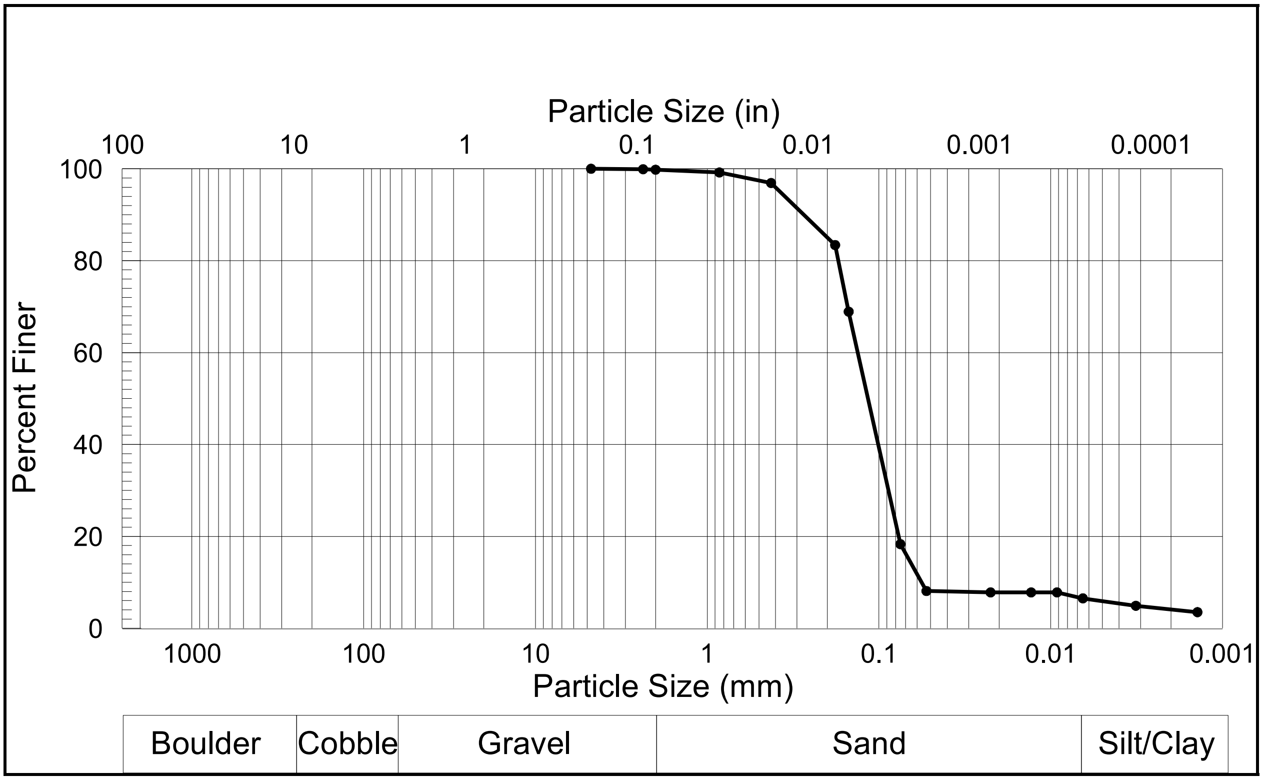

Figure A.5-12. Particle size distribution for mainstem sample BM-11.

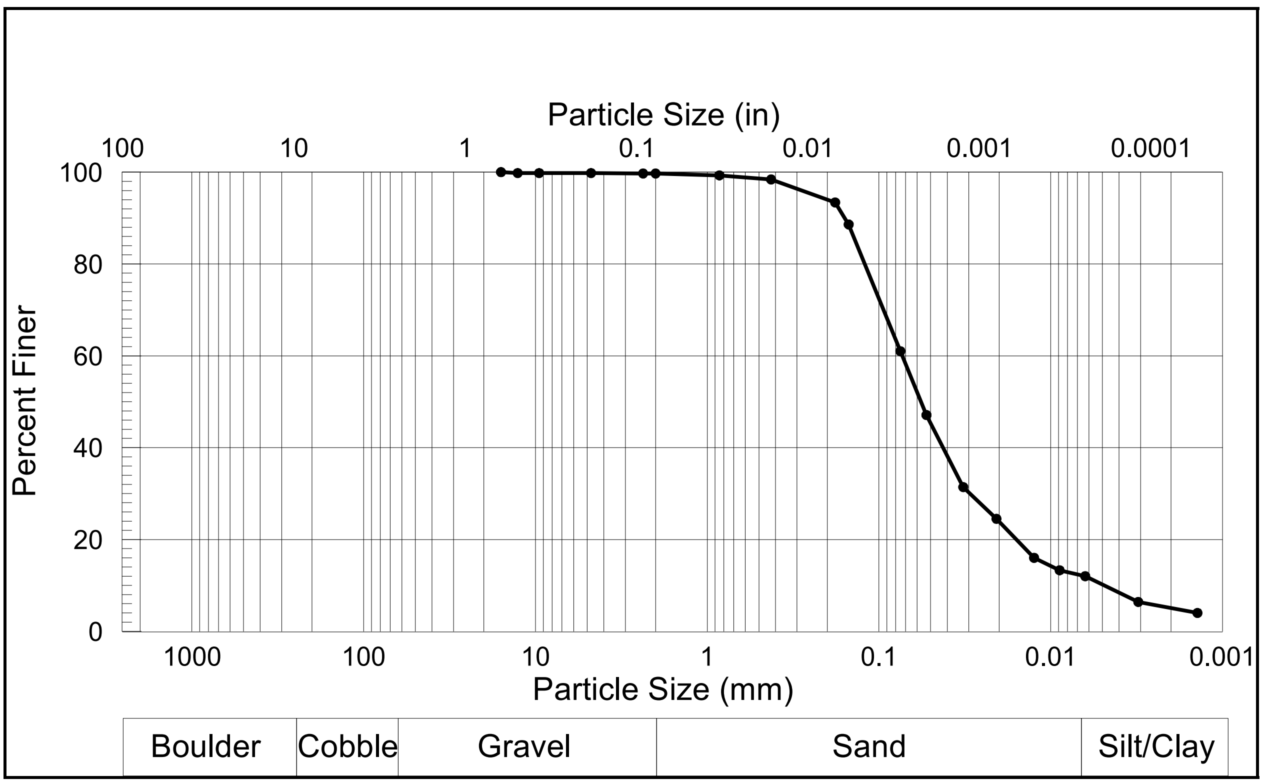

Figure A.5-13. Particle size distribution for mainstem sample BM-12.

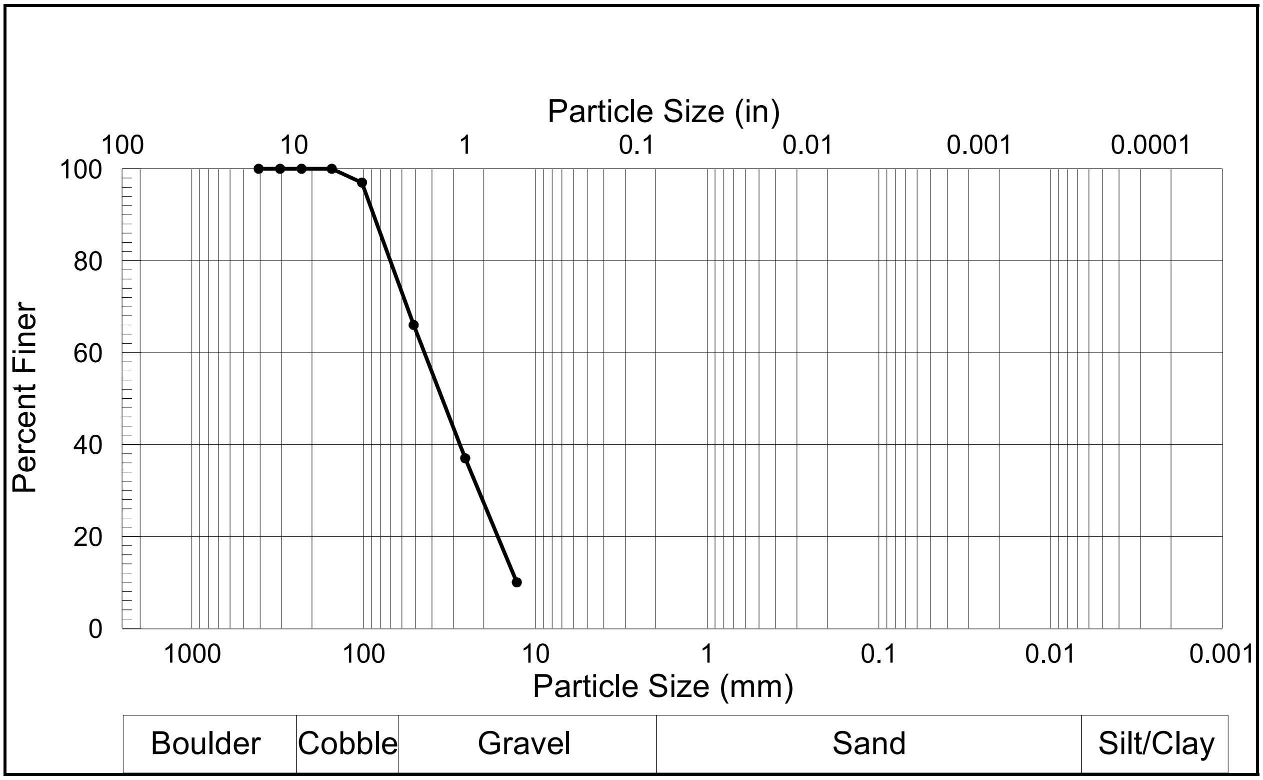

Figure A.5-14. Particle size distribution for mainstem sample BM-13.

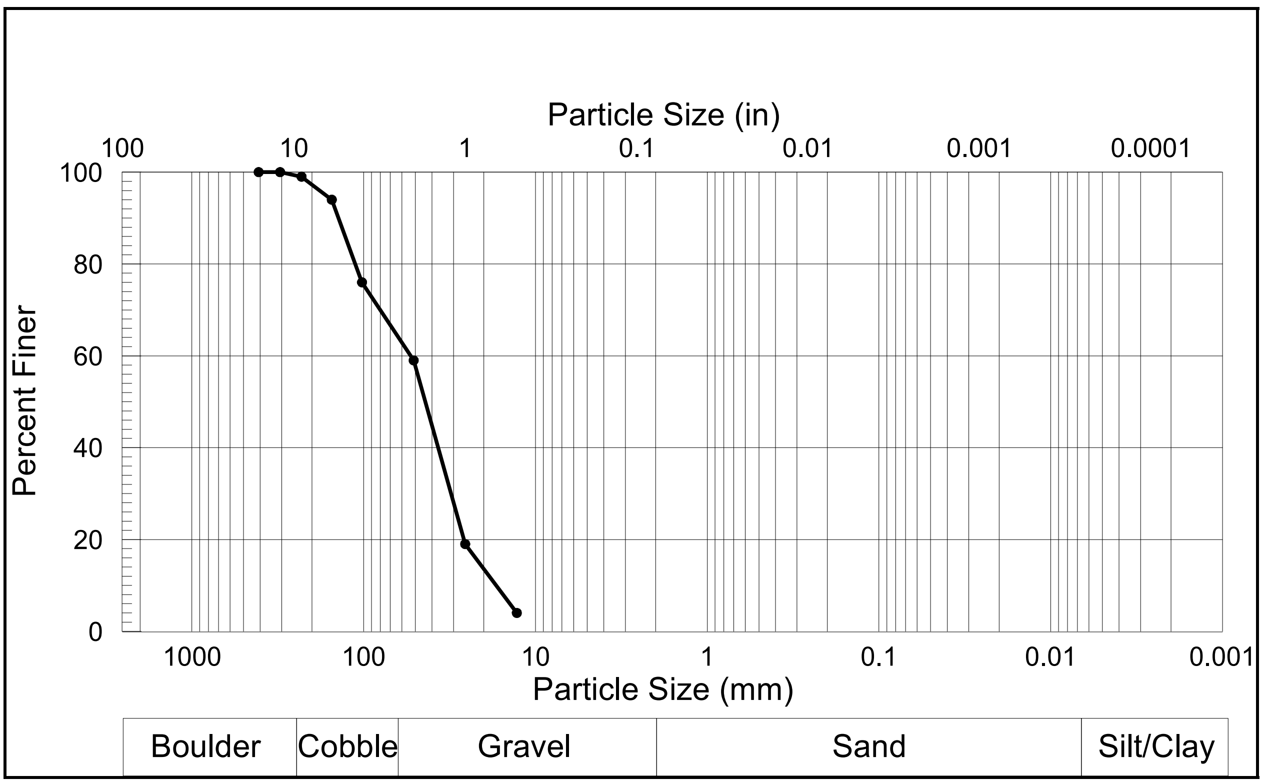

Figure A.5-15. Particle size distribution for mainstem sample BM-14.

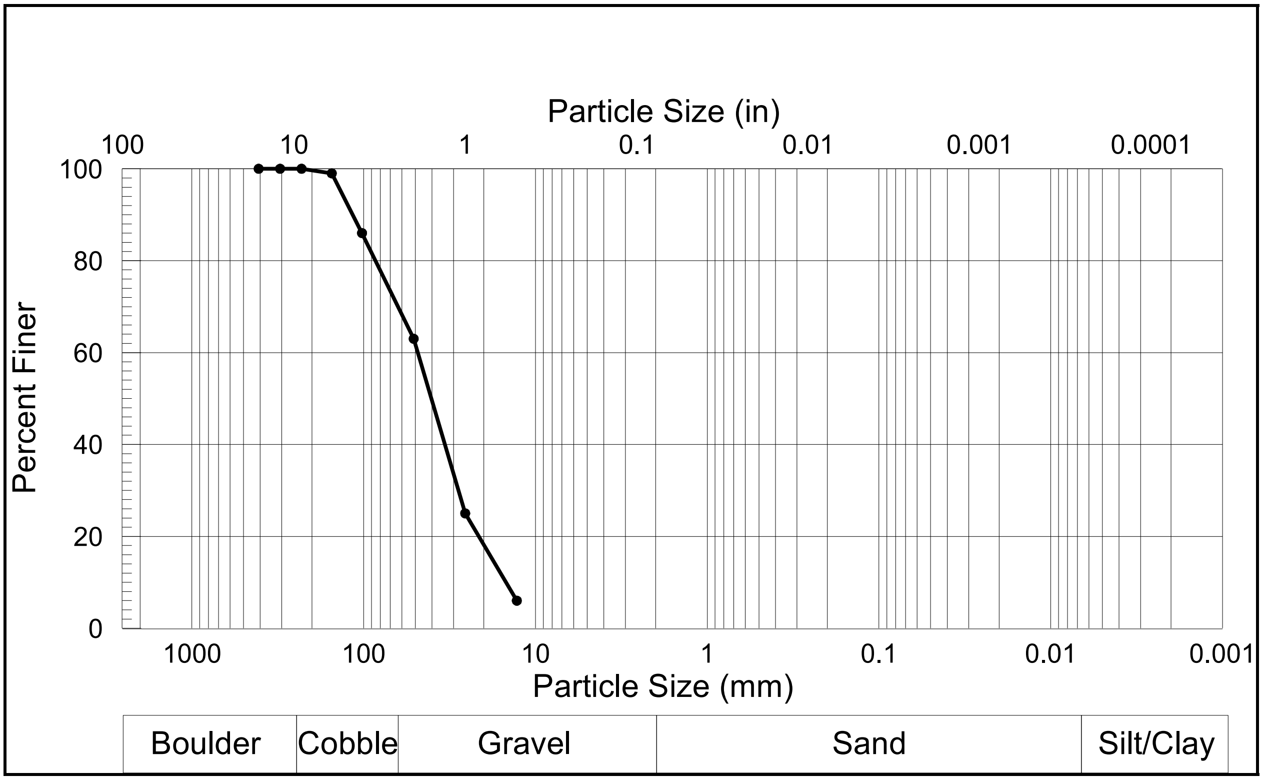

Figure A.5-16. Particle size distribution for mainstem sample BM-15.

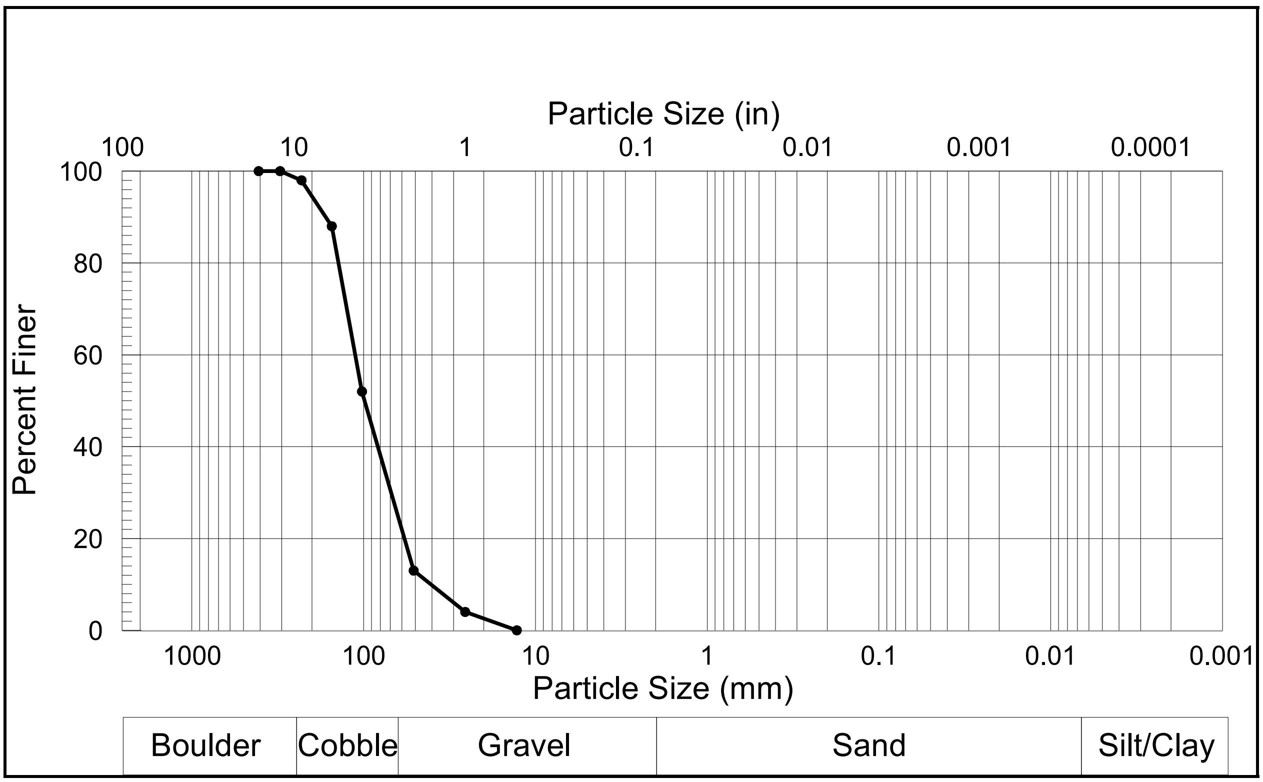

Figure A.5-17. Particle size distribution for mainstem sample BM-16.

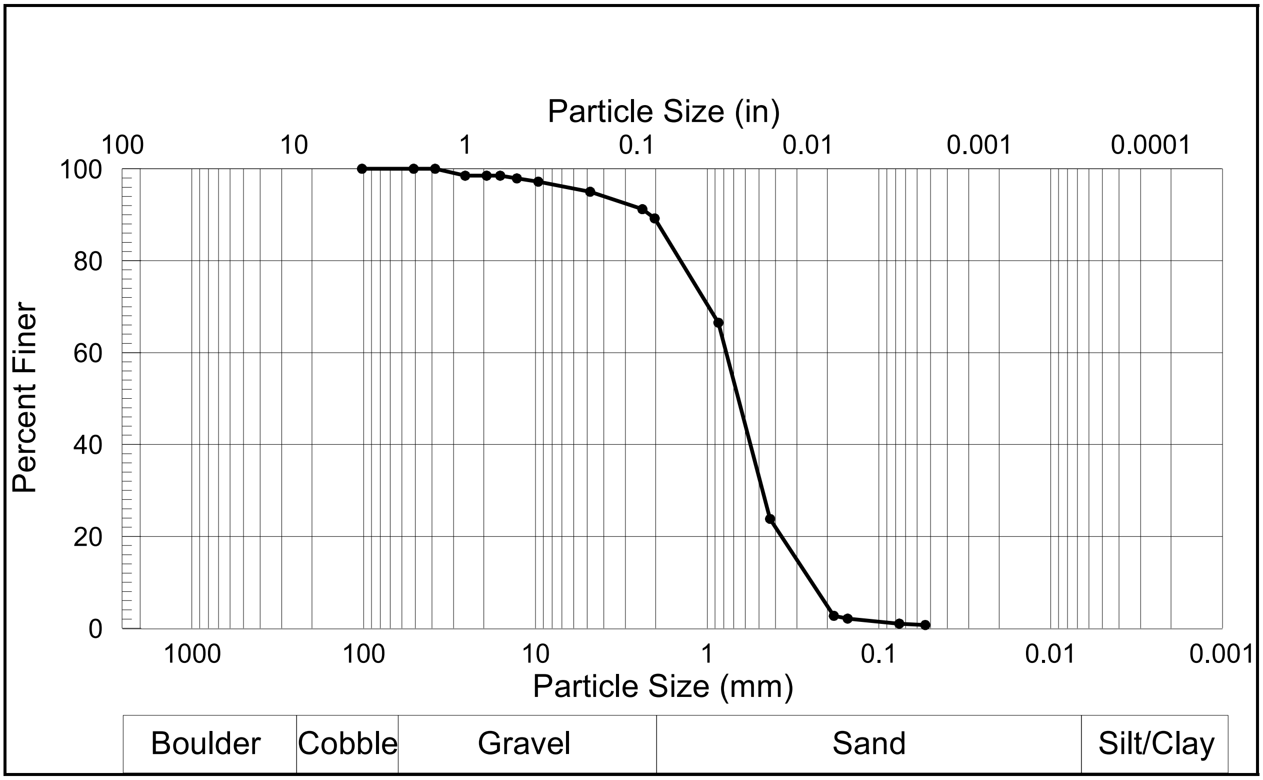

Figure A.5-18. Particle size distribution for mainstem sample BM-17.

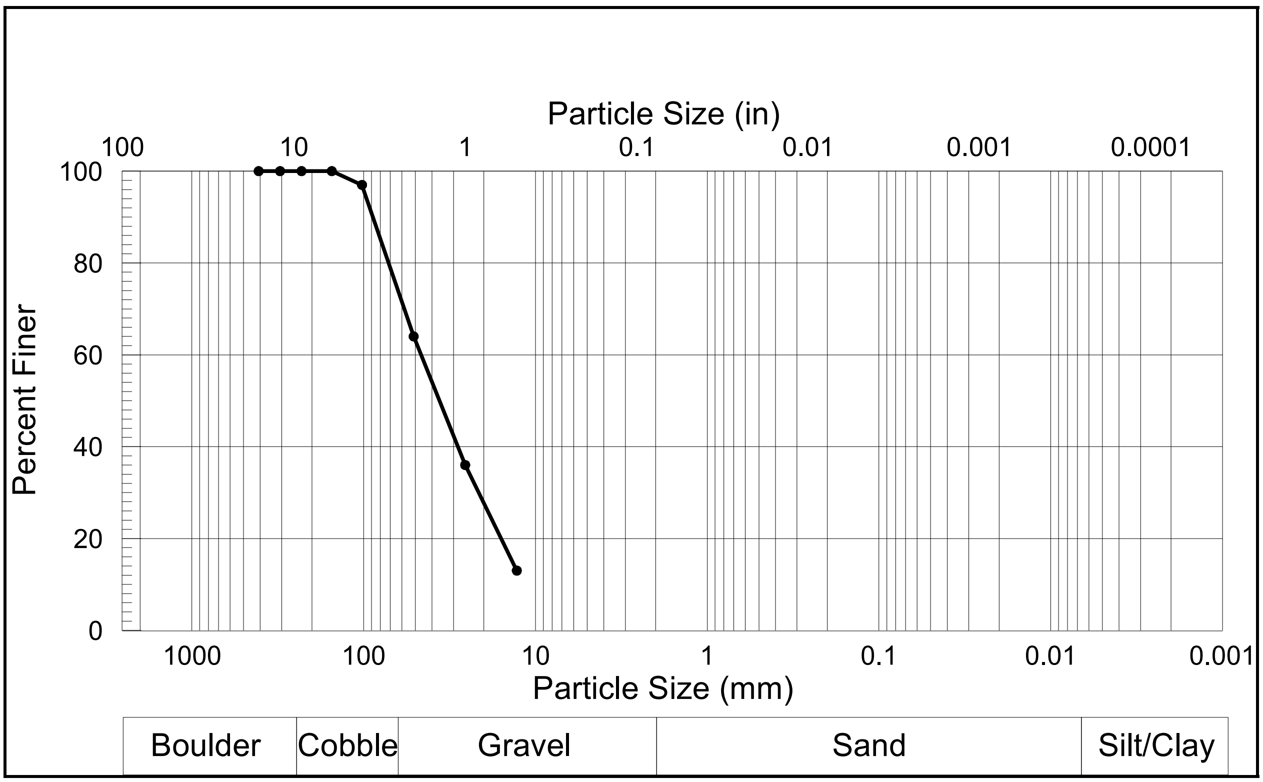

Figure A.5-19. Particle size distribution for mainstem sample BM-18.

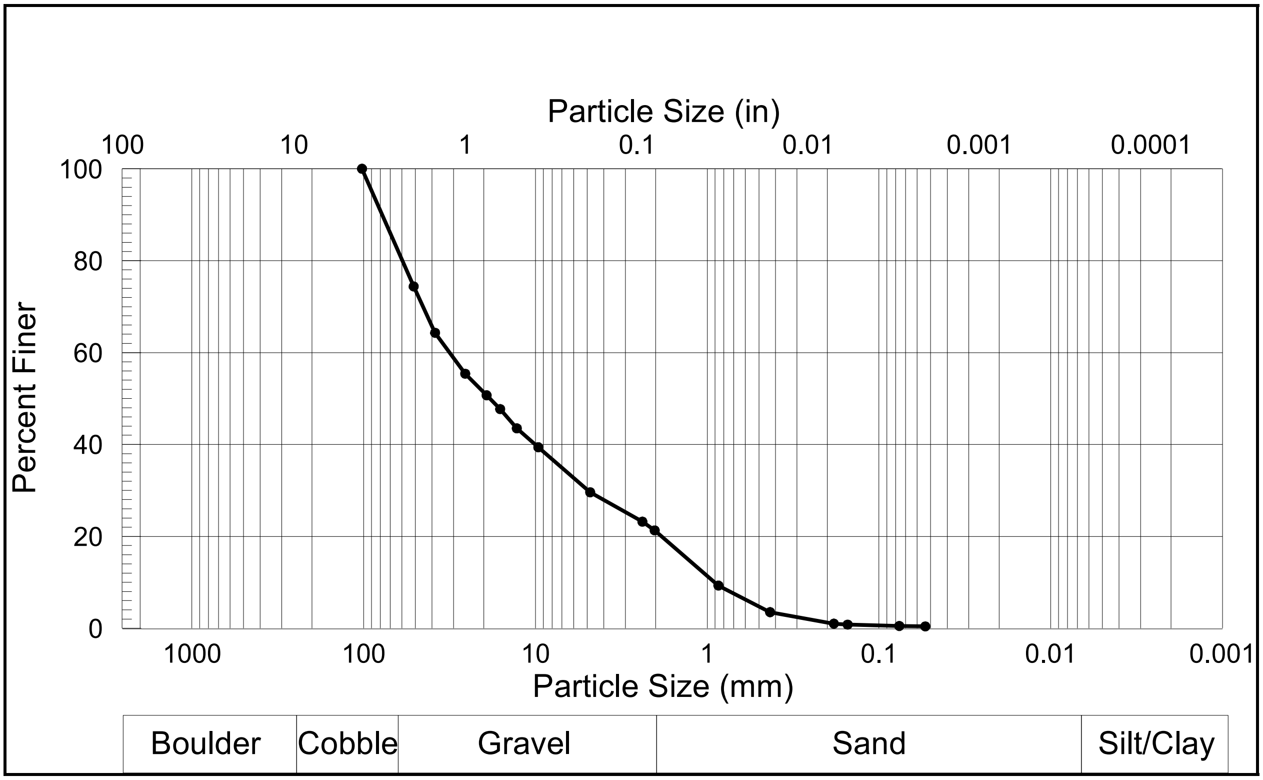

Figure A.5-20. Particle size distribution for mainstem sample BM-19.

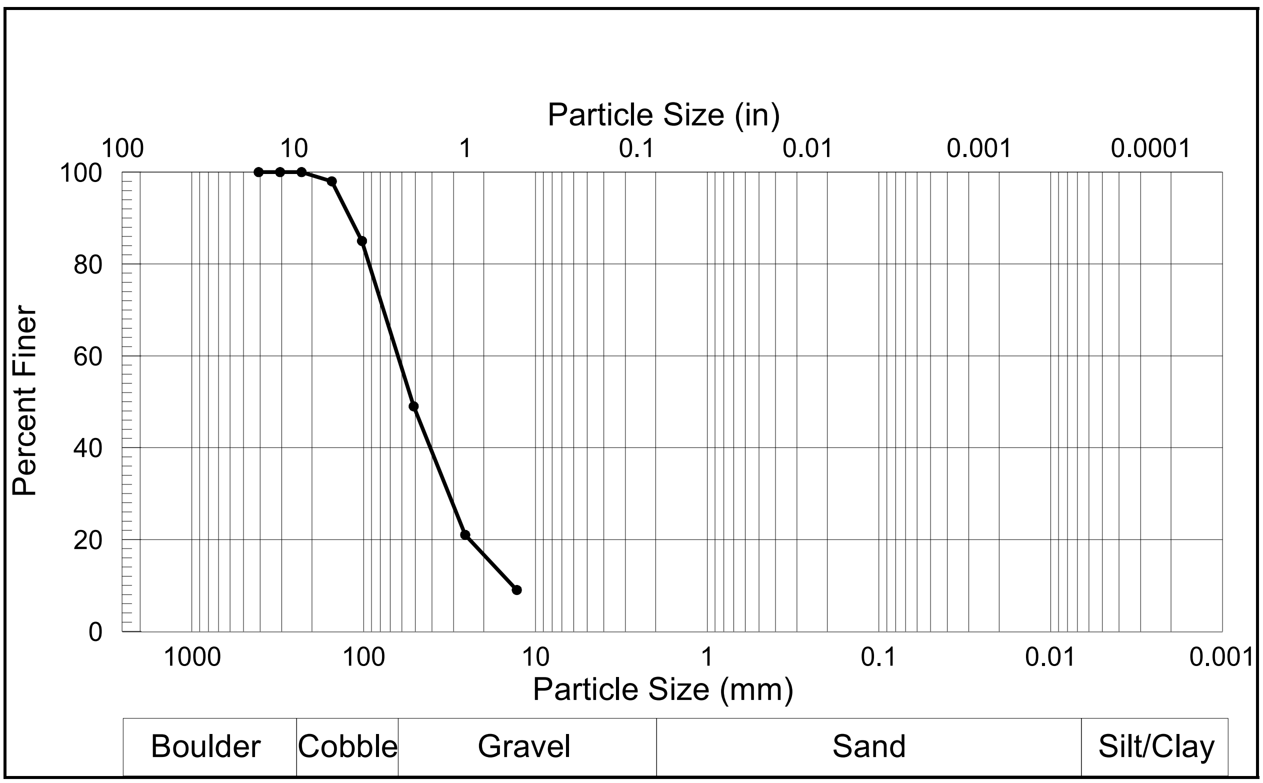

Figure A.5-21. Particle size distribution for mainstem sample BM-20.

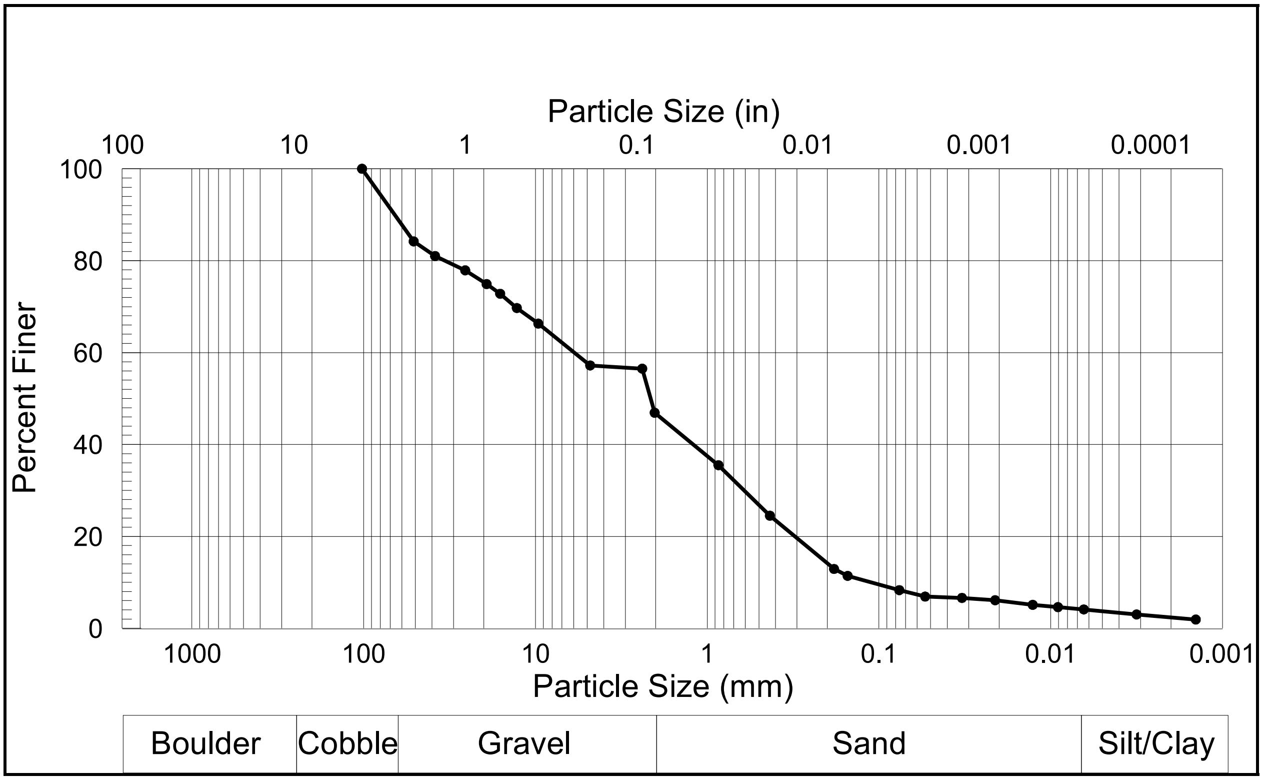

Figure A.5-22. Particle size distribution for mainstem sample BM-21.

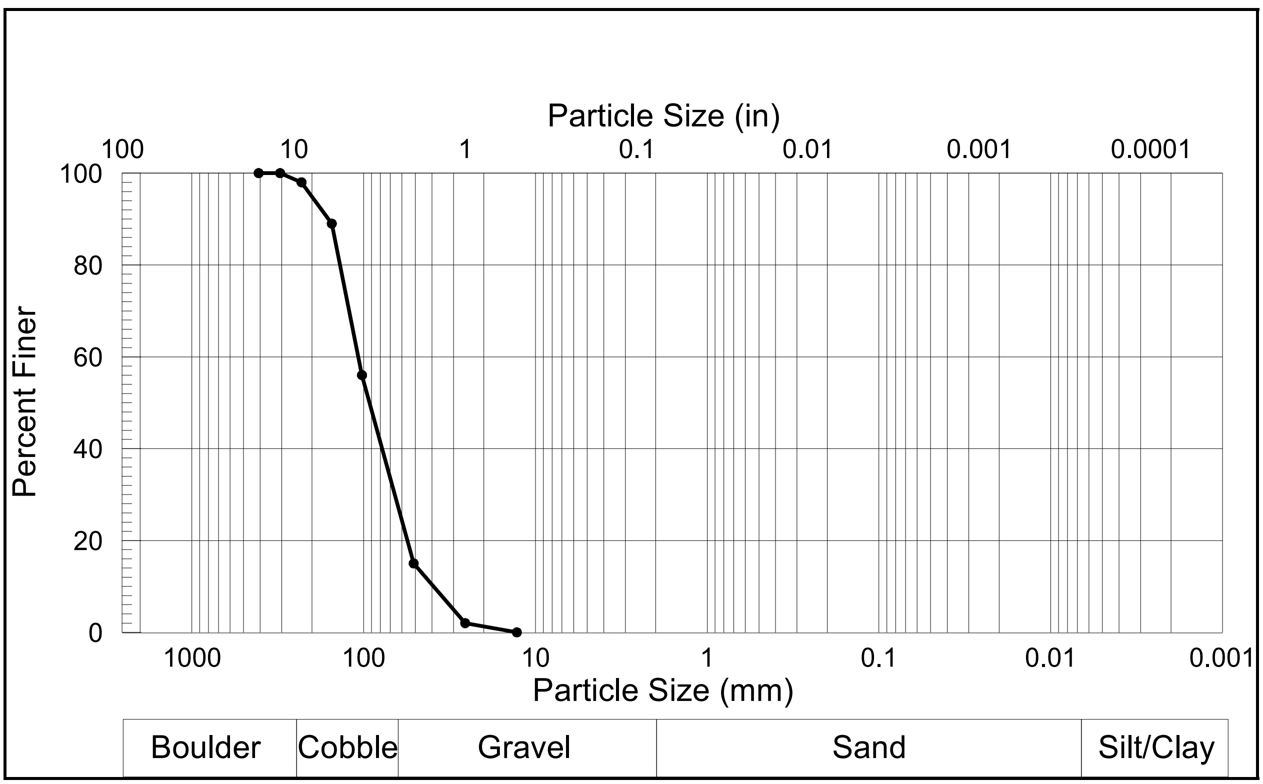

Figure A.5-23. Particle size distribution for mainstem sample BM-22.

Appendix 6. Details on Candidate Sediment Transport Models

HEC-6 Features

Relevant features of the model include capability to analyze networks of streams, several options for computation of sediment transport rates, and calculation of sediment transport rates for grain sizes up to 2,048 mm. The sediment transport function for bed material load is selected by the user. Transport functions available in HEC-6 include the following:

- Toffaleti's (1966) transport function
- Madden's (1963) modification of Laursen's (1958) relationship
- Yang's (1973) stream power for sands
- DuBoys' transport function (Vanoni 1975)
- Ackers-White (1973) transport function
- Colby (1964) transport function
- Toffaleti (1966) and Schoklitsch (1930) combination
- Meyer-Peter and Müller (1948)
- Toffaleti and Meyer-Peter and Müller combination
- Madden's (1985, unpublished) modification of Laursen's (1958) relationship
- Modification by Ariathurai and Krone (1976) of Parthenaides' (1965) method for scour and Krone's (1962) method for deposition of cohesive sediments
- Copeland's (1990) modification of Laursen's relationship (Copeland and Thomas 1989)
- User specification of transport coefficients based upon observed data

The above methods (except for Toffaleti (1966)), utilize the Colby (1964) method for adjusting the sediment transport potential when the wash load concentration is high. Armoring and destruction of the armor layer are simulated based upon Gessler's (1970) approach. Deposition or scour is modeled by moving each cross-section point within the movable bed (i.e., the area which is shifted vertically each time step due to sediment movement). The movable bed limits may extend beyond the channel bank "limits". Deposition is allowed to occur in all wetted areas, even if the wetted areas are beyond the conveyance or movable bed limits. Scour occurs only within the movable bed limits. Sediment transport potential is based upon the hydraulic and sediment characteristics of the channel alone. Simulation of geological controls such as bedrock or a clay layer may be done by specifying a minimum elevation for the movable bed at any particular cross section. The sediment boundary conditions (inflowing sediment load as a function of water discharge) for the main river channel, its tributaries and local inflow/outflow points can be changed with time. HEC-6 has the capability to simulate the diversion of water and sediment by grain size. A transmissive boundary condition is available at each downstream boundary; this boundary condition forces all sediment entering that section to pass it, resulting in no scour or deposition at that section.

HEC-6T Features

The following list represents the most significant enhancements over the features in HEC-6 (Thomas 1991):

- Calculation of flow around islands and balance of the discharge on each side

- Prescription of the percentage of flow around an island or into a distributary and have the program write a record of the head that is required to provide that discharge
- Represent flow passing into distributaries or multiple strips across the channel and floodplains
- Separation of the width of the erosion zone from the width of the deposition zone in the cross section
- Variation of *n*-values with depth in addition to discharge and elevation
- Variation of *n*-values with the depth of deposit
- Calculation of bed roughness with the Brownlie or Limerinos bed roughness equations or with Jarrett's *n*-value equation
- Representation of failed channel banks with degradation of the invert
- Control of the invert erosion depth to prevent erosion below the model bottom
- Coding the channel as bed and bank subsections for assigning roughness
- Inclusion of subsidence
- Coding cross sections as YZ-coordinate pairs or ZY-coordinate pairs
- User interfaces to facilitate editing of input data
- Module to import geometry data from HEC-RAS model
- Post-processor plotter to facilitate presentation of model output

EFDC1D Features

The following list presents features included in EFDC1D:

- Box or reach based spatial data structure, compatible with existing HSPF data structure, for representing one-dimensional channel networks.
- Channel network option using HEC type cross-section data.
- Utilization of water surface elevation dependent descriptions of channel cross-section area, surface width, wetted perimeter and buoyancy centroid, including representation of overbank regions.
- Bi-directional unsteady flow and the ability to accommodate unsteady inflows and outflows associated with upstream inflows, lateral inflows and withdrawals, groundwater-surface water interaction, evaporation and direct rainfall. The model includes representation of hydraulic structures such as dams and culverts. Downstream boundary conditions include rating curves and time varying water surface elevation.
- For sediment transport, the model includes settling, deposition and resuspension of multiple size classes of cohesive and noncohesive sediments. The bed is represented by multiple layers of mixed sediment classes. A bed consolidation model is implemented to predict time variations of bed depth, void ratio, bulk density and shear strength. The sediment bed representation is dynamically coupled to the cross-sectional area representation to account for area changes due to deposition and resuspension.
- Sediment bed geomechanics represent armoring, cohesion effects, and finite strain consolidation.

Process routines from the EFDC model are utilized to satisfy the following requirements:

- A fully dynamic one-dimensional solver for the momentum and continuity equations with channel cross-section area, surface width, bottom width, wetted perimeter and buoyancy centroid as functions of the water surface elevation.
- Time varying upstream inflows, and lateral inflows and withdrawals including corresponding sediment loads.
- Hydraulic control structures and rating curve boundary conditions.
- Time varying downstream boundary conditions for water surface elevation, salinity, temperature and sediment concentration.
- A generic one-dimensional transport solver utilizing a monotone, positive definite scheme which minimizes numerical diffusion
- A fully predictive surface heat exchange formulation which includes evaporation
- An equation of state relating density to salinity and temperature.
- A multiple class sediment processes module that incorporates a wide variety of parameterization for settling, deposition and resuspension of cohesive and noncohesive sediments.
- A multiple layer bed module that includes a bed consolidation solver and parameterizations relating void ratio, bulk and dry density, and shear strength.

Non-cohesive, bedload sediment transport functions available in EFDC1D include:

- Meyer-Peter and Muller (1948)
- Bagnold (1956)
- Englund-Hansen (1972)
- Simplified Einstein (1950)
- Van Rijn (1984a)

Non-cohesive, suspended sediment transport functions available in EFDC1D include:

- Van Rijn (1984b)
- Smith and McLean (1977)
- Garcia and Parker (1991)

SRH-1D Features

SRH-1D is a one-dimensional hydraulic and sediment transport model for use in natural rivers and manmade canals. It is a mobile boundary model that simulates changes caused by sediment transport. It can estimate sediment concentrations throughout a waterway given the sediment inflows, bed material, hydrology, and hydraulics of that waterway. Some of the model's capabilities include:

- Computation of water surface profiles in a single channel or multi-channel looped networks
- Steady and unsteady flows
- Subcritical, supercritical, and transcritical flows in an unsteady hydraulic simulation
- Steady and unsteady sediment transport

- Transport of cohesive and non-cohesive sediments
- Sediment concentration tracking using either the Exner or advection-dispersion equations
- Cohesive sediment aggregation, deposition, erosion, and consolidation
- Multiple non-cohesive sediment transport equations that are applicable to a wide range of hydraulic and sediment conditions
- Simulation of changes to bed material gradations across multiple bed layers
- Cross stream variation in hydraulic roughness
- Fractional sediment transport, bed sorting, and armoring
- Computation of width changes using theories of minimum stream power and other minimizations
- Simulation of bank erosion using angle of repose conditions
- Point and non-point sources of flow and sediments
- Internal boundary conditions, such as time-water surface elevation tables, rating curves, weirs, bridges, and radial gates
- Channel geometry data is similar to HEC-RAS
- Microsoft Excel can be used to generate input files
- Model output is multiple structured text files.

The following non-cohesive sediment transport functions are available in SRH-1D:

- Meyer-Peter and Muller (1948) – modified by Wong and Parker (2006)
- Laursen (1958)
- Modified Laursen's Formula (Madden 1993)
- Engelund and Hansen (1972)
- Ackers and White (1973)
- Ackers and White (HR Wallingford, 1990)
- Yang (1973) + Yang (1984)
- Yang (1979) + Yang (1984)
- Brownlie (1981)
- Yang et al. (1996)
- Parker (1990)
- Wilcock and Crowe (2003)
- Wu (2004)

The surface erosion rate of cohesive sediment can be represented using the approach developed by Partheniades (1965).

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