GE-03 SEDIMENT DEPOSITION IN RESERVOIRS AFFECTING RESOURCE AREAS OF CONCERN STUDY INTERIM REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT FERC NO. 553

Seattle City Light

Prepared by:
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March 2022
Initial Study Report

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List of Acronyms and Abbreviations

1-D ....one-dimensional
2-D ....two-dimensional
cfs ....cubic feet per second
City Light ....Seattle City Light
CoSD..........................City of Seattle datum
cu yds ....cubic yards
DHSVM ....Distributed Hydrology Soil Vegetation Model
FERC..........................Federal Energy Regulatory Commission
ft ....feet
GIS ....Geographic Information System
ISR ....Initial Study Report
LiDAR........................Light Detection and Ranging
LP ....licensing participant
m ....meter
mm ....millimeter
NAIP ....National Agriculture Imagery Program
NAVD 88 ....North American Vertical Datum of 1988
NPS ....National Park Service
Project ....Skagit River Hydroelectric Project
RSP ....Revised Study Plan
sq. mi..........................square mile(s)
SR...............................State Route
USACE ......................U.S. Army Corps of Engineers
USGS .........................U.S. Geological Survey
USR............................Updated Study Report
yr ....year

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1.0 INTRODUCTION

The GE-03 Sediment Deposition in Reservoirs Affecting Resource Areas of Concern Study (Sediment Deposition Study) is being conducted in support of the relicensing of the Skagit River Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC) No. 553, as identified in the Revised Study Plan (RSP) submitted by Seattle City Light (City Light) on April 7, 2021 (City Light 2021). On June 9, 2021, City Light filed a "Notice of Certain Agreements on Study Plans for the Skagit Relicensing" (June 9, 2021 Notice)[1] that detailed additional modifications to the RSP agreed to between City Light and supporting licensing participants (LP) (which include the Swinomish Indian Tribal Community, Upper Skagit Indian Tribe, National Marine Fisheries Service, National Park Service [NPS], U.S. Fish and Wildlife Service, Washington State Department of Ecology, and Washington Department of Fish and Wildlife). The June 9, 2021 Notice included agreed to modifications to the Sediment Deposition Study.

In its July 16, 2021 Study Plan Determination, FERC approved the Sediment Deposition Study without modification.

This interim report on the 2021 study efforts is being filed with FERC as part of City Light's Initial Study Report (ISR). City Light will perform additional work for this study in 2022 and include a report in the Updated Study Report (USR) in March 2023.

1 Referred to by FERC in its July 16, 2021 Study Plan Determination as the "updated RSP."

2.0 STUDY GOALS AND OBJECTIVES

The goal of the Sediment Deposition Study as stated in the RSP is to evaluate the effects of deposition on four specific locations within Ross, Diablo, and Gorge lakes with identified recreational resources and/or Project operations impacts. The study will develop an understanding of the physical conditions (rate of deposition, grain size of deposits) under which deposition occurs at the four locations. Specific objectives are as follows:

- Describe and map the location and history of sediment deposition in the:
  - Hozomeen inlet in Ross Lake (i.e., the large arm of upper Ross Lake that has sediment contributed by the Skagit River);
  - Sourdough Creek inlet in Diablo Lake (i.e., the small arm of Diablo Lake into which Sourdough Creek flows);
  - Thunder Arm in Diablo Lake (i.e., the large arm within Diablo Lake into which Thunder Creek, Colonial Creek, and Rhode Creek flow); and
  - Stetattle Creek delta in Gorge Lake (i.e., the sediment deposited at the mouth of Stetattle Creek where it enters Gorge Lake and the sediment deposited between Stetattle Creek and the State Route [SR] 20 bridge crossing).
- Determine rate and grain size of sediment input, quantify total volume of sediment deposition in the four inlets and deltas, and estimate rate and patterns of deposition.
- Identify likely future zones and patterns of deposition with respect to recreational resources and operational impacts.

As part of the June 9, 2021 Notice, the following commitments were made by City Light with respect to this study:

- Quantify sediment supply of all size ranges (i.e., grain size distribution estimate) in Ross, Diablo, and Gorge lakes as an average annual rate by using the existing Distributed Hydrology Soil Vegetation Model (DHSVM), historical contours, and updated bathymetry information;
- Assess (map) deposition and erosion in the drawdown zone; and
- Use a one-dimensional (1-D) backwater model to estimate magnitude and location of reservoir backwater effects in the four study deltas as appropriate.

3.0 STUDY AREA

The study area for the first three study objectives includes specific portions of the Skagit River inlet near Hozomeen (Ross Lake), Thunder Arm (Diablo Lake), Sourdough Creek inlet (Diablo Lake), and Stetattle Creek delta (Gorge Lake) (Figure 3.0-1).[2] These specific study areas include inlets/deltas at four locations with identified recreational or operational impacts in the Project Boundary:

- Hozomeen inlet at the head of Ross Lake – recreational resource: Hozomeen and Winnebago Flats boat launches;
- Thunder inlet in Diablo Lake – recreational resource: Colonial Creek Boat Launch and Boat House;
- Sourdough inlet in Diablo Lake – City Light resources: City Light Boat Launch, City Light Boat House, City Light Dry Dock; recreational resources: West Ferry Landing, Environmental Learning Center Canoe and Kayak Dock; and
- Stetattle Creek delta in Gorge Lake – recreational resource: whitewater training and instruction, Gorge Lake Campground Boat Launch and Dock; operational resource: City Light Diablo Powerhouse Tailrace.

Figures 3.0-2 through 3.0-5 show the extent of the depositional area that was investigated for the four specific study locations. Each figure includes the location of the resource(s) of concern. Figure 3.0-2 also includes an area south of the Hozomeen area boat launches in case, upon field review, the area has substantially more deposition that could affect the boat launch than is visible from the aerial photographs.[3] In addition to the deposition zones shown in the figures, the study area includes the watersheds of each of the creeks to help estimate current/future sediment inputs based on watershed area, geology, and extent of glacial cover.

The Skagit River inlet in the Hozomeen area includes areas within Canada (Figure 3.0-2). The study area within Canada was evaluated using remote sensing data (Light Detecting and Ranging [LiDAR], aerial photographs); field work in Canada is not necessary.

[2] As a result of commitments in the June 9, 2021 Notice, the study area has been expanded to include the drawdown zone within all three Project reservoirs, an expansion of the four areas shown in Figure 3.0-1.

[3] Field work showed that there was not substantial deposition around the boat launches, so the Hozomeen study are did not need to extend as far south as shown in Figure 3.0-2.

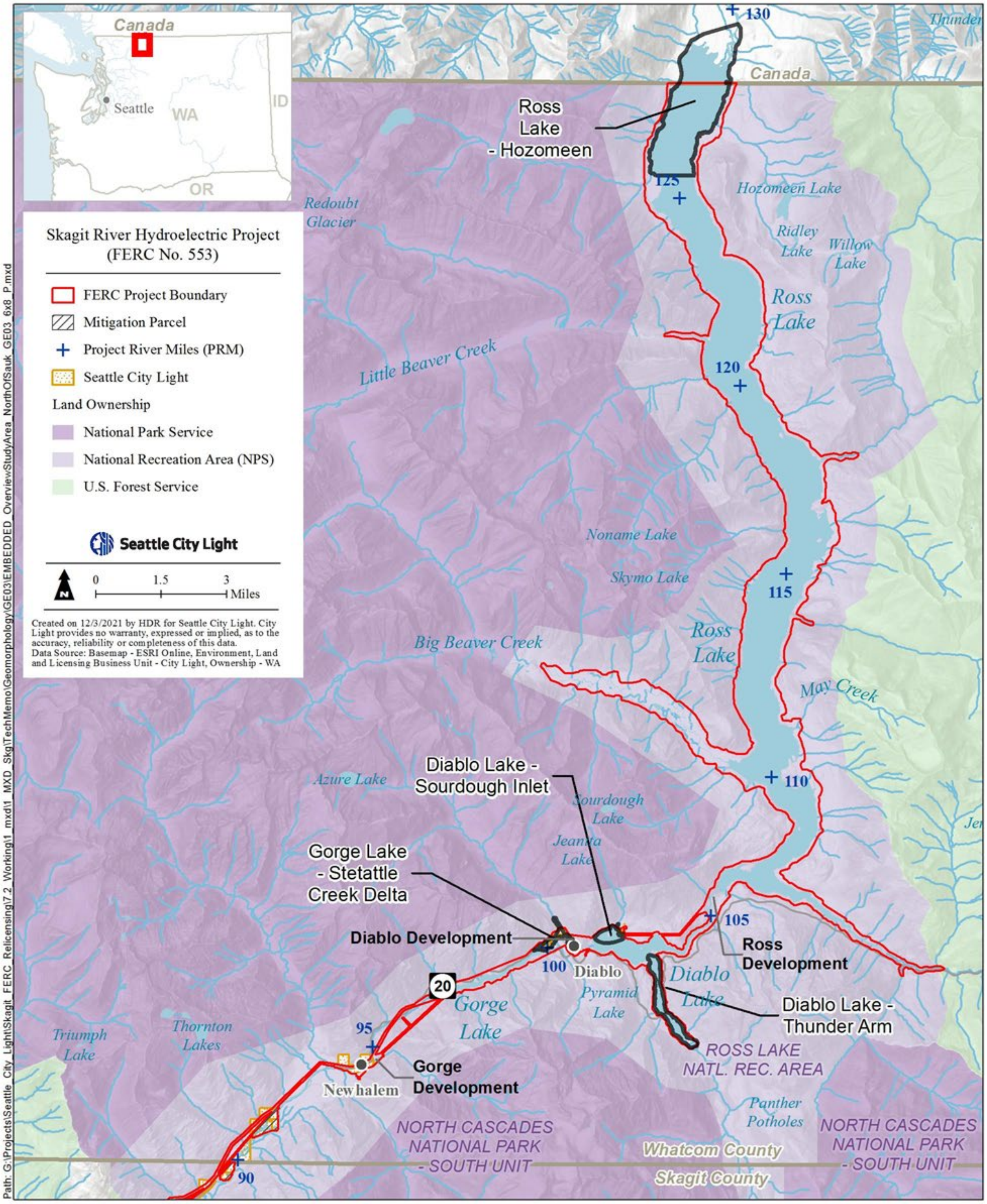


Figure 3.0-1. Overview of study area.

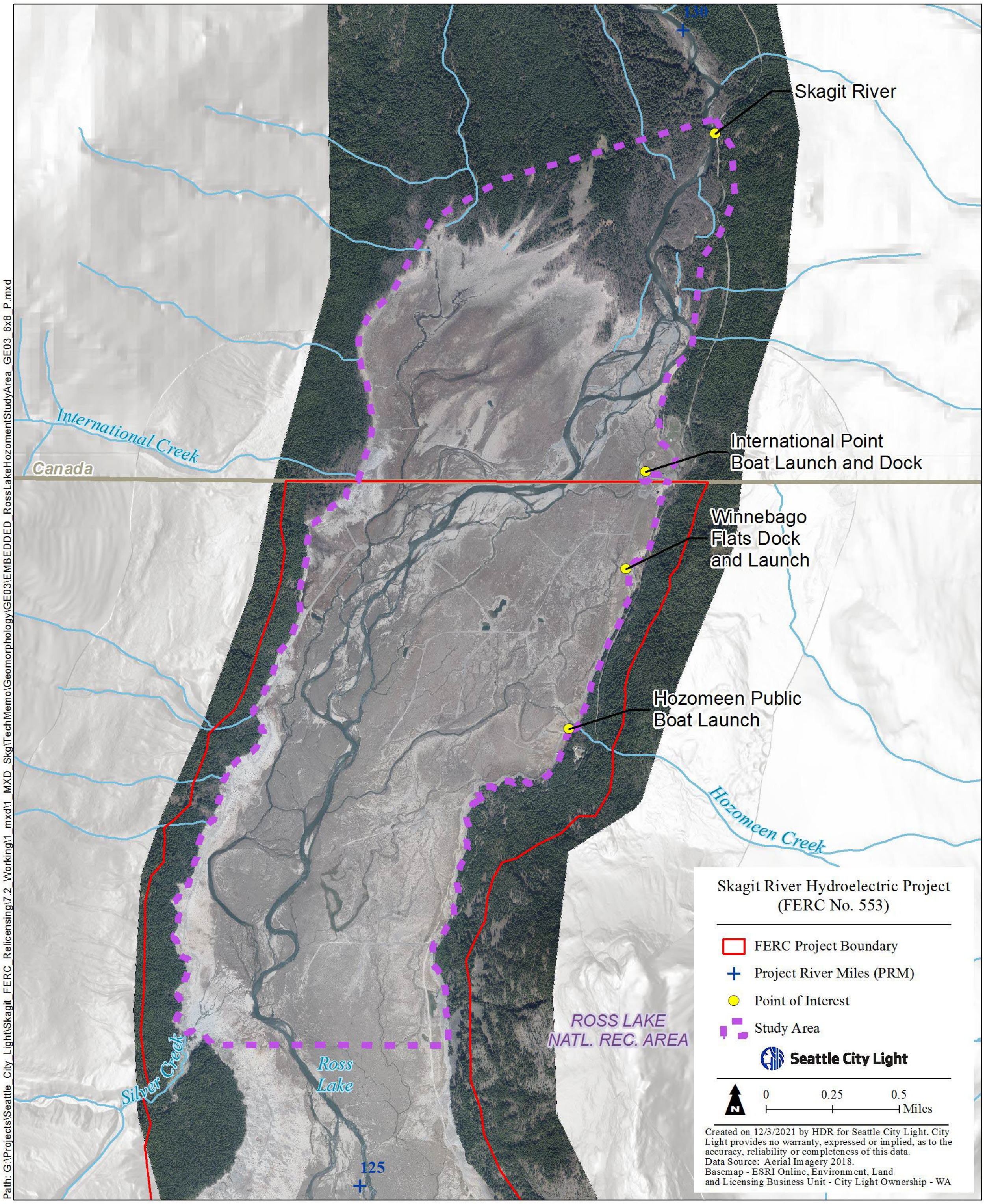


Figure 3.0-2. Study area – Ross Lake – Hozomeen inlet with Winnebago Flats Dock and Launch and Hozomeen Public Boat Launch.

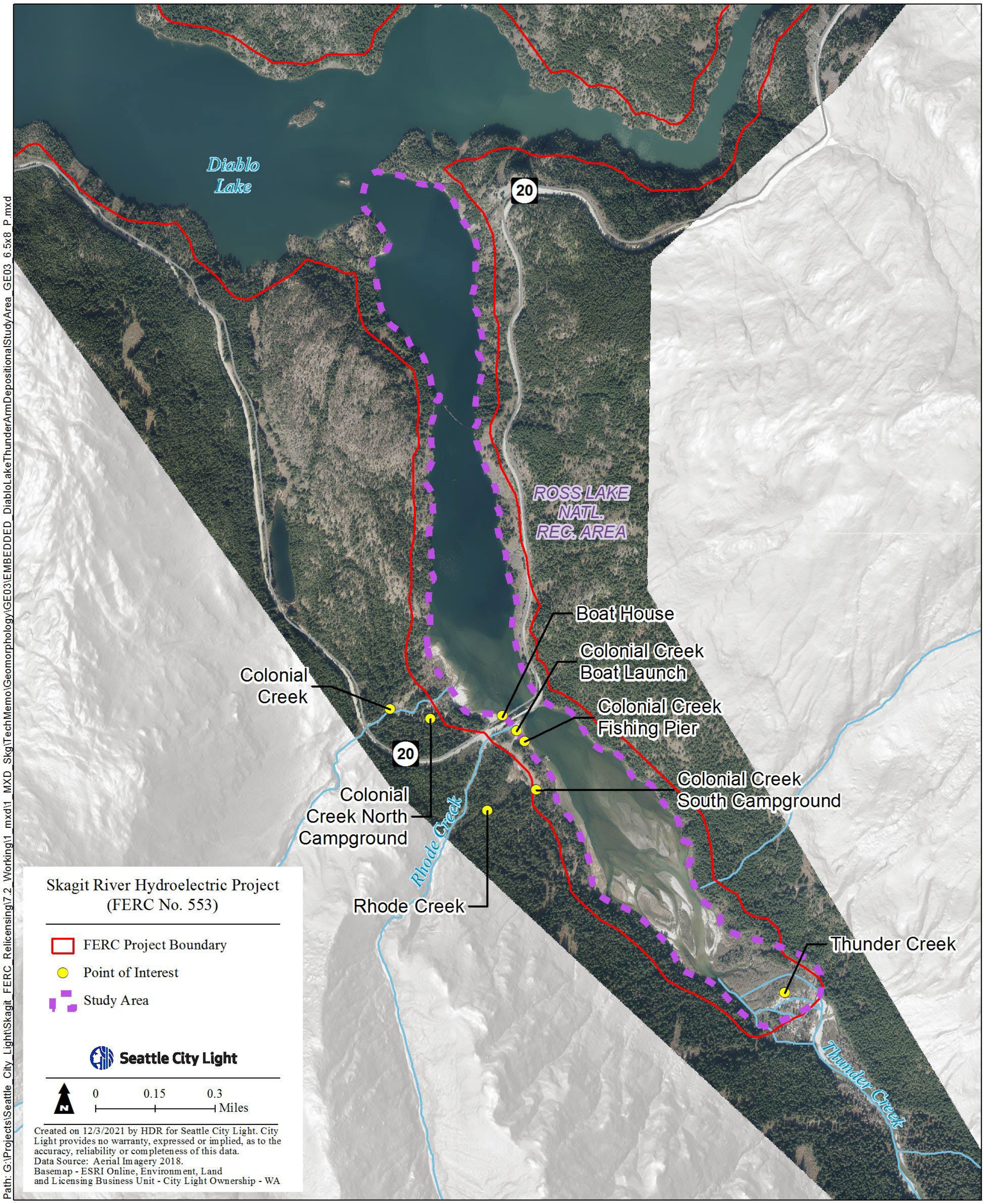


Figure 3.0-3. Study area – Diablo Lake – Thunder Arm inlet, with Colonial Creek Boat Launch/Dock.

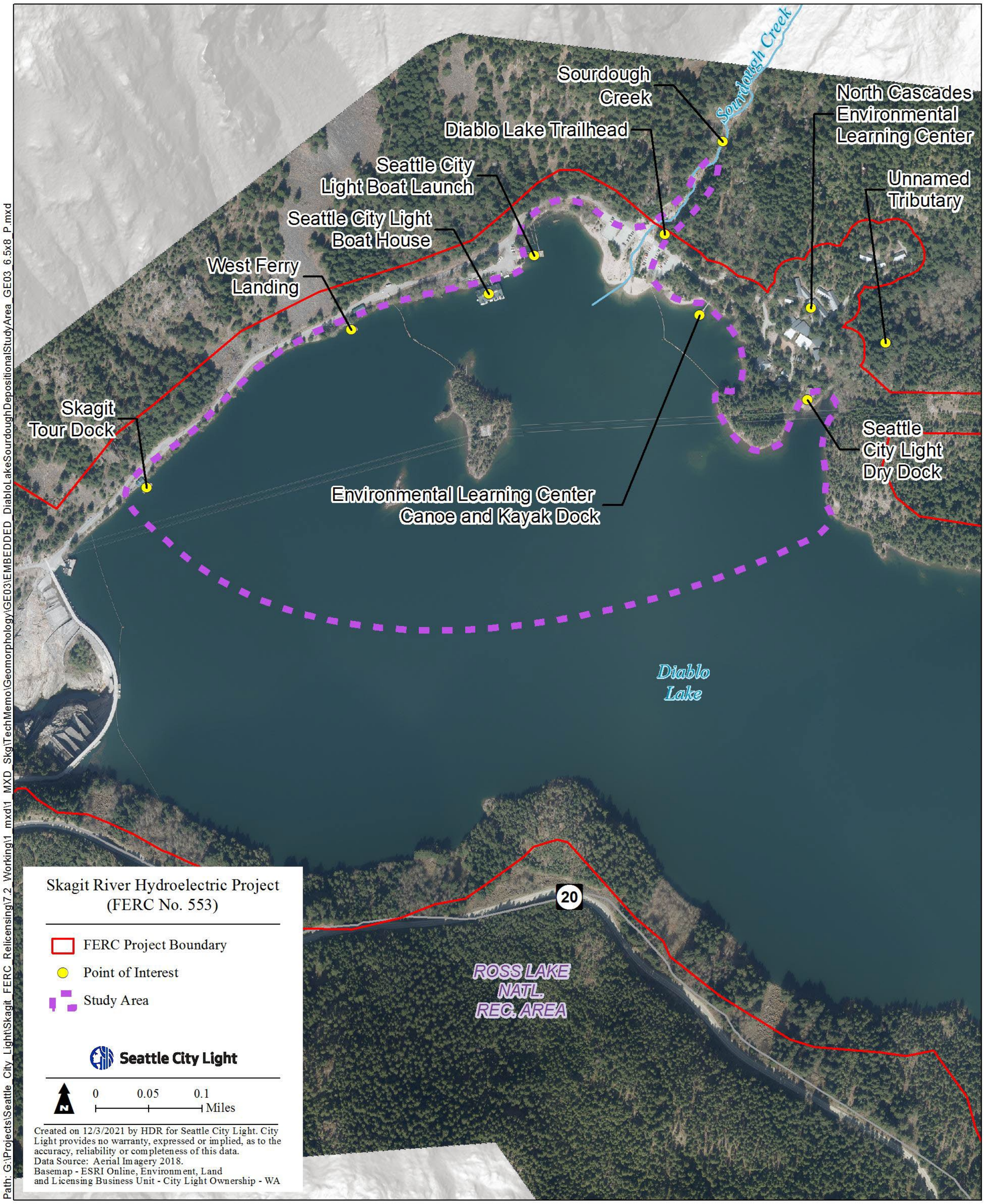


Figure 3.0-4. **Study area – Diablo Lake – Sourdough Creek inlet with City Light Boat Launch, City Light Boat House, City Light Dry Dock, West Ferry Landing, Environmental Learning Center Canoe and Kayak Dock, and Skagit Tour Dock.**

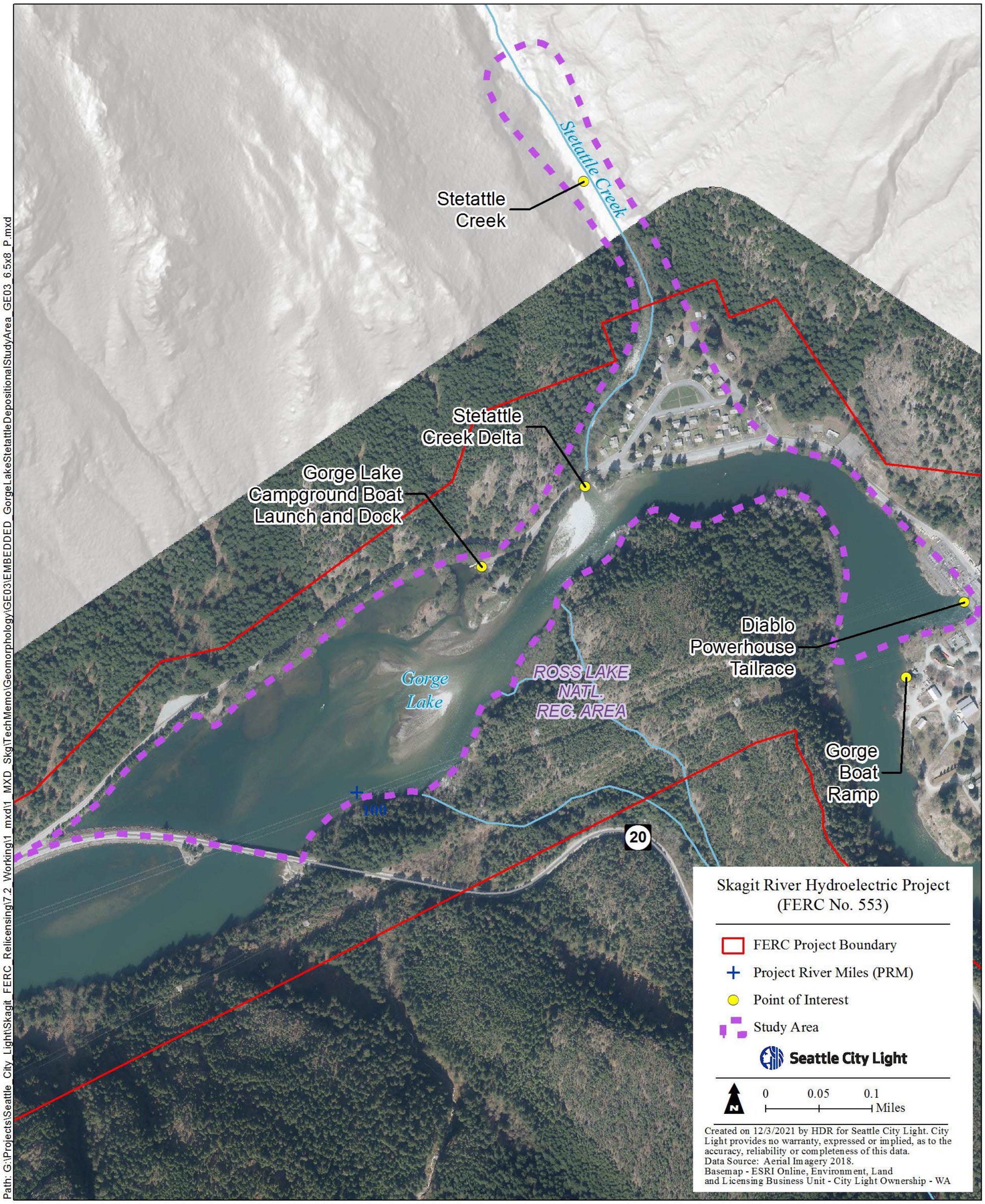


Figure 3.0-5. Study area – Gorge Lake - Stetattle Creek delta, with Gorge Lake Campground Boat Launch and Dock, Stetattle delta deposit, and Diablo Powerhouse tailrace.

4.0 METHODS

The following sections describe the methods used in 2021 in this study report. Field data and analyses completed through October 2021 are included in this report. Additional analyses to complete the study will be done in 2022, as described in Section 6 of this study report, and to be included in the USR. Table 4.0-1 lists the status of each RSP or June 9, 2021 Notice element of the study.

Table 4.0-1. Status of study plan and June 9, 2021 Notice elements.

Element	Status
RSP Section 2.6.1, compile and assess existing information.	Information compiled as described in Section 4.1, information used in analyses reported on in ISR; some information will be used for 2022 analyses and be reported in USR as noted in following sections of this table.
RSP Section 2.6.2, bathymetry.	To be completed in 2022 and reported in the USR.
RSP Section 2.6.2.2, sediment transport and deposition zones.	Analysis complete for Stetattle Creek (see Sections 5.4.6). Analysis for Hozomeen, Thunder, and Sourdough will be completed in 2022 and reported in the USR.
RSP Section 2.6.2.3, mapping of inlet area deposits.	Completed using methods in Section 4.2 and reported in Sections 5.1.2, 5.2.2, 5.3.1, and 5.4.5.
RSP Section 2.6.3, analysis deliverables.	Facies maps have been completed for Hozomeen (Figure 5.1-3), Thunder (Figure 5.2-6), Sourdough (Figure 5.3-2) and Stetattle (Figure 5.4-36). Other deliverables will be included in the USR.
June 9, 2021 Notice: City Light will quantify sediment supply of all size ranges (i.e., grain size distribution estimate) into Ross, Diablo, and Gorge Reservoirs as an annual rate by using the existing DHSVM model, historical contours, and updated bathymetry information. Workgroup will discuss sediment size and characterization available from DHSVM model.	To be completed in 2022 and reported in USR. A complete status update is provided in Table 6.1-1.
June 9, 2021 Notice: City Light will clarify that mapping of the sediment and erosion deposition zone and tributaries are part of the existing scope of the study. Any remaining gaps will be addressed during implementation.	To be completed in 2022 and reported in USR. A complete status update is provided in Table 6.1-1.
June 9, 2021 Notice: City Light will expand the scope of GE-03 to include 1-D backwater modeling. City Light and the LPs recognize that there are limitations on the ability to calibrate aspects of this model.	To be completed in 2022 for appropriate areas (see Table 6.2-1) and reported in USR. A complete status update is provided in Table 6.1-1.

4.1 Compile and Assess Existing Information

Existing maps, drawings, aerial photographs, LiDAR, reports, and data were collected and reviewed, including:

- Diablo Powerhouse Tailwater Remediation: Stetattle Creek Delta Geomorphology Report (Watershed GeoDynamics, In Prep).
- Report on Existing Conditions of Reservoir and Streambank Erosion (Riedel 1990).
- Skagit Hydroelectric Project Erosion Control Plan (Riedel et al. 1991).
- NPS Erosion Control and Revegetation Completion Reports (2016; 2018).
- Diablo Powerhouse sediment management project (Seattle University 2008).
- Diablo Powerhouse tailwater restoration project preliminary engineering design report (R2 Resource Consultants, Inc. 2013).
- Environmental Assessment, Diablo Powerhouse tailrace restoration (NPS 2014).
- United States Geological Survey (USGS) stream gaging records and Project flow records.
- Historic still photographs and aerial photographs, drawings, and maps. (See Table 4.1-1 for aerial photography selected for analysis based on resolution/lake elevation of photography and dates of sediment input events, as described further in Section 5 of this study report.) Additional photo years were reviewed but not selected for analysis because they did not have the appropriate level of detail or lake levels to be useful for this analysis.
- LiDAR data sets from 2006 and 2018 (Table 4.1-1Table).
- Improvement of Recreational Facilities, Hozomeen Campground Lower Boat Launch Area (NPS 1999).
- Geomorphology of a Cordilleran ice sheet drainage network through breached divides in the North Cascades Mountains of Washington and British Columbia, Geomorphology (Riedel et al. 2007).
- Deposition of Mount Mazama Tephra in a Landslide-Dammed Lake on the Upper Skagit River, Washington, USA. In Volcaniclastic Sedimentation in Lacustrine Settings (Riedel et al. 2009).
- Geomorphology of the Upper Skagit watershed: Landform mapping at North Cascades National Park Service Complex, Washington (Riedel et al. 2012).
- Regional estimates of watershed sediment input. (See Section 4.3.1 for more details.)
- Contacting NPS Maintenance Supervisor to discuss Thunder Arm debris flows.

These existing sources of information were or will be used to develop initial estimates of sediment input/deposition and rates of inlet/delta sedimentation through time.

Table 4.1-1. Project vicinity aerial photograph inventory and remote sensing resources used in analysis.

Date	Image Type	Resolution	Notes
Aerial imagery			
1990	Orthophoto quads	1 meter (m)	Source: U.S. Forest Service (1990) aerials
2006	True Color National Agriculture Imagery Program (NAIP) hi-resolution	1 m	Source: NAIP
2018	Skagit Project hi-resolution	6 inches	Source: Quantum Spatial 2018b
LiDAR and Digital Elevation Models			
2017	Skagit Topobathymetric LiDAR	0.5m or 1ft	USGS QL1 standards, Source: Quantum Spatial 2017a
2017	Western Washington, 3DEP North	0.5m or 1ft	Source: Quantum Spatial 2017b
2018	Ross Lake	0.5m or 1ft	Source: Quantum Spatial 2018a
2018	Gorge and Diablo Lake Green LiDAR	0.5m or 1ft	Source: Quantum Spatial 2018b

4.2 Field Data Collection

The Hozomeen area (head of Ross Lake) was visited on May 12-16, 2021, to map existing conditions and surficial substrate at the head of the lake. Ross Lake was slowly filling, with lake elevations increasing from 1,529 to 1,536 feet (City of Seattle datum [CoSD],[4] 1,535 to 1,542 feet North American Vertical Datum 88 [NAVD 88]) over the field data collection period (Table 4.2-1).

Table 4.2-1. Skagit River flow and Ross Lake levels during Hozomeen area field visits.

Date	Ross Lake Elevation (ft)	
	NAVD 88	CoSD
May 12, 2021	1,535	1,529
May 13, 2021	1,537	1,531
May 14, 2021	1,538	1,532
May 15, 2021	1,540	1,534
May 16, 2021	1,542	1,536

Sourdough Creek and Thunder Arm, both in Diablo Lake, were visited on August 31-September 7, 2021 to map surficial substrate, survey, and collect pebble count data. Diablo Lake elevation ranged from 1,200-1,201 feet CoSD (1,206-1,207 feet NAVD 88).

Stetattle Creek and the Stetattle Creek delta were visited on several occasions to document existing conditions of the stream and delta, to map and sample substrate size, and to observe the delta

[4] Note that vertical elevations reported as CoSD and NAVD 88 datum differ; both are included in this report for clarity.

during low Gorge Lake conditions. Field visits took place on September 17-18, 2018, December 20, 2018, and April 4, 2019. Flow in the Skagit River and Gorge Lake levels on field visit dates are shown in Table 4.2-2.

Table 4.2-2. Skagit River flow and Gorge Lake levels during Stetattle Creek field visits.

Date	Skagit River flow (Diablo Powerhouse outflow plus any spill; cubic feet per second [cfs])	Gorge Lake Elevation (ft)	
		NAVD 88	CoSD
September 17, 2018	3,200	878.1	871.6
September 18, 2018	3,100	877.4	871.9
December 20, 2018	3,260	877.5	871.0
April 4, 2019	2,800	830.9	824.4

4.2.1 Surficial Substrate Mapping

Surficial sediment size was mapped in the study areas based on visual observation for exposed sediment and areas in shallow water where substrate size could be observed. Dominant and sub-dominant size classes were recorded using the following categories: boulder, cobble, gravel, sand, fines (silt/clay). For areas covered by deep or opaque water in Diablo Lake, a Petit Ponar sampler was deployed from a boat to obtain a surface grab sample. Areas with similar-sized dominant and subdominant sediment (e.g., cobble/gravel) were drawn on a set of laminated 2018 aerial photograph maps for later transfer to Geographical Information System (GIS) polygons.

4.2.2 Pebble Counts

On September 17 and 18, 2018, pebble counts were collected at seven locations within Stetattle Creek and the Stetattle Creek delta area, four sites in Sourdough Creek/delta, and one location on Thunder Creek. No pebble counts were taken in the Hozomeen area due to concerns about disturbing cultural resources.

Wolman (1954) pebble counts of 100 particles were taken at sites composed of primarily coarse-grained (gravel-cobble-boulder) material. At each site, 100 particles were selected by walking along a grid pattern covering the facies to be sampled. Each particle was passed through a gravelometer and binned by half phi size class into < 2 millimeter (mm), 2 mm, 4 mm, 5.7 mm, 8 mm, etc., up to over 1,080 mm size for the largest boulders sampled.

Two shovel samples were taken of finer-grained sand-fine gravel substrate at the upstream end of the Stetattle Creek delta. The shovel samples were returned to the City Light materials processing lab and sieved to obtain information on grain size.

Results of the pebble counts and shovel samples were entered into an Excel® spreadsheet for analysis and graphing.

4.2.3 Stream Profile and Cross Section Surveying

In Sourdough Creek, a stream thalweg profile was surveyed on September 6, 2021 (Diablo elevation 1,201 feet CoSD [1,207 feet NAVD 88]) using a laser level and tape from as deep in

Diablo Lake as was wadable to a point upstream of the road crossing to supplement the LiDAR data (because Diablo Lake was full when the LiDAR was flown).

4.3 Delta Deposition Rates

Delta deposition rates in the Stetattle Creek delta were estimated using two different methods:

- Estimate of sediment supply based on regional sediment input rates and watershed size; and
- Estimate of coarse-grained sediment supply based on comparison of change in topography/bathymetry through time in the Stetattle delta area.

These methods will also be applied to the other study deltas in 2022 when more data are available for the Hozomeen, Thunder Arm, and Sourdough study areas.

4.3.1 Regional Sediment Input Rates

Several estimates of regional sediment input rates in the Skagit River watershed have been made using different methods and are summarized in Table 4.3-1.

Table 4.3-1. Regional sediment input rates.

Location	Average annual sediment input (cu yd/sq mi of watershed/ year [yr])	Notes	Reference
Diablo Lake, 1930-1936	85	Estimated from reservoir sedimentation over 6 years (1930-1936) with no high peak flows.	U.S. Soil Conservation Service (1950) as described in R2 Resource, Inc. (2013)
Jackman Creek	3,800	Mass wasting, surface erosion, soil creek estimate. Included one extremely large landslide that resulted in a high average yield; likely not representative.	Paulson (1997) as reported in U.S. Army Corps of Engineers (USACE 2008)
Illabot Creek	160	Mass wasting, surface erosion, soil creek estimate, forested/logging primary land use.	Paulson (1997) as reported in USACE 2008
Finney Creek	800	Mass wasting, surface erosion, soil creek estimate, forested/logging primary land use.	Paulson (1997) as reported in USACE 2008
Skagit River upstream of Cascade River	280	Compilation of rates from several watersheds.	USACE 2008
Skagit River at Mt. Vernon	490-2,300	Based on suspended sediment measurements; includes Sauk River drainage with major glacial input.	USACE 2008

R2 Resources, Inc. (2013) estimated a reservoir sedimentation rate in Diablo Lake from 1930-1936 (prior to construction of upstream reservoirs) of 85 cubic yards/square mile/year (cu yd/sq mi/yr) based on comparisons of bathymetry in the reservoir. There were no high peak flows in the 1930-1936 period, so this value represents deposition under a "normal" flow scenario with the highest peak equivalent to approximately the 5-year peak flow. In addition, this estimate may not include all sediment supplied from upstream since the finest-grained silt and clay particles may not have been trapped in the lake.

Paulson (1997) estimated sediment input to several small, forested basins in the Skagit watershed based on input from mass wasting, surface erosion, and soil creep. These basins were being managed for forest practices, and mass wasting was the primary input mechanism. Estimated input ranged from 160 to 3,800 cu yd/sq mi/yr. The large range in estimates was the result of the variability in the number of large landslides in different basins. USACE (2008) used a compiled average of 280 cu yd/sq mi/yr for the upper Skagit River watershed.

USGS and USACE sampled suspended sediment in the Skagit River at Mt. Vernon for several different periods of time. USACE (2008) reports an average annual suspended sediment yield of 490-2,300 cu yd/sq mi/yr at this location. The wide range in the estimate is due to the inherent variability in suspended sediment measurements and the necessity of extrapolating limited measurements to a long-term flow record. This estimate also includes input from the Sauk River drainage, which includes several glaciated areas with high suspended sediment inputs. The Skagit River suspended sediment yield range is consistent with the regional range of 830–2,500 tons/sq mi/yr of sediment from glacier-fed rivers compiled by R2 Resource Consultants (2004) for Puget Sound Energy. Nichols (2006) estimated glaciated areas in the Pacific Northwest produce 2,600 tons/sq mi/yr or around 1,900 cu yd/sq mi/yr.

While none of the watershed-level estimates of sediment input are directly comparable to the topography and land use practices in the four study watersheds, the estimates provide initial bounding estimates of likely average annual sediment input rates in the region. In addition to the rates listed in Table 4.3-1, the City Light team is working on a fine sediment yield relationship based on measured fine sediment yield from basins in the North Cascades and Canada and a statistical predictive relationship using basin characteristics like geology, slope gradient, etc. This analysis will be included in the USR.

4.4 Stetattle Creek Sediment Transport Analysis

In Stetattle Creek, output from a two-dimensional (2-D) hydraulic model of the Project vicinity prepared by Alden Labs was used to calculate sediment transport potential based on critical shear stress of particles that could be entrained under a given flow within the lower 0.5 miles of Stetattle Creek and within the Skagit River near the confluence with Stetattle Creek.

The critical diameter (largest diameter of the substrate that can be moved under given flow conditions) was computed for each cell in the 2-D model output using the method described in Appendix B of Engineering Manual 1110-2-1418 "Channel Stability Assessment for Flood Control Projects" (USACE 1994). This method is based upon the Manning's equation and assumes a Shields number of 0.045, and roughness height (k) equal to 3 times the median grain size (D_{50}). For this analysis, the Shields number was adjusted to 0.03 based on a study of bed-load transport in similar gravel bed streams (Mueller et al. 2005). Additionally, studies have shown the assumption that $k = 3D_{50}$ was considered too low; the ratio $k = 6.8D_{50}$ is more appropriate for use in gravel-bed streams (Clifford et al. 1992) and was, therefore, applied. Application of the adjustments noted above resulted in the following relationship for calculation of the critical diameter:

$$D_{crit} = 0.686\frac{V^3}{\sqrt{d}}$$

where:

D_{crit} = critical diameter (mm)

V = Velocity (ft/s)

d = Depth (ft)

5.0 PRELIMINARY RESULTS

The results presented in this study report include field data collection and data analysis through October 2021. Additional analyses and data collection will be completed in 2022 and reported in the USR as described in Section 6.2, Next Steps.

The Stetattle Creek analysis reported in this study report has a greater level of detail than the other three study areas because several existing analyses of the Stetattle Creek area were available for reference and included more detailed analysis (e.g., 2-D HEC-RAS modeling) than is being conducted at the other three delta study areas. The Stetattle Creek analysis was undertaken prior to the relicensing process as part of investigation of the potential for restoring hydraulic capacity of the Diablo Powerhouse and spanned over a decade of studies.

5.1 Hozomeen

The **Hydrology and Lake Level**

The Skagit River upstream from Ross Lake has a drainage area of approximately 380 square miles. Flows are highest from May to July in response to snowmelt, with the highest peaks in June.

Water surface elevation in Ross Lake varies seasonally in response to inflow, outflow, and power needs. Lake elevation curves (2007-2019) and annual percent exceedance curves of water surface elevations for Ross Lake from 1991 to 2018 are provided in Figures 5.1-1 and 5.1-2. Exceedance values refer to the value that is exceeded for the specified percent of the time. For example, the 40 percent exceedance elevation in Ross Lake is 1,589 feet CoSD (1,595.26 feet NAVD 88), which means that the reservoir elevation was above this level 40 percent of the time for the period 1991–2018, and lower than this level 60 percent of the time.

Ross Lake is drawn down as much as 120 feet seasonally, with normal maximum water surface elevation generally maintained between July 31 and Labor Day each year. License Article 403 of the existing license requires that City Light: (1) fill Ross Lake as soon as possible after April 15; (2) achieve normal maximum water surface elevation by July 31; and (3) maintain normal maximum water surface elevation through Labor Day subject adequate runoff, anadromous fish protection flows downstream of the Project, flood protection, spill minimization, and firm power generation needs.

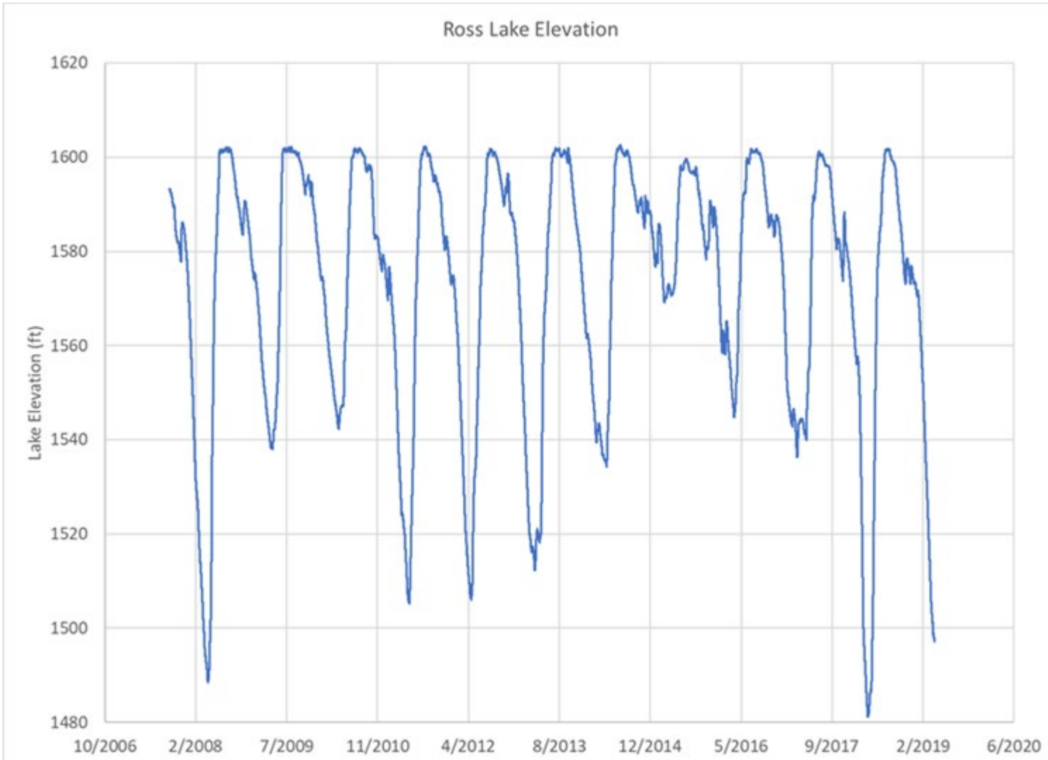


Figure 5.1-1. Ross Lake elevation, 2007-2019 (elevations in CoSD).

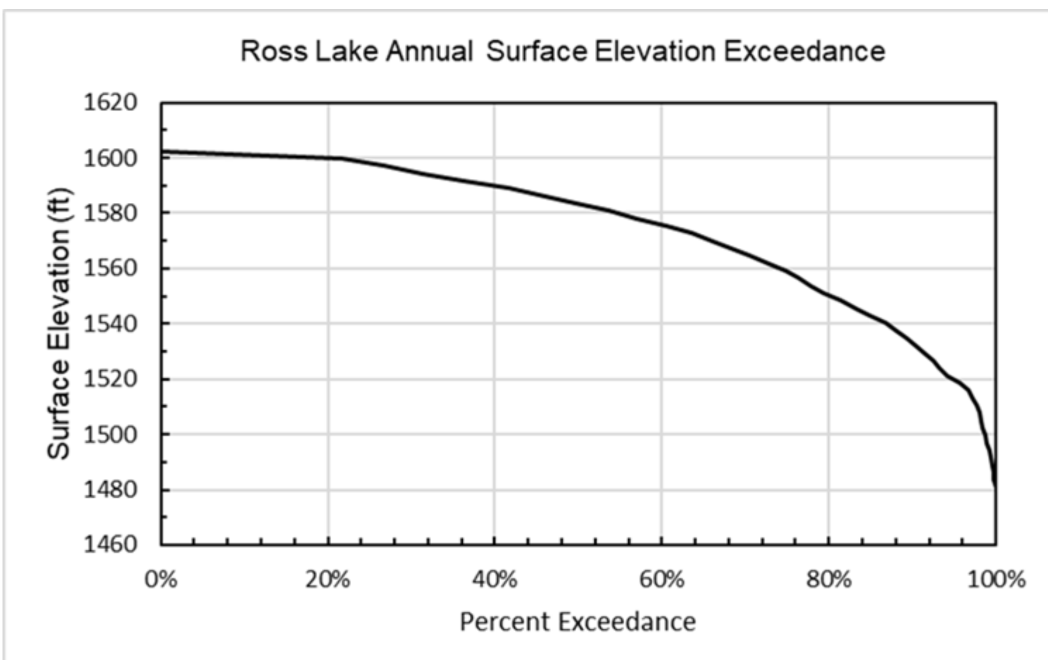
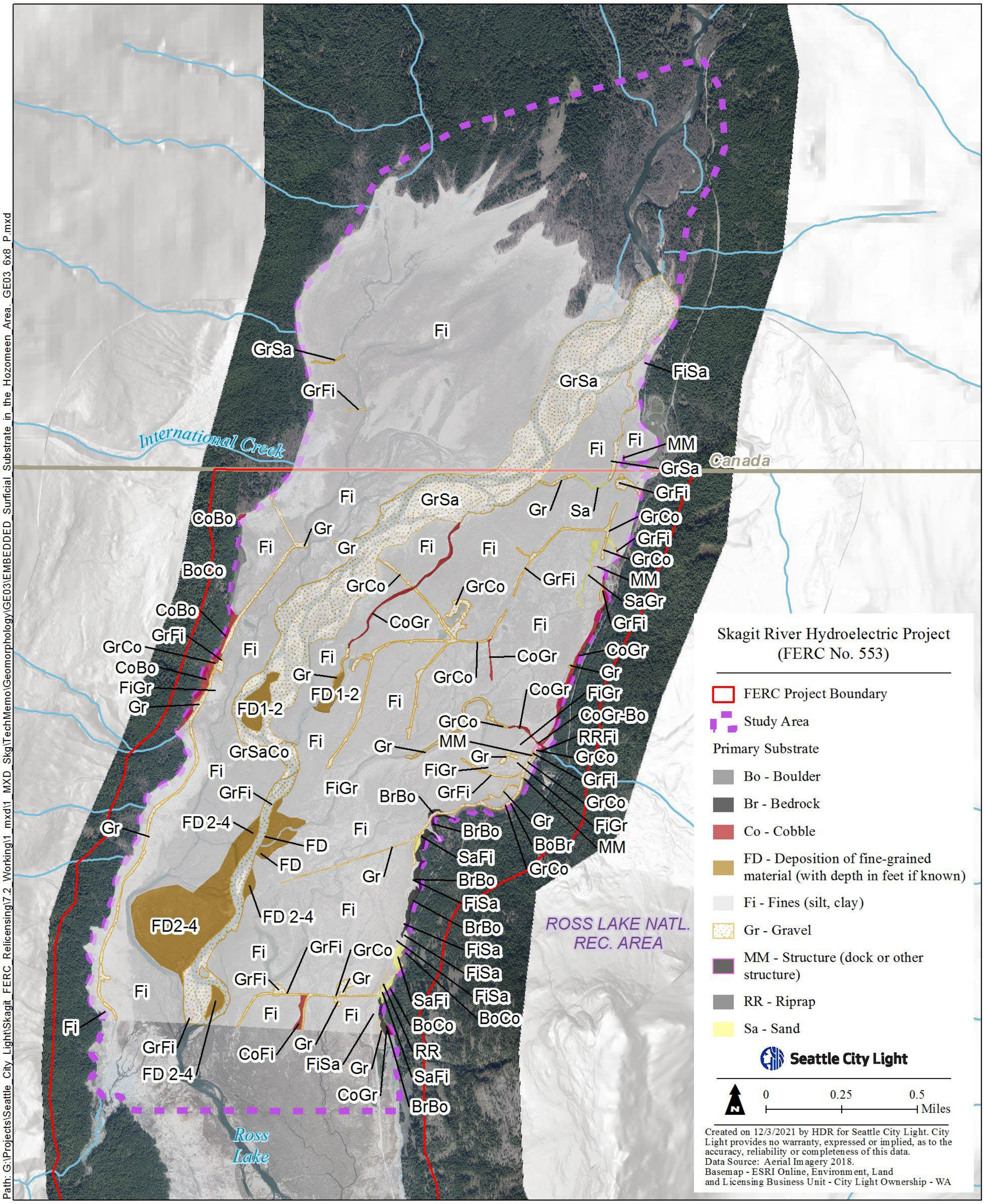


Figure 5.1-2. Annual percent exceedance curve of water surface elevations for Ross Lake, based on the period 1991–2018 (elevations in CoSD).

5.1.2 Surficial Substrate

Surficial substrate in the Hozomeen area is primarily fine-grained sediment (silt/clay) with areas of boulder/cobble/gravel around the margins of the lake that are subject to wave activity during the summer months (Figure 5.1-3). There is gravel, sand, and some cobble material in stream and river channels within the area. Based on observations of exposed tree stumps, most of the area showed little evidence of deposition or erosion (Figure 5.1-4). Fine-grained deposition of 1 foot to 4 feet was observed along the main Skagit River channel in two areas based on tree stump exposure—one area is between elevation 1,569-1,571 feet CoSD (1,575-1,577 feet NAVD 88), and another is between 1,557-1,374 feet CoSD (1,563-1,570 feet NAVD 88), as seen on Figures 5.1-3 and 5.1-4.

The low levels of deposition at the upper end of Ross Lake suggest either that sediment input from the Skagit River is relatively low or that sediment is deposited at elevations lower than those during the field inventory. Future analyses of sediment input rates and net deposition as described in the study plan will explore these observations and will be reported in the USR.



Note: Substrate mapping did not extend south to the study area boundary because, as noted in RSP, if based on field review there was substantially more deposition south of the boat launches than noted on the aerial photographs it would be mapped. Based on field review there was not substantial deposition, so the mapping was stopped north of the study area boundary.

Figure 5.1-3. Surficial substrate in the Hozomeen area.


Fine-grained substrate with old gravel road in foreground


Deposition around tree stumps

Figure 5.1-4. Photos of substrate in the Hozomeen area.

5.1.3 Hozomeen Area Boat Launches

The two public boat launches within the United States in the Hozomeen area were visited to determine if sediment deposition was occurring in the vicinity of the ramps. The end of the Hozomeen ramp has been excavated to allow boat access; there does not appear to be substantial recent deposition in the area (Figure 5.1-5). The Winnebago Flats boat ramp ends at a stream channel (during low lake elevations) and, likewise, has little recent deposition.


Hozomeen boat ramp


Winnebago Flats boat ramp

Figure 5.1-5. Photos of ends of public boat ramps in the United States portion of the Hozomeen area.

5.2 Thunder Arm

Thunder Arm is a long, narrow embayment on the south side of Diablo Lake (Figure 5.2-1). The arm is crossed by SR 20. The Colonial Creek Campground is located on the western shore of Thunder Arm; sediment deposition limits usefulness of the boat launch and boat house within the campground complex.

There are three primary sources of inflow and sediment to Thunder Arm: Thunder Creek, Rhode Creek, and Colonial Creek. Thunder Creek drains a large watershed that includes runoff from 51 glaciers (12.8 percent of the basin; Chennault 2004). The glaciers contribute fine-grained sediment to the runoff, particularly during the summer and early fall. Rhode Creek and Colonial Creek are steep streams that have built alluvial fans on the western shores of Thunder Arm.

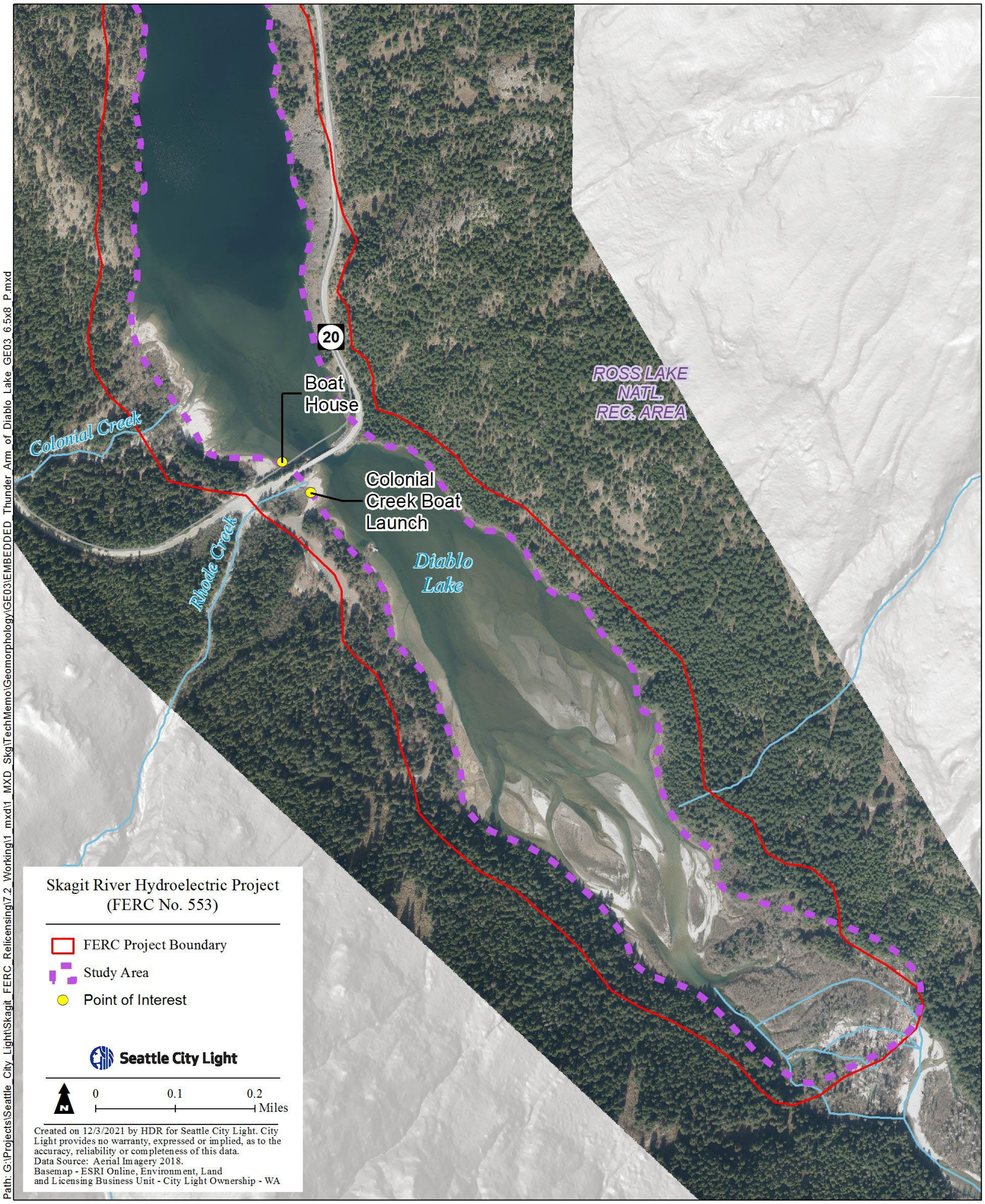


Figure 5.2-1. Thunder Arm of Diablo Lake.

5.2.1 Hydrology and Lake Level

The volume of sediment input and location of sediment deposition in Thunder Arm is dependent on incoming sediment carried by streams and lake levels in Diablo Lake. USGS maintains a stream gage on Thunder Creek. Colonial and Rhode creeks are not gaged. In addition to streamflow, debris torrents occur in Rhode Creek.

5.2.1.1 Thunder Creek Flow

Thunder Creek has a drainage area of approximately 105 square miles at the USGS gage located 0.4 miles upstream from Diablo Lake. The gage is located just upstream from the Thunder Creek trail bridge.

Mean daily flows in Thunder Creek are highest from May through July in response to snowmelt (Figure 5.2-2). Glacial melt keeps flows relatively high through October in contrast to non-glacial streams in the Pacific Northwest. Lowest flows generally occur in February and March when much of the watershed is covered in snow.

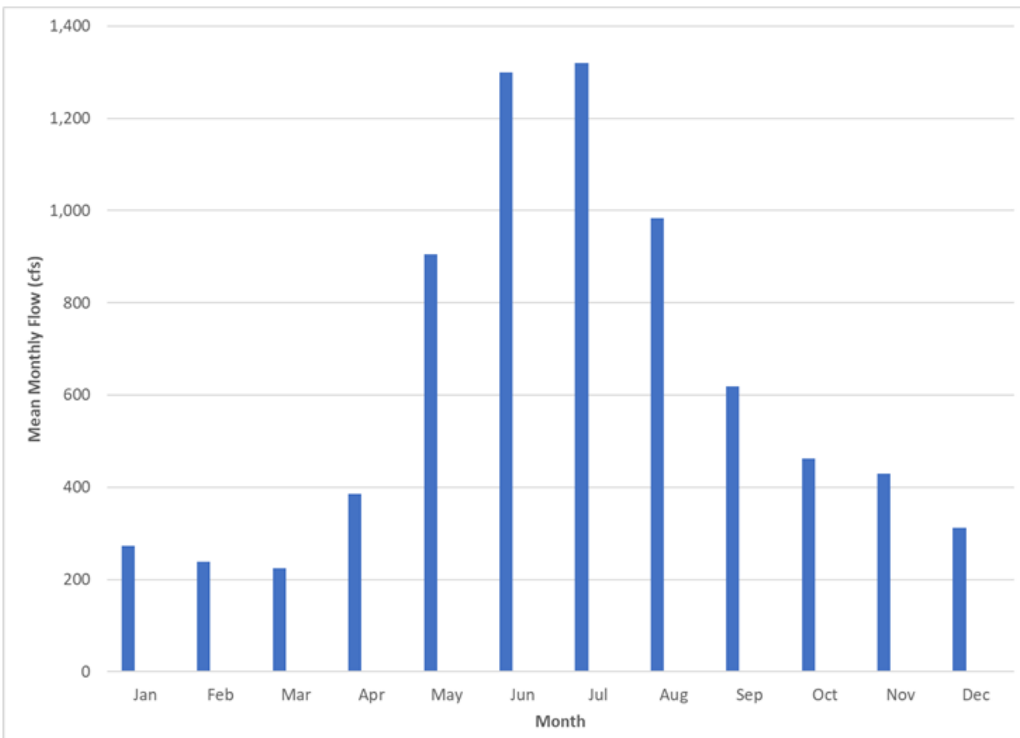


Figure 5.2-2. Thunder Creek mean monthly flows (1931-2020).

In addition to suspended sediment carried from glacial sources during normal daily flows, high flow events have enough energy to transport coarser gravel and cobble as bedload. Annual peak flow events for the period of record (1931-2020) are shown in Figure 5.2-3. Figure 5.2-4 shows timing of peak flows during the year; the flow of record occured in October 2003 in response to a major regional rainfall event. Other large peaks occured from rain and rain-on-snow events.

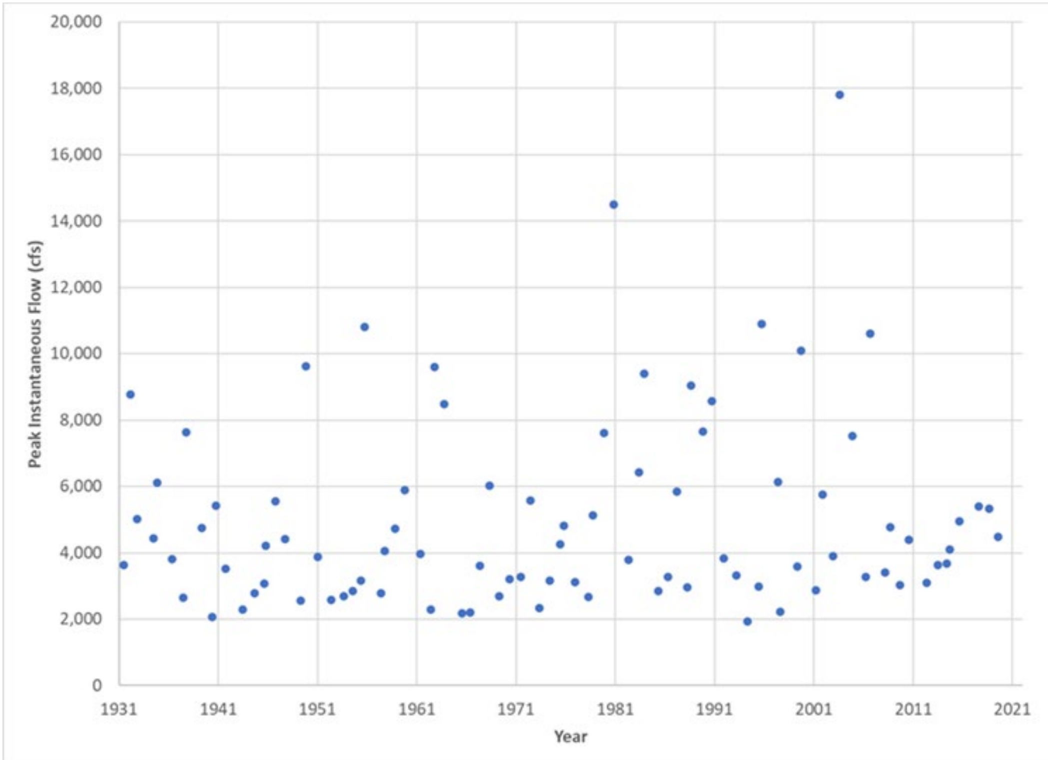


Figure 5.2-3. Thunder Creek peak instantaneous flows (1931-2020).

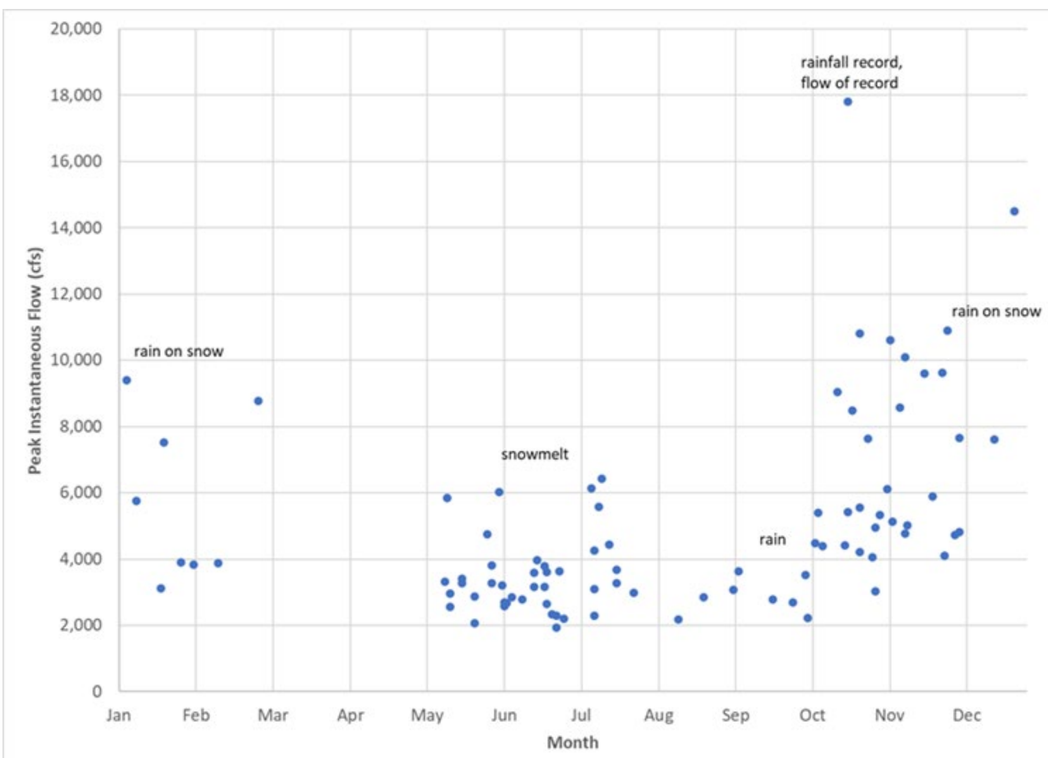


Figure 5.2-4. Thunder Creek peak flow timing.

5.2.1.2 Diablo Lake Levels

Water surface elevation in Diablo Lake is generally held between 1,200 and 1,205 feet CoSD (approximately 1,206 to 1,211 NAVD 88) and varies up to 5 feet daily in response to inflow, outflow, and power needs. The annual percent exceedance curves of water surface elevation for Diablo Lake from 1991 to 2018 is provided in Figure 5.2-5.

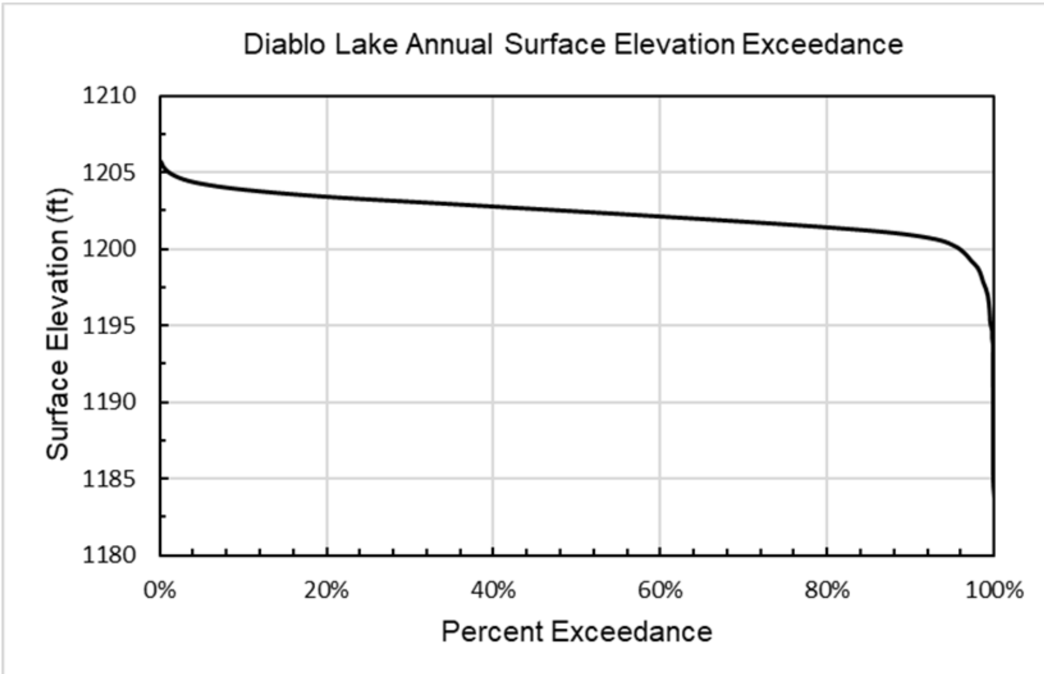


Figure 5.2-5. Annual percent exceedance curve of water surface elevations for Diablo Lake, based on the period 1991–2018 (elevations in CoSD).

5.2.2 Surficial Substrate

Surficial sediment in Thunder Arm is dominated by fine-grained sediment in the main part of the arm (Figure 5.2-6). The fine sediment grades to sand and then gravel and cobble where Thunder Creek enters the lake forming a delta. The Rhode Creek alluvial fan is also building out into Diablo Lake and grades from boulder to cobble to gravel to sand in a downstream direction. Rhode Creek fan deposits occur on both sides of SR 20. Colonial Creek has a wider fan with cobble and gravel in areas that are currently active and gravel and sand in areas of past deposition.

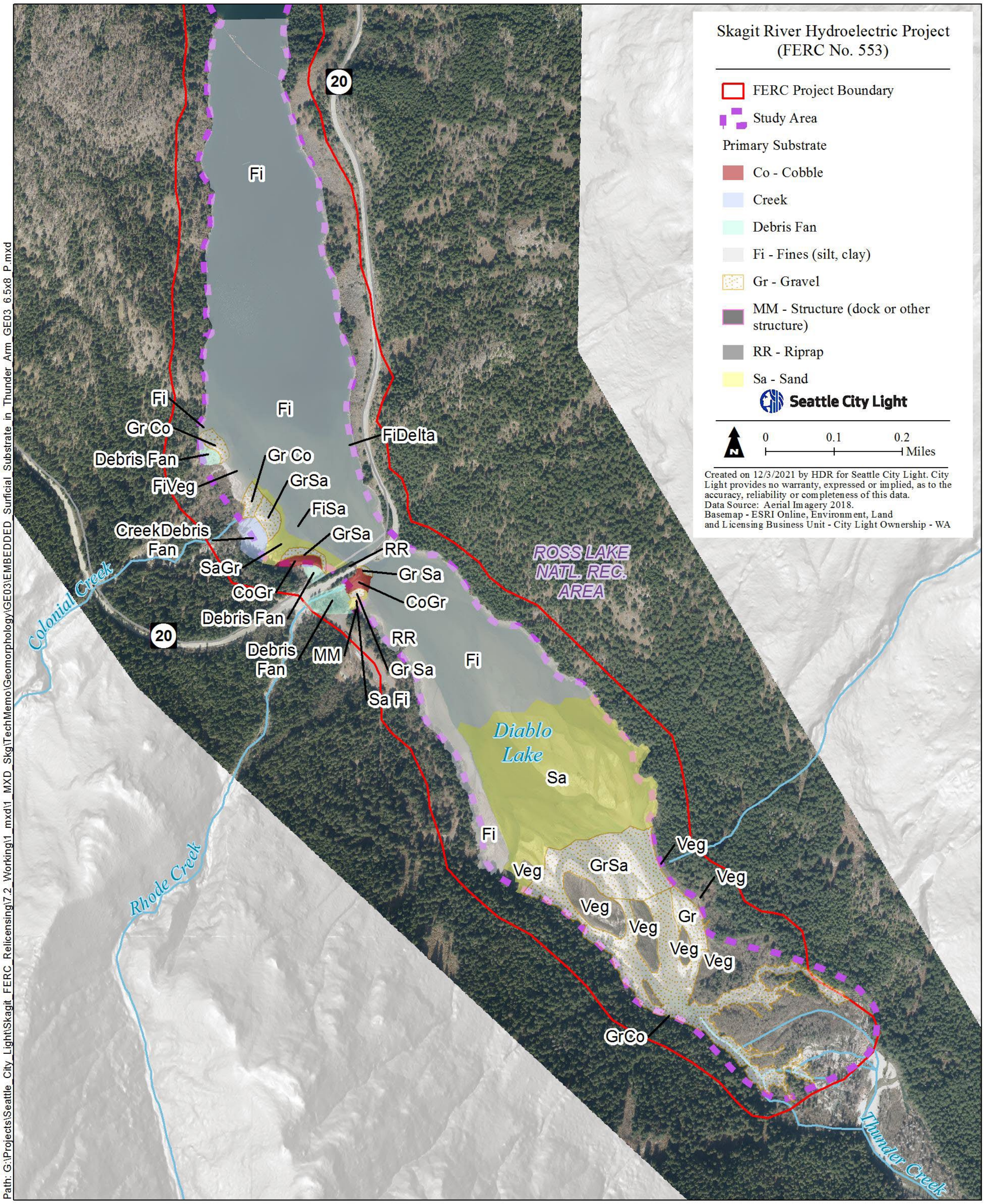


Figure 5.2-6. Surficial substrate in Thunder Arm.

One pebble count was made in Thunder Creek on a point bar just downstream from the trail bridge/USGS gage area. The sample was composed of 58 percent cobble and 42 percent gravel with a median grain diameter of 70 mm (Figure 5.2-7).

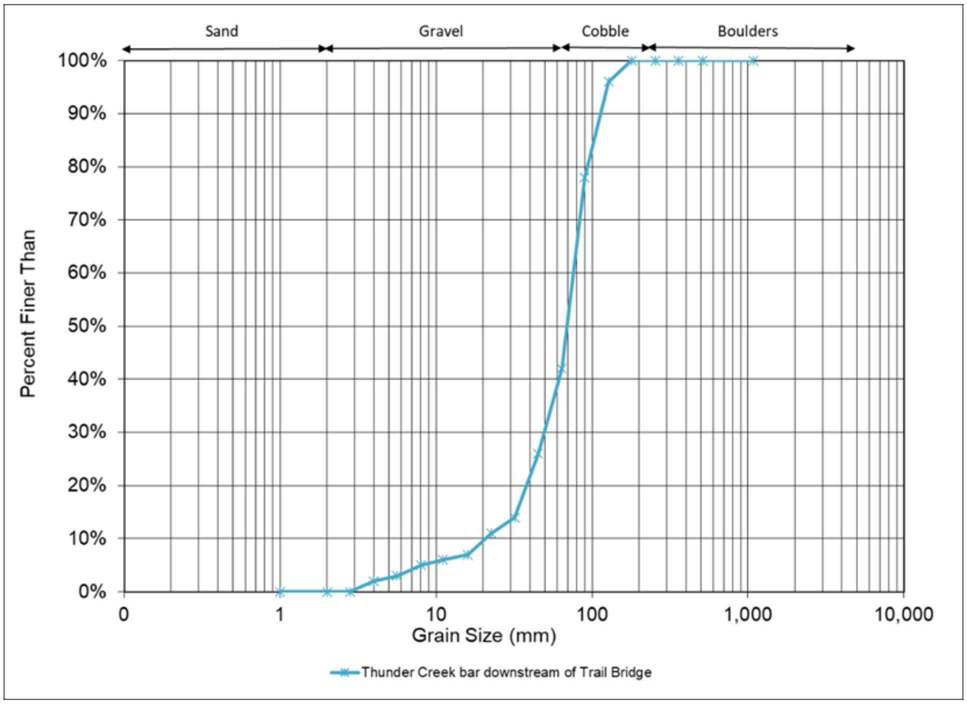
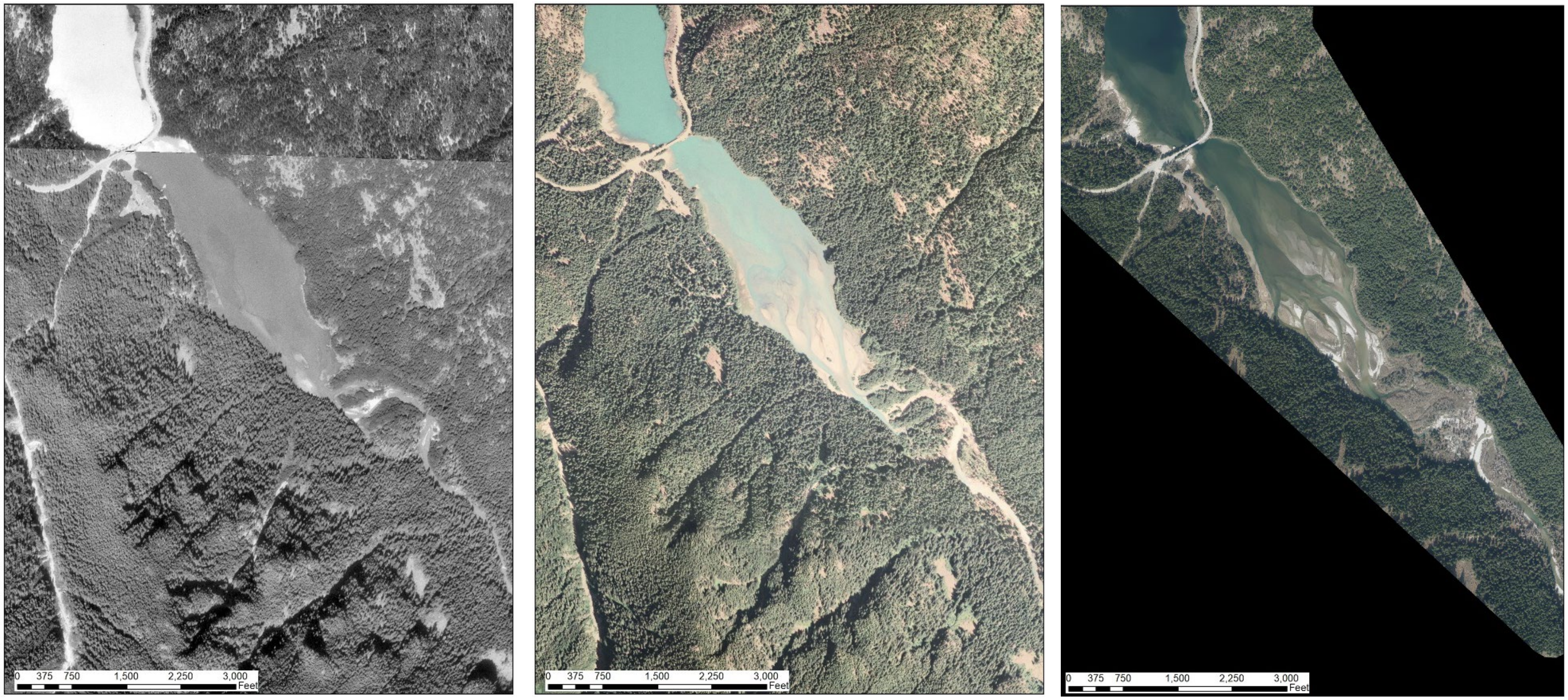


Figure 5.2-7. Thunder Creek substrate sample grain size distribution.

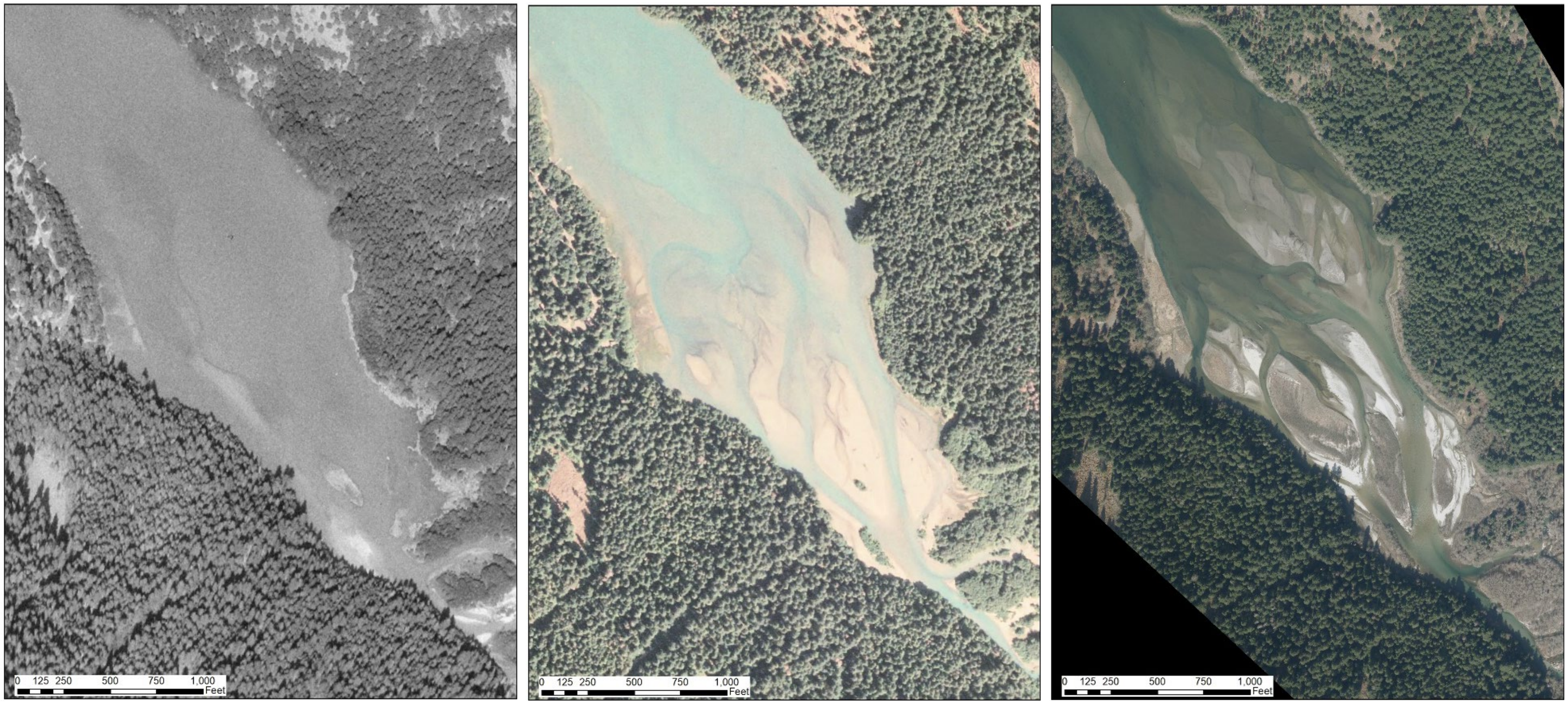
5.2.3 Thunder Arm Changes Through Time

Three sets of aerial photographs (1990, 2006, and 2018) were compared to determine how deposits in Thunder Arm changed through time (Figure 5.2-8). Lake levels and water clarity vary in each of the aerial photographs but general sediment deposition patterns and trends can still be determined. The October 20, 2003 peak flow event (17,800 cfs instantaneous peak—largest flow on record) resulted in substantial areas of deposition in Thunder Arm. Many bars developed in the Thunder Creek delta at the confluence of the creek and Diablo Lake and a large log jam filled the northern meander bend at the mouth of the stream as seen in the 2006 aerial photographs (Figures 5.2-9 and 5.2-10). Deposition in the delta continued through time resulting in the formation of vegetated islands at the upper end of the delta and additional deposition in the delta by 2018. The deposits from the 2003 flood appear to have resulted in aggradation within the stream. Some floodplain trees that were alive in the 1990 aerial photograph were dead in the 2006 photo. The zone of dead trees extends approximately 0.5 miles upstream from the high lake elevation and was mapped as North Pacific Lowland Riparian Forest and Woodland Group in the TR-01 Vegetation Mapping Study (City Light 2022). A longitudinal profile of Thunder Creek was compiled from 2018 LiDAR elevation data (Figure 5.2-11). The 2018 LiDAR includes topographic and bathymetric data, so it shows stream bed elevation including riffles and pools. The remnant 2006 sediment and wood deposits at the head of the lake can be seen between station 7,500 and 9,000. Future analysis of the extent of deposition and backwater effects in Thunder Creek is planned for 2022, as described in Section 6.2 of this study report.



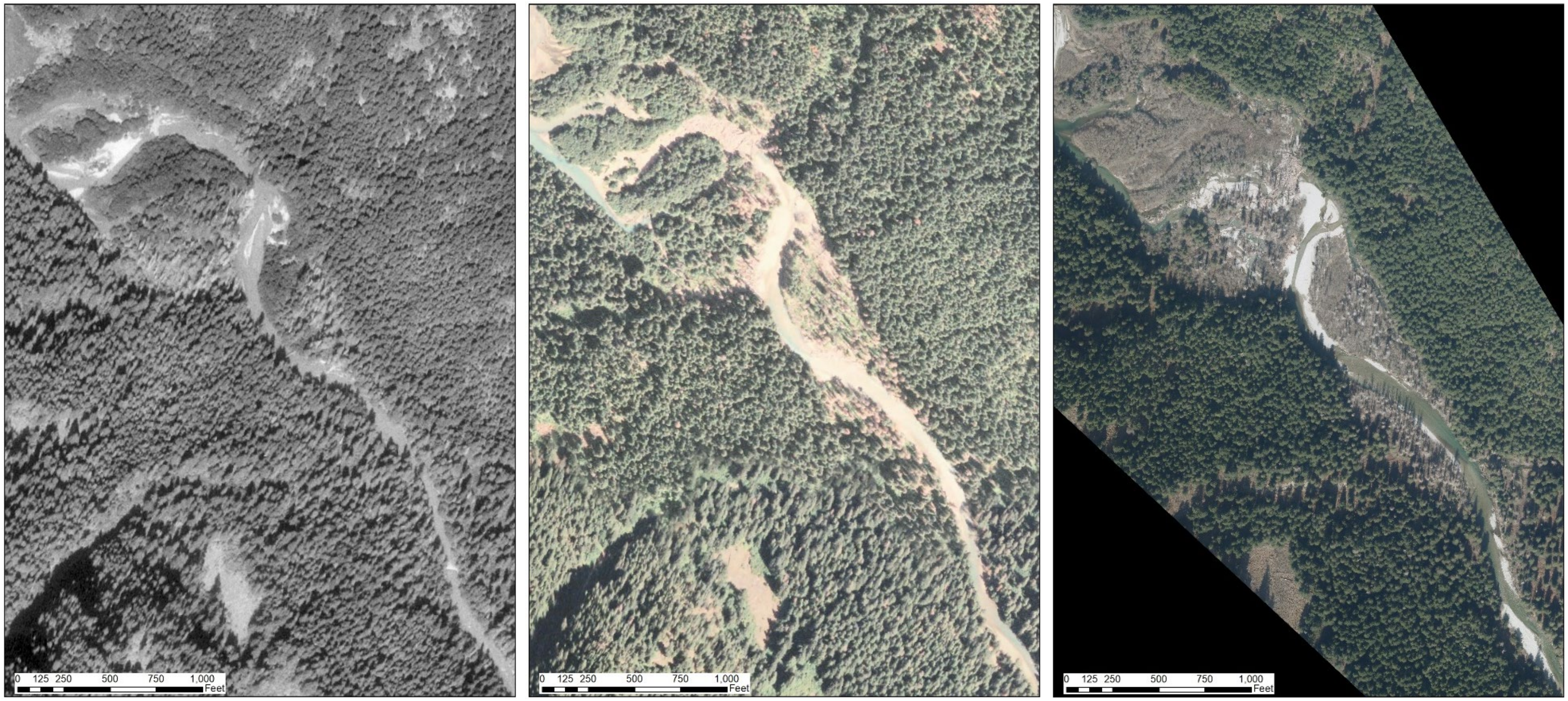
1990 2006 2018

Figure 5.2-8. Thunder Arm changes through time.



1990 2006 2018

Figure 5.2-9. Thunder Arm upper delta through time.



1990 2006 2018

Figure 5.2-10. Mouth of Thunder Creek through time.

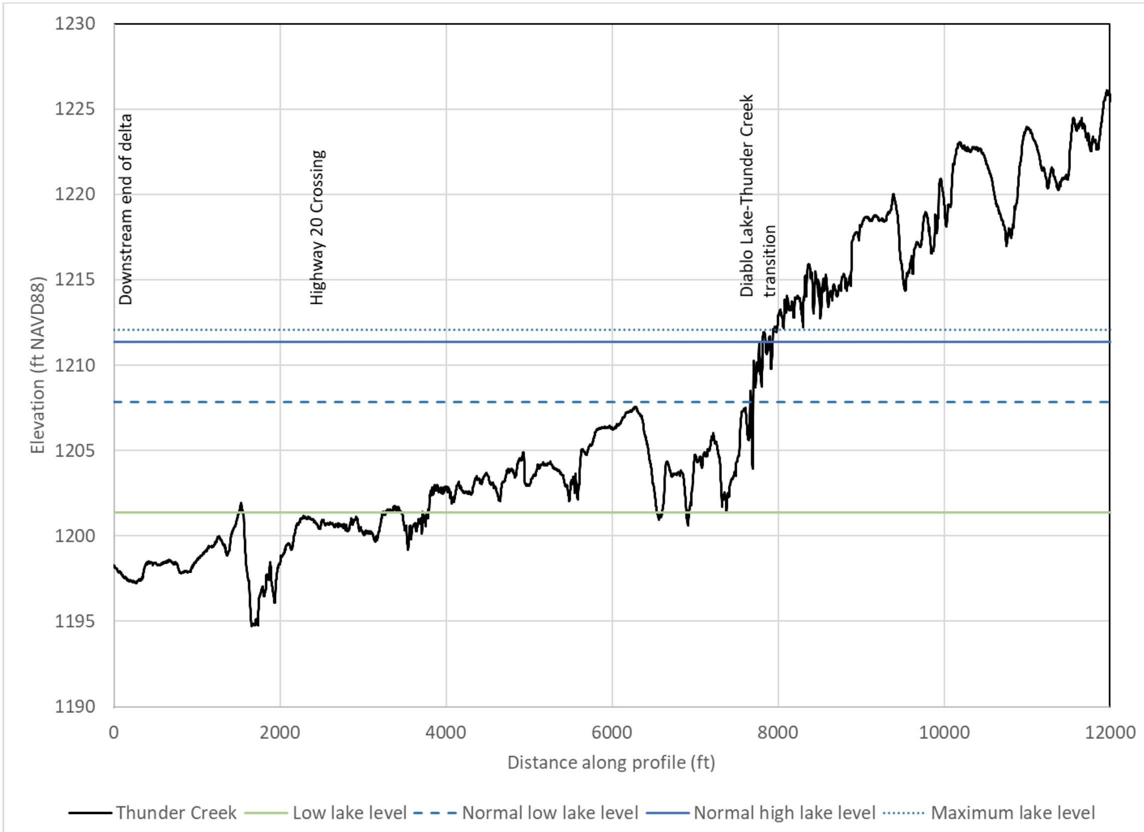


Figure 5.2-11. Thunder Creek profile (2018 LiDAR).

5.2.4 Colonial Creek Campground Boat House and Boat Ramp

Deposition at the boathouse and boat ramp at the Colonial Creek Campground limits the usefulness of these facilities, particularly at low lake levels. Observations at the facilities suggest that the primary source of sediment at both facilities is Rhode Creek. SR 20 and the Colonial Creek Campground southern entrance road are constructed in the depositional zone of the Rhode Creek fan (Figure 5.2-12). Alan Schoblom, the NPS Skagit District Maintenance Supervisor, says that during most fall/winter seasons sediment coming down Rhode Creek plugs the culvert under the campground entrance road (shown as an orange circle on Figure 5.2-12) and then splits, flowing over SR 20 toward the boathouse and over the campground access road toward the boat launch (Schoblom 2021). Typically, 50 to 100 cu yd of sediment and debris are deposited during each event. Deposits in lake near the boathouse and boat ramp include gravel, sand, and fines (Figures 5.2-13 through 5.2-15).

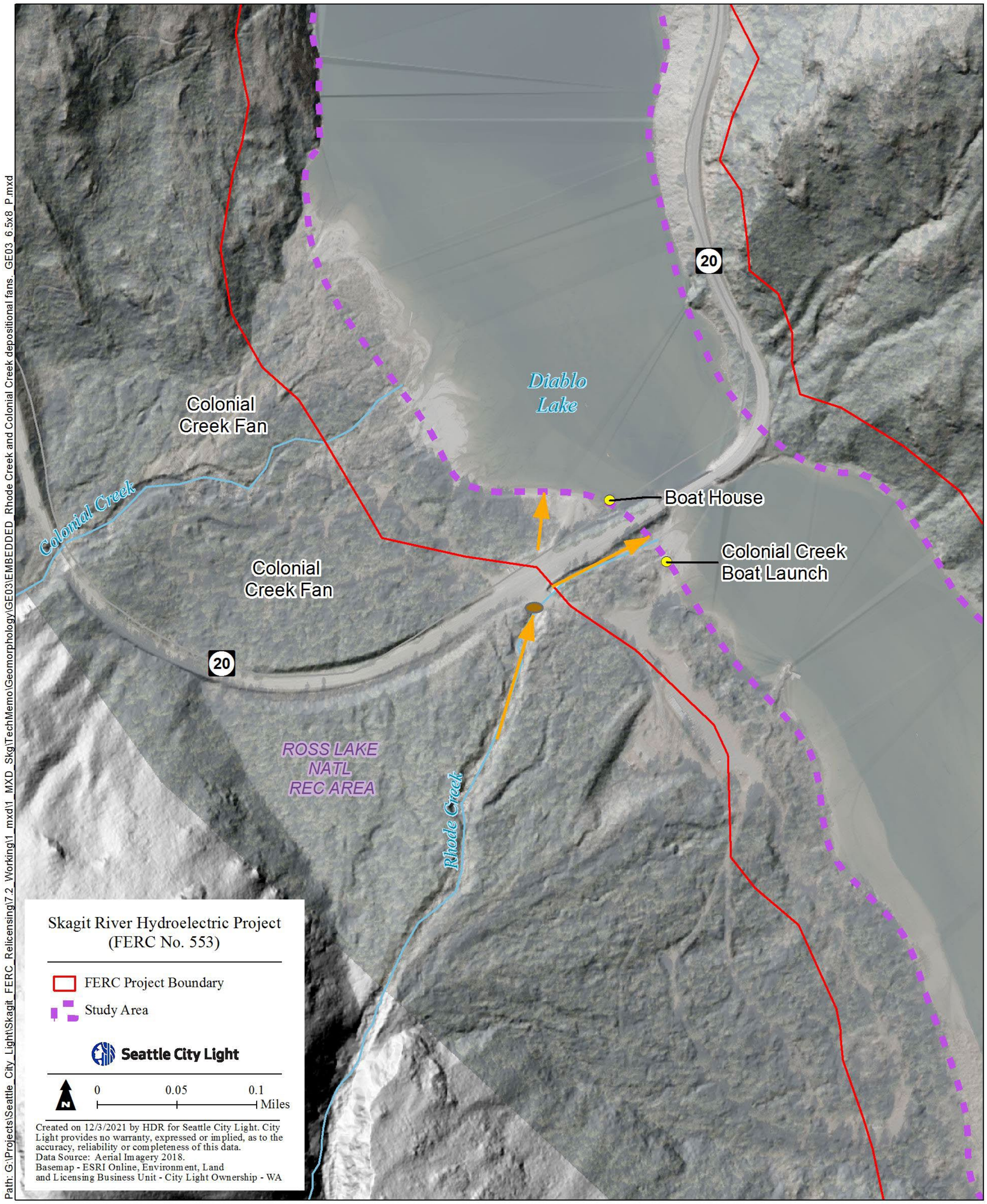


Figure 5.2-12. Rhode Creek and Colonial Creek depositional fans.

Figure 5.2-13. Rhode Creek deposition just downstream from culvert that routinely plugs (SR 20 on left).

Figure 5.2-14. Rhode Creek deposition near Colonial Creek boat house.

Figure 5.2-15. Rhode Creek deposition near the Colonial Creek boat ramp.

5.3 Sourdough Creek

Sourdough Creek is a tributary to the north side of Diablo Lake between the City Light boathouse and the North Cascades Institute. Facilities in the area include the City Light boathouse, boat ramp, and barge loading dock; parking areas for public use; beaches; and North Cascades Institute swim area and boating facilities. Sourdough Creek is a high gradient (10 percent) stream that has formed an alluvial fan; the parking lots and swim/beach facilities are built on past fan deposits (Figure 5.3-1). A vented ford was constructed across Sourdough Creek between 2006 and 2009.

No gaging records are available for Sourdough Creek. Diablo Lake elevations are shown in Figure 5.2-5 above.

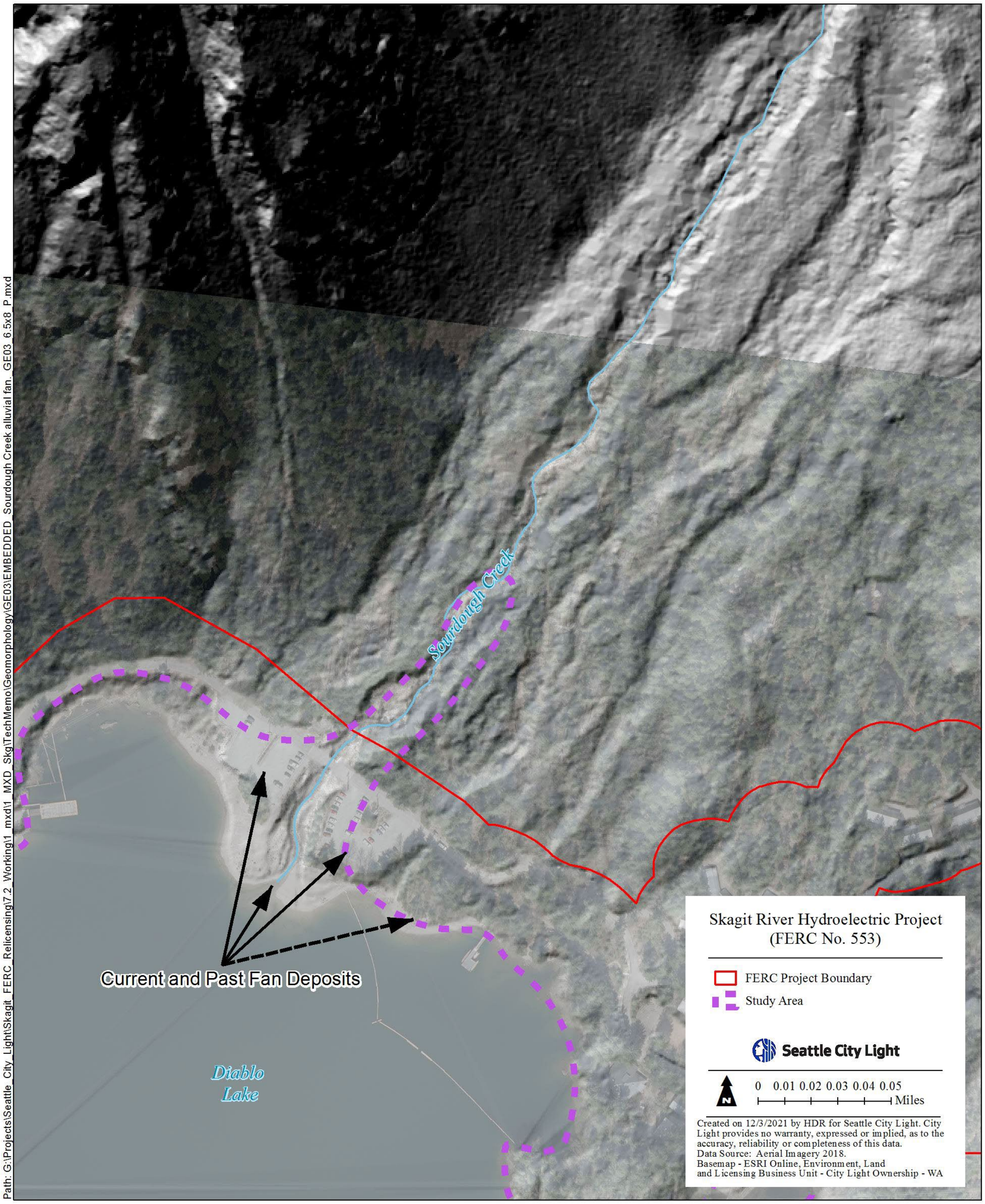
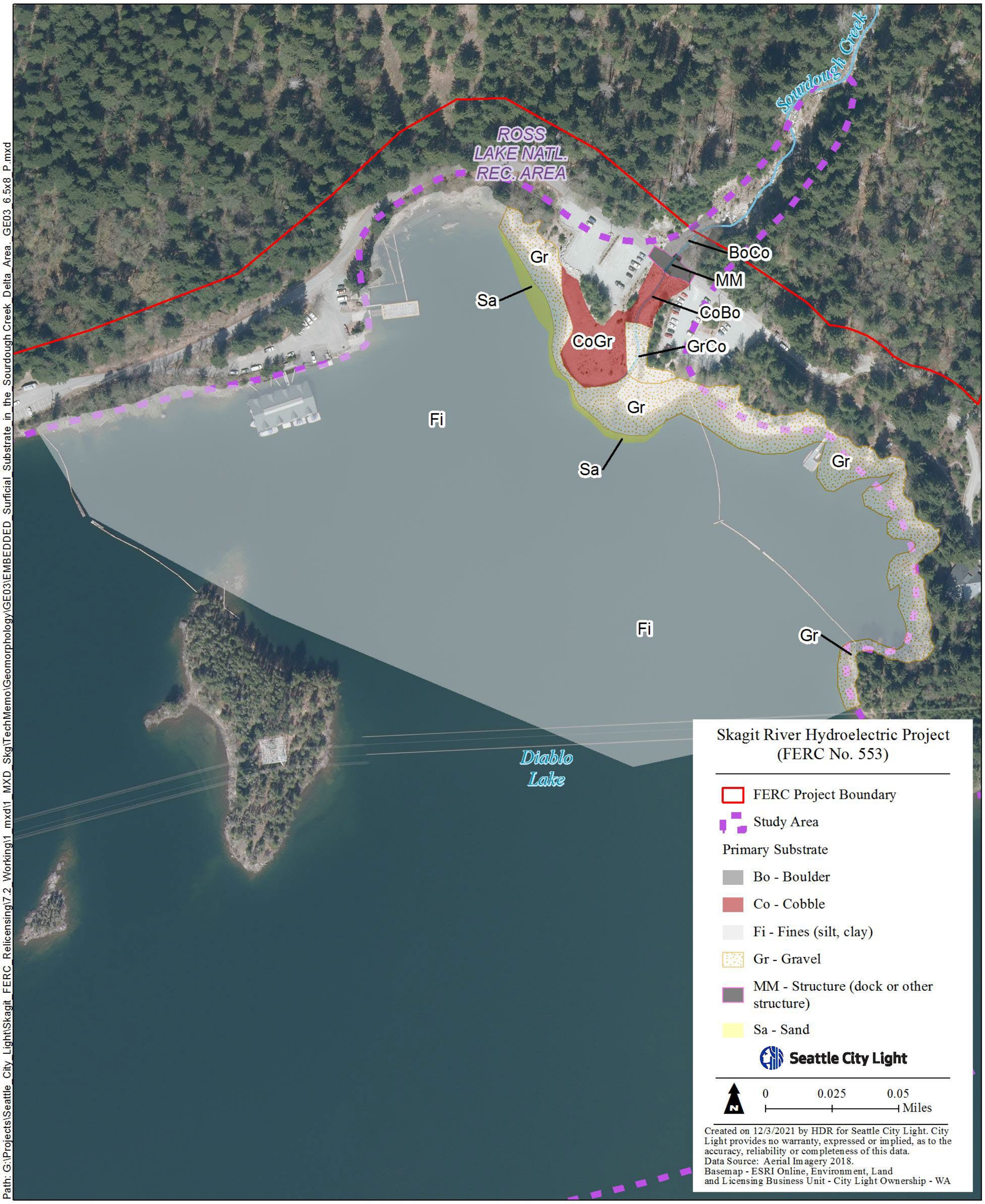


Figure 5.3-1. Sourdough Creek alluvial fan.

5.3.1 Surficial Substrate

Surficial substrate in Sourdough Creek includes boulder, cobble, and gravel material and generally fines in a downstream direction from boulder/cobble upstream of the road crossing to gravel in Diablo Lake (Figure 5.3-2). Substrate becomes finer off the face of the delta, with sand grading to silt and clay in the main body of the lake.

Pebble counts in Sourdough Creek and the delta confirmed the fining-downstream pattern and were dominated by cobble and gravel sized particles with boulders in the stream and sand in the delta area (Figure 5.3-3). Median grain diameter ranged from 50 mm in the stream to 11 mm in the finer-grained delta sample.



Path: G:\Projects\Seattle_City_Light\Skagit_FERC_Relicensing\7.2_Working\1_mxd\1_MXD_Skg\TechMemo\Geomorphology\GE03\EMBEDDED_Surficial_Substrate_in_the_Sourdough Creek_Delta_Area_GE03_6.5x8_P.mxd

Figure 5.3-2. Surficial substrate in the Sourdough Creek delta area.

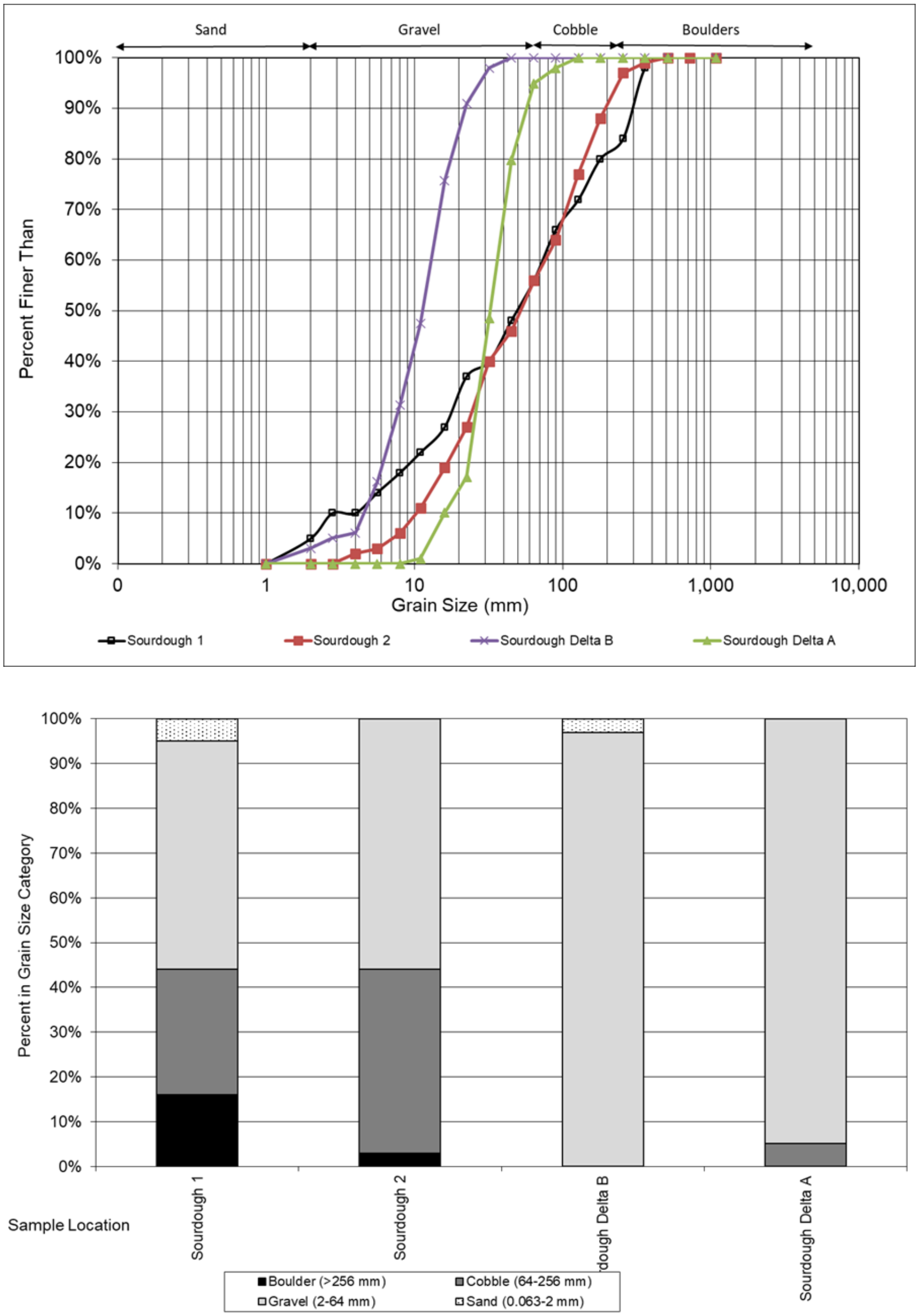


Figure 5.3-3. Sourdough Creek substrate samples grain size distribution (top) and percent in each grain size category (bottom).

5.3.2 Delta Changes Through Time

Three sets of aerial photographs were compared to determine how the Sourdough delta changes through time (Figure 5.3-4). The main Sourdough Creek channel has not substantially changed position since 1990. Between 2006 and 2019, a concrete crossing structure (vented ford) was constructed approximately 250 feet upstream from the mouth of Sourdough Creek with metal grates on the upstream side to help capture sediment and debris flows coming down the stream and to maintain vehicle access. This structure also provides a grade control. The stream has been confined to a single central channel since construction of the crossing structure and parking lots. NPS reports that most sediment and debris sluice through the structure and needs cleaning every few years (Schoblom 2021).

The delta grew between 1990 and 2006, likely in response to the large 2003 storm event. Based on the aerial photographs, the front edge of the delta advanced up to 70 feet into Diablo Lake from 1990-2006. Between 2006 and 2018, the edge of the delta advanced another 20-45 feet into the lake. Note that these distances are based on the visible leading edge of delta deposits in the aerial photographs. Differences in lake levels and water visibility at the time the photos were taken likely result in errors associated with absolute measurements using this method, but the conclusion that the delta grew through time is evident.

A longitudinal profile of Sourdough Creek was compiled from LiDAR elevation data (upstream from the lake surface) supplemented with field-measured elevations within the lake since the available LiDAR data measured the surface elevation of Diablo Lake instead of the underwater portions of the delta (Figure 5.3-5). The steep gradient of the stream, coarse nature of the sediment supply, and grade control structure suggest that any backwater effects from Diablo Lake extend less than 100 feet upstream from the lake. No evidence of sediment or debris deposits were observed that suggest backwater effects extend farther upstream. No further analysis of backwater effects on Sourdough Creek are needed to confirm these conclusions.

1990 2006 2018

Figure 5.3-4. Sourdough Creek delta changes through time.

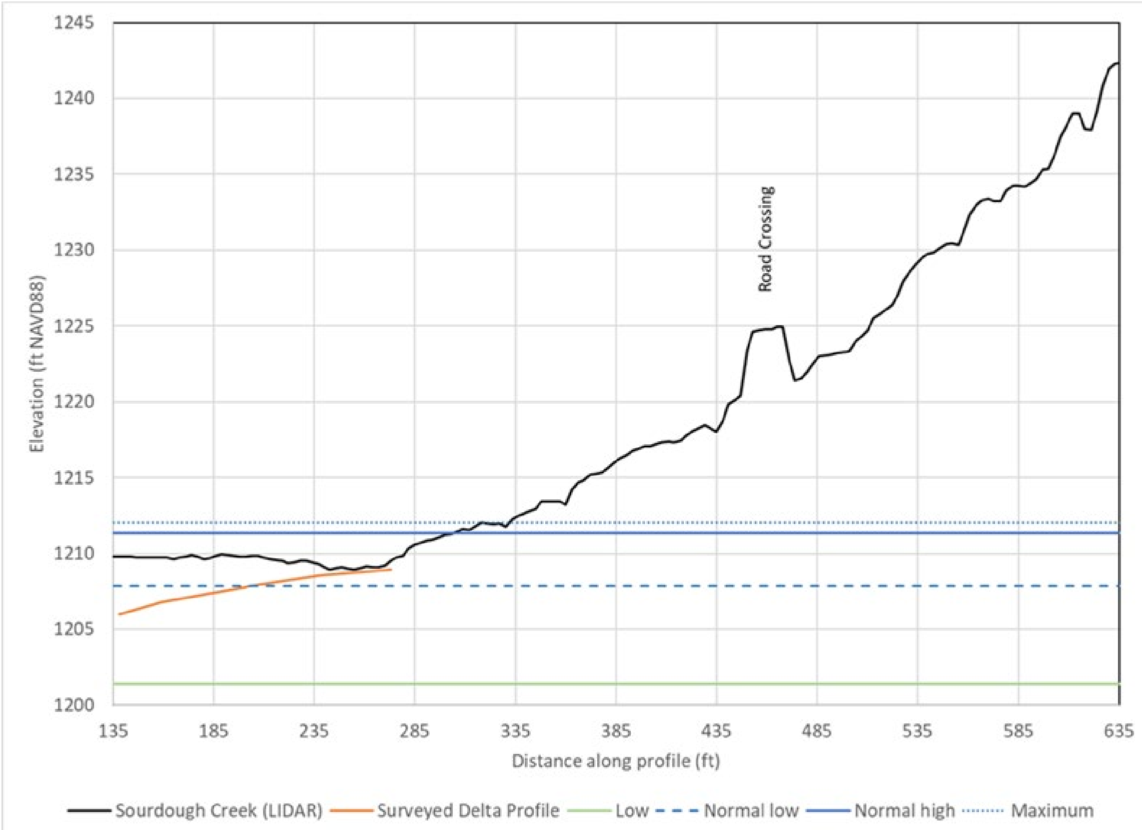


Figure 5.3-5. Sourdough Creek profile.

5.4 Stetattle Creek

More detailed analyses took place for the Stetattle Creek delta area under a previous, separate study (Watershed GeoDynamics, in prep). Those results are summarized here.

5.4.1 Basin Characteristics

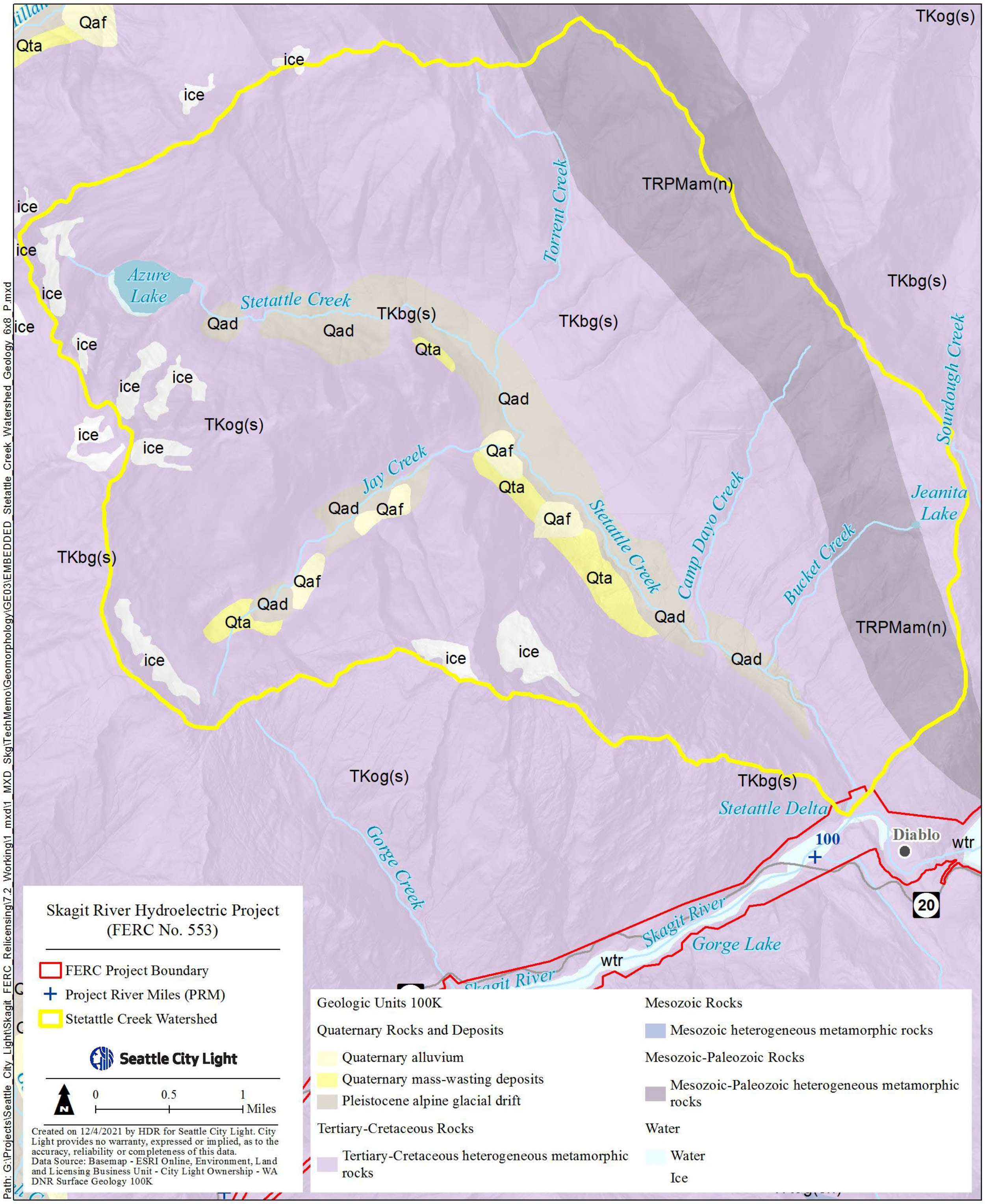
The Stetattle Creek watershed is in the North Cascades region of Washington State and encompasses 22.8 sq mi. The basin is within the Ross Lake National Recreation Area and is primarily undeveloped except for hiking trails and the Hollywood Hills residential area, which is located on the historic alluvial fan at the mouth of the creek (see discussion in Section 5.4.4 of this study report).

The topography of the North Cascades in the Stetattle Creek area reflects multiple alpine glaciations overlain on a relatively young, uplifted, and faulted landscape. The glaciers carved deep valleys, steep valley walls, and jagged horns and arêtes. Stetattle Creek has several remnant ice fields, avalanche chutes, and areas of rockfall and talus that are actively contributing sediment to the creek.

Stetattle Creek is underlain by rocks of the North Cascades Metamorphic Core Domain; these rocks have high levels of metamorphism and are more resistant to weathering and erosion, resulting in the high peaks of the North Cascades. These geologic units include gneiss, orthogneiss, and schist, which underlie the Project dams, Gorge Lake, Diablo Lake, and the southern part of Ross Lake. While resistant to erosion, the steep valleys formed in these hard rocks are subject to rockfalls, landslides, and avalanches. Geologic units in the Stetattle Creek area include (Figure 5.4-1):

- Qad – Alpine drift (glacial deposits) from Fraser-age alpine glaciers;
- Qaf – alluvial fan deposits;
- Qta – talus;
- Tkgs(s), Tkog(s), TRog(sn) – Skagit Gneiss including banded and orthogneiss;
- TRPMam(n) – Napeequa Schist;
- ice – perennial ice field; and
- wtr - lakes.

Stetattle Creek is a relatively steep tributary to the Skagit River with an average gradient of 2 percent near the confluence with the Skagit River (Figure 5.4-2). Gradient generally increases in an upstream direction with an average gradient of 6 percent in the middle reaches and over 30 percent in the headwaters. The high gradient results in transport of coarse-grained material, up to boulder size, through the stream and into the Stetattle Creek delta in the Project vicinity. The Skagit River near the confluence with Stetattle Creek is relatively low gradient, with an average gradient of less than 0.1 percent between SR 20 and the powerhouse and with a local maximum gradient of 0.3 percent at the Stetattle Creek confluence.



Source: Washington Department of Natural Resources online geologic mapping downloaded from https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

Figure 5.4-1. Stetattle Creek watershed geology.

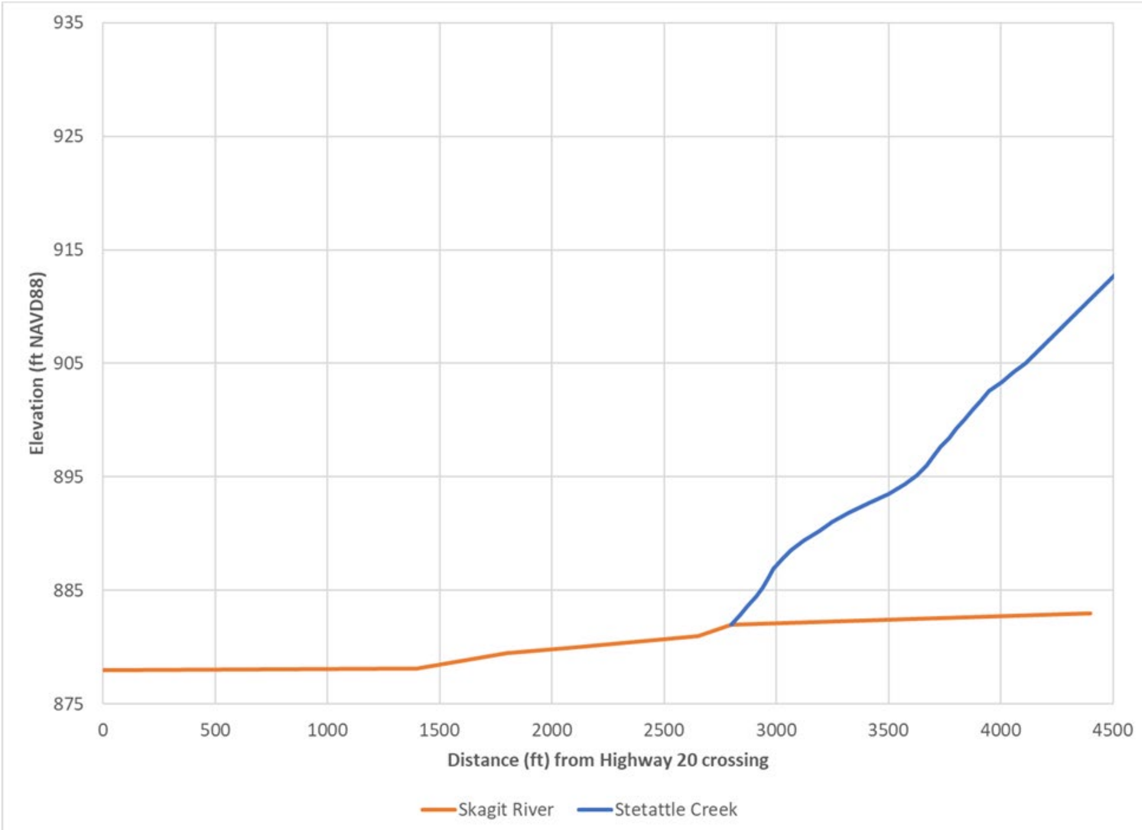


Figure 5.4-2. Skagit River and Stetattle Creek profiles (elevations in NAVD 88).

5.4.2 Hydrology and Lake Level

Transport and deposition of sediment in Stetattle Creek and the Skagit River is controlled by stream/river flow rates and the elevation of Gorge Lake (as well as stream gradient as discussed in the previous section). Stetattle Creek is an unregulated stream; flows in the Skagit River at the confluence with Stetattle Creek are controlled by storage in the upstream Ross and Diablo lakes. Flow in the Skagit River at the project site is the sum of outflow from Diablo Powerhouse plus any spill over Diablo Dam. The elevation of Gorge Lake, downstream from the Stetattle Creek confluence, determines the point where the Skagit River flow changes from riverine to lacustrine.

5.4.2.1 Stetattle Creek Flow

Streamflow in Stetattle Creek was recorded at a stream gage operated by the USGS from 1933-1982. The gage was located approximately 0.5 miles upstream from the confluence with the Skagit River. Mean monthly flows over the period of record ranged from 100 cfs in March to over 350 cfs in June and were generally highest during snowmelt (May-June-July) and lowest in September and March when either rainfall is lowest (September) or just prior to snowmelt (March; Figure 5.4-3 Daily flows in Stetattle Creek vary depending upon recent precipitation and snowmelt patterns (Figure 5.4-4), and they generally follow the mean monthly flow pattern with variations for rainfall or snowmelt events.

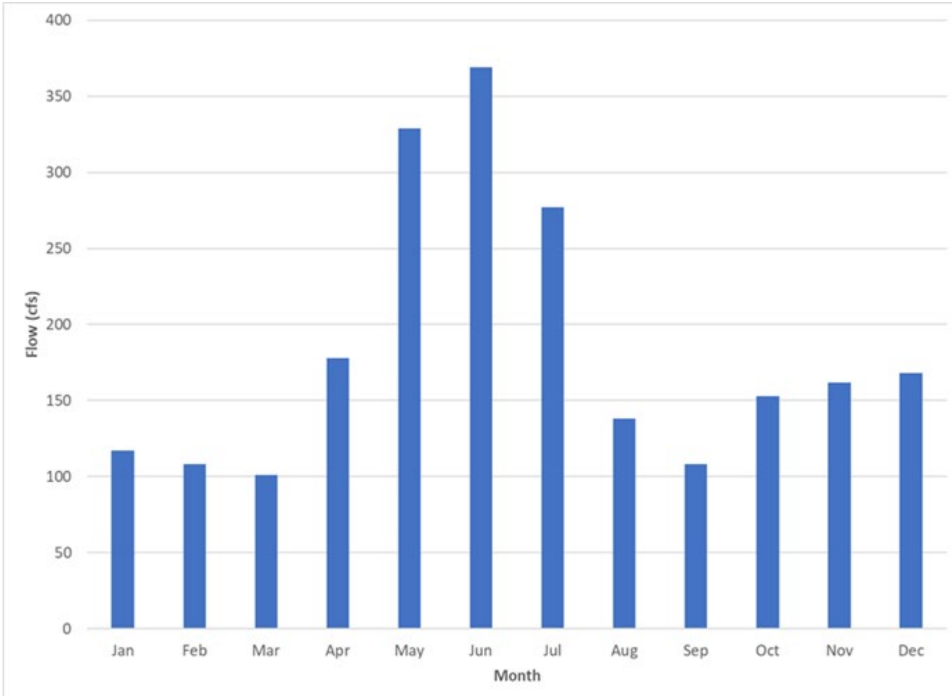


Figure 5.4-3. Stetattle Creek mean monthly flow (USGS 12177500, period of record 1933-1982).

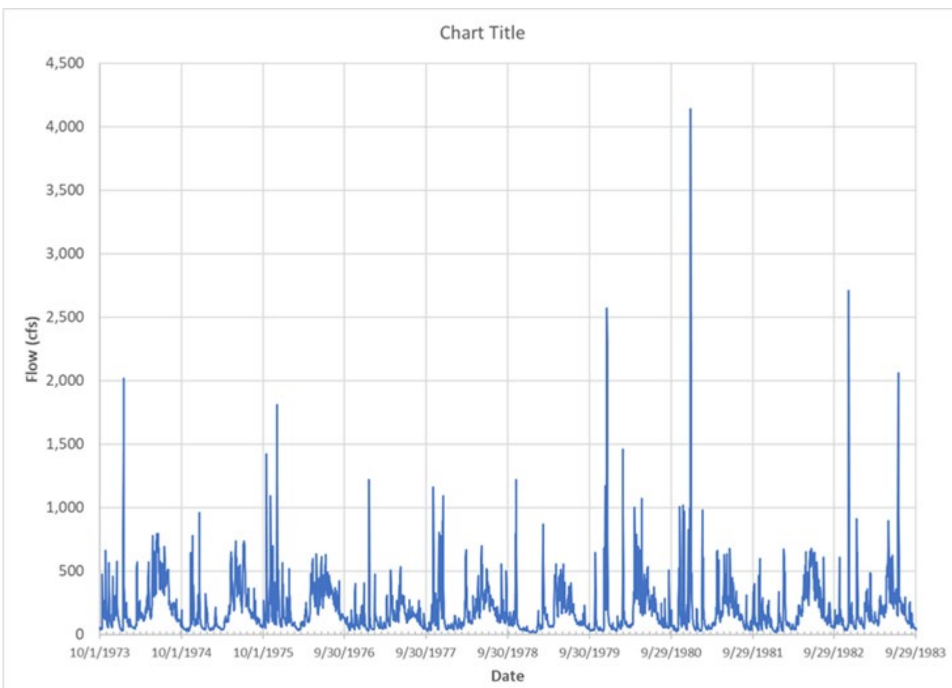


Figure 5.4-4. Stetattle Creek mean daily flow variation example (USGS 12177500, period of record 1973-1983).

Bedload transport and geomorphic change occur primarily during high flow conditions when velocities are high enough to transport coarse-grained material on the streambed. Annual peak flows in Stetattle Creek for the period of record (1933-1982) ranged from less than 1,000 cfs to over 9,000 cfs, with the highest peak flows occurring in November and December as a result of rain-on-snow events and more moderate peak flows occurring as a result of rainstorms from October through February or snowmelt during June and July (Figure 5.4-5). Peak flow recurrence intervals and exceedance probabilities were calculated for the period of record (Table 5.4-1). The 2-year peak flow (50 percent chance of occurring during a given year) is calculated to be 2,000 cfs, and the 20-year peak flow (5 percent chance of occurring during a given year) is 6,490 cfs.

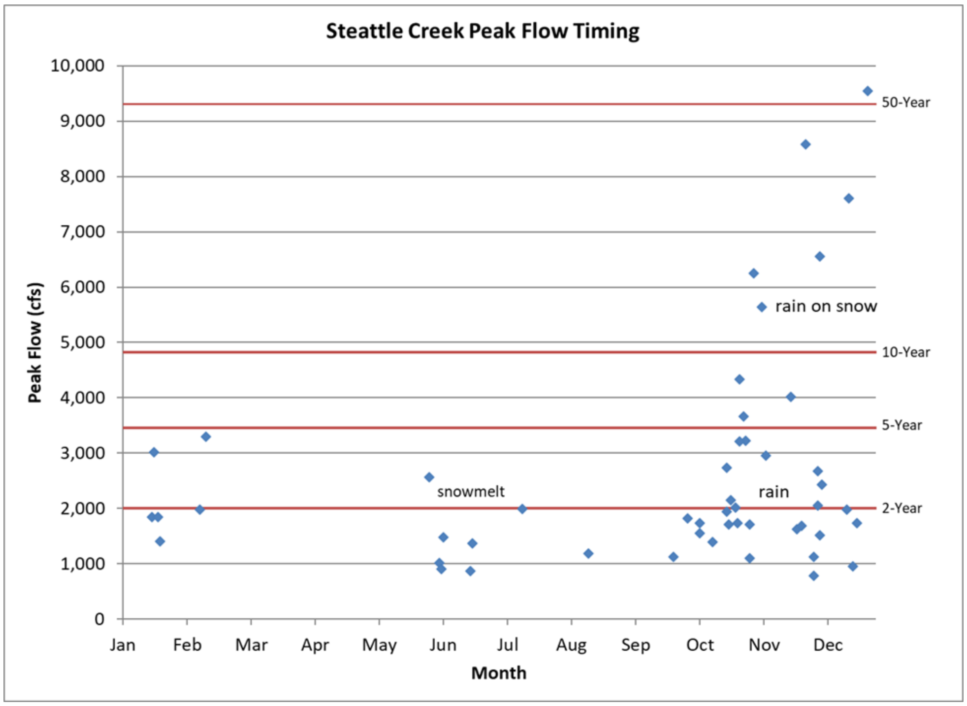


Figure 5.4-5. Stetattle Creek peak flow timing (USGS 12177500, period of record 1933-1982).

Table 5.4-1. Stetattle Creek peak flow recurrence interval and percent chance exceedance.[1]

Recurrence interval (years)	Percent chance exceedance	Flow (cfs)
100	1%	12,000
50	2%	9,310
20	5%	6,490
10	10%	4,820
5	20%	3,460
2	50%	2,000

1 Data from USGS, gage 12177500, period of record 1933-1982. Bulletin 17B analysis.

5.4.2.2 Diablo Powerhouse Flow and Spill

Flow in the Skagit River at the confluence with Stetattle Creek is controlled by flow through the Diablo Powerhouse and spill over Diablo Dam. The annual flow duration curve showing percent of time flow is exceed is shown in Figure 5.4-6; the 50 percent exceedance flow is approximately 3,500 cfs.

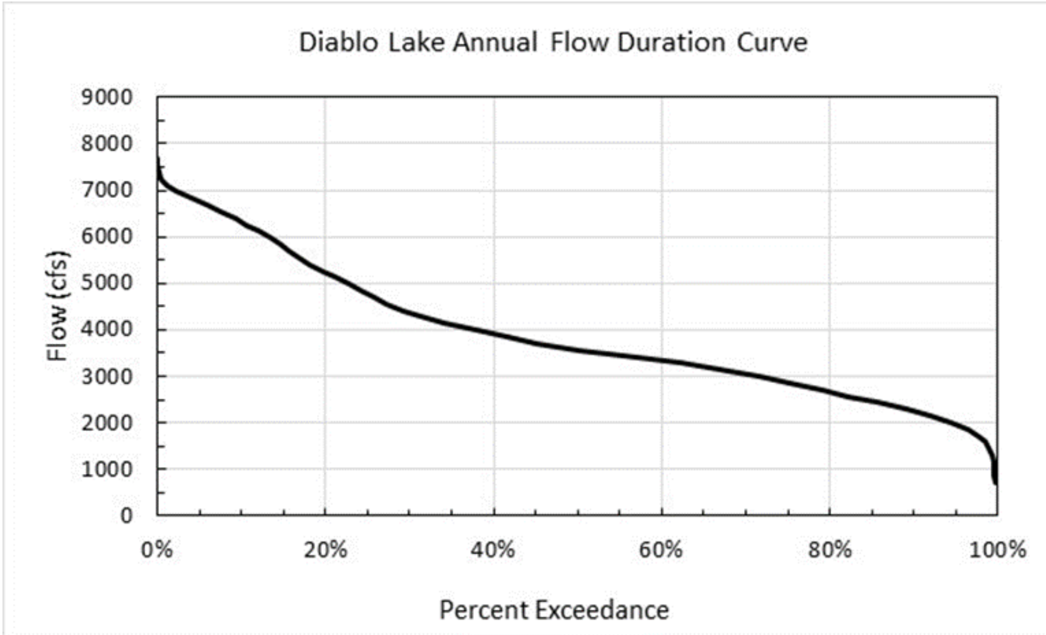


Figure 5.4-6. Annual flow duration curve for Diablo Lake outflows (1991-2018).

Based on the 2-D hydraulic model, the current primary hydraulic control for the Diablo Dam tailwater is the constriction formed by the Stetattle Creek delta at the confluence with the Skagit River and, secondarily, the delta deposits formed further upstream of SR 20. The tailwater elevation has changed through time (Figure 5.4-7), with a substantial increase in tailwater elevation between 1999 and 2000 and another increase between 2003 and 2004. Both increases corresponded to large high flow events that likely caused a large input of sediment from Stetattle Creek that was deposited within the Skagit River. A high flow event in 2006 did not substantially change the tailwater elevation. Two test flushing spills occurred in June 2007 and resulted in a reduction in the tailwater elevation—a spill of 22,800 cfs on June 20, 2007 resulted in a 9-inch reduction in tailwater elevation, and a higher spill of 32,000 cfs on June 27, 2007 reduced the tailwater elevation by another 6 inches. The tailwater elevation has been declining slightly in the past few years.

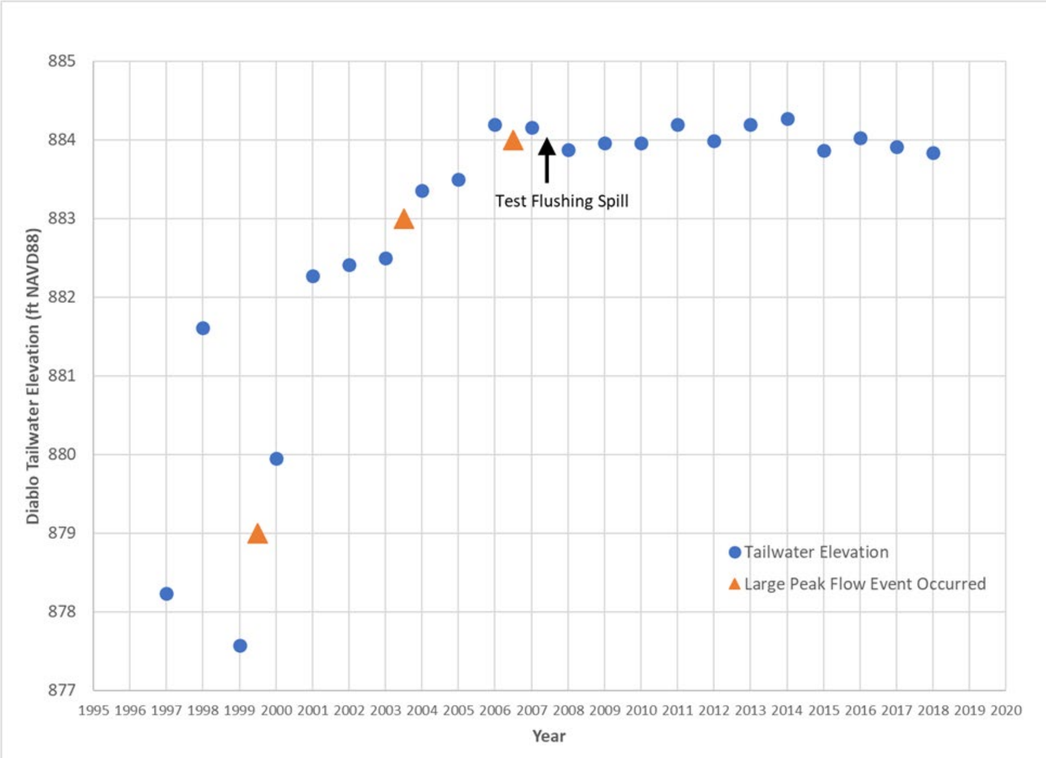


Figure 5.4-7. Changes in Diablo tailwater elevation (elevations in NAVD 88).

5.4.2.3 Gorge Lake Elevation

Gorge Lake elevation varies based on operations of Gorge Powerhouse. Prior to 1961, Gorge Lake elevation was much lower than at present; construction of Gorge High Dam raised the level of Gorge Lake to the current operational levels. Under current conditions, Gorge Lake generally varies between approximate elevation of 870-876 feet CoSD (approximately 876.5-882.5 feet NAVD 88), but it is occasionally drawn down lower for maintenance or operational needs (Figure 5.4-8). The annual surface elevation exceedance curve is shown in Figure 5.4-9.

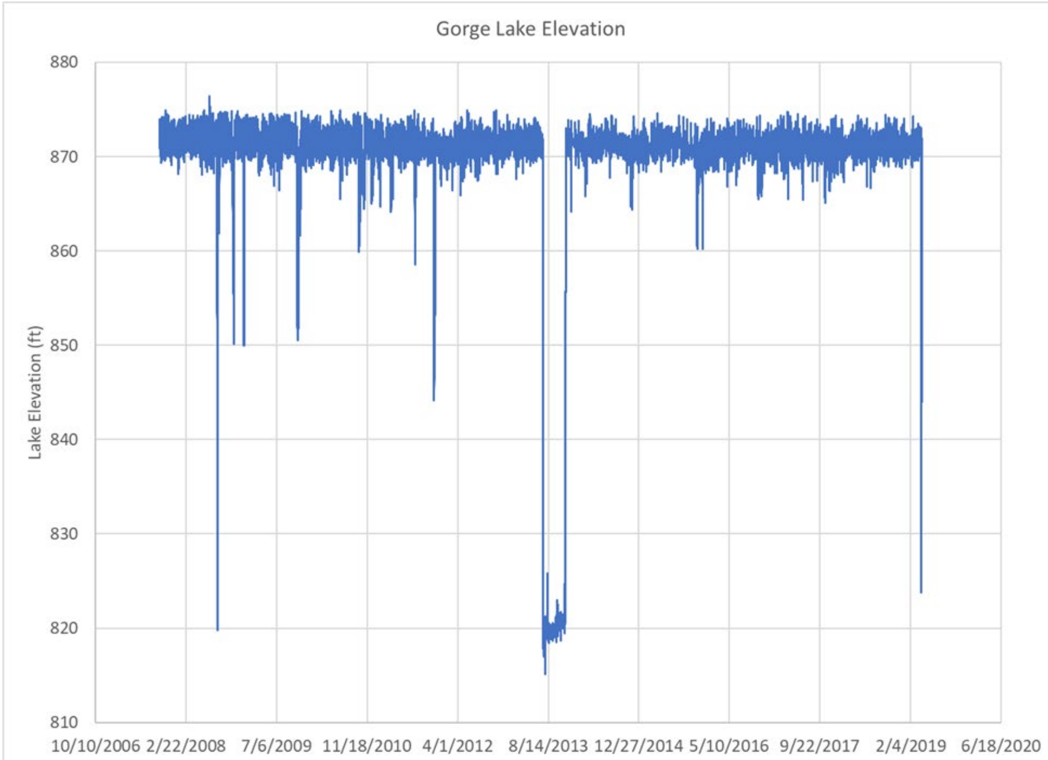


Figure 5.4-8. Gorge Lake elevation variation, 2007-2019 (elevations in CoSD).

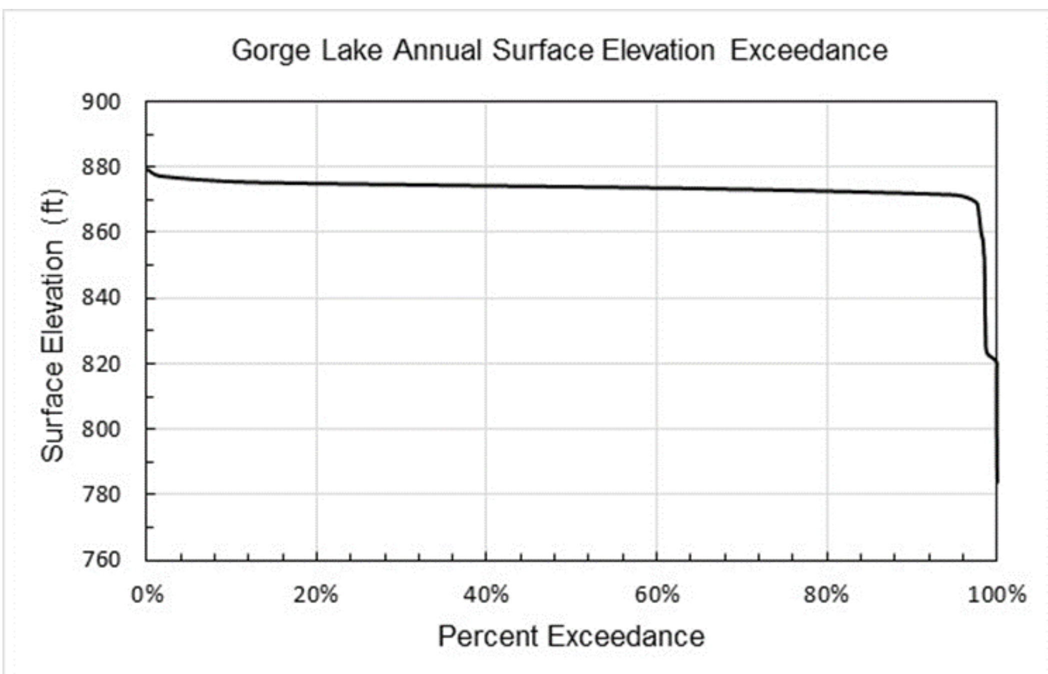


Figure 5.4-9. Annual percent exceedance curve of water surface elevations for Gorge Lake, based on the period 1991-2018 (elevations in CoSD).

5.4.2.4 Asynchronous Peak Flows in Stetattle Creek and the Skagit River

Under current conditions with the Skagit Hydroelectric Project operating normally, large peak flows in Stetattle Creek and the Skagit River do not occur simultaneously. When a large storm is forecast for the region, system control operations generally draw down Gorge Lake to capture the anticipated high flows coming in from Stetattle Creek. During the storm event, Stetattle Creek has a large peak flow that delivers water and sediment to the confluence with the Skagit River. Flows in the Skagit River are relatively low because Skagit River inflow is being stored in the upstream Ross and Diablo lakes. If the flood is very large and upstream lake storage fills, spill over Ross or Diablo dams may occur, but this is generally well after the peak in Stetattle Creek.

One effect of these asynchronous peak flows is that bedload sediment coming down Stetattle Creek is deposited at the confluence with the Skagit River and in the secondary delta just downstream from the confluence (at the elevation of Gorge Lake). While the deposition of the largest particles (e.g., boulders) would occur even if flows in the Skagit River were high, because the Skagit River is much lower gradient and would not have enough energy to transport boulders, the regulated flows in the Skagit River exacerbate the effect and coupled with the water level in Gorge Lake result in deposition of all of the coarse-grained sediment. When flows subsequently increase in the Skagit River, the deposited sediment becomes armored with a lag deposit, which protects the underlying deposits and results in on-going aggradation.

5.4.3 Sediment Supply

Sediment supply to the Stetattle Creek delta comes primarily from the Stetattle Creek watershed, although small amounts of sediment may be supplied from stored sediments in the riverine section of the Skagit River between Diablo Dam and the delta. The Stetattle Creek watershed has many unvegetated areas of mass wasting (rockfalls, landslides, debris torrents), avalanche chutes, and perennial ice that are actively contributing sediment to the drainage (Figure 5.4-10). Due to the underlying geology (primarily gneiss, alpine glacial deposits and talus slopes) and steep topography, there is an abundant source of coarse sediment to Stetattle Creek. The gneiss underlying most of the watershed is a relatively hard rock that is not abraded very quickly by transport in the stream but produces primarily sand-sized particles (rather than silt and clay) when it does break down. Evidence of local sediment inputs, such as discrete mass wasting events, can be seen within the Stetattle Creek streambed; angular particles have not been transported far from the source slide and are readily differentiated from rounded particles that have been transported from upstream sources or from alpine glacial deposits (Figure 5.4-11 and 5.4-12). The steep gradient and high peak flows in Stetattle Creek allow even boulder-sized rocks to be transported to the delta in the Skagit River.

There are no direct measurements of sediment input or transport in Stetattle Creek. Two methods were used to estimate long-term average annual sediment input from the watershed:

- Estimate of sediment supply based on regional sediment input rates and watershed size; and
- Estimate of coarse-grained sediment supply based on comparison of change in topography/bathymetry through time in the Stetattle delta area.

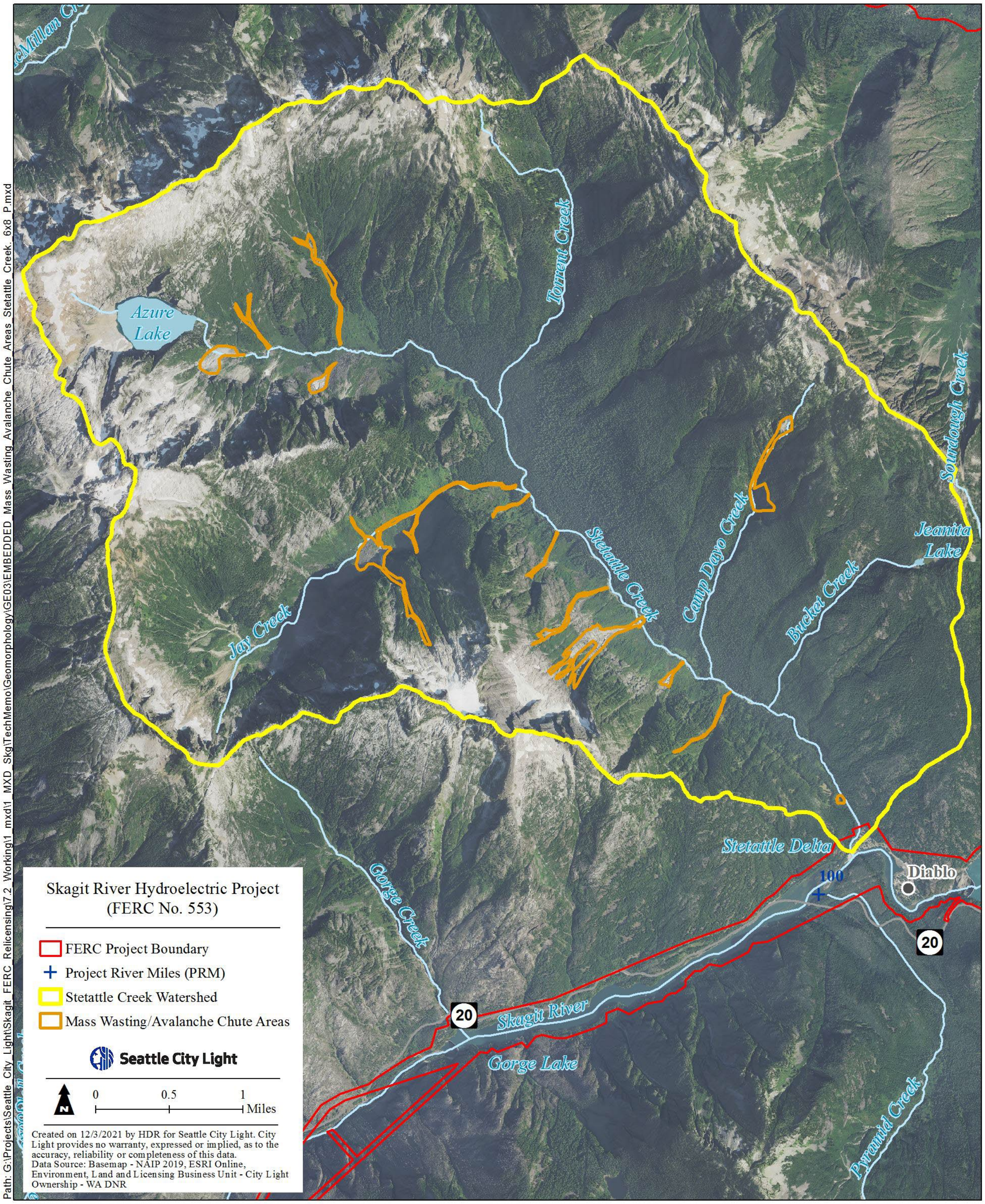


Figure 5.4-10. Mass wasting and avalanche chute areas contributing sediment to Stetattle Creek.

Figure 5.4-11. Stetattle Creek mass wasting site near USGS gage location.

Figure 5.4-12. Stetattle Creek coarse substrate, near mass wasting site showing angular particles (local source) and rounded particles (transport from upstream source).

5.4.3.1 Estimated Stetattle Creek Sediment Load Based on Regional Sediment Yields

Based on the 1930-1936 sedimentation rate in Gorge Lake, Stetattle Creek could yield an average of 1,900 cu yd/yr of sediment; this is likely a reasonable estimate of sediment yield under average flow conditions in years with no large peak flows.

Based on the range of regional sediment yields (Table 4.3-1), the 22.8 sq mi watershed of Stetattle Creek could yield an average of 3,600 to 18,200 cu yd/yr of sediment. This estimate includes all grain sizes (boulders to clay particles) and is more representative of a long-term average that includes very large peak flow conditions (e.g., the 2003 or 2006 flood events) that episodically provide large volumes of sediment and markedly change the Stetattle delta configuration.

5.4.3.2 Comparison of Topography and Bathymetry in Stetattle Creek Delta

Based on Civil3D modelling of estimated topographic contours pre-construction compared to 2017 bathymetric data, at least 257,000 cu yd of sediment has been deposited in the upper reaches of Gorge Lake as of 2017. There are two significant deposition locations. The first is at the mouth of Stetattle Creek (upper delta) and the second is in the area between Stetattle Creek and the SR 20 causeway (lower delta). Approximately 32,000 cu yd have been deposited in the upper delta and approximately 215,000 cu yd have been deposited in the lower delta.

These volumes were determined in Civil3D by using existing, limited topographical and bathymetric survey data and historical aerial photography prior to construction of Gorge High Dam from several sources. Because of the limited detail and approximation needed to recreate a historical terrain surface, the calculated volumes should be considered an estimate using best known available data. However, enough historical information was available to make a reasonable approximation of volume and to illustrate the depositional patterns.

In order to convert the total volume estimates to average annual deposition rates, the construction history of upstream and downstream dams needs to be considered. The first Gorge Dam was completed in 1924, but the wooden crib dam was not high enough to cause deposition in the study area. The second Gorge Dam (concrete) was completed in 1950 and, likewise, was not high enough to cause impoundments in the study area. It was not until the completion of Gorge High Dam in 1961 that water impounded in Gorge Lake caused deposition in the study area. The upstream Diablo Dam was completed in 1929, so all coarse-grained sediment deposited in the study area is from Stetattle Creek. Therefore, the Civil3D estimated 257,000 cu yd accumulated between 1961 and 2017 (56 years), which is an average of 4,590 cu yd/yr. Note that this does not include the majority of the silt and clay portion of the load from Stetattle Creek (or any fine sediment from Diablo Lake). This estimate is within the range of 3,600 to 18,200 cu yd/yr calculated using regional estimates (see Section 5.4.3.1 of this study report).

5.4.4 Stetattle Creek Delta Development

Construction and operation of the Skagit River Project and the levee protecting the Hollywood residential area have altered sediment deposition patterns in the lower 0.5 miles of Stetattle Creek and at the confluence of Stetattle Creek and the Skagit River. Current Stetattle Creek deposits in the Skagit River include the relatively coarse-grained delta that is evident at the mouth of Stetattle Creek, as well as the gravel and sand deposits that are accumulating at the head of Gorge Lake in the area just upstream from the SR 20 crossing and finer-grained sediment that is accumulating over the historic Davis Ranch area and near the campground boat launch. The location and timing of deposition of the sediment coming from Stetattle Creek is controlled by a relatively complex interaction of flow and sediment input rates from Stetattle Creek, flow in the Skagit River, and the elevation of Gorge Lake as described in Section 5.4.2.4 of this study report.

Changes in the lower part of Stetattle Creek can be seen by comparing the photos in Figures 5.4-13 (early 1900s) through 5.4-15 (2018), all taken from or near the bridge crossing at the mouth of the creek. The 1955 photo shows the newly constructed levee; the 2018 photo shows how vegetation has grown on the levee and the coarse stream deposits in the channel just upstream from the bridge. Figure 5.4-16 shows the boulder and cobble deposits in a mid-channel bar located between 400-800 feet upstream from the mouth; this bar is continuing to grow and is diverting water to both sides of the stream, resulting in levee erosion on the left bank.

Growth of the Stetattle Creek delta at the confluence with the Skagit River and the secondary deposits downstream can be seen in the photos and maps in Figure 5.4-17 through 5.4-31. Prior to the construction of Gorge High Dam in 1961, the primary delta at the confluence of Stetattle Creek and the Skagit River grew as the coarsest bedload sediment (boulders) were deposited in the lower gradient Skagit River. Smaller cobble and gravel material was transported downstream in the Skagit River to the head of Gorge Lake, which was much farther downstream than the current lake location. Since 1961, a secondary delta of cobble, gravel, and sand has been building upstream of the SR 20 bridge crossing. This can be seen as a growth of a series of mid-channel islands, which are currently diverting the main flow of the river toward the left and right banks approximately half way between Stetattle Creek and the bridge. Bank erosion is occurring on the left bank at this location as the main flow is directed at erodible areas of the shoreline.

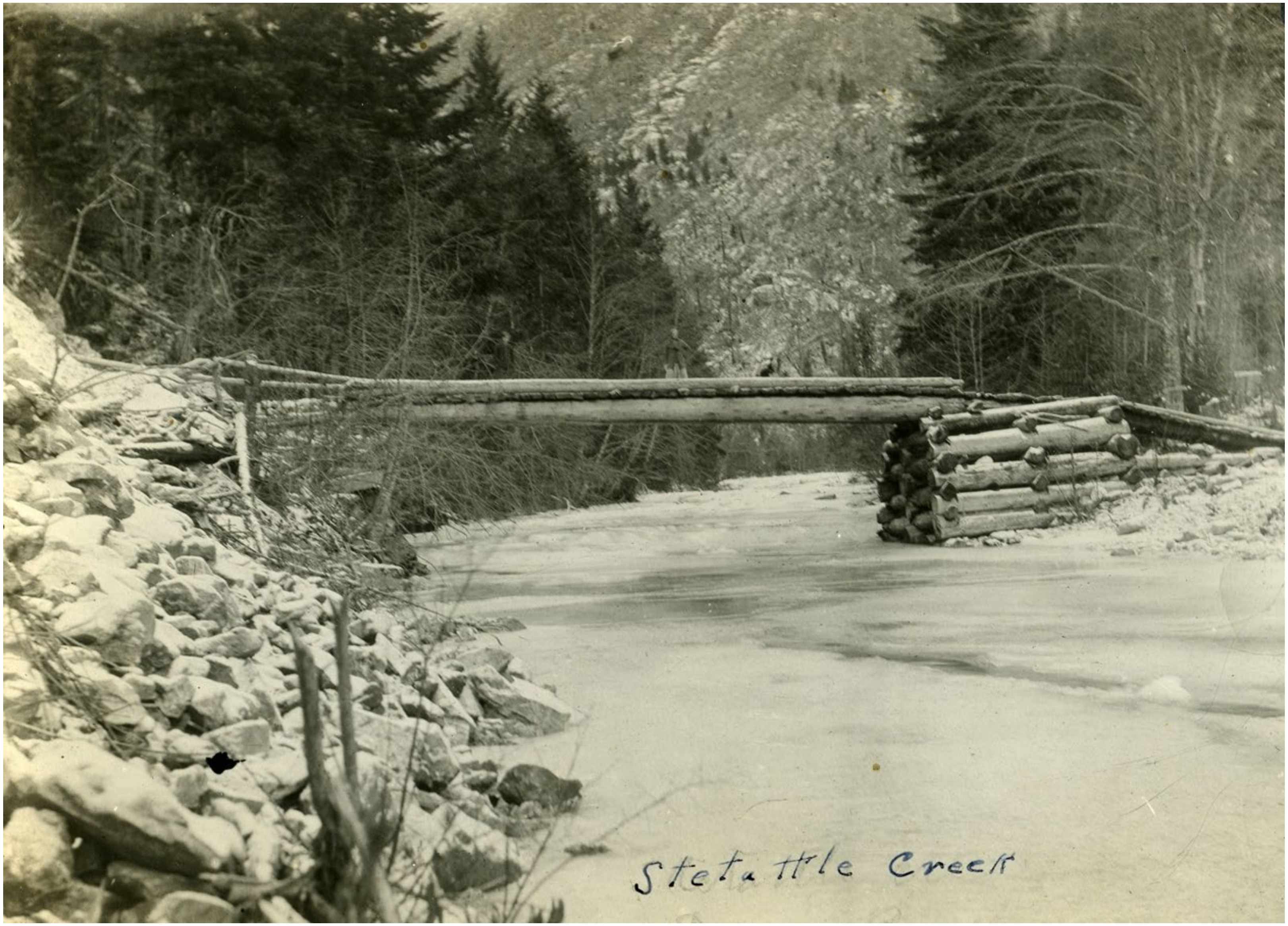


Figure 5.4-13. Stetattle Creek looking upstream from mouth, early 1900s.

Figure 5.4-14. Stetattle Creek looking upstream from road bridge, 1955.

Figure 5.4-15. Stetattle Creek looking upstream from road bridge, 2018.

Figure 5.4-16. Deposition in Stetattle Creek leveed area, approximately 800 and 400 feet upstream from mouth, 2018.

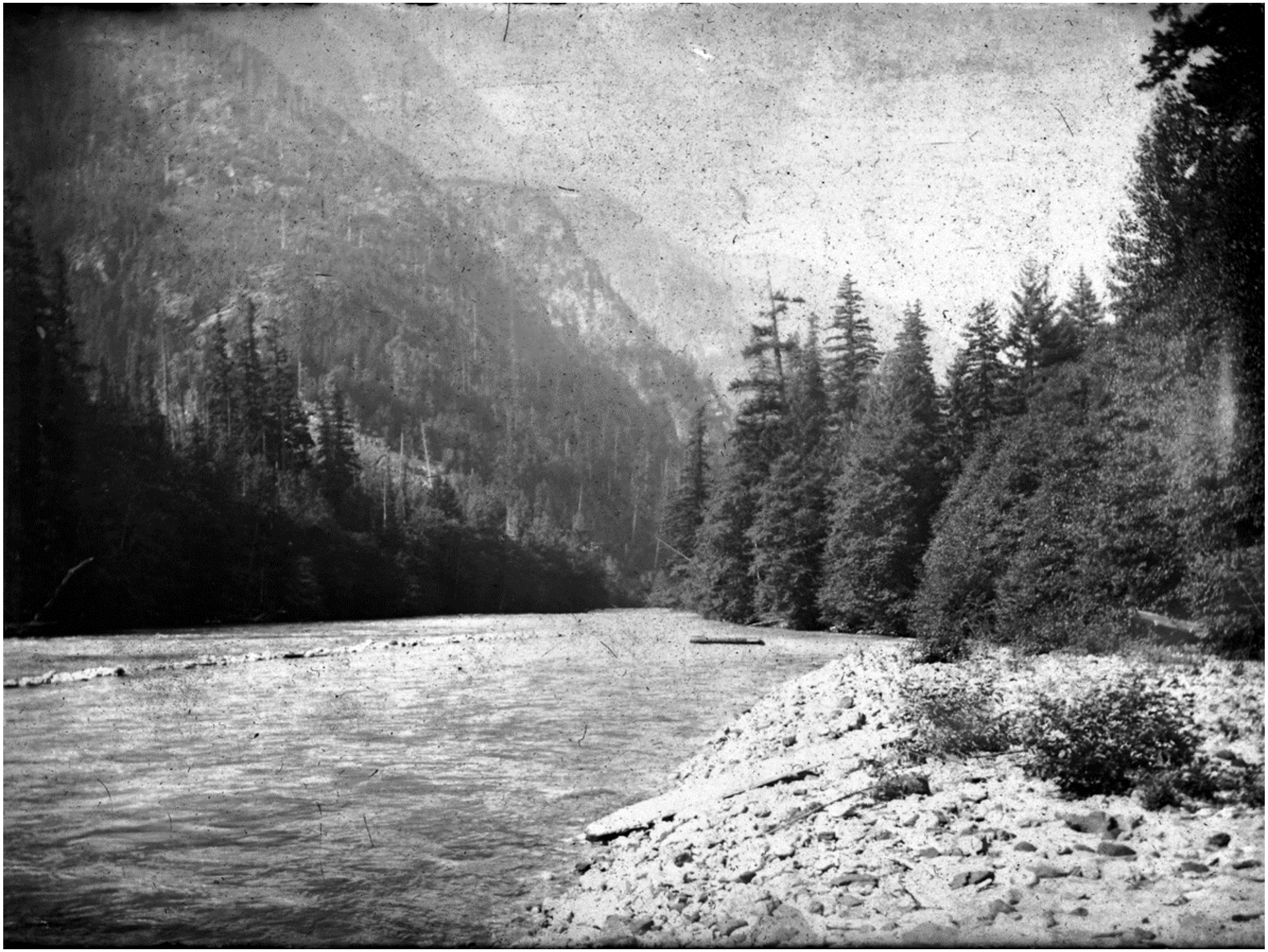


Figure 5.4-17. Stetattle Creek delta looking downstream, circa 1920.

Note: Arrows show location of Stetattle Creek channel.

Figure 5.4-18. Stetattle Creek delta looking downstream during Gorge Lake drawdown, April 2014.

Figure 5.4-19. Stetattle Creek delta looking upstream, early 1900's (undated).

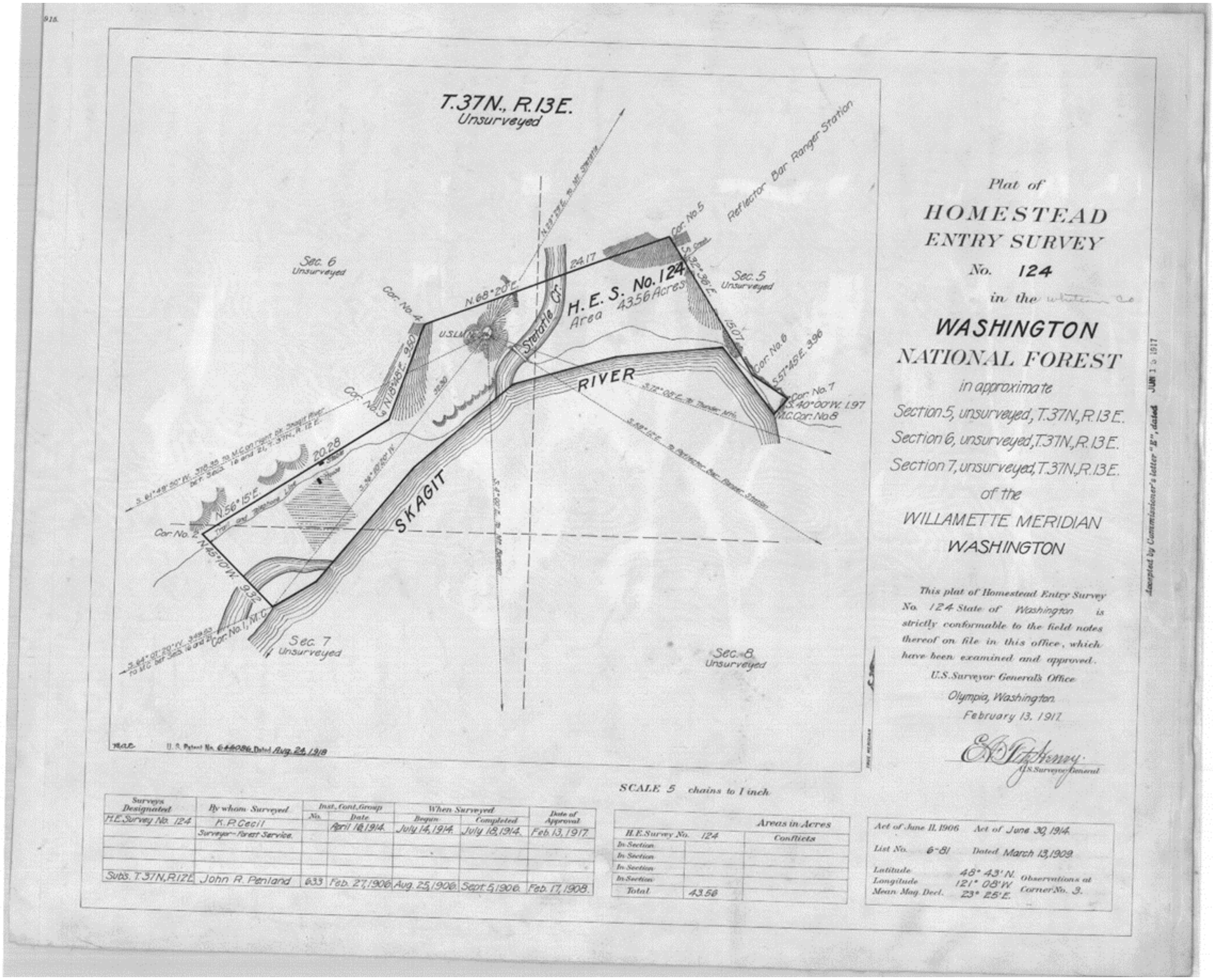


Figure 5.4-20. Stetattle Creek and Skagit River confluence, 1917 map.

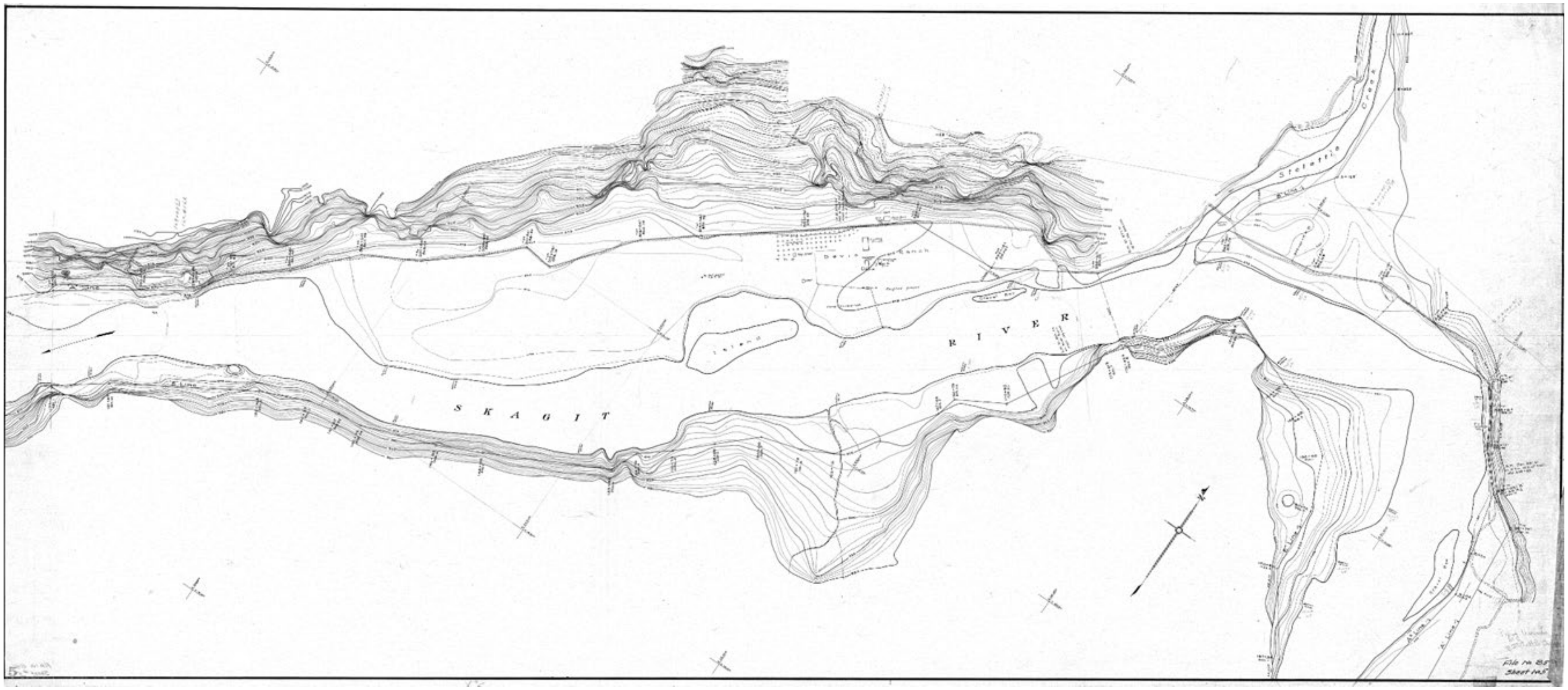


Figure 5.4-21. Stetattle Creek and Skagit River confluence, circa 1919 topographic map.

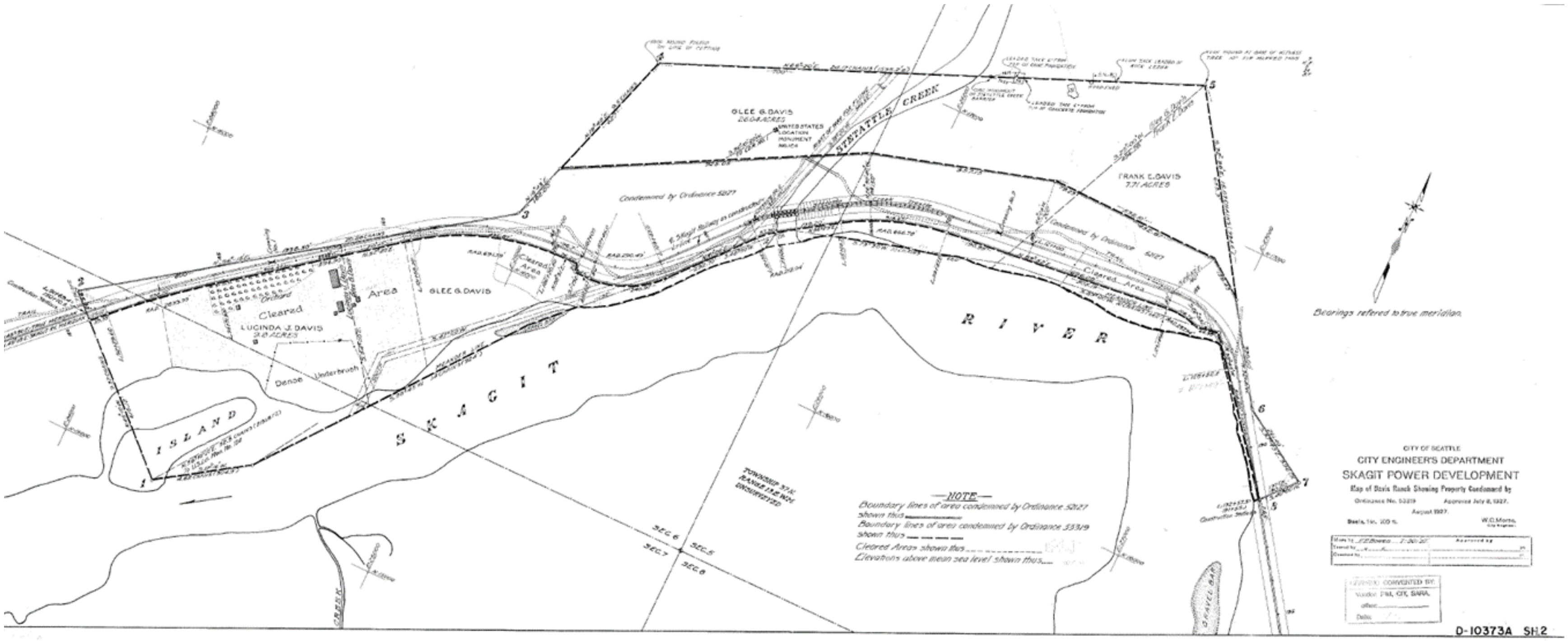


Figure 5.4-22. Stetattle Creek and Skagit River confluence, 1927 map.

Figure 5.4-23. Stetattle Creek Delta area, 1945 (photo credit KS Melson).

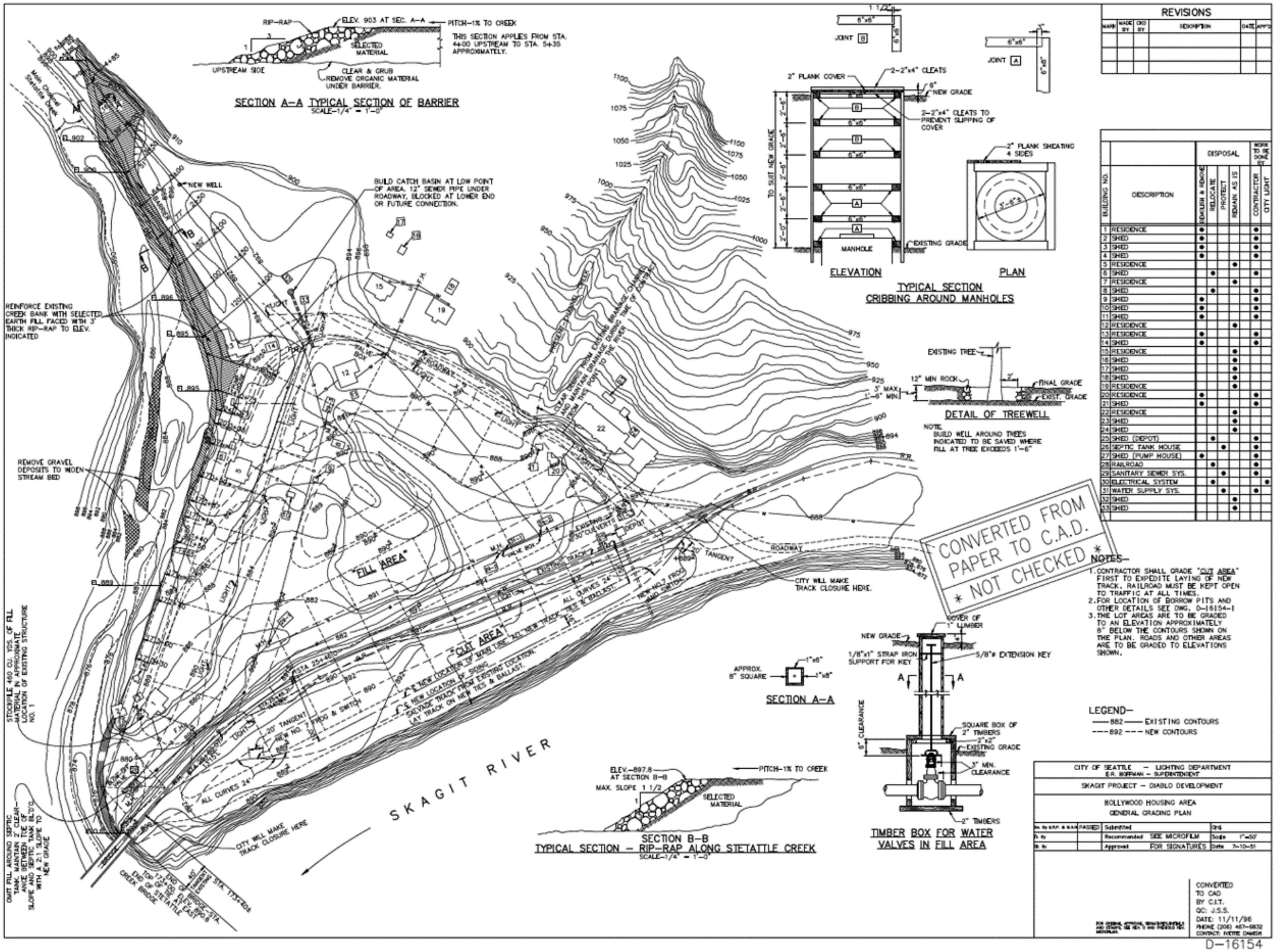


Figure 5.4-24. Stetattle Creek and Hollywood development plans, 1951.

Figure 5.4-25. Stetattle Creek Delta area, August 1955 (prior to Gorge High Dam).

Figure 5.4-26. Stetattle Creek Delta area, August 1990.

Figure 5.4-27. Stetattle Creek Delta area, July 22, 1998.

Figure 5.4-28. Stetattle Creek Delta area, circa 2008.

Figure 5.4-29. Stetattle Creek Delta area oblique photo, August 2013 (Gorge Lake drawdown).

Figure 5.4-30. Stetattle Creek delta area, 2018.

Figure 5.4-31. Stetattle Creek delta area, April 4, 2019 oblique photo (Gorge Lake drawdown).

5.4.5 Surficial Substrate

Stetattle Creek is a high gradient system that transports up to boulder-sized material to the mouth of the stream. Pebble count and grab sample data taken during this and previous studies show surficial grain size in the delta area varies greatly between different areas (Table 5.4-2, Figure 5.4-32 through 5.4-35).

Substrate within the lower portions of Stetattle Creek include boulder, cobble, and gravel material. The mid-channel bar that has been building between 400-800 feet upstream from the confluence has a median (d_{50}) grain size of 159 mm and is primarily boulder and cobble material (Figure 5.4-36).

Substrate on the primary delta at the confluence of Stetattle Creek and the Skagit River is very coarse-grained on the western (downstream) side, with median grain size of 90-200 mm. There are finer-grained deposits building into the deep pool on the eastern (upstream) side of the delta that have a median grain size of 3-21 mm and are composed primarily of sand and gravel.

No grain size samples were taken on the secondary delta, but visual estimates showed these deposits are composed primarily of gravel and sand.

Table 5.4-2. Stetattle Creek and delta grain size parameters.

Sample	Armor D_{65} (mm)	Armor D_{50} (mm)	Boulder (>256 mm)	Cobble (64-256 mm)	Gravel (2-64 mm)	Sand (0.063-2 mm)
Stetattle Mid Channel Bar 6	201	159	18%	72%	3%	7%
Stetattle Delta 1	118	93	3%	66%	31%	0%
Stetattle Delta 2	277	201	39%	46%	16%	0%
Stetattle Delta 5	89	74	0%	59%	41%	0%
Stetattle Delta 4	29	21	0%	4%	94%	2%
Delta Fines Site 4 - Sample B	18	9	0%	0%	77%	22%
Delta Fines Sample A	6	3	0%	0%	51%	47%

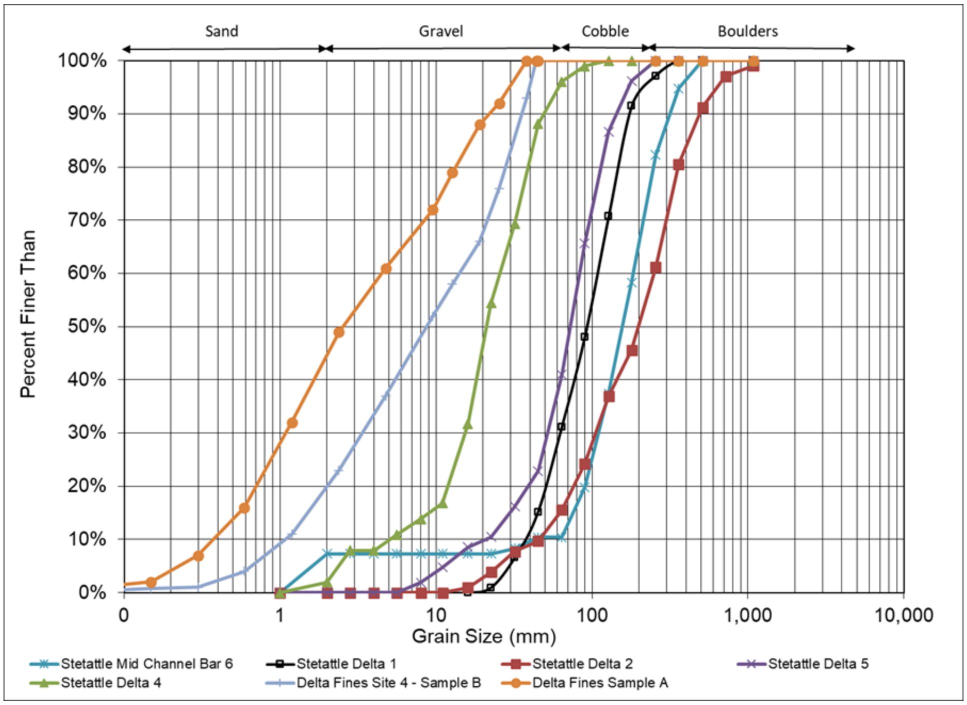


Figure 5.4-32. Stetattle Creek and delta substrate samples grain size distribution, September 2018.

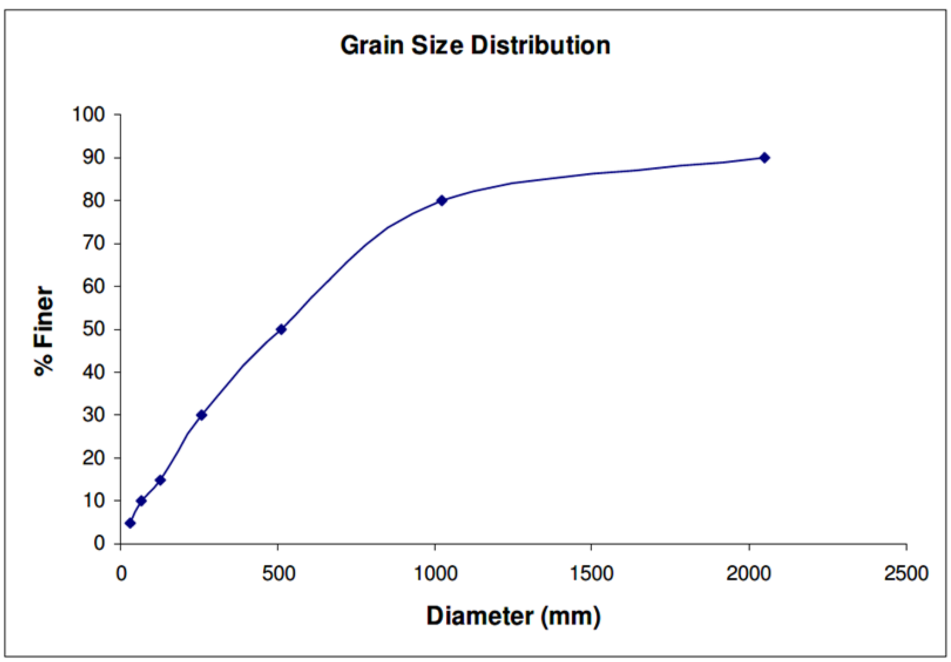


Figure 5.4-33. Stetattle Creek delta substrate sample, October 27, 2007 (4 months after spill event; from Seattle University 2008).

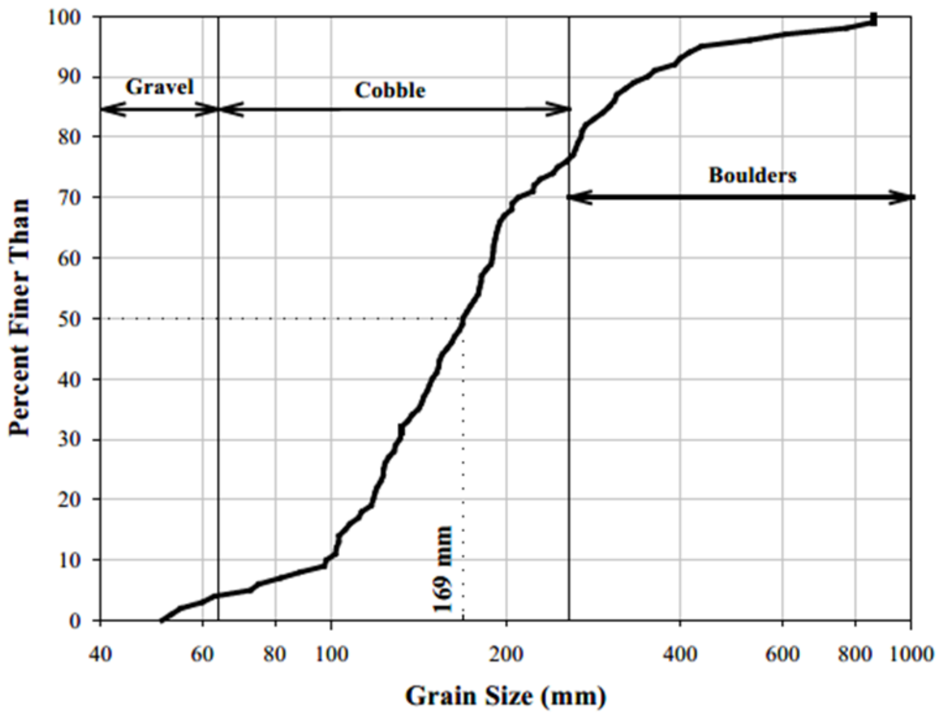


Figure 5.4-34. Stetattle Creek delta substrate sample, August 8, 2011 (R2 Resources, Inc. 2013).

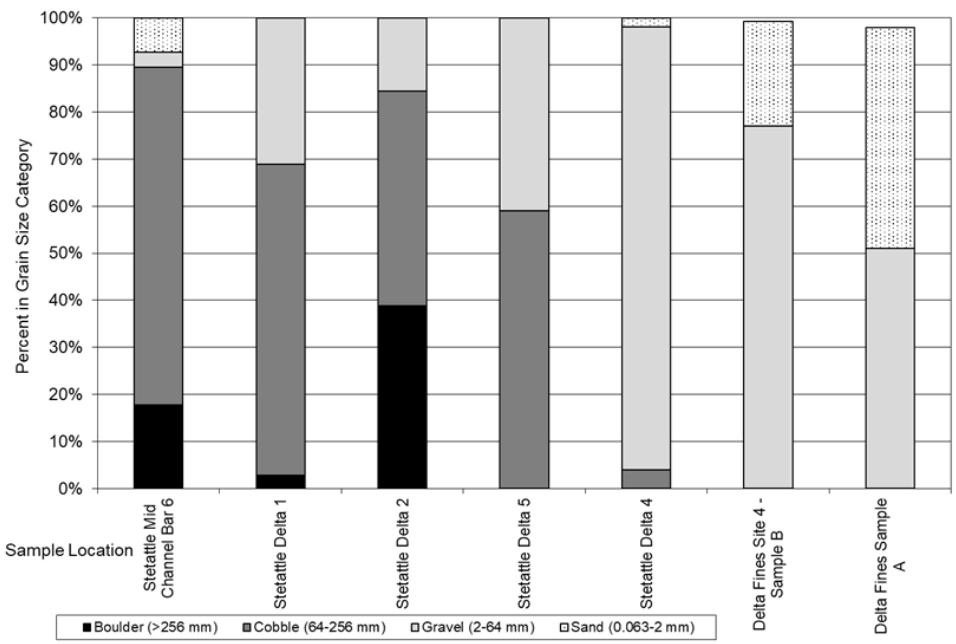


Figure 5.4-35. Stetattle Creek and delta substrate samples percent boulder, cobble, gravel, sand, 2018.

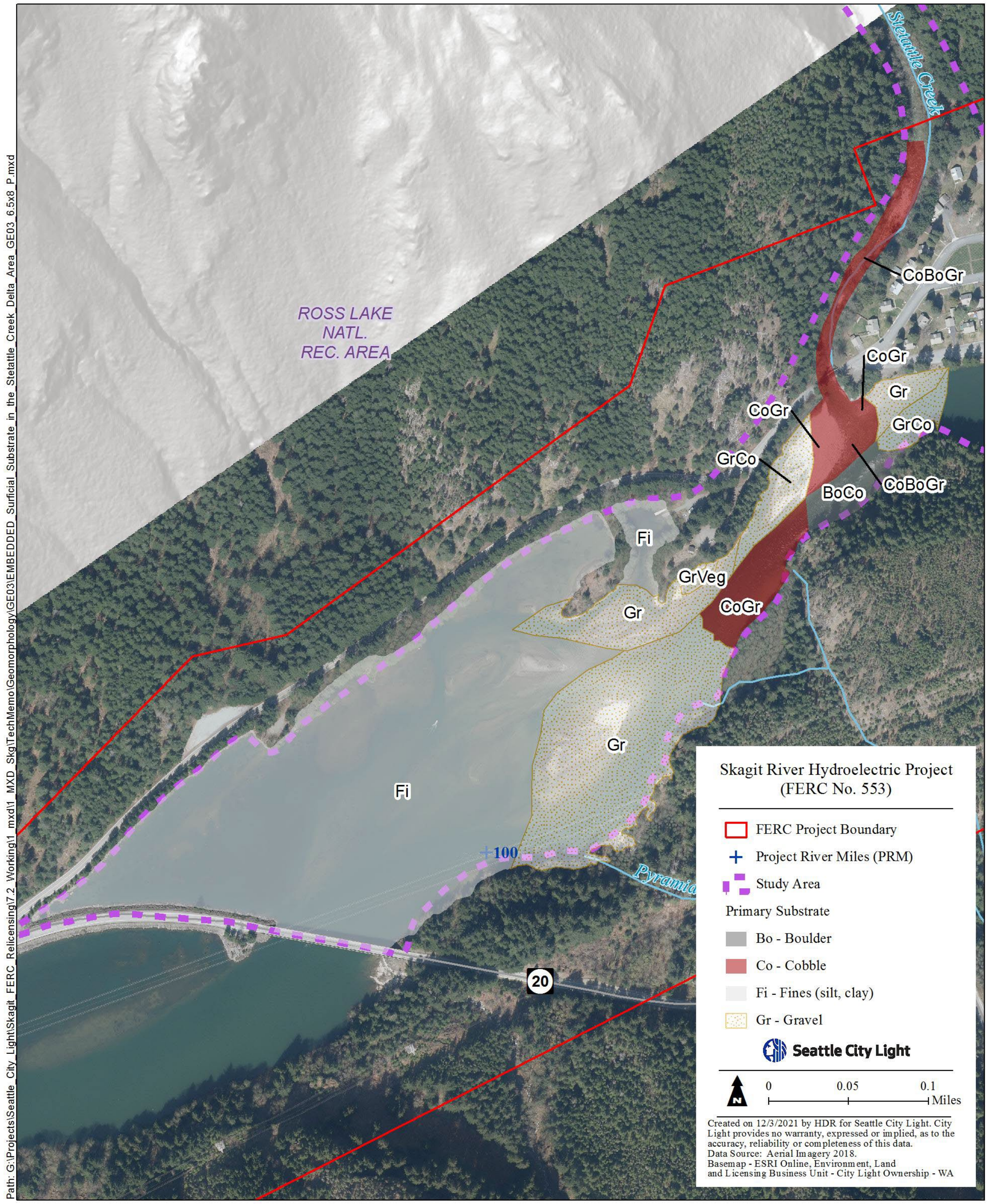


Figure 5.4-36. Surficial substrate in the Stetattle Creek delta area.

5.4.6 Sediment Transport Analysis

Sediment movement in lower Stetattle Creek and the delta area was assessed using the output from the 2-D hydraulic model to predict the critical grain size of sediment that could be picked up and transported under a variety of flows in Stetattle Creek and the Skagit River. Since peak flows in Stetattle Creek and the Skagit River are asynchronous (see discussion in Section 5.4.2.4 of this study report), the model was run with either peak flows in Stetattle Creek and low flows (3,500 cfs) in the Skagit River or high flows in the Skagit River and lower flows (500 cfs) in Stetattle Creek.

In Stetattle Creek, flows of 2,000 cfs (approximately a 2-year recurrence interval peak flow) are predicted to mobilize material up to 64 mm in size (coarse gravel and smaller particles), with cobble transport in some portions of the stream (Figure 5.4-37). In the primary delta, where Stetattle Creek enters the Skagit River, the coarse gravel material is predicted to settle out in the main channel with finer material on the upstream and downstream margins of the delta. Material up to boulder size can be transported under flows of 5,000 cfs (approximately 10-year recurrence interval, Figure 5.4-38) and large boulders under flows of 7,000 cfs (approximately 20-year recurrence interval, Figure 5.4-39). These findings are consistent with observations in Stetattle Creek and the primary delta, where cobble and boulder material show signs of frequent transport, and fresh deposits of cobble and boulder were seen on the delta covering small alders (Figure 5.4-40).

In the Skagit River, the critical grain diameter analysis suggested that only smaller material (gravel and finer) could be transported in the narrowest parts of the main channel under normal flows of 3,500 cfs (half powerhouse capacity, Figure 5.4-41) and, under flows of 6,000 cfs (approximately full powerhouse capacity, Figure 5.4-42), the gravel could be transported downstream into the secondary delta closer to the SR 20 bridge where deposits of gravel and cobble were observed. Under spill conditions (30,000 cfs), material up to coarse gravel and cobble size can be transported into the secondary delta (Figure 5.4-43).

These critical grain size analyses show that Stetattle Creek has a much higher competence to transport material than the Skagit River under existing conditions. Stetattle Creek can carry larger-sized material than the Skagit River, resulting in deposition of cobble and boulder material on the primary delta and gravel and finer material on the secondary delta.

Growth of the primary delta toward the opposite (left) bank of the Skagit River is limited due to the bedrock on the left bank that forms an immovable constriction and results in a narrow, high velocity chute that minimized deposition. As a result, the delta is growing upstream and downstream from the confluence as material is deposited in the upstream deep pool and downstream secondary delta.

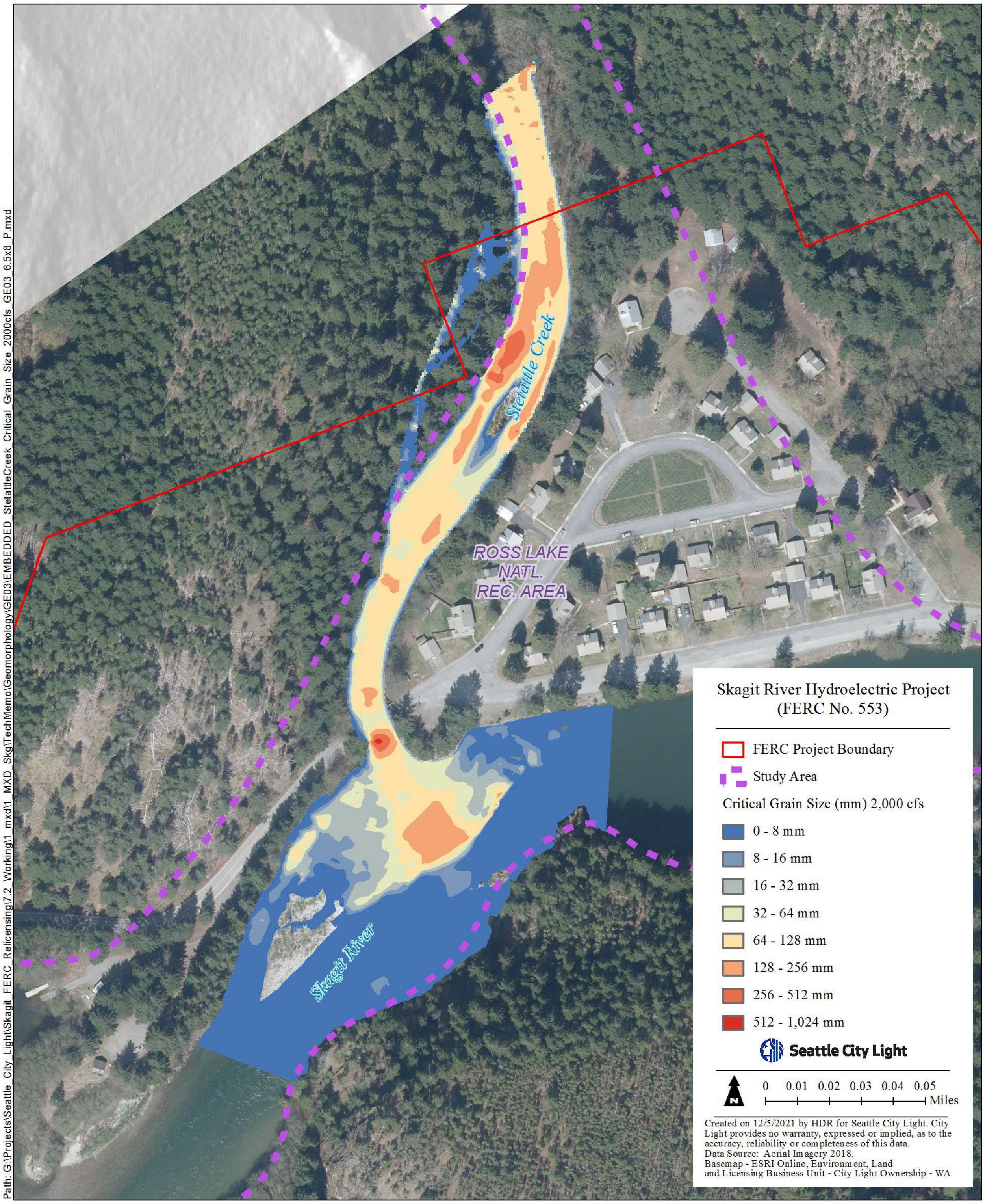


Figure 5.4-37. Critical grain size (mm) with flow of 2,000 cfs in Stetattle Creek.

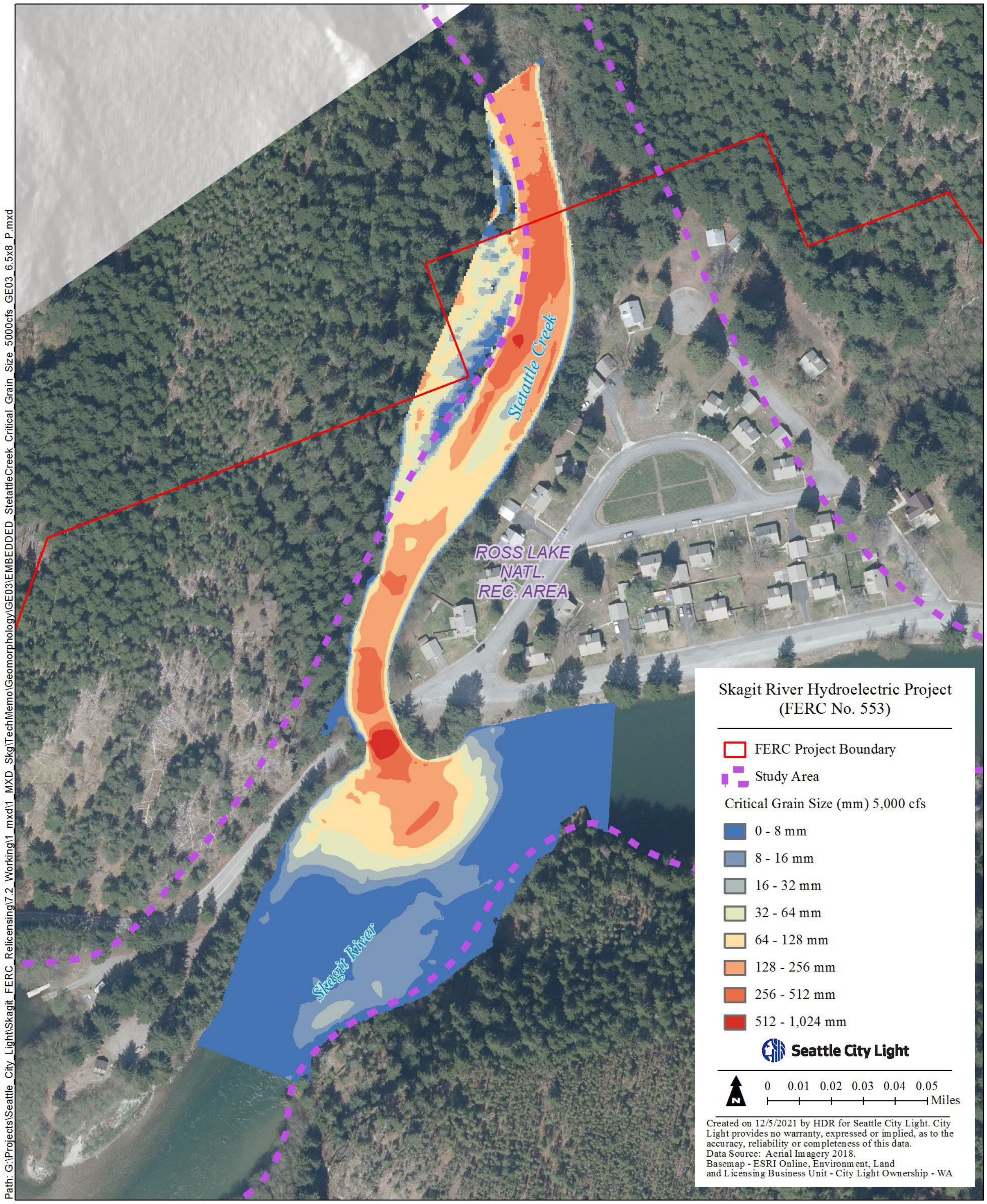
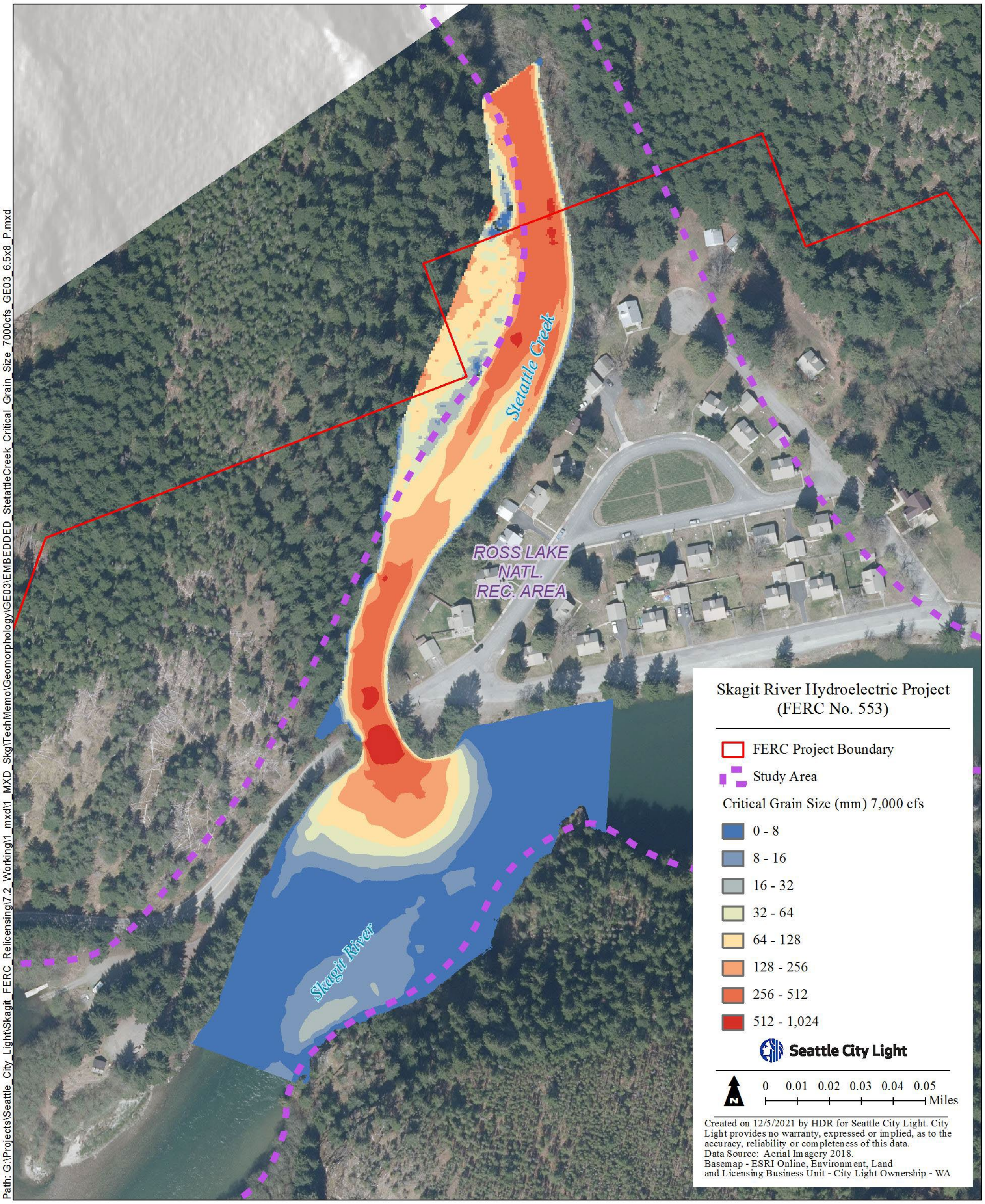


Figure 5.4-38. Critical grain size (mm) with flow of 5,000 cfs in Stetattle Creek.



Path: G:\Projects\Seattle_City_Light\Skagit_FERC_Relicensing\7.2_Working\1_mxd\1_MXD_Skg\TechMemo\Geomorphology\GE03\EMBEDDED_StetattleCreek_Critical_Grain_Size_7000cfs_GE03_6.5x8_P.mxd

Figure 5.4-39. Critical grain size (mm) with flow of 7,000 cfs in Stetattle Creek.

Figure 5.4-40. Stetattle Creek delta 2018 showing recent deposition of cobbles and boulders on young alders.

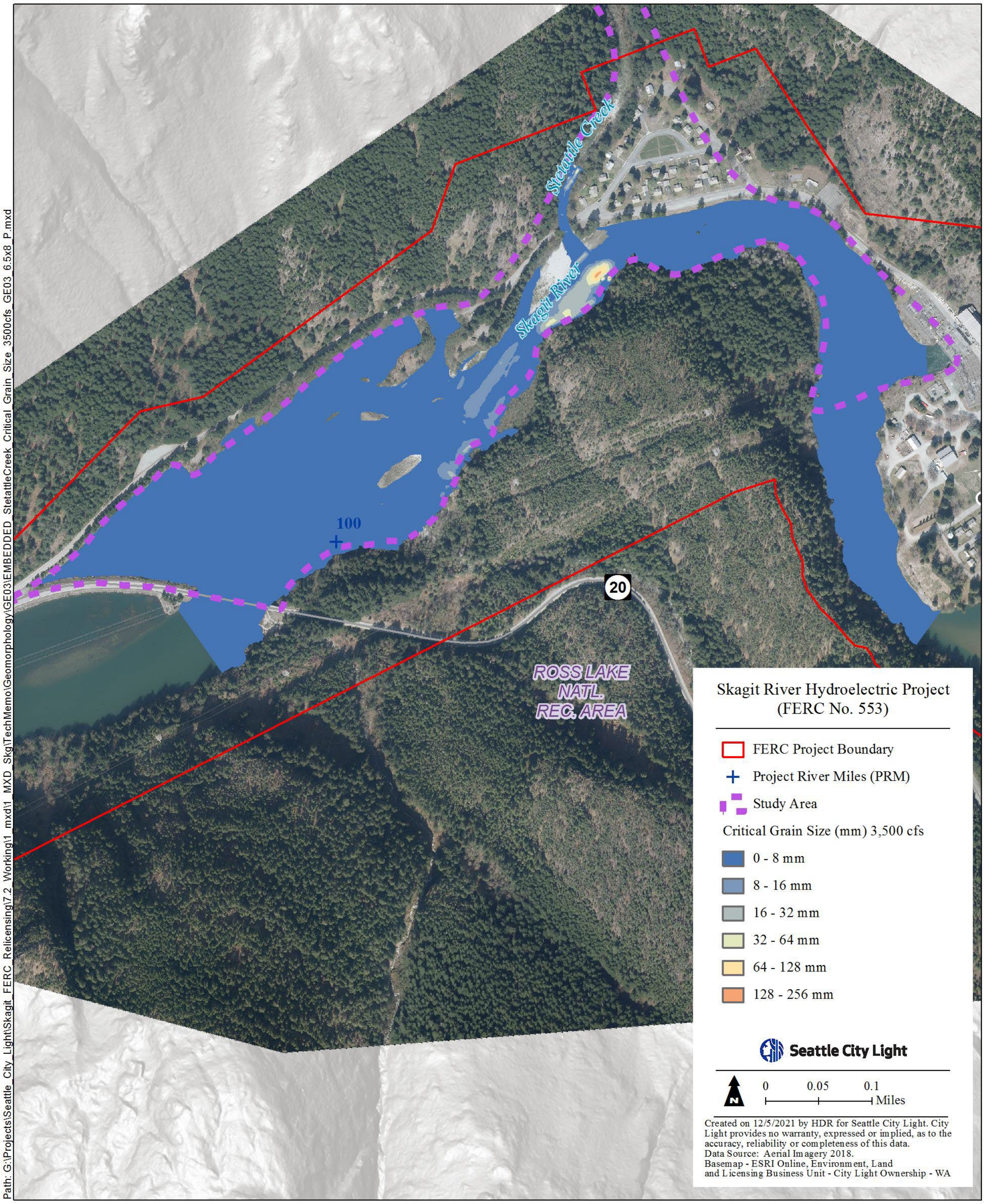


Figure 5.4-41. Critical grain size (mm) with flow of 3,500 cfs in Skagit River.

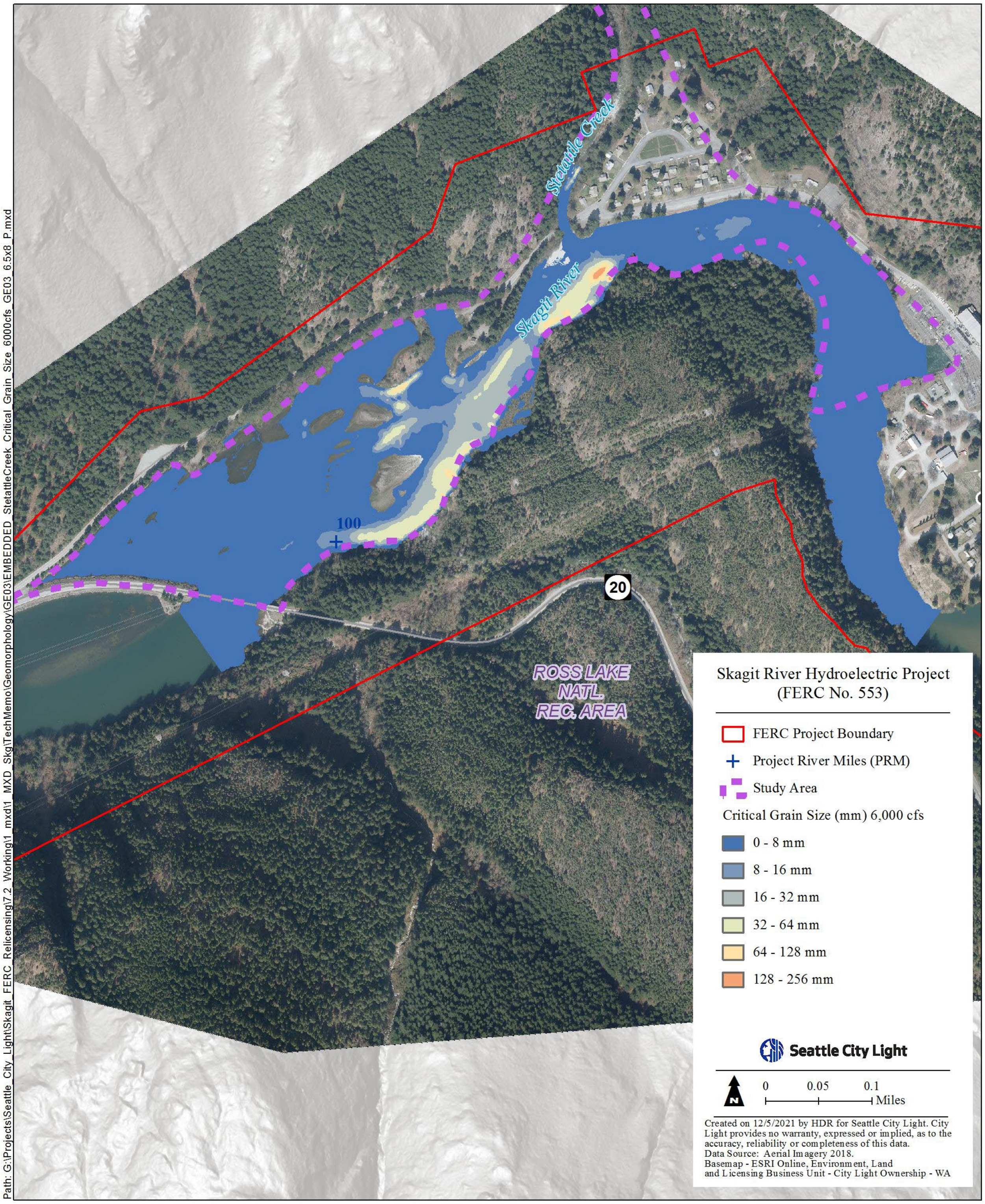


Figure 5.4-42. Critical grain size (mm) with flow of 6,000 cfs in the Skagit River.

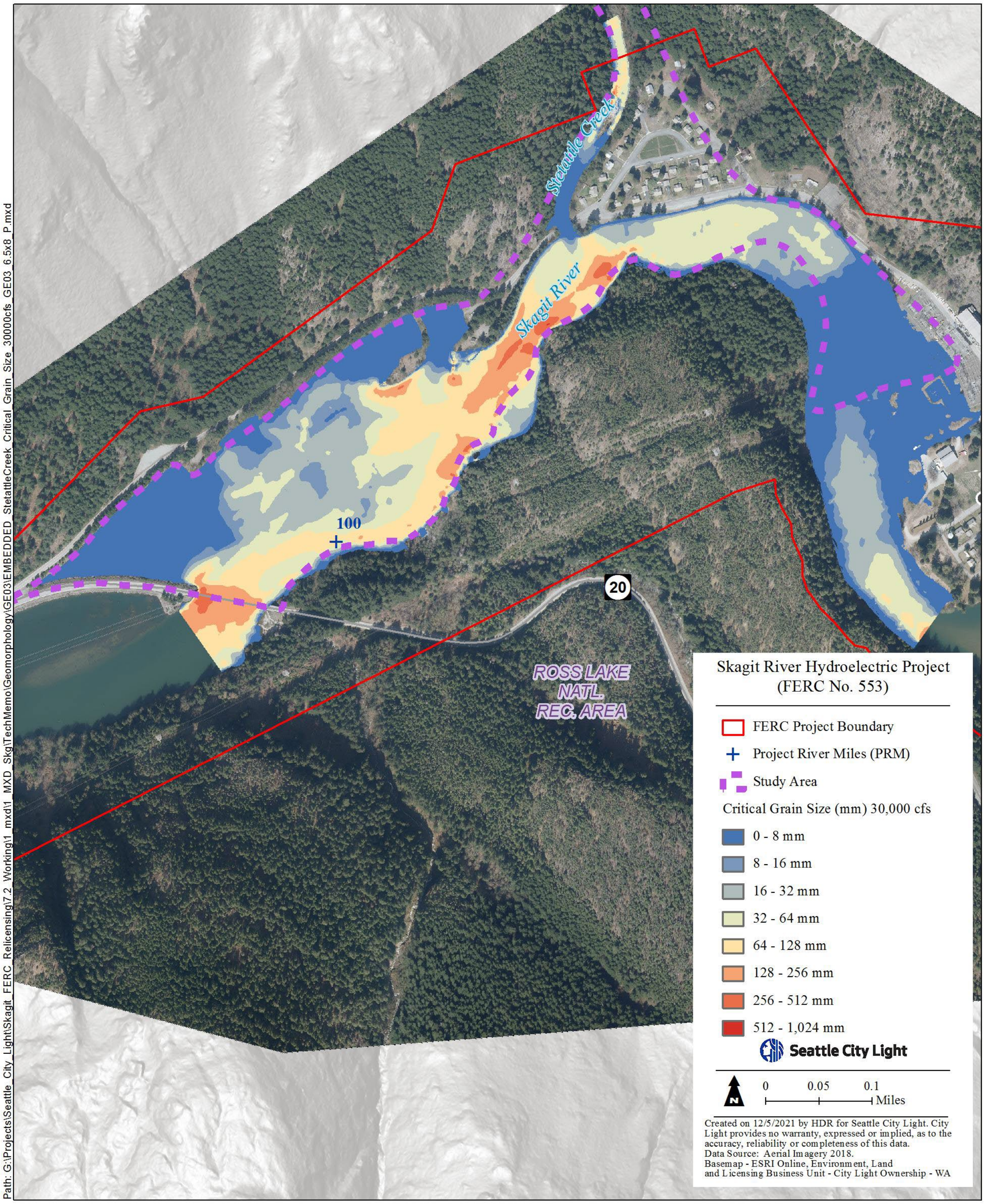


Figure 5.4-43. Critical grain size (mm) with flow of 30,000 cfs in the Skagit River.

5.4.7 Gorge Lake Boat Launch

The Gorge Lake boat launch is located in an embayment on the north side of Gorge Lake near the campground. This embayment is a location of fine sediment deposition. In addition, gravel deposition in the secondary delta area results in very shallow water depths at the outlet to the boat launch embayment, which precludes many large boats from using the launch to reach the lake, particularly when Gorge Lake levels are low.

6.0 SUMMARY

This interim report includes data and analysis completed through October 2021. Field work to map surficial substrate in the four delta study areas is complete. An initial assessment of delta growth/deposition areas through time from 1990 through 2018 has been made for Sourdough Creek and Thunder Arm. Total sediment deposition in the Stetattle Creek delta was estimated based on pre-project topography and recent bathymetric data and an analysis of initiation of substrate movement in the Stetattle Creek/Skagit River confluence study area has been made.

Bathymetric data was not available to complete the planned 2021 analyses, and additional field work has been added to this study as part of the June 9, 2021 Notice. Additional field work and analyses to complete this study planned for 2022 are described below. The additional field work is necessary to map erosion and deposition zones in the Ross Lake drawdown zone as discussed with Geomorphology Work Group members at the January 11, 2022 meeting. This work could not be completed in 2021 because work needs to be completed during drawdown in Ross Lake, which occurs in the late winter/spring.

6.1 Status of June 9, 2021 Notice

As part of the June 9, 2021 Notice, several commitments were made by City Light to augment the Sediment Deposition Study. The status of each of these commitments is summarized in Table 6.1-1.

Table 6.1-1. Status of Sediment Deposition Study modifications identified in the June 9, 2021 Notice.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
Assess sediment sequestration quantity and character in all three project reservoirs; add a comprehensive sediment survey in reservoirs. City Light will quantify sediment supply of all size ranges (i.e., grain size distribution estimate) into Ross, Diablo, and Gorge Reservoirs as an annual rate by using the existing DHSVM model, historical contours, and updated bathymetry information. Workgroup will discuss sediment size and characterization available from DHSVM model.	Upon further analysis, the DHSVM model is not an appropriate tool to use to estimate sediment supply to the reservoirs so it will not be used for this study. Instead, the comparison of historical contours with updated bathymetry will be used as well as a fine sediment yield regression relationship that is being developed as described in the November 9, 2021 Geomorphology Work Group Standing Meeting. The regression relationship will provide a better estimate of sediment yield to reservoirs than the DHSVM model. Both of these analyses will be completed in 2022 and reported in the USR.
Assess deposition and erosion in the drawdown zone. City Light will clarify that mapping of the sediment and erosion deposition zone and tributaries are part of the existing scope of the study. Any remaining gaps will be addressed during implementation.	Sediment erosion and deposition zones within the drawdown zones will be mapped using remote sensing and field-based methods in 2022 and reported in the USR. Details of methodology are being developed in consultation with LPs through Geomorphology Work Group consultation.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
Use a 1-D backwater model instead of the geomorphic 'inflection point" to estimate the magnitude and location of the reservoir backwater effect. City Light will expand the scope of GE-03 to include this modeling. City Light and the LPs recognize that there are limitations on the ability to calibrate aspects of this model.	Based on further analysis, City Light proposes that the reservoir backwater effect will be analyzed in the four delta study areas using the most appropriate method for each particular area as follows: ▪ Hozomeen inlet: the detailed topographic data needed to develop a 1-D topographic model for the Skagit River would extend into Canada and is not available. Therefore, a 1-D HEC-RAS model will not be developed. ▪ Sourdough Creek: the longitudinal profile measured from 2018 LiDAR and 2021 survey data shows that due to the steep gradient of Sourdough Creek, and the grade control/drop at the existing road crossing structure, the backwater effect cannot extend up Sourdough Creek (see Section 5.3). A 1-D HEC-RAS model is not needed, and there is no hydrologic data to calibrate the model. ▪ Thunder Arm: a 1-D HEC-RAS model will be developed in 2022 for Thunder Arm. This is appropriate because Thunder Creek is relatively low gradient, there is evidence of backwater effects (see Section 5.2) and there is existing detailed topographic (LiDAR) and hydraulic (USGS gage) data available for Thunder Creek to enable calibration of the model. ▪ Stetattle Creek: a 2-D HEC-RAS model (more detailed than a 1-D HEC-RAS model) has been developed as part of a previous study and will be used to analyze backwater effects.

6.2 Next Steps

Work in 2022 will include field work and analysis to finalize results to meet RSP study objectives and the June 9, 2021 Notice commitments as described Section 6.1.

Specific work planned for 2022 to meet the RSP objectives and deliverables includes:

- Collecting bathymetric data in the three Project reservoirs to produce a digital elevation model of the reservoirs from bathymetry and existing topography.
- Finalizing the analysis of reservoir deposition amounts and rates (estimated volume/year) in three detailed study areas (Hozomeen area, Thunder Arm, Sourdough Creek) based on a comparison of pre-Project topographic mapping and bathymetry data and watershed-level sediment yield relationships. (Note: this task for Stetattle Creek has been completed.) Shaded relief maps of accumulated sediments will be produced and estimates of volume by grain size category will be made.
- Further analysis of sediment transport/deposition zones and backwater effects in the Hozomeen, Thunder Arm, and Sourdough Creek tributary streams.
- A qualitative assessment of future deposition amount and patterns for the four detailed study areas to help assesses impacts to recreational resources and operations.

In order to meet the commitments in the June 9, 2021 Notice, City Light will complete the following tasks in 2022:

- An estimate of total sediment deposition in the three Project reservoirs based on:
  - A comparison of available pre-Project topographic mapping and recent bathymetry data.
  - Sediment yield relationships based on measured fine sediment yield from basins in the North Cascades and Canada and a statistical predictive relationship using basin characteristics like geology, slope gradient, etc.
- Estimates of percent of total reservoir deposits by grain size category (e.g., boulder, cobble, gravel, sand, silt/clay).
- Mapping of erosion and deposition areas in the Ross Lake drawdown zone.
- An assessment of the Diablo Lake backwater extent in Thunder Creek using HEC-RAS or similar hydraulic modeling.

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

This report contains work completed through October 2021 with remaining work to be completed in 2022, as described in Section 6.2 of this study report. As described above, City Light proposes the following modifications to this study:

- Field efforts, analysis and reporting will extend into 2022 and will be described in the USR to be filed with FERC in March 2023.
- Existing detailed topographic LiDAR data available for Thunder Creek are sufficient to analyze sediment transport/deposition using a 1-D HEC-RAS model, so field-surveyed cross sections and slope are not needed (Section 2.6.2.2 of the RSP).
- Existing detailed topographic LiDAR data for the Skagit River upstream from Ross Lake will be used for the analysis of sediment transport/deposition; these data extend approximately two miles upstream from the head of Ross Lake and are of sufficient detail for the analysis. No field-surveyed cross sections or slope will be measured. No pebble counts will be made in the Skagit River outside of the United States due to limitations of field work in Canada.

Changes to the methods committed to as part of the June 9, 2021 Notice are described in Table 6.1-1. The objectives of the commitments will be met, but more appropriate methods will be used.

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