GE-04 SKAGIT RIVER GEOMORPHOLOGY BETWEEN GORGE DAM AND THE SAUK RIVER STUDY INTERIM REPORT

SKAGIT RIVER HYDROELECTRIC PROJECT FERC NO. 553

Seattle City Light

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Initial Study Report

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List of Acronyms and Abbreviations

1-D ....one-dimensional
2-D ....two-dimensional
ABSS..........................above Shovel Spur
B&W..........................black and white
BMM..........................below Marblemount
cfs..............................cubic feet per second
City Light..................Seattle City Light
dbh.............................diameter at breast height
DNR ....Department of Natural Resources (Washington State)
Ecology ....Washington State Department of Ecology
FERC..........................Federal Energy Regulatory Commission
ft ....foot/feet
GIS ....Geographic Information System
GPS ....Global Positioning System
HEC-RAS ....Hydrologic Engineering Center River Analysis System
IHA ....Indicators of Hydraulic Alteration
IQR............................interquartile range
ISR ....Initial Study Report
kg...............................kilogram
kHz............................kilohertz
LB ....left bank
LiDAR.......................Light Detection and Ranging
LP ....licensing participant
LWD ....large woody debris
m ....meter
mm ....millimeter
MHz ....megahertz
NPS ....National Park Service
NSD...........................Natural Systems Design
PAD...........................Pre-Application Document
PRM ....Project River Mile

Project ....Skagit River Hydroelectric Project
QSI ....Quantum Spatial, Inc.
RB ....right bank
RCI ....River Complexity Index
REM...........................relative elevation model
RFID ....Radio Frequency Identification Device
RSP ....Revised Study Plan
SR...............................State Route
SRSC..........................Skagit River System Cooperative
SWIFD ....Statewide Washington Integrated Fish Distribution
UBCRM ....University of British Columbia Regime Model
USACE ......................U.S. Army Corps of Engineers
USFS ..........................U.S. Forest Service
USGS .........................U.S. Geological Survey
USR............................Updated Study Report
WDFW.......................Washington Department of Fish and Wildlife
WSDOT ....Washington State Department of Transportation
yr ....year

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1.0 INTRODUCTION

The GE-04 Skagit River Geomorphology Between Gorge Dam and the Sauk River Study (Geomorphology 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 2021a). 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 [Ecology], and Washington Department of Fish and Wildlife [WDFW]). The June 9, 2021 Notice included agreed to modifications to the Geomorphology Study.

In its July 16, 2021 Study Plan Determination, FERC approved the Geomorphology Study with modifications. Specifically, FERC did not require City Light to quantify the amount of sediment transported into Ross Lake on an annual basis (which was an agreed to modification in the June 9, 2021 Notice). Notwithstanding, City Light is implementing the Geomorphology Study as proposed in the RSP with the agreed to modifications described in the June 9, 2021 Notice.

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 goals of the Geomorphology Study are to characterize the current condition of aquatic habitat within the 30-mile segment of the Skagit River between Gorge Dam and the Sauk River confluence and to characterize how Project-related changes in peak flows affect geomorphic processes, which will be used to evaluate the Project's contribution to cumulative effects in the reach. Specific objectives include:

- Use aerial photograph and Light Detection and Ranging (LiDAR) data and collect field data noting current conditions and changes to document:
  - Baseline channel configuration and migration patterns;
  - Distribution of aquatic habitat types, characteristics, and availability;
  - Side channels and off-channel habitat, including hydraulically-connected wetlands;
  - Substrate size and distribution;
  - Sediment sources and delivery mechanisms; and
  - Large wood input, transport and retention.
- Determine flow rates that may result in redd scour to help guide management of peak flow releases from Gorge Dam and Powerhouse.
- Investigate flows that result in geomorphic/habitat changes (process flows) for the following processes:
  - Mobilize deposits at tributary mouths along the mainstem Skagit River;
  - Mobilize riverbed and bars;
  - Erode riverbanks and result in channel migration;
  - Instigate side channel development/maintenance; and
  - Hydraulically connect side channel and off-channel habitat.

Per the June 9, 2021 Notice, additional commitments related to study efforts below the Sauk River Confluence were incorporated into the Geomorphology Study and are described in this study report. These commitments, as well as the status of their implementation, are described in Section 6.2 of this study report.

3.0 STUDY AREA

The primary study area includes the 30-mile segment of the Skagit River between Gorge Dam and the Sauk River confluence (Figure 3.0-1). Side channels and off-channel habitat areas included in the primary study area were selected through a collaborative process involving the LPs, City Light staff, and consultant teams. There are 20 named tributary streams that drain into the Skagit River within the primary study area (Figure 3.0-2; Table 3.0-1). Fieldwork and analysis are generally limited to the tributary junctions defined as a distance of 500 feet (ft) upstream of the confluence with the Skagit River at each tributary. Additional review of previous geomorphic studies downstream of the Sauk River confluence was completed and included in an annotated bibliography found in Attachment A.

The downstream extent of the sediment transport study area is the location where the riverbed material shifts from gravel to sand (called the gravel-sand transition) around Project River Mile (PRM) 21 near Sedro-Woolley, about 11 miles upstream of the channel bifurcation at the head of the delta where the channel debouches into the estuary where tidal processes begin to dominate channel forming processes. Section 7.3 of this study report explains the rationale for choosing this location as the downstream boundary for the sediment transport modeling program.

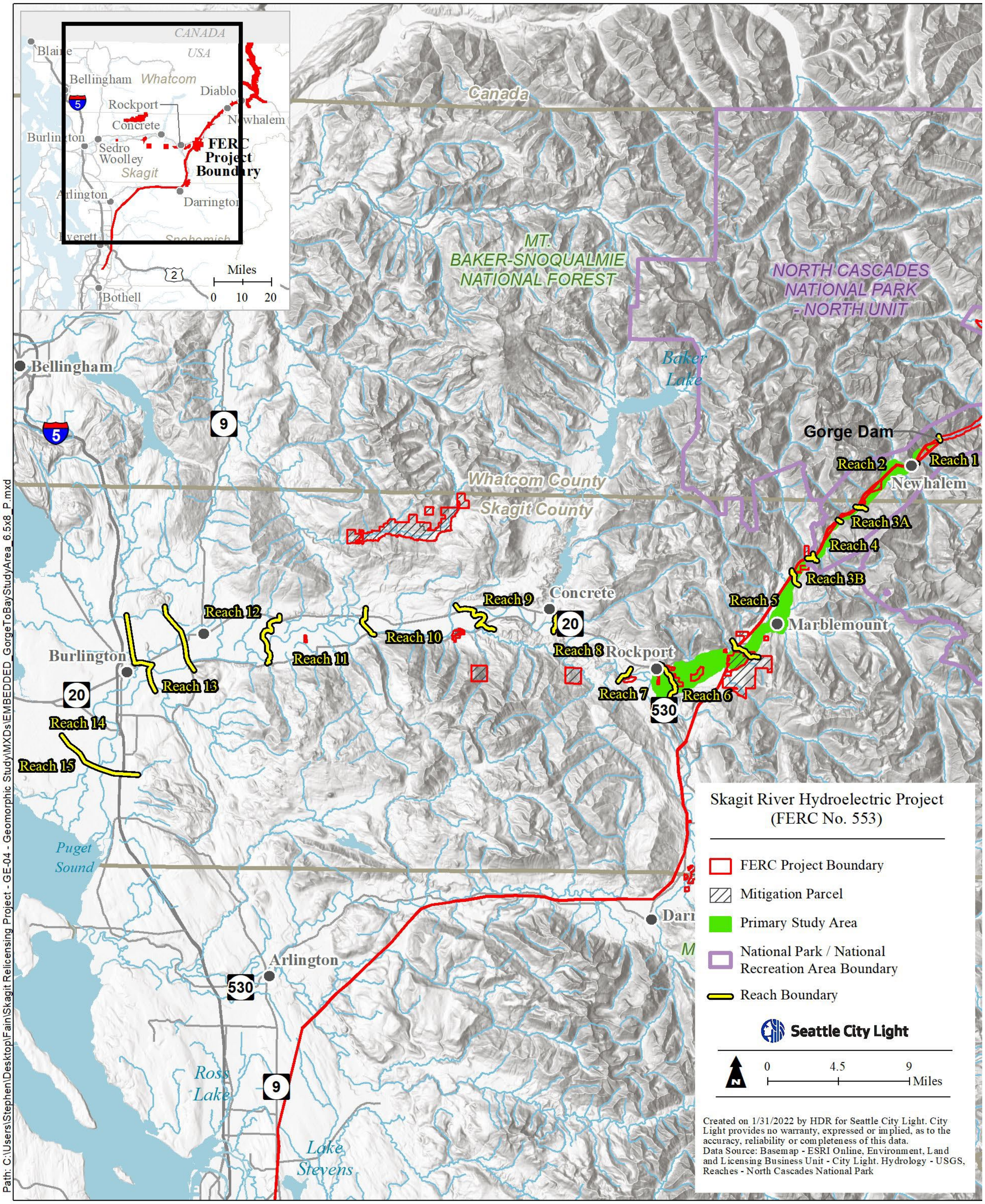

Figure 3.0-1. Overview map of the Skagit River from Gorge Dam to the estuary including geomorphic reach boundaries from Riedel et al. (2020) and highlighting the primary study area from Gorge Dam to Sauk River confluence.

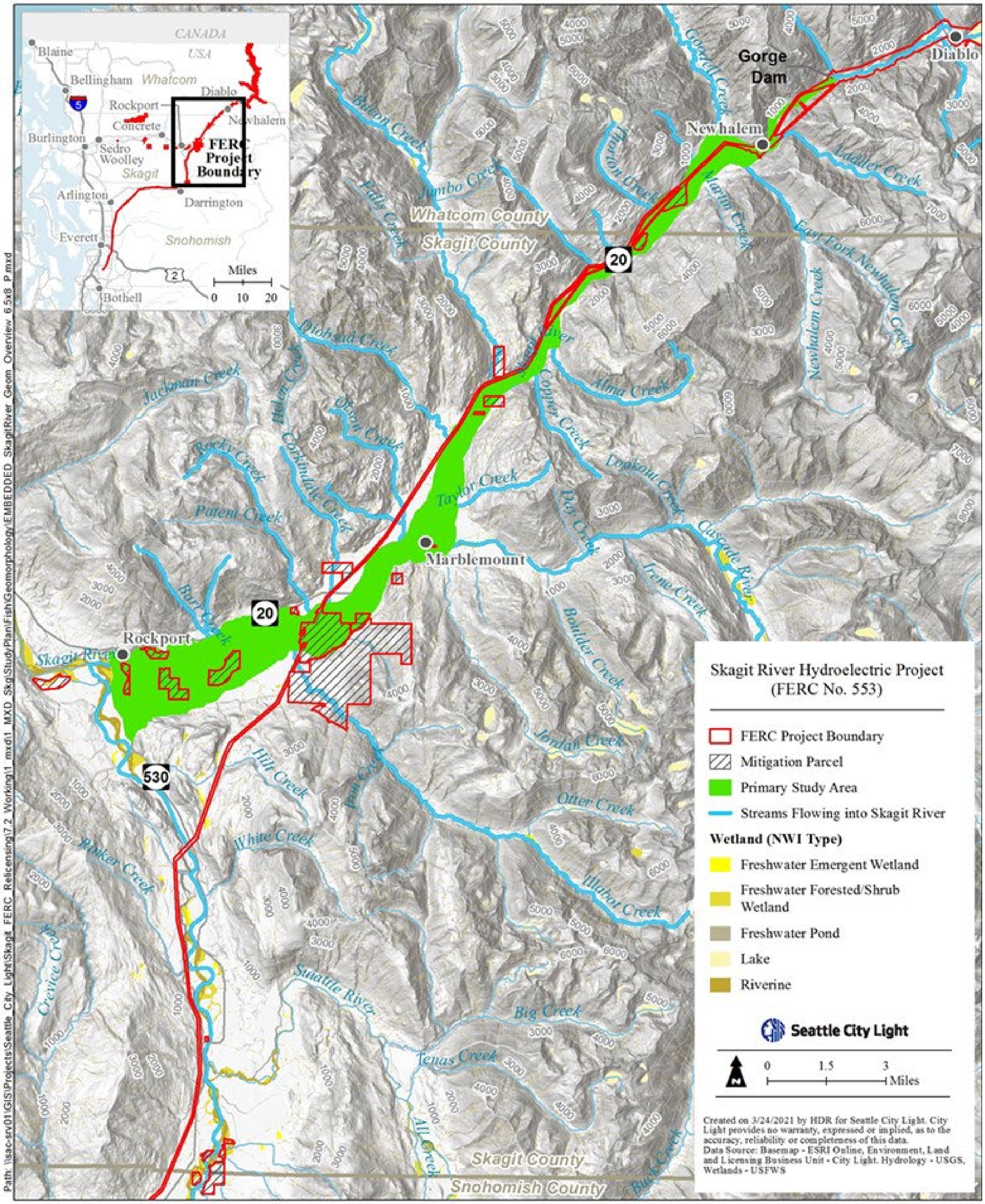

Figure 3.0-2. Overview of primary study area: Gorge Dam to Sauk River confluence.

Table 3.0-1. Tributaries in primary study area.

Tributary	Project River Mile (PRM)	Left Bank (LB) / Right Bank (RB) Looking Downstream
Ladder Creek	94.6	LB
Newhalem Creek	93.8	LB
Goodell Creek	93.3	RB
Babcock Creek	92.1	RB
Martin Creek	91.4	LB
Thornton Creek	90.5	RB
Sky Creek	88.6	RB
Damnation Creek	88.0	RB
Alma Creek	85.5	LB
Copper Creek	84.4	LB
Bacon Creek	83.2	RB
Diobsud Creek	81.0	RB
Taylor Creek	79.1	LB
Cascade River	78.2	LB
Olson Creek	77.2	RB
Corkindale Creek	74.3	RB
Rocky Creek	73.8	RB
Illabot Creek	73.0	LB
Sutter Creek	71.0	RB
Barr/Swift Creek	70.8	RB

4.0 METHODS

The Geomorphology Study includes pre-field analysis of existing information, field work to inventory aquatic habitat and current geomorphic conditions in the Skagit River, redd scour monitoring, scour monitoring at tributary junctions and river bars, sediment transport modeling, and post-field analysis and report writing. This study report is organized by topic areas to present methods for the following subsections as described in the RSP:

- Geomorphic Change;
- Aquatic Habitat;
- Side Channels and Off-Channel Habitat;
- Substrate/Sediment;
- Large Wood Inventory;
- Large Wood Transport; and
- Process Flows.

Per Section 2.6.1 of the RSP, existing information providing a basis for understanding geomorphic processes in the Skagit River was compiled and includes the following studies:

- A baseline fluvial geomorphology report was prepared for the Skagit River basin (Gorge Powerhouse to estuary) by the U.S. Army Corps of Engineers (USACE) that includes an estimated sediment input budget based on basin sediment budgets and suspended load data and a description of fluvial geomorphic reaches (USACE 2008).
- Channel incision was identified as a potential issue during the Skagit River Project's last relicensing in the early 1990s. Analysis of U.S. Geological Survey (USGS) gage records at that time showed incision at the Alma gage (no longer in service) and little variation to 0.4 ft of aggradation at the Newhalem gage (Riedel 1990).
- The Water Resource Inventory Areas Limiting Factors Assessment for the Skagit River (Smith 2003) identifies types of habitat/conditions that are limiting fish production in the river. Information on substrate quality, streambed stability, and large woody debris (LWD) are listed as data gaps in the upper Skagit River (Newhalem to Sauk River confluence).
- The Skagit Watershed Council produced Geographic Information System (GIS)-based analyses of relative sediment input, riparian conditions, and bank hardening areas in the Skagit River system (Beamer et. al 2000). This information was used for a reach assessment of the Middle Skagit River (Sauk River confluence to Sedro-Woolley) that analyzed potential areas for targeting habitat restoration based on habitat, geomorphology, and land uses (Smith et al. 2011).
- The Upper Skagit Indian Tribe (Hartson and Shannahan 2015) conducted a field inventory of hydromodified banks along the Upper Skagit River.
- A sediment budget of the Middle Skagit River (Rockport to Sedro-Woolley) was developed by Rothleutner (2017) and included an analysis of historical channel migration rates and sediment input from river meandering.

- The Skagit Watershed Council commissioned a report on LWD in the Skagit River system (Natural Systems Design [NSD] 2017) that included a summary of existing factors affecting LWD recruitment and potential methods to analyze/inventory LWD in the watershed.
- Geomorphology, hydrology, and hydraulics studies undertaken for the Barnaby Reach restoration project provide detailed information on the Skagit River channel, off-channel areas, and floodplain in the area just upstream of the Sauk River confluence (Skagit River System Cooperative [SRSC] and NSD 2019).
- Suspended sediment monitoring by the USGS on the lower Skagit River (Curran et al. 2016) and Sauk River (Jaeger et al. 2017).
- Geomorphic mapping and landform analysis being conducted by NPS (Riedel et al. 2020).

A compilation of relevant studies describing Skagit River geomorphology downstream from the Sauk River confluence were reviewed and summarized in an annotated bibliography included in Attachment A. A summary of Skagit River geomorphic conditions downstream from the Sauk River confluence will be included in the USR pending the completion of the Landform Mapping Study downstream of the Sauk River confluence being conducted by NPS.

The primary study area upstream of the Sauk River in which field data were collected in 2021 is divided into seven geomorphic reaches based on landform mapping by NPS (Riedel et al. 2020). A geomorphic reach is a defined segment of the river having a relatively consistent suite of valley and channel characteristics. The geomorphic reaches are influenced by the bedrock geology, glacial history, and inputs from adjoining tributaries and hillslope processes. Study reaches vary between 2 and 7 miles in length with select subreaches identified as shorter segments with a minimum length of 1.2 miles. Figures 4.0-1 to 4.0-4 identify the reach boundaries and locations of major tributaries draining to the Skagit River within the primary study area. The longitudinal profile in Figure 4.0-5 shows channel slope relative to reach boundaries.

Reach 1 (Gorge bypass reach) is a steep, narrow valley cut into the Crystalline Core of the North Cascades (Figure 4.0-1). Bedrock geology in this zone is largely composed of relatively hard, metamorphic rock of the Skagit Gneiss Complex (orthogneiss and banded gneiss) previously buried and heated inside the crust then brought to the surface by tectonic uplift (Tabor and Haugarud 1999). The Skagit River Gorge was created by drainage from proglacial lakes that spilled over a hydrologic divide during the early Pleistocene and increased the size of the Skagit Basin by capturing drainage that formerly flowed north to the Fraser River (Riedel et al. 2007).

Reach 2 begins downstream of the Gorge bypass reach where the channel slope decreases and valley widens at Newhalem (Figure 4.0-5) due to the influence of alpine glaciers that advanced from the Goodell Creek and Newhalem Creek watersheds (Riedel et al. 2020). Reach 2 has been further divided into subreaches by this study (Figure 4.0-1): Reach 2A represents the segment from Gorge Powerhouse near PRM 94.7 to the bridge crossing at PRM 93.6; and Reach 2B continues to the downstream limit of alpine glaciation (PRM 89.4) just south of the County Line separating Whatcom and Skagit counties. Major tributary streams draining into the Skagit River within Reach 2 include Ladder Creek, Newhalem Creek, Goodell Creek, Babcock Creek, Martin Creek, and Thornton Creek. City Light maintains two former gravel mine sites in the reach at Newhalem Aggregate (Agg) Ponds and County Line Ponds as off-channel fish habitat.

Reach 3 narrows in relation to Reach 2 as a result of resistant bedrock and limited alpine glaciation (Riedel et al. 2020). Reach 3 is split into two segments that are separated by Reach 4 (Figure 4.0-2). Reach 3A begins near the County Line (PRM 89.4) and continues downstream past the tributary junction with Damnation Creek to the beginning of Reach 4 at PRM 87.5.

Reach 4 is the landslide zone that spans 3.5-miles (PRM 87.5 to 84.0) between Damnation Creek and Bacon Creek. The reach is bound by two fault zones that define the regional geology and landslide deposits that confine the valley (Riedel et al. 2020). Reach 3B continues downstream of the landslide zone from PRM 84 to the change in geology where the Skagit River crosses the Straight Creek Fault (PRM 82). Alma Creek, Copper Creek, and Bacon Creek join with the Skagit River in Reach 3B.

Reach 5 continues downstream of the Straight Creek Fault (PRM 82) to Rocky Creek (PRM 74). The valley widens relative to upstream reaches due to a change in the underlying bedrock geology that results in decreased erosional resistance west of the fault. The channel is incised into a series of terraces that occupy much of the valley bottom. The community of Marblemount is located on a terrace surface just upstream and across from the junction with the Cascade River at PRM 78.2. The Cascade River is the largest tributary entering the Skagit River between Gorge Dam and the Sauk River and is an important source of water, sediment, and wood to Reaches 5 and 6. Additional tributary inflows within Reach 5 include Diobsud Creek, Olson Creek, and Corkindale Creek. For this study, Reach 5 was split into two subreaches defined by segments upstream (Reach 5A) and downstream (Reach 5B) of the Cascade River (Figure 4.0-3).

Reach 6 (Barnaby Reach) begins at Rocky Creek (PRM 74) and continues downstream to the upstream edge of the Sauk River alluvial fan near PRM 68. Barr Creek and Sutter Creek both join with the Skagit near PRM 71 and have formed coalescing debris cones that extend into the valley from the north. Tributary inflow from O'Brien Creek and Illabot Creek drain into the Skagit River floodplain from the south in the upper segment of Reach 6. A meander cutoff in the early 1900s left an abandoned channel that is now occupied by Illabot Creek where it flows north across the Skagit River floodplain (Figure 4.0-3). Downstream of Illabot Creek, the floodplain contains a series of relict meanders (Figure 4.0-4). The meander complex represents up to 5,800 years of fluvial history in the valley (Riedel 2019). The youngest of these meanders is known as Barnaby Slough and was cut off during the late 1800s to early 1900s. Barnaby Slough and adjacent floodplain features, such as Harrison Pond and Lucas Slough (collectively known as the "Barnaby Complex"), have been modified since the 1960s to create rearing habitat for hatchery steelhead. Use of the facility was discontinued in 2007, and the Barnaby Complex is the site of ongoing restoration activities to improve habitat conditions in the reach.

Reach 7 is characterized by the influence of the Sauk River alluvial fan that has formed at the confluence of the Sauk River and the Skagit River near the community of Rockport (Figure 4.0-4). State Route (SR) 530 crosses the Skagit River at Rockport and heads south across the Sauk River alluvial fan. Relict channels from the Sauk River extend upstream to the east of SR 53, including much of the low-lying area in the floodplain along Martin Road. Over a timescale of tens to hundreds of years, the position of the Sauk River confluence shifts upstream and downstream within the valley and exerts an influence over hydraulic and geomorphic processes in Reach 6. As recent as the early 1900s, the confluence of the Sauk River was approximately 1 mile upstream of its present location and much closer to the area around Rockport. For this study, Reach

7 was split into two subreaches upstream (Reach 7A) and downstream (Reach 7B) of the Sauk River confluence near PRM 66.8 (Figure 4.0-4). Field mapping of bank conditions, aquatic habitat, and large wood inventory was limited to the segments upstream of the Sauk River Confluence (Reach 7A). Bed material sampling extended downstream of the confluence to include a site in Reach 7B.

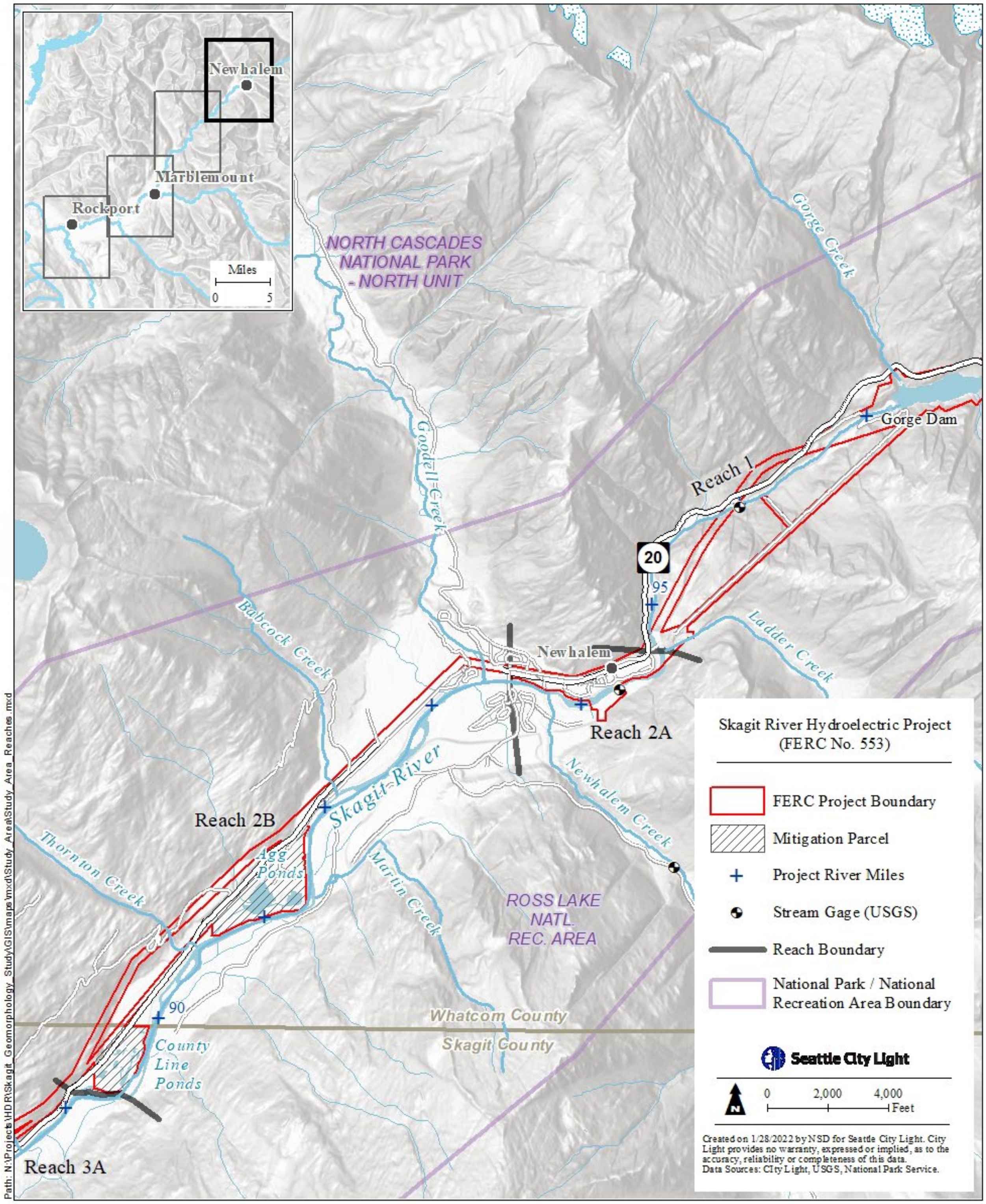

Figure 4.0-1. Northern portion of primary study area from Gorge Dam to the County Line including Reach 1, 2A, and 2B.

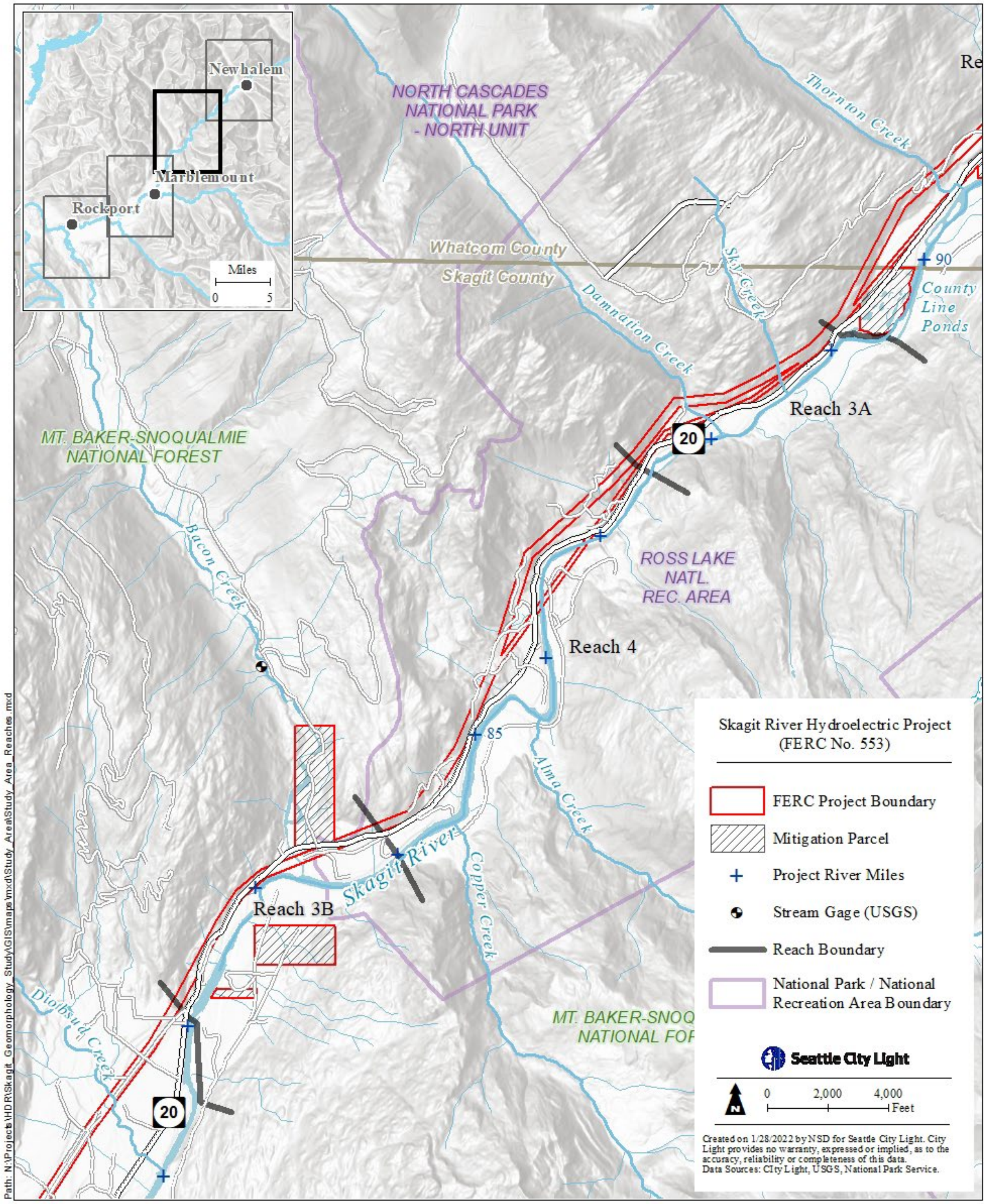

Figure 4.0-2. Primary study area reaches from County Line to the Straight Creek Fault Zone near Diobsud Creek including the Narrow Upper Skagit Reaches 3A/3B and the landslide zone (Reach 4).

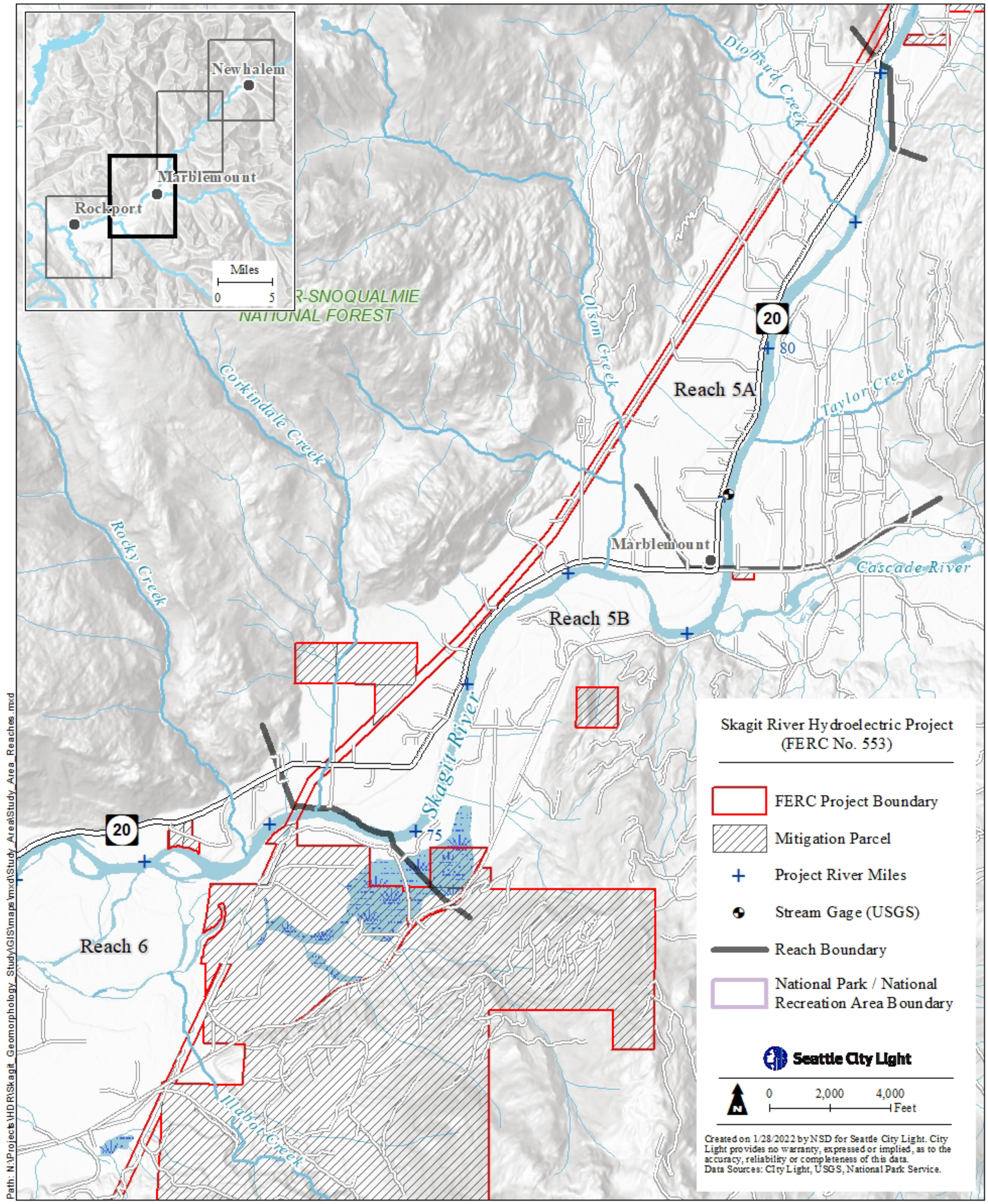

Figure 4.0-3. **Primary study area reaches from the Straight Creek Fault Zone to the Cascade River (Reach 5A), Cascade River to Rocky Creek (Reach 5B), and the upper segments of Reach 6 near Illabot Creek.**

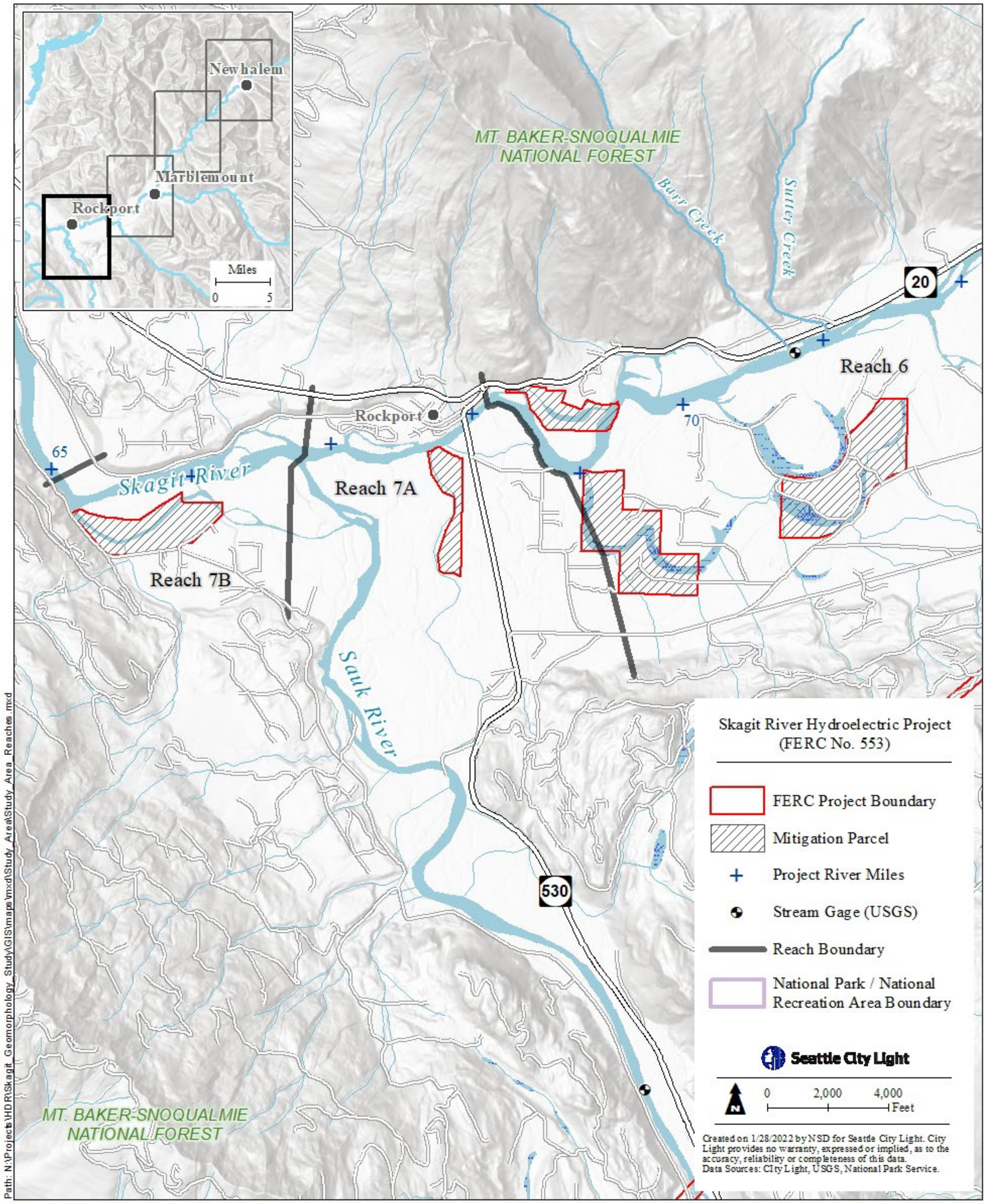

Figure 4.0-4. Downstream portion of the primary study area including the Barnaby Meanders (Reach 6) and Sauk River confluence (Reach 7).

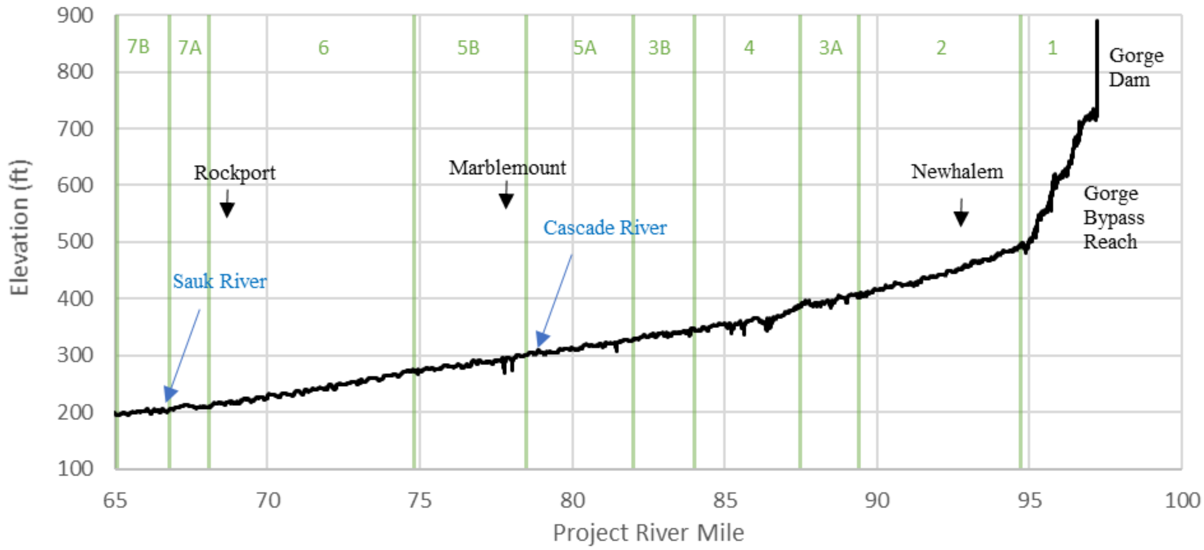

Figure 4.0-5. Longitudinal profile of the Skagit River from Gorge Dam to the Sauk River with overlay of reach boundaries. Elevation data from 2017 and 2018 topobathymetric LiDAR surface (Quantum Spatial, Inc. [QSI] 2017, 2018). Small dips in profile represent pool features in the bathymetric data.

4.1 Geomorphic Change

The analysis of geomorphic change includes a characterization of lateral channel migration and vertical channel changes (incision or aggradation) following methods defined in Section 2.6.2 of the RSP.

4.1.1 Mapping Active Channels

Upstream of the Sauk River confluence, active river channels were mapped for Reaches 2-7 using LiDAR, aerial photographs, and digital aerial imagery from multiple time steps between 1944 and 2019 to evaluate historic channel conditions (Table 4.1-1). Channel features were not digitized from historical imagery in Reach 1 given the bedrock-controlled morphology that limits channel migration and increased error in georeferencing imagery in the Gorge bypass reach due to the steep topography and limited availability of stable control points.

Channel features digitized as part of previous work by SRSC were utilized for channel reaches between the Sauk River confluence and Marblemount (SRSC 2019). Additional imagery was then compiled from the list of available imagery presented in Table 2.6-1 of the RSP to extend the data set of historical imagery for channel reaches upstream of Marblemount. Several of the data sources were limited in spatial extent and did not include full coverage of the primary study area. Multiple data sources were combined to create a composite for select time periods that included imagery from different data sources that spanned two consecutive years. The resulting time series included the following years: 1944, 1963-64, 1978-79, 1998, 2006-07, 2019 (Table 4.1-1).

The peak flow history at USGS gaging stations in the Skagit River at Newhalem (USGS 12178000) and at Marblemount (USGS 12181000) are overlaid with years selected in time series of aerial imagery in Figure 4.1-1 and 4.1-2. The gage record at Newhalem dates to 1908 and the three highest recorded flows (all greater than 40,000 cubic feet per second [cfs]) occurred prior to time series of aerial imagery used in this study. Several tributaries drain into the Skagit River between the USGS gaging stations at Newhalem and Marblemount increasing the contributing drainage area from 1,175 to 1,381 square miles, respectively (an 18 percent increase in drainage area). The gage record at Marblemount begins in 1943 and includes a period with no data during the interval 1957-1975.

Channel digitizing practices and classification codes were based on methods described by SRSC for the reaches downstream of Marblemount, and digitization was continued from Marblemount to the Gorge Dam using consistent rules and practices. These methods are briefly outlined below.

Digitization involved classifying areas into discrete polygons. As derived from SRSC digitization methods (SRSC 2019), polygon classes included low flow channel (water), unvegetated area (bars), vegetating area (sparsely or annually vegetated bars), and forested islands. Active channels include areas within the river where the combination of sediment transport intensity and hydroperiod prevent establishment of vegetation and is therefore comprised of low flow channel and unvegetated area classes. Forested islands and vegetating areas were classified only if fully surrounded in planform by active channel. Active channel width, sinuosity, and braiding intensity were calculated for appropriate geomorphic reaches (reaches with similar confinement characteristics).

Multiple data sources were used to evaluate the historic channel alignment (Table 4.1-1), including those listed in Table 2.6-1 in the RSP (City Light 2021a). Data sets were reviewed and those with the highest spatial resolution, ranging from 0.5- to 3-ft cell sizes, were incorporated. Historic aerial imagery was not orthorectified. As such, georeferencing of the historic images could not align perfectly. The root mean square of image alignment to a series of user-defined control points was generated during georeferencing and used as an indicator of accuracy, coupled with manual review.

Table 4.1-1. Data sources compiled for mapping active channel areas and evaluation of lateral channel migration.

Year	Map/Image Type	Scale/ Resolution	Source/Notes
1915[1]	Historic map	1:10,000	USGS
1944	Black and white (B&W) stereo photos	Unknown	USACE; georeferenced by Collins and Sheikh (2002)
1963/1964	B&W stereo photos	1:12,000	U.S. Forest Service (USFS); images downstream of Marblemount georeferenced by SRSC (2019); additional images upstream of Marblemount acquired for this study
1978	Color stereo photos	1:24,000	NPS; upstream of Bacon Creek only
1979	Color stereo photos	Unknown	USFS; downstream of Marblemount only; Georeferenced by SRSC (2019)
1998	Color stereo photos	1:24,000	NPS; upstream of Bacon Creek only
1998	Color stereo photos	Unknown	USFS; downstream of Marblemount only; georeferenced by SRSC (2019)
1998	Digital imagery	1 m^2	USGS

Year	Map/Image Type	Scale/ Resolution	Source/Notes
2006	Digital imagery	1 m	National Agricultural Imagery Program
2007	Digital imagery	1 ft	Skagit County Pictometry
2018	Digital imagery	0.5 ft	City Light (QSI 2018)
2019	Digital imagery	0.75 ft	Skagit County Pictometry

1 1915 map not digitized.
2 m = meter.

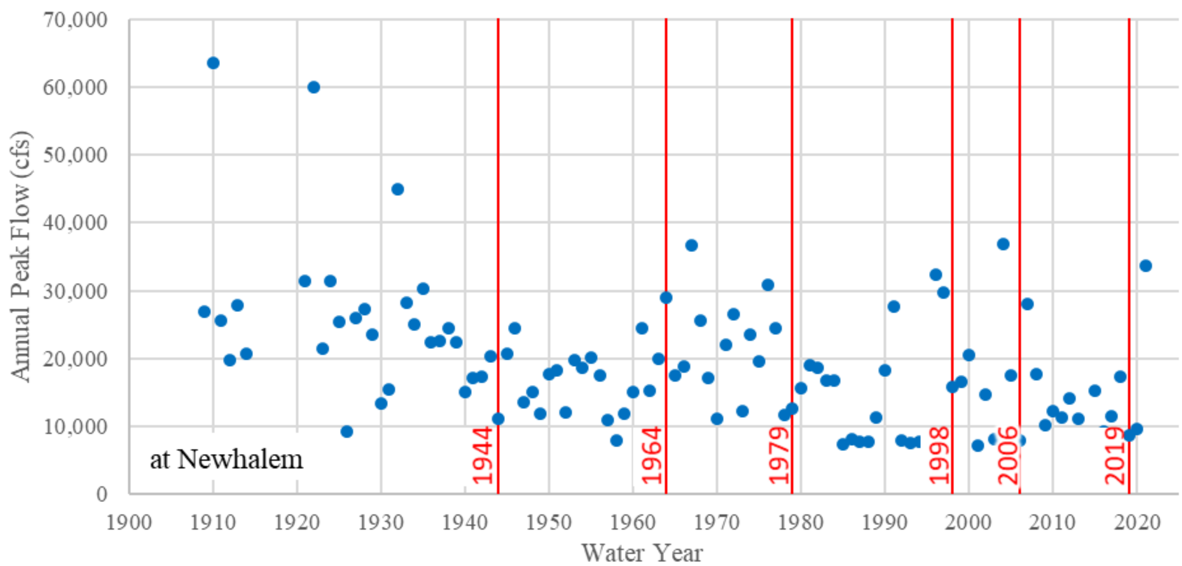

Figure 4.1-1. Time series of annual peak flow (1908-2021) for the Skagit River at USGS gaging stations at Newhalem (USGS 12178000) with overlay of aerial photo sets used in mapping historical channel change. Preliminary data for 2021 flood shown for reference.

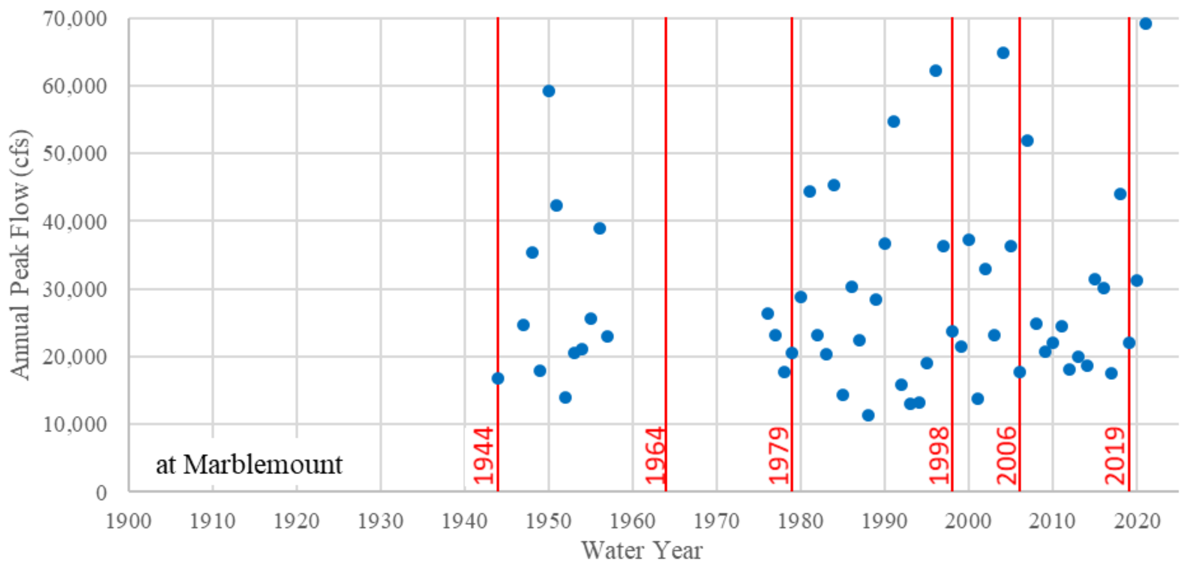

Figure 4.1-2. Time series of annual peak flow (1943-1956; 1976-2021) for the Skagit River at USGS gaging stations at Marblemount (USGS 12181000) with overlay of aerial photo sets used in mapping historical channel change. Preliminary data for 2021 flood shown for reference.

4.1.2 Channel Migration Rates

Areas of lateral channel migration were identified by overlying banklines from consecutive years in the time series using GIS tools in the "Channel Migration Toolbox" from Ecology (Legg et al. 2014). Areas of channel migration were delineated for each bank of the river separately. Channel migration rates were calculated by summing the difference in new channel planform area between aerial photograph years and dividing by reach length. Rates are calculated based only on eroded area where change between imagery was from vegetated floodplain to channel and do not include areas of bar building in calculations. Transects were digitized across the channel migration zone at a longitudinal spacing of 500 ft. Channel width and lateral channel migration between successive years in the time series was recorded along each transect for the period 1944-2019.

Channel migration rates were compared to peak flow conditions between aerial photograph years (Figure 4.1-1 and 4.1-2) and changes to sediment inputs and large wood loading to determine conditions that contribute to bank erosion and channel migration. Channel migration history over the existing license period was represented by historic channel occupancy maps and maps illustrating historic channel positions. Bank protection was considered when analyzing channel migration.

4.1.3 Streambank Characterization

Locations of eroding riverbanks were mapped in the field as part of geomorphic reconnaissance in 2021. Grain size of eroded bank material was described by visual estimate of percent boulder, cobble, gravel, sand, and fines (silt/clay). The location and extent of bank protection limiting channel migration processes was mapped using the existing GIS database from the Upper Skagit

Indian Tribe (Hartson and Shannahan 2015) and verified in the field as part of geomorphic reconnaissance.

This information will be used along with the channel migration analysis to estimate sediment input from bank erosion as part of work to be completed in 2022 based on the methods used by Rothleutner (2017) in the middle Skagit River to allow direct comparison with that study and, for the more recent period with available LiDAR data, by comparing geomorphic change between LiDAR surfaces.

4.1.4 Vertical Channel Changes

As part of work to be completed in 2022, an analysis of USGS gage rating curve changes during the term of the current license (from 1990 to present) will be made at the Skagit River at Newhalem gage (USGS 12178000), Skagit River at Marblemount gage (USGS 12181000), and Skagit River near Rockport gage (USGS 12184700) to evaluate potential channel incision or aggradation as described in Section 2.6.2 of the RSP. These data will be combined with rating curve change analysis from the previous licensing studies (Riedel 1990). If feasible, historic cross-section data at other locations between the Gorge Dam and the Sauk River will be compared with available topobathymetric LiDAR data (QSI 2017, 2018) to evaluate channel changes at locations between gages. A complete assessment of change in stored sediment volume will be completed by comparing the 2017/18 topobathymetric LiDAR data with LiDAR data that will be collected in winter or early spring 2022. Building upon the methods in Section 2.6.2 of the RSP, elevation contours from a 1915 topographic map of the Skagit River produced by USGS will be compared with the current river profile to evaluate vertical channel changes over the period 1915-present.

The Relative Elevation Map based on 2017 and 2018 LiDAR data (QSI 2017, 2018) will be used to analyze channel evolution stage between Gorge Dam and the Sauk River based on the Stream Evolution Model in Cluer and Thorne (2013).

4.2 Aquatic Habitat

The purpose of the Aquatic Habitat Section of this report is to summarize existing information on the status and location of habitat units as well as other mainstem, side channel, and tributary features. The goals and objectives that are associated with aquatic habitat from the list above include the documentation of the following:

- Distribution of aquatic habitat types, characteristics, and availability;
- Substrate size and distribution;
- Large wood input, transport and retention; and
- Process flows that mobilize riverbed and bars.

Some of these objectives integrate information from other studies. The substrate and cover information come from field work conducted under the FA-02 Instream Flow Model Development Study (City Light 2022a) and FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study (Bypass Instream Flow Model Development Study; City Light 2022b). Additionally, once available, modeling output from the FA-02 Instream Flow Model Development Study will be used to identify and validate channel unit types and the distribution of edge habitat. The large wood input, retention/presence information comes from the Large Wood Section within this Geomorphology Study but will be incorporated into the Aquatic Habitat analysis as well.

4.2.1 Habitat Mapping

Per the description in Section 2.6.3 of the RSP, aquatic habitat in the mainstem and side channels of the Skagit River was evaluated using digital resources prior to field verification. The pre-field evaluation was designed to digitize channel units on the Skagit River between Gorge Dam and confluence with Sauk River using remote sensing data. These data were also used to characterize the habitat in the Gorge bypass reach above the Gorge Dam Powerhouse. The data sources used for this effort included multiple LiDAR data sets, aerial imagery, water surface profiles, and landform mapping data sets. Table 4.2-1 lists the specific resources that were included in the desktop analysis of aquatic habitat. The terrain model used to generate the relative elevation models (REM) is a mosaic of the LiDAR data sets from 2017 and 2018 identified in Table 4.2-1 along with field-collected bathymetric and topographic data to fill gaps in terrain coverage and was developed as part of the FA-02 Instream Flow Model Development Study (City Light 2022a). This REM is not the same one used by the NPS for landform mapping (Riedel et al. 2020) as this surface was created from more recent data.

Channel unit definitions in the mainstem were based on relevant literature sources (Table 4.2-2). Channel units included those within the mainstem, as well as blind and flow-through side channels and off-channel habitat that is disconnected to the mainstem via surface water. Tributary mouths were also identified as channel unit types and were assessed as part of the fish passage evaluation as described in Section 2.6.3 of the RSP. The data sets identified in Table 4.2-1 were used to determine the boundaries of each channel unit. The size and detail on the channel unit boundaries were based on the resolution of the data sets rather than on any specific minimum size criteria. The combination of the REM and the water surface elevation allowed for visualization of the bedform, which aided in identification of unit boundaries, specifically pools. Aerial photos were also used to look for evidence of turbulence in surface flow and channel features, such as log jams that would likely cause scour or other deformations of the channel bed. Table 4.2-2 includes the classifications used for channel units along with their descriptions and applicable references.

The process for digitizing the channel units used the 2018 and 2017 topobathymetric LiDAR to first create a wetted edge polygon based on the wetted extents at the time of the LiDAR flights. The wetted extent polygon was then split into individual channel units using the editor in ArcMap. The classification for each channel unit was then assigned according to the classifications listed in Table 4.2-2.

Table 4.2-1. Data resources used in Aquatic Habitat desktop evaluation.

Data Type	Year	Extent	Notes/Reference	Flow at Time of Flight (cfs)[1]
Topobathymetric LiDAR	2018	Gorge Dam to PRM 75.9	REM in development; (QSI 2018)	6,000 to 7,500
Topobathymetric LiDAR	2017	PRM 75.9 to Sauk River	REM created and used (QSI 2017)	8,000
Aerial Imagery	2018	Gorge Dam to PRM 75.9	0.5 ft Quantum Spatial image (QSI 2018)	6,000 to 7,500
Aerial Imagery	2017	PRM 75.9 to Sauk River	Skagit County data set (no report, May 2017 identified in metadata)	5,310 to 14,900 during May 2017
Water Surface Profile	2018	Gorge Dam to Sauk River	Created during hydraulic model calibration (City Light 2022a)	6,000 to 7,500
Landform Mapping	2016	Gorge Dam to Sauk River	NPS data layer (Riedel et al. 2020)	Multiple flows from March 2016 - June 2017

1 Flows are presented at USGS Gage 12181000, Skagit River at Marblemount.

Table 4.2-2. Channel unit classifications used for aquatic habitat.

Channel Unit	Description	Reference(s)
Pool	Obvious scoured depression in bed, often with notable pool tail crest.	Beechie et al. 2005; Bisson et al. 1988
Glide	Steeper than pools but less steep than runs, no obvious depression in the bed and little surface turbulence.	Beechie et al. 2005
Riffle	Turbulent flow, shallow, generally 1-4 percent gradient.	Bisson et al. 1988
Run	Generally, 1-4 percent gradient (steeper than glides), laminar flow.	
Rapid	Turbulent flow, generally > 4 percent gradient.	Bisson et al. 1988
Cascade	Steep unit > 4% gradient with series of drops and step pools noted in the water surface elevation profile.	Bisson et al. 1988
Backwater	Slow water unit formed along the bank of mainstem.	Hawkins et al. 1993; Bisson et al. 1988
Blind Side Channel	Side channel to the mainstem with less flow than the mainstem and separated by an island with permanent vegetation; connected at one end of the channel per surface water connection depicted in 2018 and 2019 aerial photos and field observations from August 2021.	Side channels to be included in the survey were presented during engagements with the LPs
Flow-Through Side Channel	Side channel to the mainstem with less flow than the mainstem and separated by an island with permanent vegetation; connected at both inlet and outlet per surface water connection depicted in 2018 and 2019 aerial photos and field observations from August 2021.	Side channels to be included in the survey were presented during engagements with the LPs
Off-Channel Habitat	Disconnected aquatic habitat per surface water connection depicted in 2018 and 2019 aerial photos and field observations from August 2021.	

After the initial desktop-based channel unit mapping was completed, the study areas were surveyed by boat or foot in the field during August 2021 (multiple dates between August 12 and 27) to validate unit classifications and boundaries. Flows during this time frame ranged from 2,500 cfs to 4200 cfs on the Marblemount Gage (USGS Gage 1218100) (Figures 4.2-1 and 4.2-2). At the Concrete gage (USGS 1219400) flows ranged from 5,500 cfs to 11,300 cfs. Bacon Creek flows (USGS 12179900) ranged from 100 to 200 cfs, while the Cascade River (USGS 12182500) fluctuated between 380 and 900 cfs. Any differences between the assigned unit classifications or unit boundaries and the observed conditions in the field were logged with Global Positioning System (GPS) coordinates and notes describing the needed edits. Revisions were made in ArcMap to the channel unit polygons using points and descriptions collected in the field. Cover data was mapped as a part of the FA-02 Instream Flow Model Development Study (City Light 2022a). Velocity, depth, and cover information will be integrated once the FA-02 Instream Flow Model Development Study hydraulic model is complete (e.g., for edge habitat metrics identified in Table 4.2-3) and will be reported in the USR in 2022.

Quality Assurance and Quality Control procedures were implemented by two senior staff members on the study team (a Senior Fish Biologist and a Principal Geomorphologist) to verify the boundaries and classifications of the habitat map layer. Channel units were then used as the spatial basis to characterize quantity and quality of habitat across the study area. Unit boundaries were applied to the data collected on substrate (from FA-02 Instream Flow Model Development Study [City Light 2022a]) and large wood to summarize habitat conditions throughout the study area. Data on cover (from FA-02 Instream Flow Model Development Study) will be integrated in 2022 and reported in the USR. Analytical procedures were then applied to these data sets to calculate metrics to be used to summarize the current habitat conditions in the mainstem and tributary habitats.

Analysis of the unit specific data used the same reaches that were designated as part of the NPS Landform Study (Riedel et al. 2020), with some of the reaches subdivided into subreaches (see Section 4.0 of this study report). The original seven reaches from the landform survey were divided into 10 subreaches for further summary and analysis based on differences in sediment transport and geomorphic context. Figures 4.0-1 through 4.0-4 above show the reaches and subreaches used in the summary of aquatic habitat data for the mainstem Skagit River.

Habitat metrics in the analysis include those used in the Puget Sound Status and Trend Monitoring Program (Beechie et al. 2017) for large rivers and other metrics commonly used to describe habitat quality. Table 4.2-3 includes the metrics proposed to summarize the quantity and quality of aquatic habitat. Some of these metrics that can be calculated with available data are included in Section 5.2 of this study report. Centerline length and area by channel unit classifications were calculated from the composite surface and water surface profile used in FA-02 Instream Flow Model Development Study (City Light 2022a). Edge habitat metrics rely on output from the hydraulic model (velocity and depth) and will be reported in the USR. Per Section 2.6.3 in the RSP, depth data will be provided and validated as part of the FA-02 Instream Flow Model Development Study.

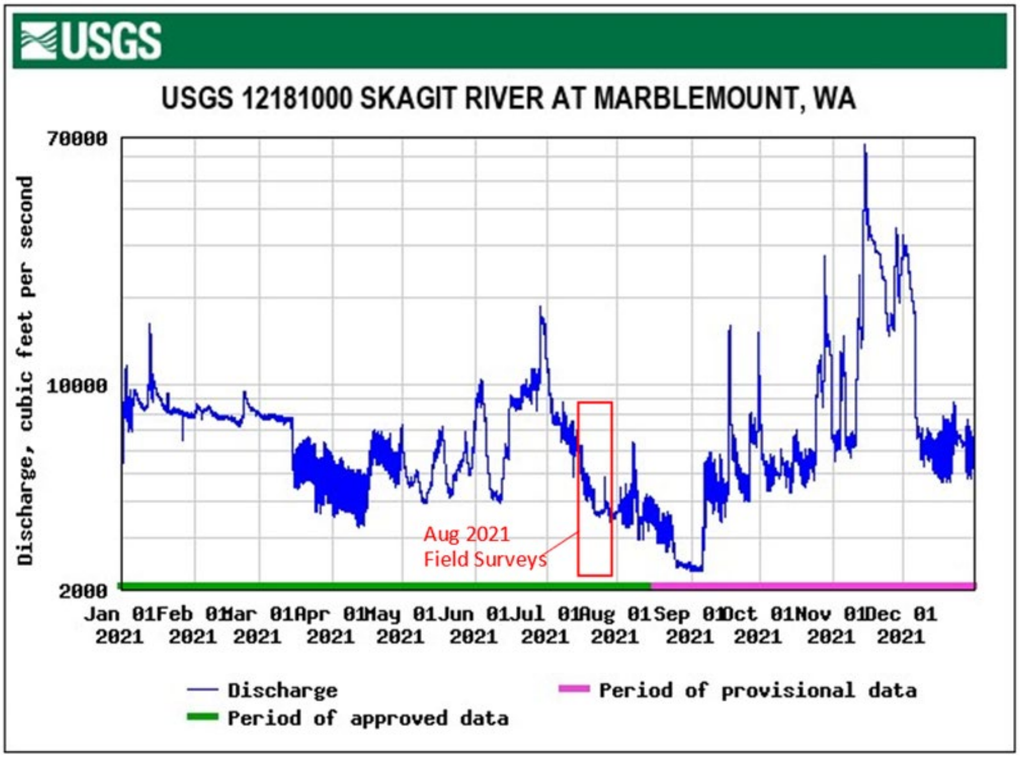

Figure 4.2-1. Skagit River flows during 2021 (USGS 12181000).

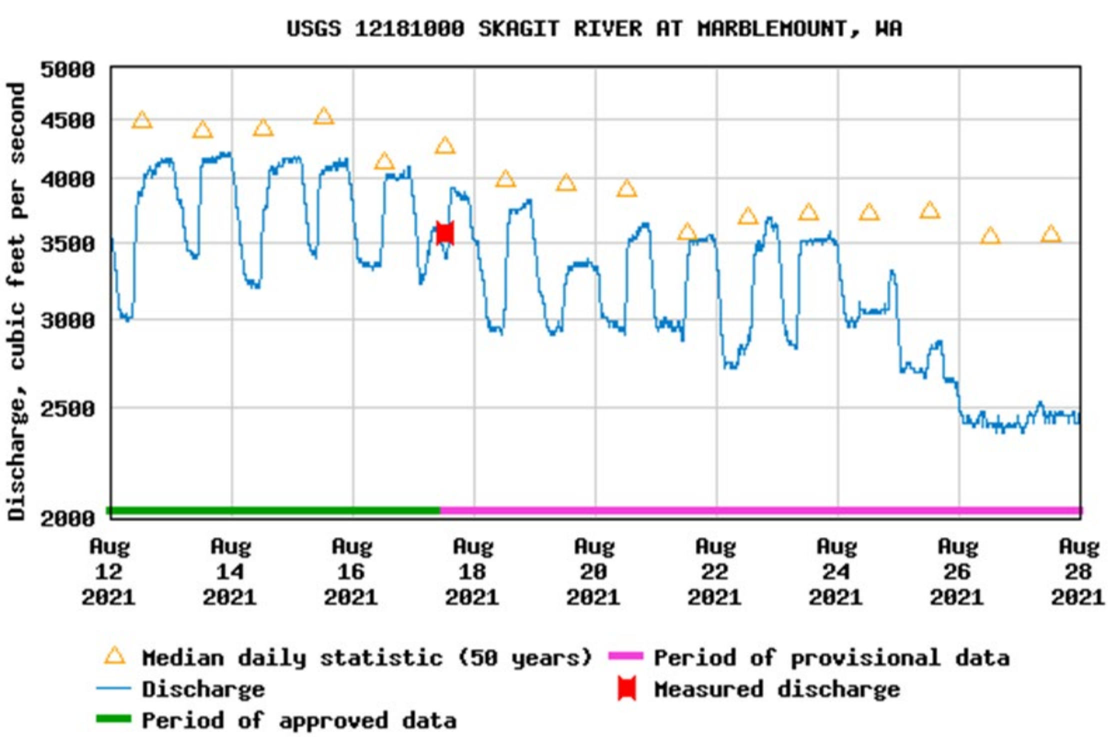

Figure 4.2-2. Skagit River flows during the 2021 Habitat Mapping field survey (USGS 12181000).

Table 4.2-3. Habitat metrics for aquatic habitat mapping summary.

Habitat Metric	Description	Metric
Centerline Length	Length of the mainstem channel	miles
Area by Channel Unit Classifications[2]	Area of each channel unit summed across the classification	ft^2
Area of Edge Habitat[3]	Area of habitat with less than 0.15 m/s velocity and less than 0.6 m depth	ft^2
Area of Edge Habitat with Cover[4]	Area of habitat with less than 0.15 m/s velocity and less than 0.6 m depth that also has cover mapped	ft^2
Percent Hydromodified	Proportion of length on right and left banks that is hydromodified	percent
Percent Actively Eroding	Proportion of length on right and left banks that is actively eroding	percent
Dominate Substrate	Proportion of pool habitat with specific class of substrate	percent
Number of Log Jams	Number of jams with greater than 10 qualified pieces	number
Number of Key Pieces	Number of qualified key pieces	number
Number of Bar Apex Jams	Number of apex jams	number
Pools per Mile with Cover	Number of pools with >10 percent cover divided by the length of centerline	number/mile
Pools per Channel Width	Pool frequency scaled by bankfull width	number/(reach length/bankfull width)
Average Pool Depth	Average of each pool depth summed for the reach	ft
Wetted Width[1]	Width of each channel unit	ft
Bankfull Width	Average bankfull width	ft
Bankfull Depth	Average bankfull depth	ft
Number of Channel Units per Mile	Number of total channel units per mile of centerline	number/mile
Percent Cover	Percent of surface area with cover	percent

1 Wetted width will be calculated for each channel unit, but only reported as part of ArcGIS deliverable.
2 Area values were calculated from the 2017 and 2018 LIDAR with flows of 8,000 cfs and 6,000-7,500 cfs respectively.
3 Edge habitat calculations rely on output from FA-02 Instream Flow Model Development Study (City Light 2022a) and will be completed for the USR.
4 Cover data will be incorporated for the USR.

Similarly, cover data was collected as part of the FA-02 Instream Flow Model Development Study and will be included in the USR. Cover includes the following categories: undercut banks, overhanging vegetation, rootwads, log jam/submerged brush pile, log(s) parallel to bank, aquatic vegetation, short (<1') terrestrial grass, tall (>3') dense grass (e.g., reed canary grass), and vegetation >3 vertical ft above stage zero flow (WDFW and Ecology 2016). Information on hydromodifications was available in a 2015 data set from the Upper Skagit Indian Tribe (Hartson and Shannahan 2015) and was summarized by percent of bank length across reaches. Percent length of channel actively eroding pertains to areas where we noted disturbance of vegetated banks or indicators of bank instability (Bauer and Burton 1993) and was calculated by comparing changes in bank alignment between the 2006 and the 2019 aerial photos as part of the Geomorphic

Change Section in this study as well as through observations made in the field. Additional information such as pools per bankfull channel width (mainstem length divided by the bankfull width were used to normalize pool frequency by channel size) are used to describe habitat quality and are included in Section 5.2.1 of this study report.

4.2.2 Tributary Analysis

Building on the habitat mapping of tributaries within the study area, field surveys in the lower 500 ft of each tributary were conducted in August 2021 when flows were projected to be at seasonal low conditions. Flows during August 2021 ranged from 2,390 to 5,400 cfs at the Marblemount gage (USGS 12179000). Figure 4.2-3 shows the 2021 water year with daily flows, with the survey timing identified. The August 2021 data collection events took place during the low flow period for the 2021 water year. Additionally, Figure 4.2-4 shows the flows in August 2021 as well as the average August daily flows through the period of record. For most of the dates in August, the flows were below the mean flow for that date across the period of record. Therefore, flow conditions were representative of common low flow conditions during the surveys.

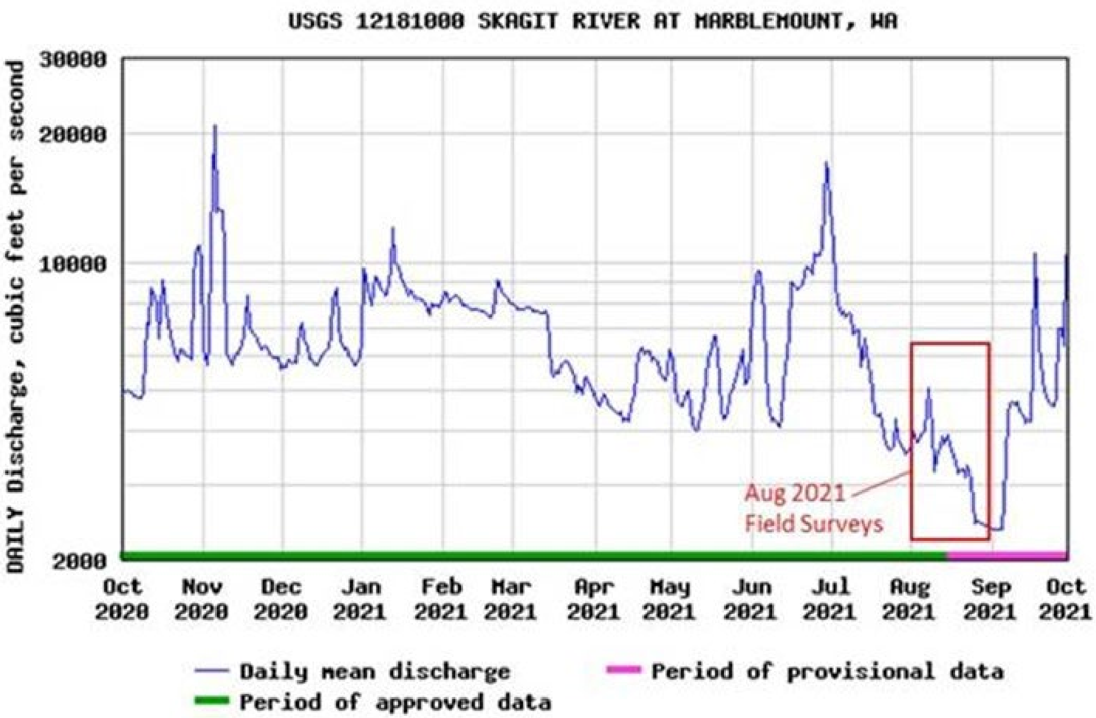

Figure 4.2-3. Skagit River flows during the 2021 water year at USGS gage 12181000.

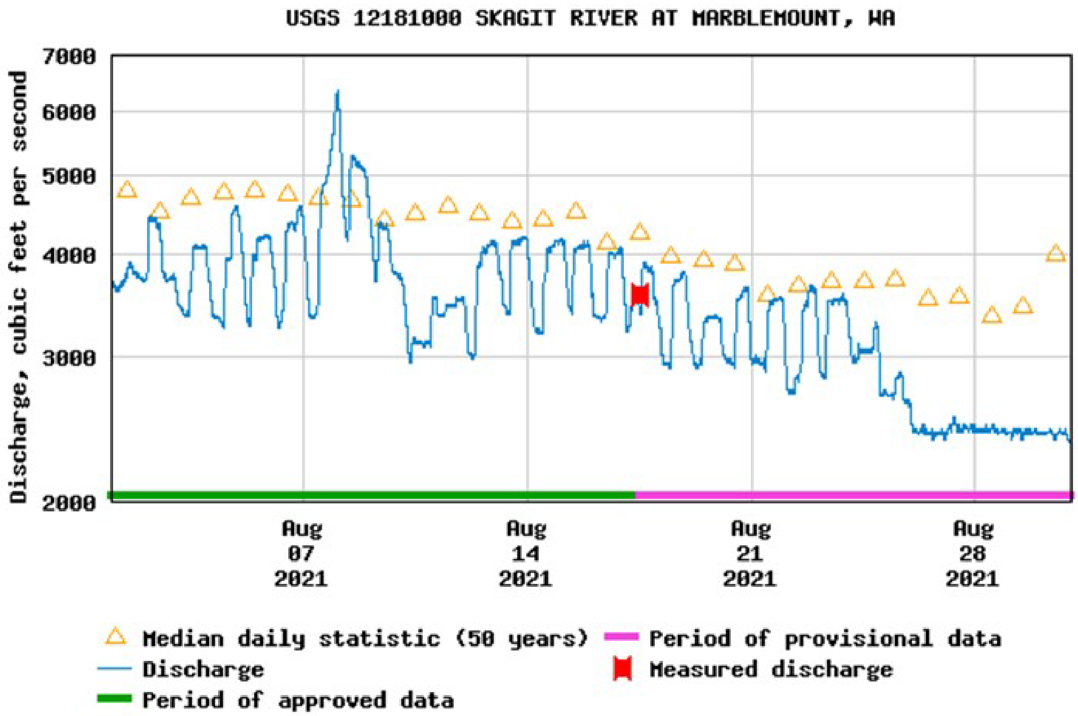

Figure 4.2-4. Skagit River flows during August 2021 at USGS gage 12181000.

Surveys were designed to assess potential fish passage issues at tributary mouths. Per Section 2.6.3 of the RSP, water depths were measured at each tributary and compared to minimum water depths required for adult migration to assess passage. Based on further literature review, the survey methods were expanded to include stream width and stream gradient. According to Reiser et al. (2006), in a study evaluating typical leaping and swimming capabilities of adult salmonids in Ward Creek, Alaska, the typical minimum swimming water depth for all five species of Pacific salmon and steelhead is 0.56-ft; however, this can be affected by extenuating circumstances such as linear distance of shallow water depths, proximity to pools large enough for adults to rest in and submerge gills in, and deterioration of adult spawners at time of passage (Reiser et al. 2006; WDFW 2019).

Minimal regulatory guidance exists around solely using water depth as an indicator of fish passage, and no specific depth criteria are present in the WDFW Fish Passage Manual (WDFW 2019) as surveys occur throughout varying times of the year and flow levels fluctuate widely. Therefore, water depth profiles, stream width, and stream gradient were all collected, as well as the presence of any other potential natural or artificial barriers per WDFW guidance. Assessment of fish passage issues was primarily guided by the WDFW Fish Passage Inventory, Assessment, and Prioritization Manual (WDFW 2019).

Field surveys used a range finder attached to a monopod, a prism, and a stadia rod to obtain water depth, wetted width, and vertical and horizontal distance measurements following guidance by WDFW 2019. Bankfull width measurements were collected instead of wetted width if no surface water was present in the stream. Bankfull width measurements followed collection criteria as outlined in WDFW 2019.

4.3 Side Channels and Off-Channel Habitat

The purpose of the Side Channels and Off-Channel Habitat Section is to characterize the existing condition and distribution of these habitats as well as discuss the processes involved in the formation and loss of side channel habitats through time. The goals and objectives that are associated with side channel and off-channel habitat from the list above include documentation of the following:

- Side channels and off-channel habitat, including hydraulically-connected wetlands;
- Substrate size and distribution;
- Large wood input, transport, and retention;
- Process flows that instigate side channel development/maintenance; and
- Process flows that hydraulically connect side channel and off-channel habitat.

Some of these objectives integrate information from other studies. The substrate and cover information comes from field work conducted under the FA-02 Instream Flow Model Development Study (City Light 2022a) and will be incorporated into this Geomorphology Study analysis. The large wood input, retention/presence information comes from within this Geomorphology Study in the Large Wood Section but will be incorporated into the Side Channel and Off-Channel Habitat Section as well. Per Section 2.6.4 of the RSP, information from the TR-02 Wetland Assessment (City Light 2022e) was reviewed to further inform the analysis of side channel and off-channel habitat.

4.3.1 Existing Condition Side Channel Field Methods

Side channels to be visited in the 2021 field season were identified by a collaborative process with City Light and LPs in July 2021. As part of this process, and as described in Section 2.6.4 of the RSP, an initial map of side channels and off-channel habitat was made. This data layer was built using the green LiDAR and geo-referenced aerial photos. The map also integrated information from the NPS landform mapping project (Riedel 2020) and the TR-02 Wetlands Assessment (City Light 2022e). Following the initial presentation of the map of proposed side channel and off-channel habitat for survey, LPs were invited to comment, as well as make additions or deletions. Information gained from LPs during these conversations was utilized in the planning of the field survey effort. Surveys of the side channels identified by City Light and LPs were then conducted in August 2021. The surveys focused on assessing how connected each side channel was to the river and geomorphic and salmonid habitat characteristics of the side channels.

Each side channel inlet and outlet were surveyed. Measurements included water depth, dominant and subdominant substrate size, and presence of large wood and hydromodifications. At select locations pebble counts and relative datum cross sections were collected. Side channels were walked and characterized, focusing on documenting features such as presence of pools, large wood, overhanging vegetation, beavers, juvenile salmonid use, measuring representative depths, substrate size, and noting conditions such as recent erosion or colonization by vegetation.

Side channel types were classified as perennial, seasonal, or inactive based on field observations. A side channel was classified as perennial if it was wetted during the August 2021 survey. More refined analysis assessing the connectivity of side channels at standardized flow recurrences will occur when hydraulic modeling results from the FA-02 Instream Flow Model Development Study are available and results will be reported on in the USR.

Additional information on substrate and fish cover collected as part of the FA-02 Instream Flow Model Development Study (City Light 2022a) will also be incorporated in this Geomorphology Study side and off-channel analysis and will be reported on in the USR.

4.3.2 Existing Condition Side Channel Desktop Analysis Methods

Side channels were digitized using REM based on August 2020 and March 2021 water surface elevation profiles collected as part of hydraulic model calibration for the FA-02 Instream Flow Model Development Study (City Light 2022a). The terrain model used for the REMs is discussed in Section 4.2.1 Habitat Mapping methods and was created as part of the FA-02 Instream Flow Model Development Study. Side channel delineations were further refined using field observations to help confirm elevations from REMs and to define the limits of side channels where LiDAR resolution was insufficient. The digitized side channels were used to calculate an approximate area for each side channel. The approximate area of each side channel is presented in the results to aide in understanding the relative size of each feature; however, the areas are provisional. Results from the FA-02 Instream Flow Model Development Study hydraulic model will help refine side channel areas relative to various river discharges and will provide additional data to compare side channel areas.

4.3.3 Time Series Analysis of Side Channel and Off-Channel Habitat

Methods for the time series analysis of side channel and off-channel habitats are described in Section 4.1 of this study report as well as in Section 2.6.4 of the RSP. The same sets of photographs were used for the identification of side channel and off-channel habitats as those used for geomorphic and channel change. Since REM data for each time step in the time series was not available, aerial photos and maps were the primary data sources for this analysis. Variance in the relative quality and season during which the photos were captured affect the level of detail in observed side channels for each time step. For example, the photos used from 2006 were taken during the leaf-off stage, while other photo sets were captured when leaves were still present in the canopy. This may result in a higher level of detail in the side-channels mapped for 2006 as compared to other years. Conversely, photos from earlier periods (e.g., 1944) were of lower resolution and may show a lower level of detail in the side channels mapped as compared to other years.

Mapped areas and lengths of side channel and off-channel habitat were then used to calculate the metrics shown in Table 4.3-1 (where feasible). Braids were identified as channels of the mainstem that were separated from the thalweg by gravel bars at time of image capture. Side channels were identified as those separated from the mainstem flow by islands with permanent vegetation. The River Complexity Index (RCI) has been used to measure the relative level of habitat diversity and quality in paleochannels and integrates sinuosity (the relationship between channel length and valley length) and the number of junctions with braids or side channels within a given length of channel (Brown 2002). See Figures 4.1-1 and 4.1-2 for annual peak flow information surrounding date of image capture.

Table 4.3-1. Side channel and off-channel metrics for time series analysis.

Metric	Description	Unit
Length of Side Channel	Length of flow-through and blind side channel habitat	Miles
Area of Side Channel/Off-Channel Habitat	Area of side channel and off-channel habitat	Ft^2
Braid Ratio	Length of channel in braids divided by length of mainstem	Ratio
Length of Side Channel/Length of Mainstem	Length of side channel divided by length of mainstem	Ratio
Braid Node Density	Number of intersections of braids with mainstem per mile of mainstem length	Number/mile
Side Channel Node Density	Number of side channel junctions per mile of mainstem length	Number/mile
River Complexity Index[1]	RCI = S(1+J) S= Sinuosity J = number of junctions in the reach	Number

1 The River Complexity Index (RCI) (Brown 2002) integrates the sinuosity (or relative meander pattern) with the number of joins or junctions in the channel to summarize channel complexity.

4.4 Substrate/Sediment

The investigation of channel substrate described in this Section is intended to document both local variability and along-channel trends in the composition of the channel boundary, as described in Section 2.6.5 of the RSP. This information will contribute to understanding the interaction of sediment supply and channel hydraulics in the river and effects of existing sediment composition and sediment transport processes on salmonid habitat quality. This Section describes methods used to document existing sediment characteristics in the study area.

Substrate conditions vary substantially over small distances in rivers (e.g., from the upstream head of a bar to the downstream tail of a bar), and so it is important to have data describing both local heterogeneity and river-scale trends in bed material composition. When evaluating river scale trends, the best approach is to focus sediment sampling in a characteristic geomorphic environment that most represents typical dominant bed material in the channel. Another important distinction to quantify is the difference between the character of the surface and subsurface sediment. The surface material of riverbed gravel and cobble deposits—the armor layer—is characteristically coarser than the subsurface material, and both the surface and the subsurface material play important roles in governing aquatic habitat, sediment transport, channel form and channel stability. Three principal methods were applied to provide a robust view of bed material sediment through the study area: Wolman (1954) pebble counts of the surficial material, bulk samples of the material below the armor layer, and facies mapping covering the active channel.

A total of 43 bulk samples and 51 pebble counts were collected from bar head locations that were believed to represent typical structural bed material in each reach (e.g., Figure 4.4-1) or pockets of material believed to be typical bedload in steep reaches where the structural bed material is interpreted to be rarely mobilized. Sample sites were selected from aerial photos, and field notes documenting the relationship of the sampled material to surrounding bed material were recorded. Figure 4.4-2 shows locations of sediment samples collected and Table 4.4-1 lists geomorphic positions of each sediment sample. Ultimately, over 26,500 pounds (12,000 kilograms [kg]) of sediment was handled in the process of collecting the bulk samples, and over 5,000 grains were measured for the pebble counts.

Figure 4.4-1. Examples of typical sediment sample locations, including the head of an island bar at PRM 90.2 (top) and head of a bank-attached point bar at PRM 78.4 (bottom).

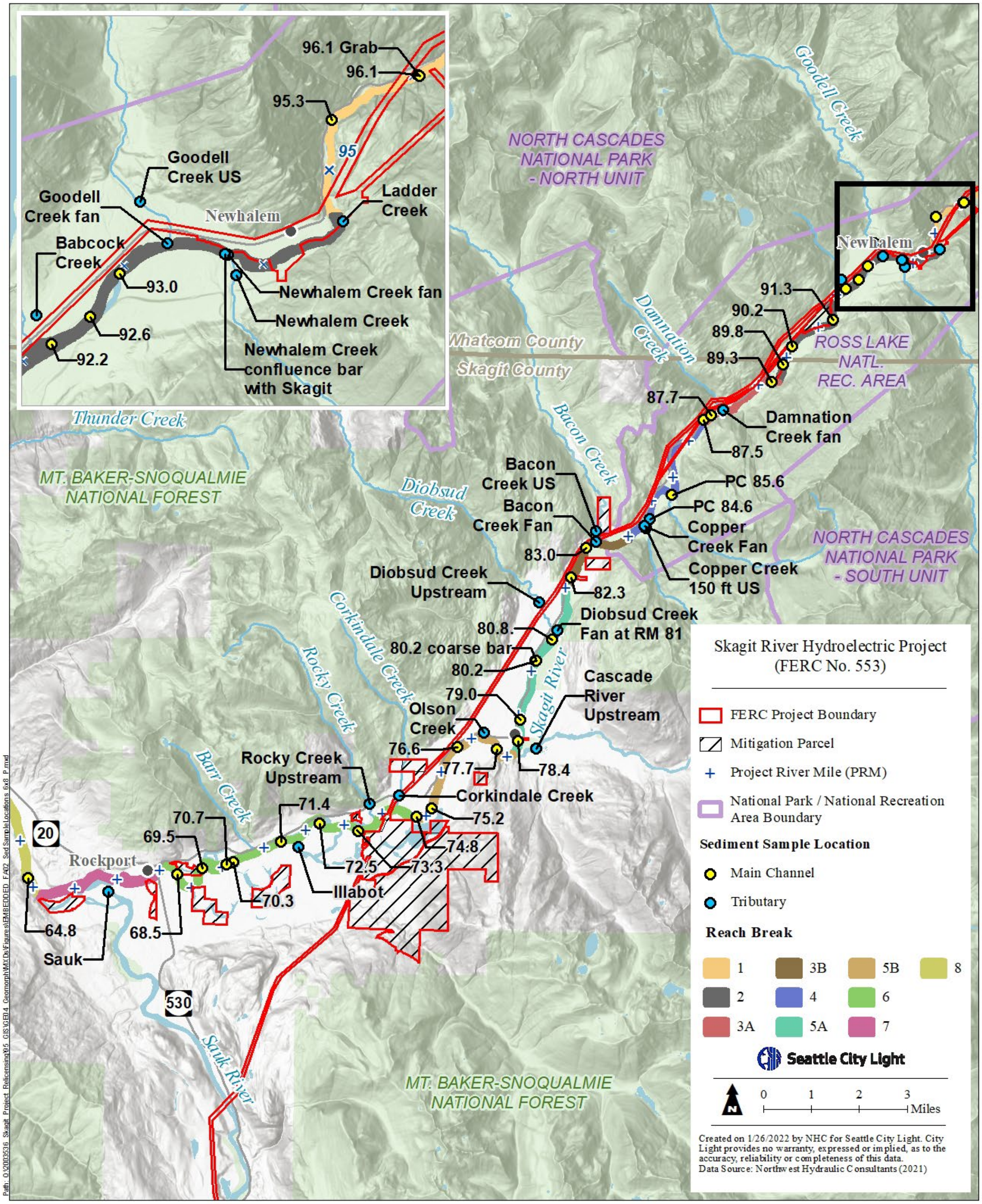

Figure 4.4-2. Overview of sediment sample locations.

Table 4.4-1. Locations of sediment samples.

Sample Location (PRM or Tributary)	Sample Type(s)	Geomorphic Position
96.1	Bulk and Pebble Count	Pocket fine mid-channel bar deposit in lee of boulders. Believed to represent throughput bedload in reach.
95.3	Pebble Count	Relatively fine-grained point bar.
93	Bulk and Pebble Count	Riffle crest bar head.
92.6	Bulk and Pebble Count	Head of point bar; anomalously coarse, some soil development beginning between cobbles, moss establishing on lg cobble to small boulder heavy periphyton growth.
92.2	Bulk and Pebble Count	Head of mid-channel island bar, similar to typical material in channel across riffle upstream.
91.3	Bulk and Pebble Count	Head of stabilizing island bar at riffle crest.
90.2	Bulk and Pebble Count	Head of stabilizing island bar at riffle crest.
89.8	Bulk and Pebble Count	Head of riffle crest bar.
89.3	Bulk and Pebble Count	Head of mid-channel bar, extremely bimodal (lg gravel and cobble and sand).
87.7	Bulk and Pebble Count	Head of large island bar, light moss and periphyton development, characteristic of typical bed material in reach.
87.5	Bulk and Pebble Count	Mid channel bar in lee of island, clearly developed by material deposited out of transport in the right bank channel, some moss, periphyton, and small willow establishing.
84.6	Bulk and Pebble Count	Head of point bar, relatively high topographic position due to higher flow at time of sampling.
83	Bulk and Pebble Count	Head of point bar that extends into riffle downstream.
82.3	Bulk and Pebble Count	Head of riffle crest bar.
80.8	Bulk and Pebble Count	Head of point bar on right bank just downstream of Diobsud Creek confluence.
80.2	Bulk and Pebble Count	Head of compound point bar.
80.2	Pebble Count	Head of coarse point bar landward of compound point bar.
79	Bulk and Pebble Count	Head of island bar.
78.4	Bulk and Pebble Count	Middle of very long point bar on inside of meander.
77.7	Bulk and Pebble Count	Head of compound point bar at riffle crest.
76.6	Pebble Count	Across large geomorphically-controlling riffle.
75.2	Bulk and Pebble Count	Head of riffle crest point bar.
74.8	Bulk and Pebble Count	Middle of very long point bar on inside of meander.
73.3	Bulk and Pebble Count	Head of stabilizing mid-channel bar that is transitioning towards a point bar similar to material at site and upstream but coarser than material in channel downstream. Some periphyton but very little moss growth.
72.5	Bulk and Pebble Count	Head of large island bar at backwater upstream of revetment where river impinges against SR 20.

Sample Location (PRM or Tributary)	Sample Type(s)	Geomorphic Position
71.4	Bulk and Pebble Count	Head of riffle crest point bar.
70.3	Bulk and Pebble Count	Head of riffle crest point bar.
70.1	Pebble Count	Across whole area of compound point bar.
69.5	Bulk and Pebble Count	Head of actively growing point bar.
68.5	Bulk and Pebble Count	Head of riffle crest point bar.
64.8	Bulk and Pebble Count	Head of very large island bar at riffle crest caused by flow expansion.
Alma Creek Fan	Bulk and Pebble Count	Point bar that is a pocket deposit interpreted to be comprised of throughput bedload. Finer than typical structural bed material that is boulder.
Babcock Creek	Bulk and Pebble Count	Riffle crest across thalweg of dry creek.
Bacon Creek Fan	Bulk and Pebble Count	Relatively coarse active lobes of fan.
Bacon Creek Upstream	Bulk and Pebble Count	Middle of point bar.
Cascade River	Bulk and Pebble Count	Head of island bar connected to riffle crest.
Copper Creek Fan	Pebble Count	Across confluence bar formed at- and downstream of creek outlet.
Copper Creek Upstream	Pebble Count	Across whole channel.
Corkindale Creek	Bulk and Pebble Count	Riffle crest across thalweg of dry creek.
Damnation Creek Fan	Bulk and Pebble Count	Relatively coarse active lobe of fan.
Diobsud Creek Fan	Bulk and Pebble Count	Head of active lobe of fan.
Diobsud Creek Upstream	Bulk and Pebble Count	Head of riffle crest point bar.
Goodell Creek Fan	Bulk and Pebble Count	Across active lobe of fan.
Goodell Creek Fan	Bulk and Pebble Count	Head of island bar.
Illabot Creek Upstream	Bulk and Pebble Count	Head of island bar (within backwater influence of Skagit River).
Ladder Creek Fan	Bulk and Pebble Count	Across terrace bar formed by recent aggradation-degradation episode.
Newhalem Creek Fan	Pebble Count	Across coarse lobes of confluence fan.
Newhalem Creek Upstream	Pebble Count	Pockets of mobile bed material just downstream of bridge, finer than structural boulder bed material in reach.
Olson Creek Upstream	Bulk and Pebble Count	Riffle crest across thalweg of dry creek.
Rocky Creek Upstream	Bulk and Pebble Count	Pocket bar deposit typical of transported bedload upstream of channel spanning large wood jam, finer than structural bed material.
Sauk River	Bulk and Pebble Count	Head of riffle crest point bar.

4.4.1 Pebble Count Methods

Pebble counts (n=100) were collected following a standard Wolman (1954) random-walk procedure and used gravelometer templates to measure particles in half-phi size classes up to a b-axis diameter of 180 millimeters (mm). The b-axis of particles larger than 180 mm was measured using a tape or measured increments on the side of the gravelometer and recorded in half-phi size bins. Pebble counts were collected from locations adjacent to bulk samples from areas with a visually similar grainsize distribution to the location of the bulk sample.

In addition to the standard particle size measurements, the lithology of each measured particle was also recorded. Lithology classes were defined to be readily field-identifiable and provide indications of the source area for the particle. The study team worked with Jon Riedel (retired North Cascades National Park Geologist) to determine these lithology classes, which are identified in Table 4.4-2.

Table 4.4-2. Lithology classes used in pebble counts.

Lithology Class	Geologic Domain	Characteristic Geologic Units[1]	Principal Tributary Basin(s)	Notes
Cherty Conglomerate	Eastern Cascades	MzPzH, Ktf	Upper Basin	
Panther Creek Conglomerate	Eastern Cascades	Kjos	Upper Basin	
Metasedimentary	Eastern Cascades	MzPzH, Ktf, KJv, Km, TKm	Upper Basin	Includes well-indurated marine sedimentary
Orthogneiss	Central Crystalline Core	Tkgo, Tkmo, TKsn, Tkso, Tkto	Upper Basin, Ladder Creek, Newhalem Creek, Goodell Creek, Alma Creek, Cascade River	
Banded Gneiss	Central Crystalline Core	Knmg, Kswg, TKmm, TKsg	Upper Basin, Ladder Creek Newhalem Creek, Cascade River, Sauk River	
Granodiorite and Other Intermediate to felsic intrusives	Central Crystalline Core	Kg, Kjya, Kmd, Kt, Ktm, QTcp, Tcai, Tcas, Tei, TKmd, TKrb	Upper Basin, Goodell Creek, Damnation Creek, Bacon Ck, Copper Creek, Cascade River, Illabot Creek, Sauk River	
Napequa Schist	Central Crystalline Core	TKns, Kns	Newhalem Creek, Alma Creek, Copper Creek, Bacon Creek, Cascade River, Illabot Creek, Sauk River	May be conflated with Blueschist, especially from units Kcs and TKcs.
Greenschist & Ultramafic	Western Cascades and Central Crystalline Core	Kes, KJts, Knu,TKcs, TKhg, TKhm, Tknu, KTsx	Bacon Creek, Diobsud Creek, Cascade River, Olson Creek, Corkindale Creek, Illabot Creek, Sauk River	
Blueschist	Western Cascades	Kcs, Kncs, TKcs	Copper Creek, Cascade River, Sauk River	May be conflated with Napequa Schist.

Lithology Class	Geologic Domain	Characteristic Geologic Units[1]	Principal Tributary Basin(s)	Notes
Metaconglomerate	Western and Eastern Cascades	Various	Upper Basin	
Clastic Sedimentary	Western and Eastern Cascades	JTrc, Kjn, Kps, PDc, Tees, Tes	Upper Basin, Bacon Creek, Corkindale Creek, Rocky Creek, Sauk River	
Darrington Phyllite	Western Cascades	Ked	Diobsud Creek, Olson Creek, Corkindale Creek, Illabot Creek, Sauk River	Higher grade material may be conflated with Blueschist
Volcanics, General	Western Cascades	Jnw, Qcav, Qtcc, Tcaf, Tcao Tev	Upper Basin, Goodell Creek, Bacon Creek, Sauk River	
Vesicular Volcanics	Western Cascades	Qcav	Sauk River	Distinctive tracer to Sauk River
Metavolcanic	Western and Eastern Cascades	Kpv, MzPzH	Upper Basin, Ladder Creek, Bacon Creek, Cascade River, Diobsud Creek, Illabot Creek, Ladder Creek	Likely includes many other lithologies with fine textured dark matrix material
Quartz & Quartzite	All	Various	N/A	
Other or not identifiable	N/A	N/A	N/A	

1 Geologic unit codes follow Haugerud and Tabor (2009).

4.4.2 Bulk Sample Methods to Characterize Sub-surface Material

Bulk samples of the material below the surface armor layer were collected following the method of Church et al. (1987). To do this, the surface armor layer was removed and then a pit was excavated until either the practical sampling limit of 440 pounds (200 kg) or a volume sufficient that the largest particles in the deposit made up no more than 1 percent of the sample weight was obtained (the 1 percent criteria). The bulk sample material was field-sieved to separate material at the 32 mm size. Material larger than 32 mm was divided into half-phi grainsize classes using a gravelometer, and the weight of each class was measured in the field. A 30-45 pound sub-sample of the material smaller than 32 mm was retained for grainsize analysis following American Society for Testing and Materials standards, and was performed by Materials Testing & Consulting, Inc. Field and lab grainsize distributions for each bulk sample were then combined based on the split ratio of the material; water weight was assumed to be evenly distributed through the <32 mm fraction.

4.4.3 Hybrid Grainsize Classification Method

Since the practical sampling limit of 200 kg determined for this study was below the recommended 1 percent criteria for many samples (Church, 1987), the hybrid method of Rice and Haschenburger (2004) was applied to characterize the coarse tail of the bulk grainsize distribution. The decision to apply this method was completed in consultation with LPs during the July 20 and July 27, 2021 Geomorphology Work Group meetings. This method assumes that the surface and subsurface material come from the same source grainsize population and that the surface armor layer formed through selective horizontal removal of fine sediment (winnowing). This implies that the ratio of the weight of a specified match fraction (between the surface and subsurface samples) and each larger grainsize fraction in the surface material can be used to determine the distribution of the coarser material more reliably than would be possible with only the undersized sample. Selection of the match fraction was determined by identifying the largest grainsize fraction meeting the 1 percent sample size criteria. In other words, the match fraction was chosen for the largest grainsize where the cumulative weight of the sample through that size class (smallest to largest) was greater than the 1 percent criteria for material of that size. For our 440-pound (200 kg) samples, the match fraction was most frequently 64-91 mm, and occasionally 91-128 mm.

4.4.4 Facies Mapping

Methods for the facies mapping are reported in the FA-02 Instream Flow Model Development Study (City Light 2022a). This mapping covered large portions of the mainstem Skagit River. These data were analyzed in this Geomorphology Study to understand spatial heterogeneity of the bed material.

4.5 Sediment Transport and Sediment Augmentation

Sediment transport and sediment augmentation studies to be completed within this geomorphic study are focused on understanding the existing conditions of sediment transport, and how patterns of sediment transport and channel morphology may be expected to respond to different inputs of flood flows, sediment, or both factors (channel process sensitivity). To do this, a modeling program has been developed in collaboration with LPs (based on commitments in the June 9, 2021 Notice and RSP) to develop tools to improve understanding of existing conditions and channel process sensitivity related to bedload transport, channel profile changes (aggradation and degradation), cross section shape and area, side channel formation and decay, lateral channel migration, and stage-discharge rating adjustments. Bed material load will be addressed with these models, while Project effects on washload will be considered through the lens of sediment yield, as described in Section 4.5.3 of this study report.

Empirical data regarding sediment mobility and sediment transport are also being collected. These data include scour monitoring of select riffle crest locations and locations of known important spawning activity, and the deployment of Radio Frequency Identification Device (RFID)-tagged particle tracers. Concurrent efforts by the USGS to monitor bedload movement using direct sampling and acoustic techniques may also provide supplementary information for quantifying sediment transport.

4.5.1 Sediment Transport Modeling Program

The RSP specified that this study would include both one dimensional (1-D) and two-dimensional (2-D) mobile bed sediment transport modeling. In addition, the June 9, 2021 Notice specified that hydraulic modeling and sediment transport studies would be extended downstream of the Sauk River Confluence. Based on the commitments in the June 9, 2021 Notice, details of the modeling program were developed in collaboration with LPs in a series of workshops held on July 20, July 27, September 28, and November 9, 2021. Conversation at these meetings resulted in some modifications relative to commitments in the June 9, 2021 Notice, which are described in Section 7 of this study report.

The modeling program includes the nested development of four kinds of models to represent key aspects of the Skagit River channel processes. Key questions regarding river processes that can be addressed with sediment transport modeling were identified in consultation with LPs at the September 28, 2021 Sediment Transport Sub-Group work session and October 12, 2021 Geomorphology Work Group Meeting. These questions, and the applicable models to inform answers to them, are listed in Table 4.5-1. Model extents (Figure 4.5-1) were selected based on preliminary understanding of which processes and questions are most important in each area of the Skagit River. These models are described in more detail below.

Table 4.5-1. Applicable models to inform key questions for sediment transport modeling.

Key Question	UBCRM	HEC RAS 1-D	HEC RAS 2-D	MAST 1-D
1. How sensitive is channel width (and therefore side channel prevalence) to channel-forming discharge in each reach? What impact could plausible alternative flow release regimes have on channel width?	X			X
2. How sensitive is channel width (and side channel prevalence) to bed material supply in each reach? How does channel width vary if both Qw and Qb vary?	X			X
3. How sensitive are the channel profile and local stage-discharge relationships to variability in bed material input (both quantity and caliber) and to variability in the flow regime?		X		X
4. How sensitive is the grainsize distribution of the bed material to variability in bed material input and flow regime?		X	X	X
5. What flows are required to mobilize/scour sediment in tributary fans? In spawning areas? Around side channel offtakes?			X	
6. How does wood density affect local and reach-scale sediment transport processes?		X	X	
7. To what extent may changes in flood regime and sediment supply trigger feedback loops that further impact sediment mobility and downstream movement?	X	X	X	X

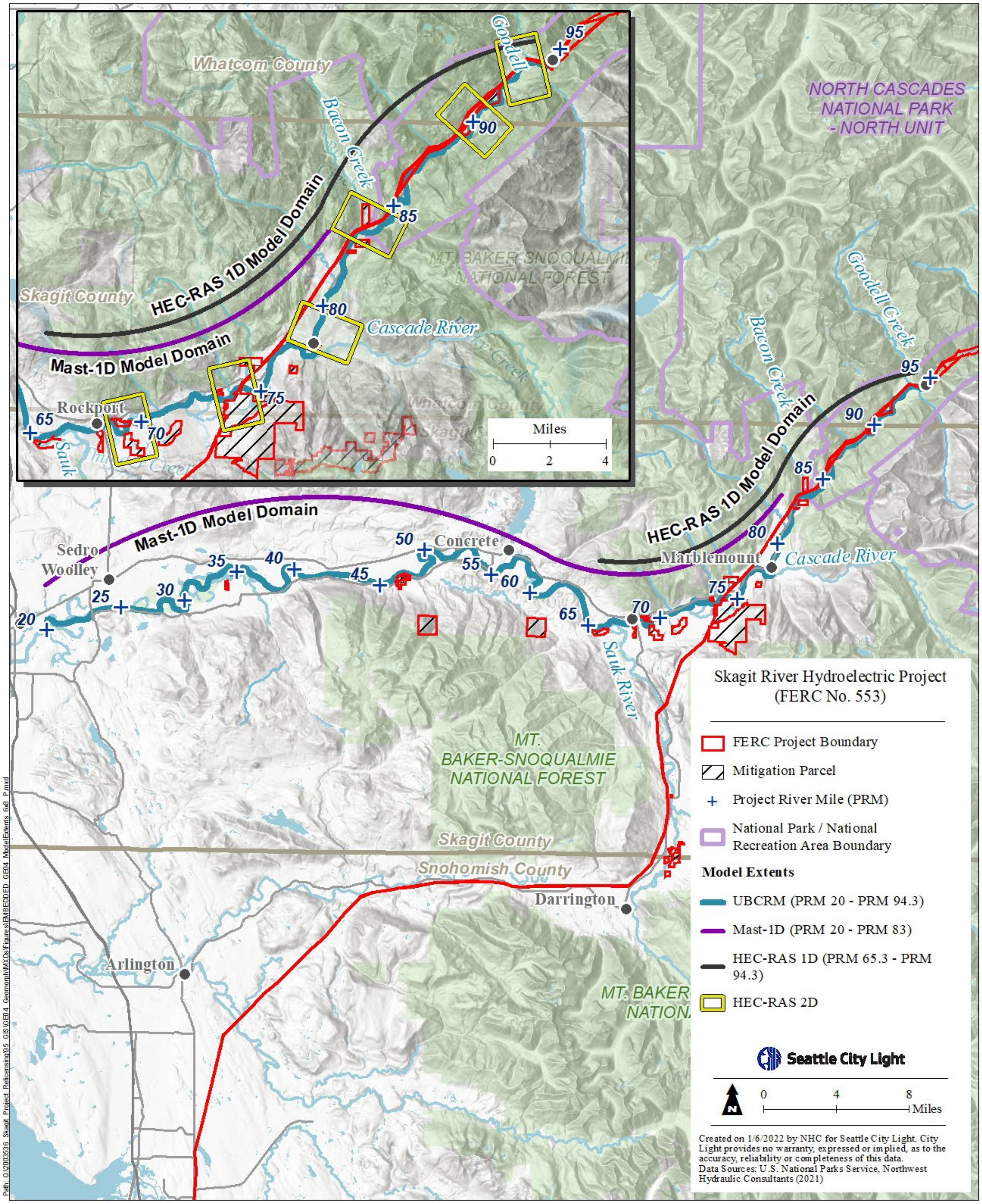

Figure 4.5-1. Initial planned model extents. All models will span the floodplain. Specific upstream and downstream boundaries for HEC-RAS 2-D subreaches will be determined during model development.

4.5.1.1 UBCRM

The University of British Columbia Regime Model (UBCRM) (Eaton 2007; Millar et al. 2014) provides a means to rapidly assess river channel hydraulic geometry and propensity for side channel or multi-channel morphologic adjustments based on prescribed hydrologic and sediment loading scenarios. Base UBCRM parameterizations will be developed for each hydrologically and geomorphically distinct reach of the Skagit River between Newhalem and the gravel-sand transition at PRM 21. For the area upstream of the Sauk River, these reaches are defined in Section 3 of this study report, and they will be defined based on similar criteria for the reach between the Sauk River and the gravel-sand transition. This modeling effort is intended to fulfill commitments in the June 9, 2021 Notice to include evaluation of lateral channel mobility in reaches where that may be an important process and to study controls over geomorphic processes downstream of the Sauk River.

UBCRM provides estimates of channel width-to-depth ratios as a function of sediment loading, slope, bank material strength, and hydrologic conditions. UBCRM comparisons of computed channel widths to those measured by the ongoing morphometric mapping activities will be completed to calibrate modeled bank material strengths throughout the study reach. UBCRM will be applied to evaluate general channel hydraulic geometry and planform sensitivity to a wide plausible range of possible sediment supply and channel forming hydrology conditions.

4.5.1.2 One-Dimensional Mobile Bed HEC-RAS Model

A 1-D mobile bed USACE Hydrologic Engineering Center River Analysis System (HEC-RAS) model will be developed to quantify long-term channel bed and hydraulic profiles of the Skagit River, as described in Section 3.2.2 of Attachment C the RSP. Cross section locations and spacing will be set to capture hydraulic and sediment transport characteristics throughout the study reach, extending from PRM 94 at Newhalem (NPS Reach 2) downstream to PRM 67 near the confluence of the Sauk River (NPS Reach 7). Typical cross section spacing will likely vary between 500 and 1,000 ft. Specific aspects of the 1-D model setup and initial applications are provided in the following points:

- Initial model testing will be to run 50 years of historical flows to assess long-term model application performance and stability.
- Hydraulic model calibration will be based on comparing modeled water surface profiles with available measured river and overbank stage data. Sediment transport calibration will be based on comparative bathymetric surveys (cross sections and comparison of LiDAR-based topobathymetric surfaces, including Winter 2022 LiDAR), measured changes in USGS stage-discharge rating curves (where available), and a qualitative comparison of model predicted locations of sediment throughput (as indicated by the lack of in-channel bar features) and storage (as indicated by the presence of in-channel bar features).
- Tributary sediment inflows will be estimated from slope-area hydraulic calculations, tributary bed material grain size characteristics, and application of appropriate bed material sediment transport relationships.
- Model sensitivity and performance will be assessed by varying hydraulic roughness parameters, and tributary and mainstem sediment inflows.

- Spin up tests may be required to assure proper model performance between measured and modeled bed material, model initial condition characteristics, and computed bed material transport rates over a range of steady state flow rates.

Upon completion of these tasks, the 1-D HEC-RAS model will be applied to describe the existing conditions of the bed material sediment budget for the modeled reach of the river and to quantify long-term evolution (i.e., several decades) of hydraulic and bed profiles for several alternative flow release schedules, flood operations, and other river management scenarios.

4.5.1.3 Two-Dimensional Mobile Bed HEC-RAS Models

A suite of 2-D HEC-RAS models of six subreaches of the Skagit River between Newhalem and the confluence of the Sauk River will be developed, as described in Section 3.2.1 of Attachment C of the RSP. These six subreaches were identified based on discussions with LPs and aim to quantify erosion and deposition processes related to key morphologic and habitat features identified in this reach. The six subreaches are located at approximately the following locations:

- PRM 69 (upstream Sauk confluence);
- PRM 73 (downstream of powerline crossing);
- PRM 79 (Marblemount);
- PRM 83 (Bacon Creek confluence);
- PRM 90 (Countyline); and
- PRM 93 (Goodell Creek confluence).

Reach lengths for each 2-D model vary between approximately 1-2 miles to capture the key morphologic features of interest, such as tributary deltas, key spawning bars, and side channel connections. The 2-D bathymetric surface will be extracted from the 2-D HEC-RAS instream flow model bathymetry presently under development in the FA-02 Instream Flow Model Development Study (City Light 2022a). Grid density may be adjusted from the 2-D instream flow model to better capture sediment transport features of interest, as well as providing reasonable model run times for mobile bed model simulations. Boundary conditions of sediment inflow and downstream starting water surface elevation for each 2-D mobile bed model reach will be extracted from the 1-D HEC-RAS model.

Calibration of the 2-D mobile bed model will be conducted by comparing modeled bed and overbank aggradation or degradation with data obtained from the ongoing bed scour monitoring, and by qualitative comparisons of bar and side channel changes, as identified in the ongoing channel morphometric mapping activities, and by comparing LiDAR topobathymetric surfaces from before and after the November 2021 peak discharge.

Model testing over a range of hydrologic events will be completed to identify reasonable run times for modeling individual or sequences of hydrologic events. Initial model testing will run a range of five steady state discharges from the mean annual flowrate up to the November 2021 peak discharge to evaluate model performance, as well as assess model spin up requirements to equilibrate specified model initial conditions with computed sediment transport, erosion, and deposition throughout each 2-D model domain.

Upon completion of these tasks the 2-D HEC-RAS models will be applied to quantify erosion and depositional characteristics on bar surfaces, and side channel connections within each sub reach for several alternative flow release schedules, flood operations, and other river management scenarios.

4.5.1.4 MAST 1-D

A MAST 1-D model of the Skagit River from below the Bacon Creek confluence at PRM 83 through the gravel-sand bed material transition at approximately PRM 21 will be developed to quantify width adjustments of the Skagit River to existing and potential future operational flow release scenarios and to evaluate patterns of bed material mobility and channel-floodplain sediment exchange downstream of the Sauk River confluence. This model is intended to fulfill commitments in the June 9, 2021 Notice to evaluate lateral channel mobility and Project effects on channel hydraulics and sediment transport downstream of the Sauk River, with modifications as described in Section 7.

MAST 1-D is an academic research code and coding development will be required for applications to the Skagit River system. Hydraulic calculations within MAST 1-D are simplified relative to 1-D HEC-RAS, but MAST 1-D has unique capabilities of simulating channel width response to a range of hydrologic and sediment loading conditions and explicitly tracking sediment exchange between the channel and floodplain. Because MAST 1-D is a one-dimensional model, its outputs do not directly show planimetric lateral channel migration, but interpretation of width changes in conjunction with mapping of historic channel movement patterns (see Section 4.1 of this study report) will allow for quantification of expected bank erosion patterns. As it provides information on channel width variability and channel-floodplain sediment exchange, application of MAST 1-D is complementary to the long-term profile and side channel connectivity modeling using 1-D or 2-D HEC-RAS, as well as width and multi-channel propensity modeling with UBCRM.

MAST 1-D hydraulic model calibration will be based on comparisons of measured water surface profiles and USGS stage-discharge rating curves within the model domain. Sediment model calibration will be based on comparisons of computed channel widths over selected time periods of interest, as determined through the ongoing morphometric mapping activities. Model sensitivity testing to changes in specified hydraulic roughness, bank material strength, bed material grain size, and Skagit River and tributary sediment inflow loadings will be completed to assess model performance.

As with the other models, once calibrated, the MAST 1-D model will be used to evaluate potential channel response to several alternative flow release schedules, flood operations, and other river management scenarios.

4.5.2 Observational Bed Mobility Data

4.5.2.1 Scour Monitoring

An analysis of initiation of gravel transport at key/representative spawning locations using scour monitors and accelerometers will help determine the flow rate that initiates movement or results in substrate scour to redd depth. A pilot redd scour monitoring project was initiated at three locations during August 2019 to help determine the feasibility of using various scour monitor/accelerometer techniques in the Skagit River. This initial monitoring work was expanded in 2020 from the three original sites to ten sites focused on areas of known important spawning activity (e.g., Figure 4.5-2), as described in Section 2.6.5 and Attachment B of the RSP.

In August 2021, staff expanded the monitoring project to include a total of 19 scour arrays, the locations of which are shown in Figure 4.5-3. The purpose of this extension was to provide data at select locations representative of typical/controlling sediment transport, at the mouths of tributaries (to meet commitments in the June 9, 2021 Notice), and at bulk sample locations for select tributaries. Six of these locations include riffle crests in the mainstem channel where scour monitoring will aid in development and calibration of the 1-D sediment transport model. Other arrays include the confluence fans of Goodell and Bacon Creeks (the Newhalem Creek fan did not have substrate suitable for scour monitor installation) and locations on Cascade River and Bacon Creek to aid in calibrating estimates of tributary sediment loads. Attachment B is a map set showing individual scour monitor installation locations.

Figure 4.5-2. Example location of redd-focused scour monitoring array located along the left bank line (right side of image at site ABSS1 [above Shovel Spur]).

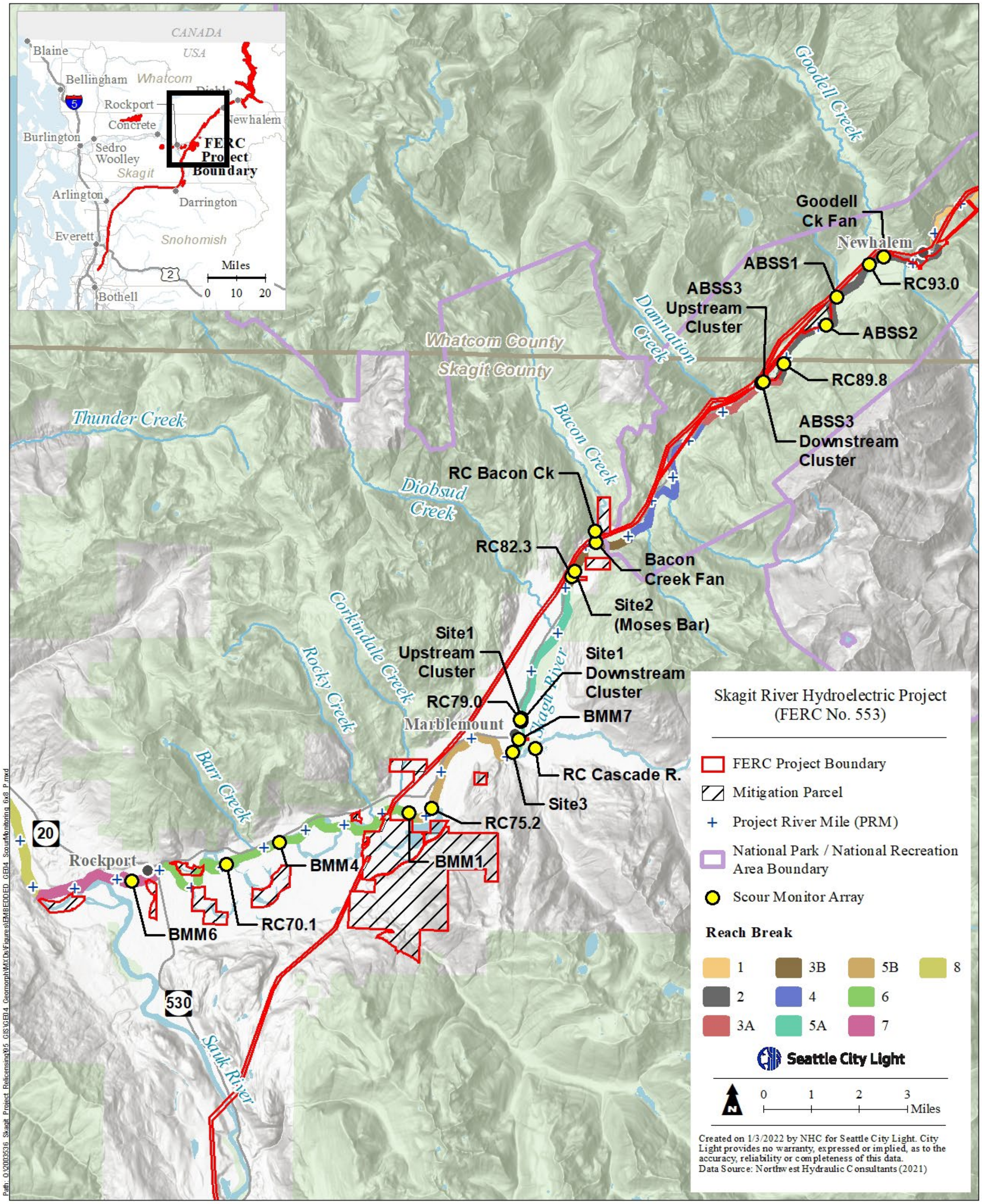

Figure 4.5-3. **Scour monitor installation locations. Site names reflect location and time of installation. 'Site' prefixes were installed in 2019, BMM (Below Marblemount) prefixes were installed in 2020 Below Marblemount, ABSS (above Shovel Spur) prefixes were installed in 2020 upstream of Shovel Spur; these are all located at spawning areas. RC sites were installed in 2021 on Riffle Crests.**

Three types of scour monitoring device were installed in the arrays. These included Sliding Bead Scour Monitors, Golf Ball Scour Monitors, and Accelerometer Arrays, which are described in detail in Attachment B of the RSP. A typical site installation includes three Sliding Bead Scour Monitors, four Golf Ball Scour Monitors, and four Accelerometer Arrays (which record data for one year and have been replaced each year following initial installation).

The Sliding Bead Scour Monitors, the smallest monitors constructed, use ¾-inch steelhead Corkies strung on 3/32-inch stainless steel aircraft cable. The advantages of these monitors are ease of installation and the ability to measure finer scale scour since each bead is ¾ inches in diameter. These devices were generally not durable enough to handle the sediment transport in the Skagit River, and so installation of them was discontinued in summer 2021.

Golf Ball Scour Monitors are similar in design to the Sliding Bead Monitors but use plastic perforated heavy-duty golf balls in place of the Corkies. The golf balls are approximately 1.7 inches in diameter, so they record scour at a coarser scale than the Corkies but proved to be generally durable through winter 2019-2020 and 2020-2021.

Arrays of two accelerometers were constructed using a design modified from Gendazak et al. (2013). Accelerometers measure x-y-z orientation at given time steps and thus record the time when movement takes place (which can be correlated with flow at that time), but they only record when scour reaches the depth at which they were buried (in the armor layer and at a depth of 7 inches, an average Chinook redd depth). To assemble accelerometer arrays, Hobo Pendant G® accelerometers were inserted into 4-inch lengths of 1-¼ inch diameter PVC pipe (Nominal Pipe Size, so the outer diameter is about 1.66 inches). A piece of 1/8-inch stainless steel aircraft cable was threaded through a hole drilled through the PVC pipe, through the eye on the accelerometer, and then crimped in place with a double cable stop. Two accelerometer pipe set ups were threaded through each anchor, with one set at 10 inches from the anchor and the other set at 17 inches from the anchor. The result was two independent cables with accelerometers set 7 inches apart from each other. This allowed for the accelerometers to be inserted into the gravel with the top accelerometer measuring movement of surface substrate (initiation of movement) and the bottom accelerometer measuring movement of material 7 inches below the surface. The accelerometers were set to record at 30-minute intervals. This allows for 1.2 years of record to be stored before the onboard memory fills.

Staff downloaded the data from the 2019-2020 and 2020-2021 accelerometers and replaced them with new devices that will be retrieved and downloaded during low flow conditions in 2022. Staff recorded the change in bed elevation at each of the surviving scour monitors using a laser level and measured the depth of fill on top of the newly installed monitors. If golf balls moved from the vertical position, the number of moved (or exposed) golf balls were recorded to determine scour depth. The majority of the 2019-2020 small bead scour monitors did not survive or were not recoverable in 2021, so staff only installed golf ball monitors in addition to accelerometers at the 2021 riffle crest monitoring arrays.

4.5.2.2 Particle Tracing

Tracer particles were deployed at six locations in early November 2021. Tracer particles give information on the pattern of sediment particle displacement during flood events and to serve as a proxy for potential sediment movement following a theoretical addition of bed material to the river near Newhalem. These sites include the confluence bars and delta fans of Ladder Creek, Newhalem Creek, Goodell Creek, and Bacon Creek and the riffle crest scour monitor sites upstream on Bacon Creek and at PRM 89.8. Early onset of significant flooding prevented deployment prior to winter 2021-22 floods at four other planned riffle crest locations downstream of Bacon Creek. At each site, approximately 100 particles were deployed, with sizes determined to match the distribution of the 45 mm and larger subsurface material present and provide duplicates (n=2 to 4) of larger size classes that would be represented by fewer particles.

Particles were tagged by epoxying RFID tags into holes drilled into the particles. The RFID tags are passive, half-duplex 1.3-in (32-mm) long provided by Oregon RFID and originally manufactured by Texas Instruments, which operate at a Low Frequency of the Radio Frequency spectrum (134.2 kilohertz [kHz]). Reliable detection ranges for these tags can be archived up to about 6 ft, and so we only expect to be able to recover particles displaced into relatively shallow water.

4.5.2.3 Washington State Department of Transportation Bedload Measurements and Acoustic Bedload Monitoring

Parallel to this effort, the USGS in cooperation with Washington State Department of Transportation (WSDOT) is studying bedload transport on the Skagit River. They installed hydrophones at Marblemount and Car Body Hole in fall 2020 to record acoustical signals of bedload movement. They intended to collect bedload transport data during high flow conditions, but, as of the writing of this report, have not been able to do that. Nonetheless, the acoustical signal of bedload movement will provide useful semi-quantitative information on the timing and degree of bed mobility at these two locations during flood events. As of the filing of this study report, these data were not yet available, and so no results of this analysis are included in this document. These results will be reported in the USR if available.

4.5.2.4 Geomorphic Change Detection

Intermediate (timescale of years) to long-term (timescale of decades) changes in bed elevation also give empirical information on the quantity of sediment that has been mobile in the channel. As described in Section 4.1.4, available topobathymetric LiDAR data will be compared with historic channel cross sections and 2017-18 topobathymetric LiDAR will be compared with winter to early-spring 2022 topobathymetric LiDAR. The comparison of the 2017-18 and 2022 LiDAR datasets will give very good information on the magnitude and pattern of bed mobility that occurred during this period, including the large November 2021 flood.

4.5.3 Fine Sediment Yield Analysis

Fine sediment (sand and finer) primarily moves in suspension through the reaches that are the focus of the bedload sediment transport modeling and only begins to form the channel bed and banks as the river approaches the estuary. Therefore, a different approach is appropriate to understand Project effects on fine sediment dynamics. This will be done through a study of known sediment yield values for surrounding river basins and subbasins, and development of a multiple linear regression model to estimate sediment yield for the subbasins of the Skagit River above the Project. These results will be integrated with results of the GE-03 Sediment Deposition in Reservoirs Affecting Resource Areas of Concern Study (City Light 2022c).

4.6 Large Wood Inventory

The purpose of the Large Wood Inventory Section of the report is to characterize large wood within the study area. This inventory was completed in accordance with Section 2.6.6 of the RSP. Large wood transport and retention methods are addressed in Section 4.7 of this study report. The study team performed a historical aerial photograph inventory and an August 2021 field inventory of individual large wood pieces and log jams. The methods used for performing these inventories is detailed in the following Sections.

4.6.1 Historical Aerial Photograph Inventory

The study team identified pieces of large wood and log jams using five remote sensing data sets presented in Table 4.6-1 that span the course of the current and previous FERC licenses. Due to limitations in resolution and spatial extent of remotely sensed data sets, 1979 and 1998 do not include all of the primary study area; however, the coverage provided in 1979 and 1998 was still sufficient to characterize the large wood in the primary study area for each time period.

Table 4.6-1. Remote sensing imaging with resolution 0.5-1.4 ft in the study area.

Year	Image Type	Resolution (ft)	Source	Study Length Covered (miles)
1979	Color Stereo Photos	1.0	SRSC	11.0
1998	Color Stereo Photos	1.4	USFS/SRSC	11.8
2009	Digital Imagery	1.0	Skagit County	27.5
2011	Digital Imagery	1.0	Skagit County	27.5
2018/2019	Digital Imagery	0.5/0.75	City Light/Skagit County	30.1

Large wood pieces were inventoried in color stereo photos and digital imagery using the following criteria.

- Piece was within the bankfull channel of the Skagit River mainstem, side channels, or tributaries. Within tributaries piece must be within 500 ft upstream of tributary confluences with the Skagit River mainstem.
- Large wood pieces longer than 25 ft and wider than one ft diameter at breast height (dbh) were included in the inventory. Large wood was digitized as a line feature in ArcMap. Width and length were measured using the measure tool.

The following attributes were assigned to each of the pieces:

- **Adjacent Tributary:** Named tributaries that are within 1,000 ft of a large wood polyline.
- **Length:** Length of large wood piece in feet.
- **Width:** Diameter of large wood piece in feet.
- **Jam Member:** Located in or out of a mapped log jam.
- **Orientation:** Orientation of large wood piece relative to flow. Classified as either parallel, perpendicular, or oblique to flow.

- **Rootwad:** Presence or absence of a rootwad, where visible.

Log jams were inventoried in high resolution images within the same extent as inventoried large wood. Log jams were defined by a minimum of five large wood pieces that met the required size criteria. Log jams were digitized as polygons. Log jam polygons were created by outlining the outer perimeter of the log jam being mapped. The following attributes were assigned to each of the log jams:

- **Adjacent Tributary:** Named tributaries that are within 1,000 ft of large wood polyline.
- **Area:** Area of log jam in square feet.
- **Change:** Difference in size of the log jam between years classified as building, decaying, stable, or variable.

Due to the 3-ft resolution of topobathymetric LiDAR, it was difficult to recognize individual pieces of large wood. The study team attempted to use the method for characterizing log jams using a difference in raster method presented in Abalharth et al. (2015). The low pulse return density resulted in a low-resolution digital elevation model in many places, which made it difficult to implement the method.

Quality Assurance and Quality Control procedures were implemented by two senior staff members of the study team (a Science Lead and a Principal Geomorphologist) to verify the identification of large wood and log jams in historical aerial photographs.

4.6.2 August 2021 Field Inventory

In August 2021, the study team performed a large wood tally, log jam tally, and detailed field survey of ten half-mile reaches. All data and photographs were collected on a GPS-enabled iPad in ArcGIS Collector. Flows during August 2021 ranged from 2,390 cfs to 5,400 cfs at the Marblemount gage (USGS 12179000) and were representative of average low flow conditions.

4.6.2.1 Large Wood and Log Jam Tally

A large wood and log jam tally was completed for 26.5 of the 30.1 miles of the mainstem Skagit River, all 56 side channels addressed in Section 5.3 of this study report, and 20 tributaries listed in Table 3.0-1. The large wood and log jam tally was not completed in the mainstem of the Skagit River between PRM 86.6-87.7 due to a section of rapids that prevented access. Additionally, the large wood and log jam tally was not completed in the Gorge bypass reach, PRM 94.7-97.2, in coordination with aquatic habitat mapping due to a lack of aquatic habitat under regulated flow conditions. Large wood that was longer than 25 ft and wider than 1 ft dbh was tallied and geolocated. For large wood that was found within log jams, the number of pieces was estimated to a bin class of either 5-9, 10-49, 50-99, or 100 plus pieces and geolocated.

Additionally, individual tallied large wood pieces were assigned the following attributes:

- **Length:** Estimated length was binned as 25-49 ft, 50-74 ft, 75-99 ft, or 100 plus ft.
- **Diameter at Breast Height (dbh):** Estimated dbh was binned as 1-1.9 ft, 2-2.9 ft, 3-3.9 ft, or 4 plus ft categories.

- **Rootwad:** Presence or absence of a rootwad.

4.6.2.2 Large Wood Inventory Detailed Areas

Ten half-mile areas within the primary study area were selected for a detailed large wood inventory. These reaches were selected to be representative of various channel morphologies present within the primary study area; they were agreed upon by LPs in a July 2021 Geomorphology Work Group meeting. The name of the detailed reach and associated geomorphic reach number is shown in Table 4.6-2. For these detailed reaches, in addition to mapping the location, abundance, and size of large wood, attributes were collected to characterize the adjacent tributary, jam member, orientation, function, decay class, bank erosion, species, stratigraphy, mobility, and residual pool depth. Each individual large wood piece was assigned a geotagged polyline representative of its location. Each log jam was assigned a geotagged polygon representative of its perimeter. Attributes that were collected for log jams include average height, location in active channel, number of pieces, occupied percentage, type, and residual pool depth. The location of these reaches is shown in Attachment C. Seven of ten detailed wood inventory areas overlap with proposed 2-D sediment modeling areas.

Table 4.6-2. Large wood inventory detailed areas and geomorphic reaches.

Detailed Wood Inventory Area	Geomorphic Reach	Project River Mile Boundary
Rockport	7A	67.4 – 67.9
Barnaby West	6	68.6 – 69.1
Barnaby East	6	69.5 – 70.0
Sutter	6	71.0 – 71.5
Cascade	5B	77.4 – 77.9
Bacon South	3B	82.5 – 83.0
Bacon North	3B	83.0 – 83.5
County Line	2B	89.4 – 89.9
Thornton	2B	90.1 – 90.6
Goodell	2B	93.0 – 93.5

The following attributes were assigned to each of the individual large wood pieces identified in the detailed reach:

- **Length:** Length of the piece in ft.
- **Diameter at Breast Height (dbh):** Diameter of the piece at breast height in ft measured to the nearest tenth of a foot.
- **Rootwad:** Presence or absence of a rootwad.
- **Rootwad Diameter:** Average diameter of rootwad in ft.
- **Adjacent Tributary:** Named tributaries that are within 1,000 ft of large wood polyline.
- **Jam Member:** Located in or out of a mapped log jam.
- **Orientation:** Orientation of large wood piece relative to flow.

- **Function:** Geomorphic function of large wood piece. These include hydraulic cover, pool forming, key piece in log jam, and log jam members.
- **Decay Class:** Level of decomposition defined as either 1 (fresh), 2 (intermediate), or 3 (rotten). Class 1 refers to wood that is very firm and often has bark and limbs. Class 2 refers to wood that is firm and often has some bark and limbs. Class 3 refers to wood that is softer and has no or very little bark and limbs.
- **Bank Erosion:** Whether the piece was recruited locally from bank erosion or not. This was determined based on the presence of the rootwad being on the bank as well as signs of local bank erosion such as scour and exposure of tree roots.
- **Species:** Identity of tree species. If species could not be determined large wood piece was defined as unknown.
- **Stratigraphy:** Location of wood in the channel. Classified as either low flow channel, partially or fully submerged, gravel bar, or floodplain.
- **Mobility:** Estimate of large wood piece stability based on how embedded the piece was in the substrate and where in relationship to flow was it located. Mobility was classified as either stable, partially stable, or not stable.
- **Pool Depth:** Residual depth of associated pool in ft (if pool is present). Measured in the field.

The following attributes were assigned to each of the log jams identified in the detailed reach:

- **Height:** Average height of log jam above the riverbed in ft.
- **Wetted Channel:** Whether the log jam was engaged with the wetted channel.
- **Number of Pieces:** Estimated number of pieces in the log jam (binned as 5-9, 10-49, 50-99, or 100-plus).
- **Occupy Percentage:** The percentage of the active channel span that the log jam occupies.
- **Type:** The type was classified as bar top, bar apex, meander, side channel, submerged or other.
- **Pool Depth:** Residual depth of associated pool in ft (if present). Measured in the field.

4.6.3 Large Wood in Reservoirs

Large wood in reservoirs is being inventoried by City Light in accordance with Section 2.0 of Attachment C in the RSP. A memorandum discussing the most up to date summary of this task are filed with the ISR separate from the Geomorphology Study report (City Light 2021b). Under current practice, City Light inventories reservoir wood by length, dbh, and rootwad presence to a maximum classification of greater than 20 ft in length and 12 inches in diameter. The wood data collection and recommendations memo suggest classifying large wood by decay class and additional length classes up to 100 ft or greater in length and 36 inches or greater in diameter.

4.7 Large Wood Tracking and Transport

The purpose of the Large Wood Tracking and Transport Section of the report is to address large wood tracking, transport, retention, and augmentation. This was completed in accordance with the June 9, 2021 Notice and Section 2.6.8 of the RSP. The completion of the transport, recruitment, and augmentation sections requires hydraulic modeling results from FA-02 Instream Flow Model Development Study to be completed and will be reported in the USR.

4.7.1 Large Wood Tracking

The large wood tracking was completed in accordance with the June 9, 2021 Notice and Section 2.6.8 of the RSP. The method used for large wood tracking was discussed with LPs during the July and October 2021 Geomorphology Work Group meetings with the LPs. The primary goals of the large wood tracking include:

- Identify and characterize what size of large wood moves in a flood peak;
- Determine distance and location of where the large wood moves and accumulates; and
- Determine characteristics of large wood that is most stable.

Active RFID (radiotags) manufactured by Lotek were used for tracking wood movement (Figure 4.7-1). The read range is greater than 1,000 ft when above water, and approximately 15 ft when below water. The tags have a lifespan of three to five years and frequency of 166.520 megahertz (MHz).

Figure 4.7-1. Lotek MFT-3A radiotag used to track large wood.

During the October 2021 Geomorphology Work Group meeting with the LPs, the study team presented a plan for tagging a variety of pieces in the mainstem, tributaries, and side channels throughout the primary study area. The pieces installed included a distribution of lengths and diameters, species, orientation, location in the active channel, and rootwad presence/absence. The study team installed the radiotags in the large wood with the following procedure:

- A piece of large wood greater than 1-ft dbh and 25-ft length was identified.
- Bark was removed from the area where the radiotag was installed.
- A hole of 1-inch by 3.5-inch dimensions was drilled in the wood (Figure 4.7-2).
- Clear silicone caulk was installed on top of the radiotag (Figure 4.7-2).
- Metal plate was screwed on top of the caulk (Figure 4.7-2).
- Antennae was laid out and stapled along the wood (Figure 4.7-2).
- When possible, bark was replaced in the area where the tag and antennae were located.

Figure 4.7-2. Large Wood installation of radiotags. Hole drilled and radiotag inserted (left). Hole filled with waterproof adhesive and metal brace screwed on top of hole and antenna stapled to log surface where bark was removed (right).

4.7.2 Large Wood Transport

Large wood transport will be estimated using the results of the large wood tracking. Additionally, the study team will utilize hydraulic modeling results from the FA-02 Instream Flow Model Development Study (City Light 2022a) to estimate transport. Wood transport will be assessed by estimating the buoyant depth and draft of individual pieces and the duration and velocity of flows predicted to mobilize wood. The analysis will also utilize data from sediment transport analysis to estimate which pieces of wood are stable after bedload transport is initiated. This will identify pieces that may become embedded and, thus, more stable. The large wood tracking described in the previous Section will be used to determine the mobility of tagged pieces and compare to estimates of wood transport.

4.7.3 Large Wood Recruitment

Large wood recruitment will be determined by utilizing the FA-02 Instream Flow Model Development Study hydraulic model results (City Light 2022a) and other data that is being analyzed to determine large wood recruitment potential. The recruitment potential is determined by whether there is large wood that meets the minimum classification criteria of 1 ft DBH and 25 ft long within the riparian zone that can be recruited by the stream. The study team will utilize historical channel migration zones, current erosion rates, stability of wood, data collected by Washington State Department of Natural Resources (DNR) on riparian tree size and stem density, and data collected for the TR-01 Vegetation Mapping Study (City Light 2022d).

4.7.4 Large Wood Augmentation

Large wood augmentation analysis will be completed after the FA-02 Instream Flow Model Development Study model results are completed (City Light 2022a). Per the June 9, 2021 Notice, City Light will determine locations and methods for wood augmentation within six months of the FA-02 Instream Flow Model Development Study model being completed. City Light will implement an augmentation pilot program with input from the LPs in 2023, unless they mutually determine a pilot program is not necessary.

4.8 Process Flows

As described in Section 2.6.7 of the RSP, process flows are identified as high flow events that support a variety of geomorphic processes and habitat values. This effort will integrate data across the hydraulic models, the sediment transport models and the sediment scour and transport monitoring, and results will be included in the USR. These data will be used to analyze initiation of bedload movement at riverbanks and tributary mouths, initiation of substrate movement at river bars, and connection of side channel and off-channel habitats with the mainstem flow at a range of flow levels. Process flows will be determined and analyzed as part of a planned iterative process involving FA-02 Instream Flow Model Development Study (City Light 2022a) team, City Light staff, and LPs. Workshops on this topic are planned for 2022.

5.0 PRELIMINARY RESULTS

Existing information collected as part of the pre-field analysis informed the implementation of this study and is integrated into analyses described below. Additional reports on Skagit River geomorphology downstream from the Sauk River confluence are summarized in Attachment A.

Preliminary results are reported for data collected in the 2021 field season and analyses completed through November 2021. Data processing and analyses for this study are ongoing through 2022 and will be reported in the USR. The preliminary results are organized by topic areas in the following subsections as described in the RSP:

- Geomorphic Change;
- Aquatic Habitat;
- Side Channels and Off-Channel Habitat;
- Substrate/Sediment;
- Large Wood Inventory;
- Large Wood Transport; and
- Process Flows.

5.1 Geomorphic Change

Preliminary results of channel migration patterns mapped from aerial imagery of the period 1944-2019 show only moderate changes in planform channel characteristics for geomorphic reaches between Newhalem and Marblemount and more pronounced channel migration activity in the reaches between Marblemount and the Sauk River confluence. Downstream variability in channel characteristics is summarized in Table 5.1-1. Attachment D presents a mapbook showing floodplain elevations relative to the low flow water surface elevation of the active channel based on composite of recent (2016-2018) LiDAR data. Channel width measured from aerial imagery shows reach scale variability between the more confined, less dynamic reaches 2 through 5 and more dynamic reaches 6 and 7 (Figure 5.1-1). The time series of channel width by reach shows minor changes in average channel width between years but no systemic trends over time (Figure 5.1-2).

Table 5.1-1. Summary of reach characteristics.

Reach	Gradient	Channel Length (miles)	Sinuosity	Average Active Channel Width (ft)	Length of Hydro-modified Banks (ft)		Percentage of Banks with Hydro-modifications	
					Left	Right	Left	Right
1	0.0189	2.7	N/A	N/A	N/A	N/A	N/A	N/A
2A	0.0036	1.2	1.14	216	0	0	0%	0%
2B	0.0031	4.1	1.10	324	0	570	0%	3%
3A	0.0015	1.9	1.20	234	0	3,680	0%	37%
4	0.0022	3.5	1.15	233	0	4,340	0%	23%

Reach	Gradient	Channel Length (miles)	Sinuosity	Average Active Channel Width (ft)	Length of Hydro-modified Banks (ft)		Percentage of Banks with Hydro-modifications	
					Left	Right	Left	Right
3B	0.0018	2	1.11	325	620	2,270	6%	21%
5A	0.0015	3.5	1.05	325	630	0	3%	0%
5B	0.0014	3.7	1.29	382	180	3,210	1%	16%
6	0.0018	6.7	1.22	537	180	7,210	1%	20%
7A	0.0004	1.3	1.05	520	0	1,430	0%	21%

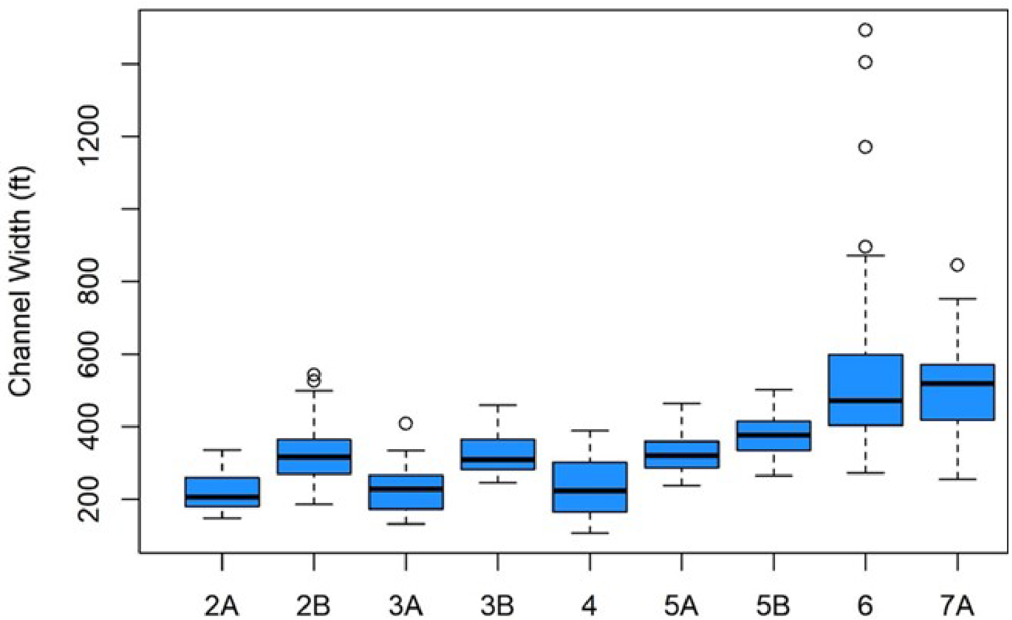

Figure 5.1-1. Variability 2019 active channel width, by reach. Horizontal bars represent the median value of transects in a given reach, boxes show the interquartile range (IQR) and whiskers extend to 1.5 x IQR.

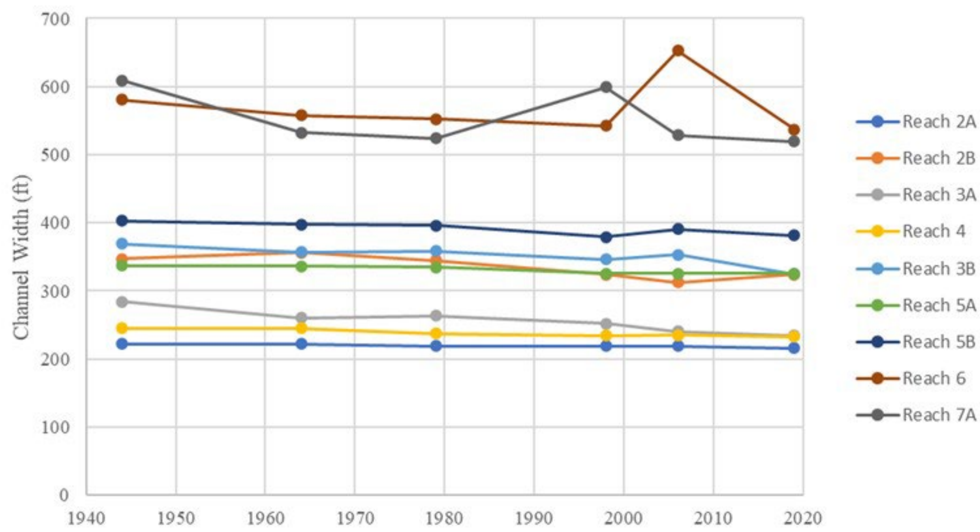

Figure 5.1-2. Trends in active channel width by reach, 1944-2019.

A time series comparing the 1915 topographic map with subsequent aerial imagery for the period 1944-2019 is included in Attachment E. Lateral migration rates (1944-2019) by reach are summarized in Table 5.1-2.

The peak flow history at USGS gaging stations in the Skagit River at Newhalem (USGS 12178000) and at Marblemount (USGS 12181000) are overlaid with years selected in time series of aerial imagery in Figure 4.1-1 and 4.1-2 and summarized by interval in the historical time series of aerial imagery in Table 5.1-3.

Measurement of lateral migration distances between intervals in the historical time series illustrates the downstream variability between reaches (Figure 5.1-3). Historical trends in lateral migration rate are summarized by reach in Figure 5.1-4 and illustrated in maps comparing 1944 imagery with 2019 imagery in Figures 5.1-5 through 5.1-15. Key findings from the evaluation of historical channel changes are summarized by reach below.

Table 5.1-2. Summary of lateral migration rates (1944-2019) by reach.

Reach	Eroded Area 1944-2019 (ft^2)	Average Lateral Migration (ft)	Lateral Migration Rate (ft/yr)
2A	0	0	0.0
2B	587,100	27	0.4
3A	66,200	7	0.1
4	30,100	3	0.0
3B	126,100	7	0.1
5A	76,800	4	0.1
5B	563,300	29	0.4
6	10,823,900	305	4.1
7A	318,000	47	0.6

Table 5.1-3. Summary of peak flow (1944-2019) by time series interval.

Reach	at Newhalem (USGS 12178000)		at Marblemount (USGS 12181000)	
	Peak Flow (cfs)	Date	Peak Flow (cfs)	Date
1944-1964	28,900	7/9/1964	59,300[1]	11/27/1949
1964-1979	36,700	6/21/1967	N/A	N/A
1979-1998	32,300	12/2/1995	62,300	11/29/1995
1998-2006	36,800	10/22/2003	64,300	10/20/2003
2006-2019	28,100	11/8/2006	52,000	11/6/2006

1 Based on partial record; no data at Marblemount 1957-1975.

Reach 1 (Gorge bypass reach) is bedrock controlled and lateral channel migration was not assessed in this study.

Reach 2A represents the transition where the Skagit River emerges into the lower gradient valley that has been widened by alpine glaciation (Figure 5.1-5). The channel is confined by terraces and armored by large cobble and boulder-sized sediments along the bank. No detectable observations of lateral channel migration were recorded in Reach 2A over the period 1944-2019.

Reach 2B continues from the bridge at Newhalem Campground downstream to the County Line. Overall, lateral migration in Reach 2B averaged 0.4 ft/yr. Observation of historical channel changes in reach 2B include:

- A gradual decrease in connectivity between the mainstem and a side channel along the left bank downstream of Goodell Creek (side channel 92.8-L; further described in Section 5.3.1 of this study report) due to sedimentation and encroaching vegetation (Figure 5.1-5; Attachment E, sheet 2).
- Little to no change in the island between the mainstem and side channel at PRM 92.8.
- Growth of a mid-channel bar at PRM 92 that has developed into a vegetated island near the confluence with Babcock Creek and deflected flow laterally into the banks opposite the developing island causing toe scour and lateral bank migration of 5 ft/yr from 1964-1979 with ongoing toe scour that maintains a near vertical bank to the north of the developing island.
- Historical channel migration between PRM 90 and 91 led to development of a side channel complex near the confluence with Thornton Creek (Figure 5.1-6; Attachment E, sheet 3). Historical mapping in 1915 shows an anabranching channel pattern with two islands or mid-channel bars in this segment at that time. The upper bar from PRM 90.5 to 91 grew in the downstream direction between 1915 and 1944 then stabilized with vegetation between 1944 and 1964. Secondary channels connecting with the Thornton side channel complex appear better defined in imagery prior to 1998 but have since narrowed with sedimentation and vegetation encroachment. A secondary channel spilling laterally from the mainstem into the side channel has grown in recent years and showed evidence of widening in 2021 field reconnaissance.
- Clearing of riparian vegetation and extraction of gravel from the floodplain at County Line Ponds resulted in channel widening between PRM 89.2 and 89.8 from 1944-1964. Subsequent

formation of a mid-channel bar has formed an island near PRM 89.5. Flow deflected toward the right bank upstream of the island breached the berm separating the pond from the mainstem between 1998 and 2006, allowing a portion of the flow to spill laterally into the pond complex.

- Toe scour along the right bank is creating localized bank migration toward the pond complex from PRM 89.8 to 90.

Reach 3A is confined by resistant bedrock, large debris fans, and riprap that lines the channel along SR 20. Observations within this reach include:

- An alluvial terrace flanks the channel from along the left bank from County Line to the confluence with Sky Creek, but the bank has been stable throughout the record of aerial imagery.
- A side channel near Damnation Creek was more clearly connected with the mainstem in the 1915 map and 1944 imagery then becomes less connected over time as the side channel is affected by sedimentation and vegetation encroachment (Figure 5.1-7).
- Minor amounts of localized bank erosion were observed downstream of Damnation Creek between PRM 87.6 and 87.8 from 1964-1979 and 1979-1998 where sediment deposition has formed bars within the channel upstream of the valley confinement entering the landslide zone.

Reach 4 is the confined valley segment within the landslide zone. Observations within this reach include:

- The channel is composed of coarse sediment and boulders and riprap armors the banks in segments along SR 20.
- Minor changes in channel planform have occurred downstream of Alma Creek near PRM 85.4 (Figure 5.1-8).

Reach 3B is a continuation of the narrow valley segment downstream of the landslide zone and includes the confluence with Bacon Creek (Figure 5.1-9). Historical channel changes in Reach 3B are minor and include:

- Development of a bar extending from the left bank downstream and across from Bacon Creek (PRM 89) associated with lateral migration towards an island on the opposite (right) bank between 1964 and 1979; subsequent development of a pond in the abandoned channel separated from the mainstem by the vegetated bar is apparent by 1998.
- Formation of a log jam at the inlet to a side channel along the right bank downstream of Bacon Creek between 1979 and 1998 and subsequent sediment deposition and vegetation encroachment decreasing connectivity with the side channel over time.

Reach 5A enters a widened valley downstream of the Straight Creek Fault; however, the channel is incised within high banks of terrace surfaces where the channel has cut into deposits from post-glacial outburst floods more than 11,000 years in age (Riedel et al. 2020). Only one area of localized bank erosion was recorded. Observations from the record of historical imagery include:

- Sedimentation and vegetation encroachment limiting side channel connectivity upstream of Diobsud Creek at PRM 81.6 (Figure 5.1-10); the side channel is well defined in 1915 USGS map, had a unvegetated channel connecting to the mainstem in 1944 imagery, and vegetation became progressively established at the upstream connection beginning with the 1964 imagery (Attachment E, sheet 6).
- Sedimentation and vegetation encroachment on the tributary fan at the confluence with Diobsud Creek; moderate deposition noted along right bank at confluence between 1944 and 1964 then establishment of vegetation stabilized the deposits between 1964 and 1979.
- Localized erosion along the left bank across from Diobsud Creek at PRM 81 concurrent with the bar growth on the opposite bank at the confluence. Erosion began between 1944 and 1964, continued between 1964 and 1979, then shifted the focus of bank erosion slightly downstream of the tributary confluence between 1979 and 1998 (Attachment E, sheet 6). No detectable erosion was noted in the periods since 1998.
- Sedimentation and vegetation encroachment limiting side channel connectivity downstream of Diobsud Creek at PRM 80.8; similar to the side channel upstream at PRM 81.6, the side channel at PRM 80.8 is well defined in 1915 USGS map, had a unvegetated channel connecting to the mainstem in 1944 imagery, and vegetation became progressively established at the upstream connection beginning with the 1964 imagery (Attachment E, sheet 6).

Reach 5B continues from the confluence with the Cascade River downstream to Rocky Creek (Figure 5.1-11). Observations within this segment include:

- Right bank erosion downstream of the Cascade River (PRM 77.6) between 1944-1964 and subsequent armoring of the eroding bank by riprap.
- Left bank erosion between PRM 77.4 and 77.6 resulting in development of a split flow channel that has persisted since the 1990s (Attachment E, sheet 7).
- Toe scour and lateral bend migration on the left bank between PRM 74.4 and 75 between 1979 and 1998 (then continuing at lower rate between 1998 and 2006) and concurrent toe scour and bend migration into the terrace on the opposite (right) bank downstream of Corkindale Creek (Figure 5.1-12; Attachment E, sheet 8).

Reach 6 represents the most dynamic segment of the study area and includes areas with large meander cutoffs near Illabot Creek and Barnaby Slough. Key observations from the record of historical maps and imagery within this reach include:

- A large-scale bend cutoff abandoned the meander known as Barnaby Slough in the early 1900s (prior to 1915 topographic map) and shortened the channel length between PRM 70.5 and 71. The bend cutoff at Barnaby Slough is further discussed in previous work by SRSC and NSD (2019).
- A second bend cutoff then occurred upstream and abandoned the meander near Illabot Creek (PRM 73 to 73.5) between 1915 and 1944 (Attachment E, sheet 9).
- The new channel that cut off the bend near Illabot Creek split into two flow paths around a developing island and erosion along the right bank near PRM 73 produced lateral migration to

the north between 1944 and 1964 that was subsequently halted by placement of riprap (Figure 5.1-13).

- The left bank to the south of developing island erosion eroded between PRM 73.2 and 73.4 from 1944 to 1964, was relatively stable from 1964-1979, then eroded further over a long segment extending from PRM 73 upstream to Rocky Creek near PRM 74 between 1979 and 1998. Ongoing left bank erosion in this segment downstream of Rocky Creek has continued episodically (Attachment E, sheet 9).
- The right bank is armored by riprap near the next bend downstream where the channel is parallel to the embankment along SR 20 between PRM 72 and 72.5.
- The left bank between the two armored sections has adjusted by migrating laterally over 1,000 ft since 1944 near PRM 72.5; toe erosion drove bank erosion between 1944 and 1964. A mid-channel bar then formed resulting in additional left bank erosion between 1964 and 1979; ongoing migration toward the left bank has since formed an extensive point bar on the opposite bank that has grown progressively over time (Attachment E, sheet 9).
- Bank protection on the right bank along SR 20 near RM 72 deflects flow to the opposite bank and the left bank has been progressively eroding near the confluence with Illabot Creek.
- The channel segment adjacent to Barnaby Slough has remained relatively static with only localized areas of left bank erosion across from a developing bar near the confluence with Barr Creek and Sutter Creek (PRM 70.6 to 71).
- A meander across from Barnaby Slough has progressively migrated downstream further shortening channel length and forming the relict channel features containing wetlands on the north side of the valley near Washington Eddy (Attachment E, sheet 10). In 1915 the outer bank was located near PRM 70.2 and then migrated 460 ft in a downstream direction between 1915-1944 (16 ft/yr), 420 ft from 1944-1964 (21 ft/yr), 440 ft from 1964-1979 (29 ft/yr), 440 ft from 1979-1998 (23 ft/yr), 170 ft from 1998-2006 (21 ft/yr), and 480 ft from 2006-2019 (37 ft/yr).
- Riprap previously armored the left bank downstream of Washington Eddy until the 1990s when erosion flanked the riprap and initiated a period of rapid lateral migration along the meander bend at PRM 69 near Martin Road (Figure 5.1-14; Attachment E, sheet 11); lateral migration of the meander bend near PRM 68.8 progressed 290 ft toward Martin Rd from 1998-2006 (36 ft/yr) and 290 ft from 2006-2019 (22 ft/yr).

Reach 7 continues along the margin of the Sauk River alluvial fan.

- The right bank is armored throughout this segment near the Rockport bridge and the segment upstream of the bridge appears to have been armored prior to the 1944 imagery.
- Channel dynamics in this reach have been dominated by westward migration of the Sauk River along the alluvial fan over the period 1944-2019.

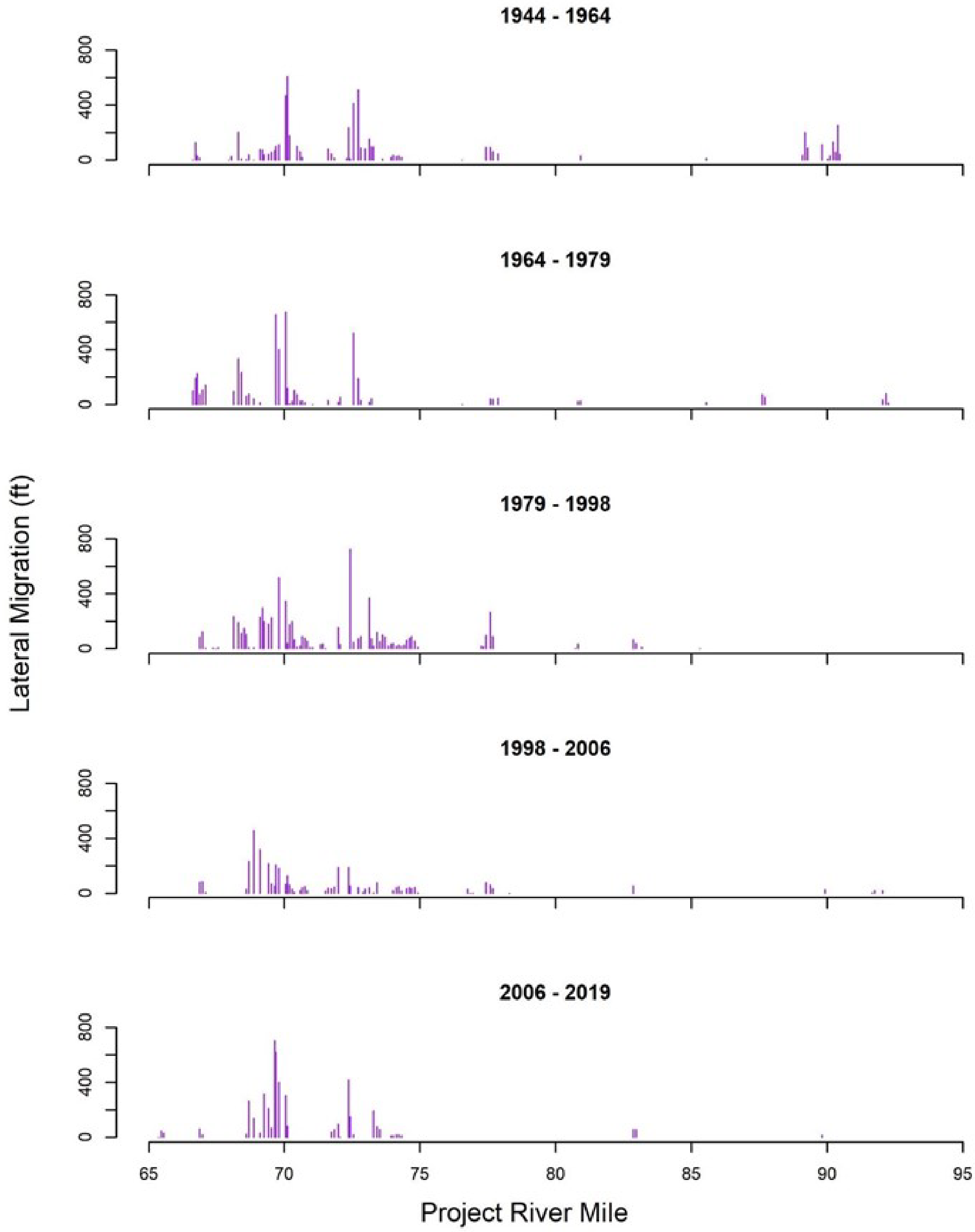

Figure 5.1-3. Downstream trends in lateral migration distance over the period 1944-2019.

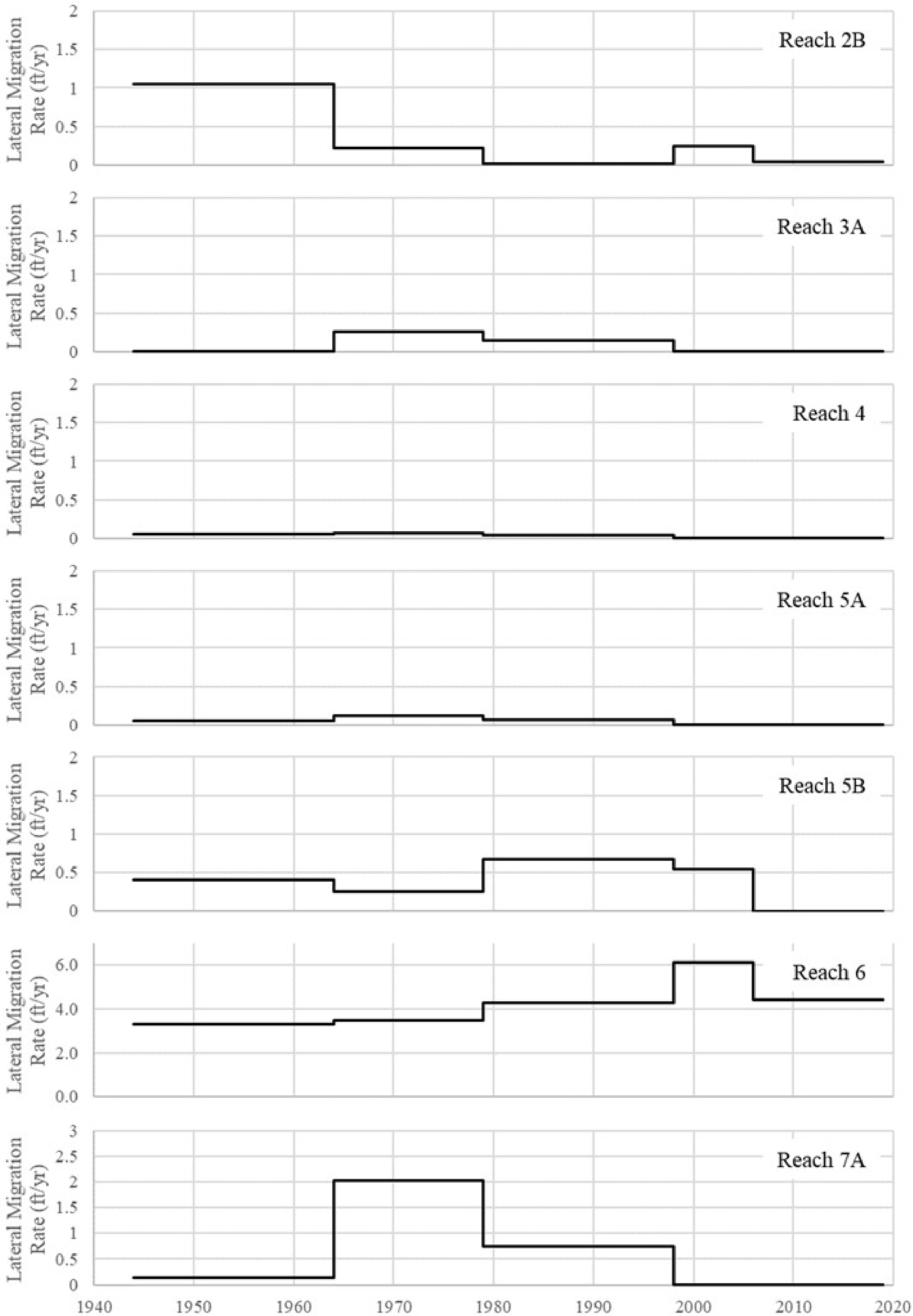

Figure 5.1-4. Time series of lateral migration rates by reach over the period 1944-2019.

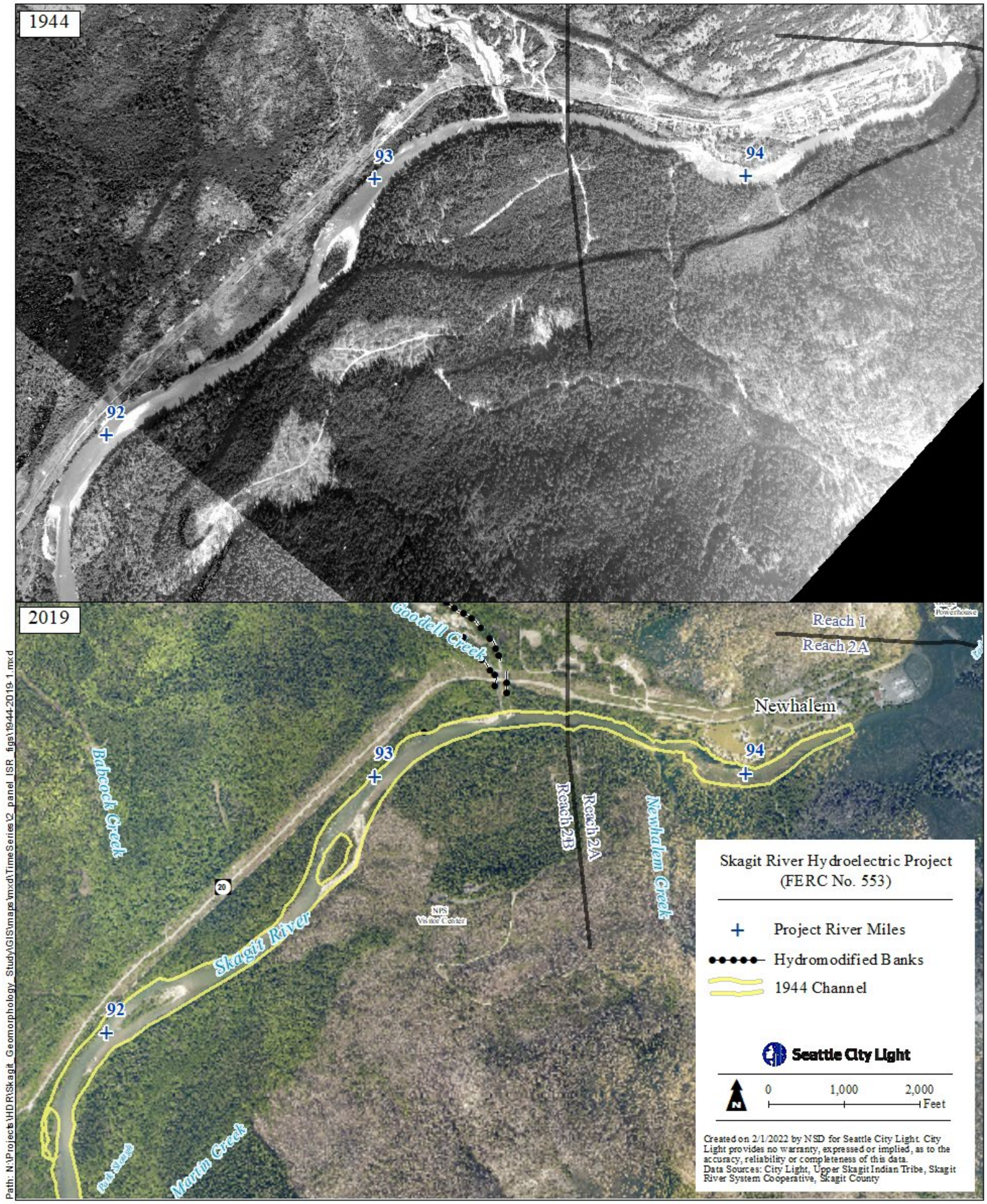

Figure 5.1-5. Comparison of 1944 and 2019 imagery in Reach 2A and upper segment of Reach 2B.

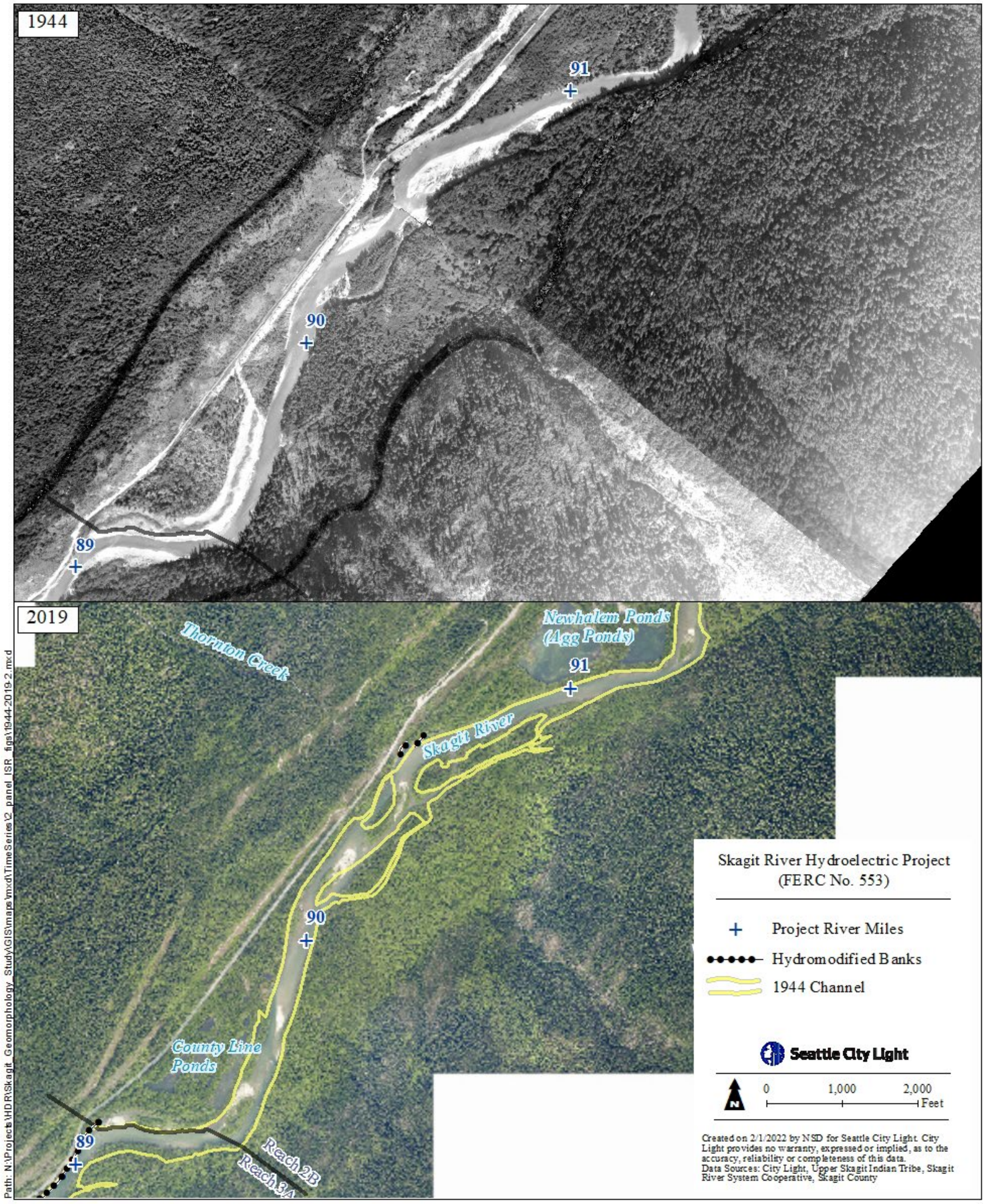

Figure 5.1-6. Comparison of 1944 and 2019 imagery in lower segment of Reach 2B.

Figure 5.1-7. Comparison of 1944 and 2019 imagery in Reach 3A and upper segment of Reach 4.

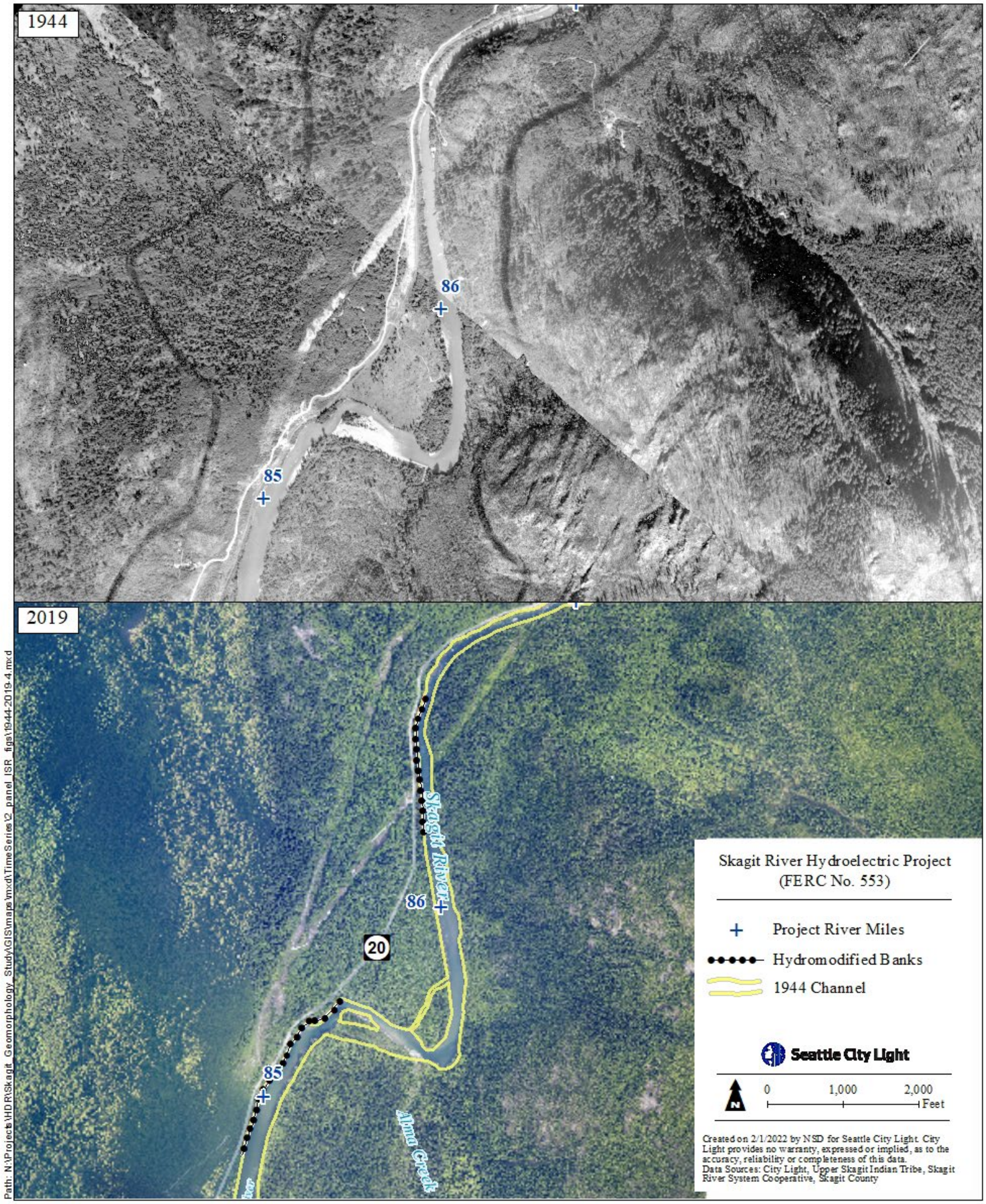

Figure 5.1-8. Comparison of 1944 and 2019 imagery in Reach 4.

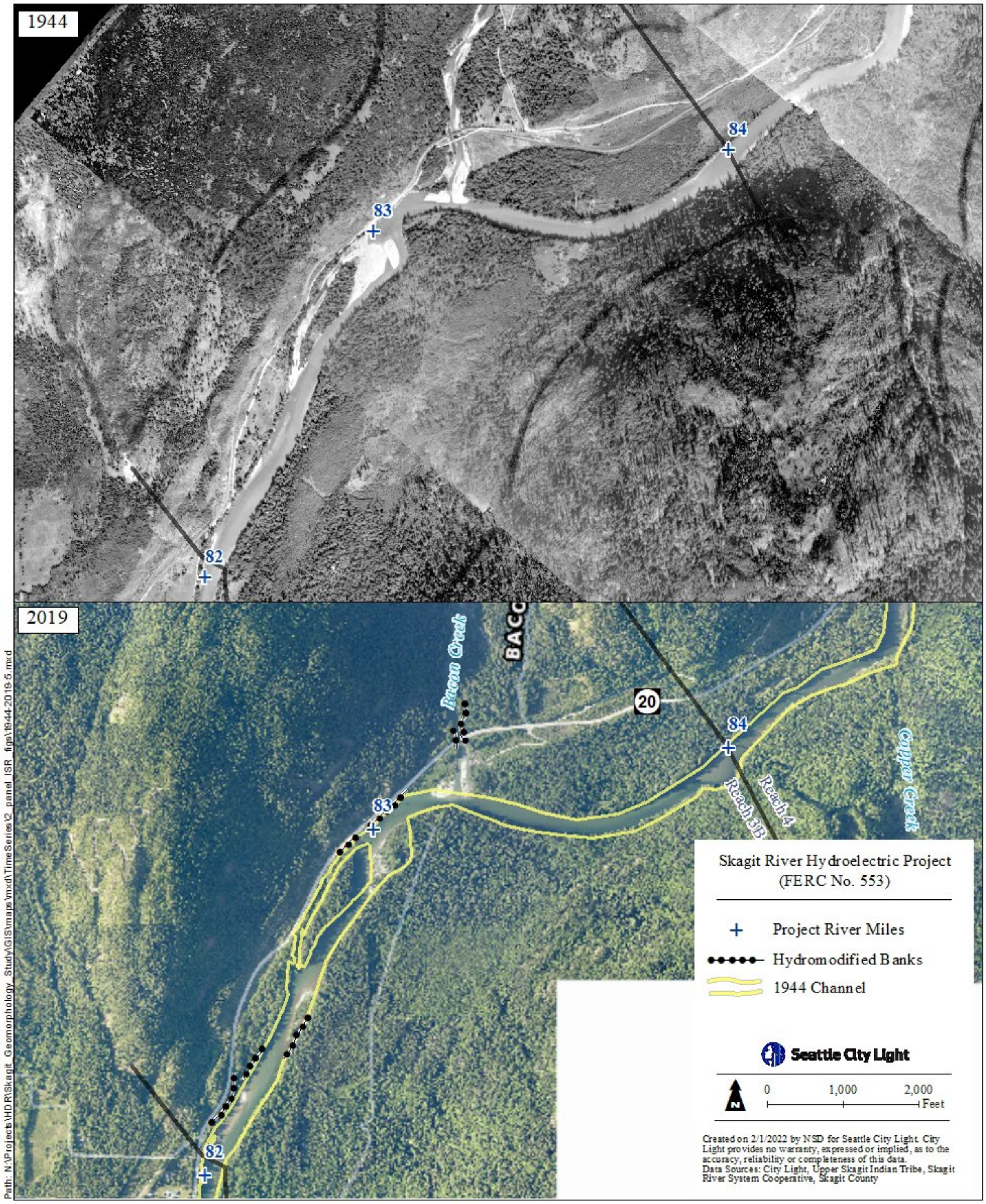

Figure 5.1-9. Comparison of 1944 and 2019 imagery in Reach 3B.

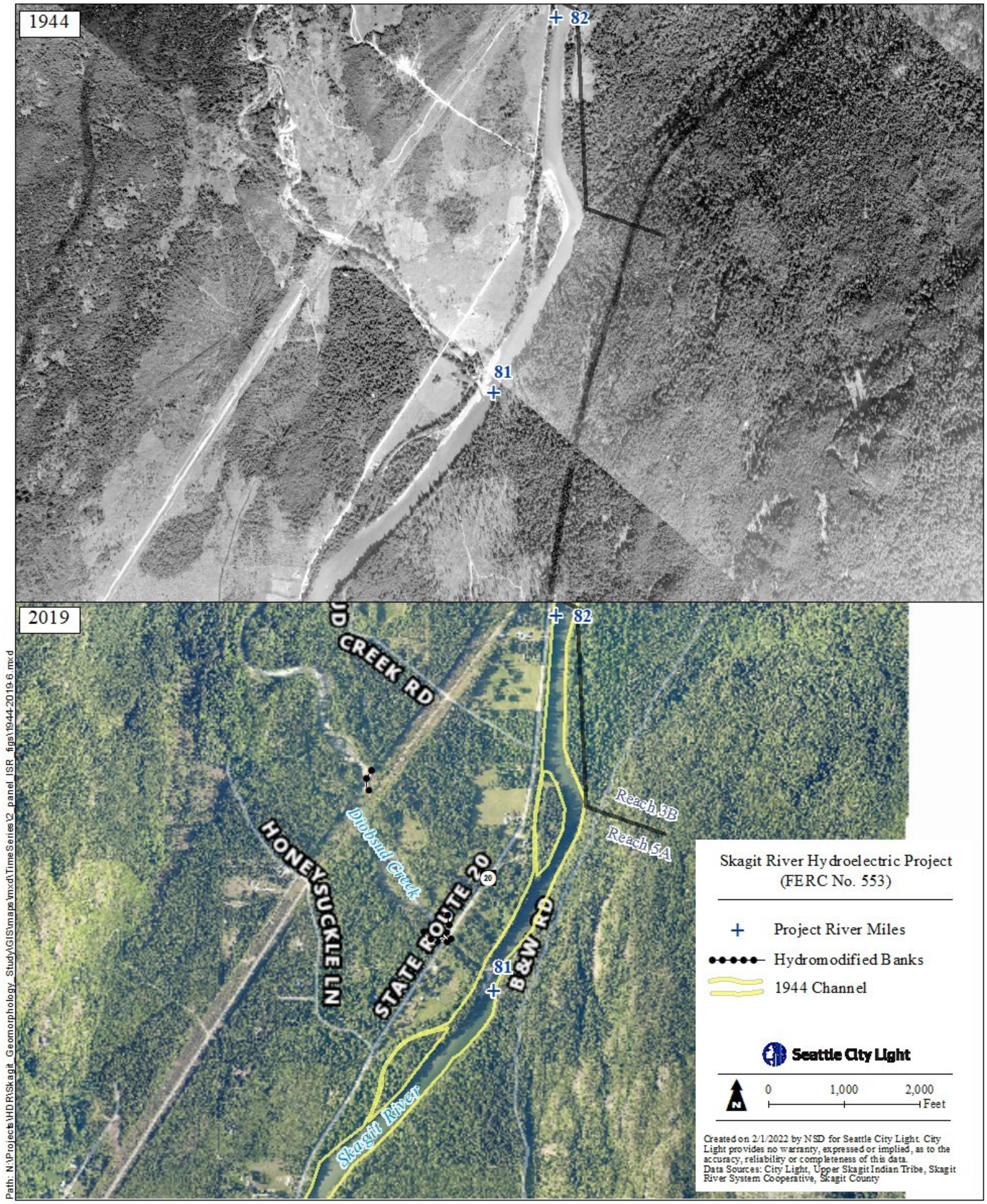

Figure 5.1-10. Comparison of 1944 and 2019 imagery in upper segment of Reach 5A.

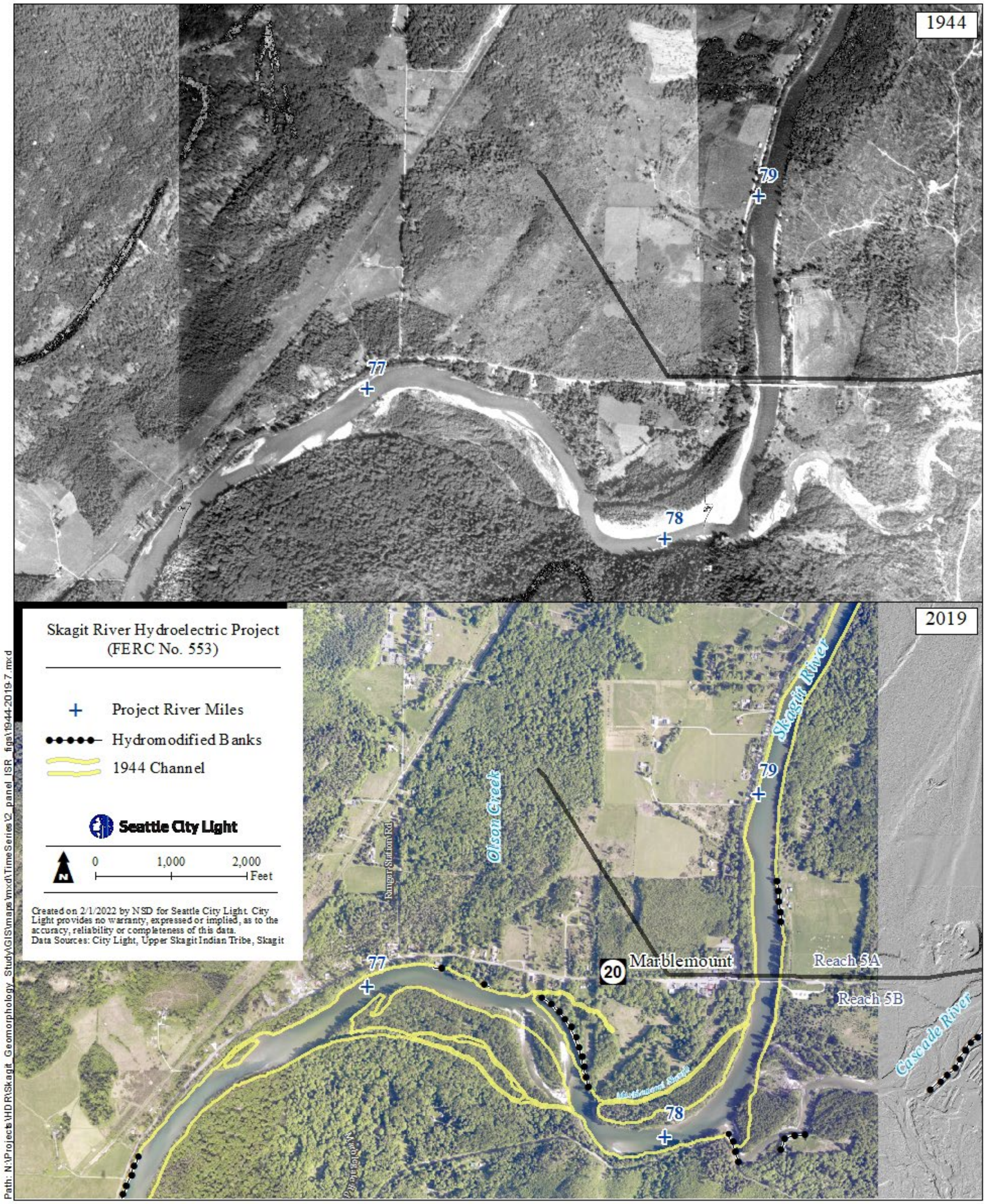

Figure 5.1-11. Comparison of 1944 and 2019 imagery in Reach 5A and upper segment of Reach 5B.

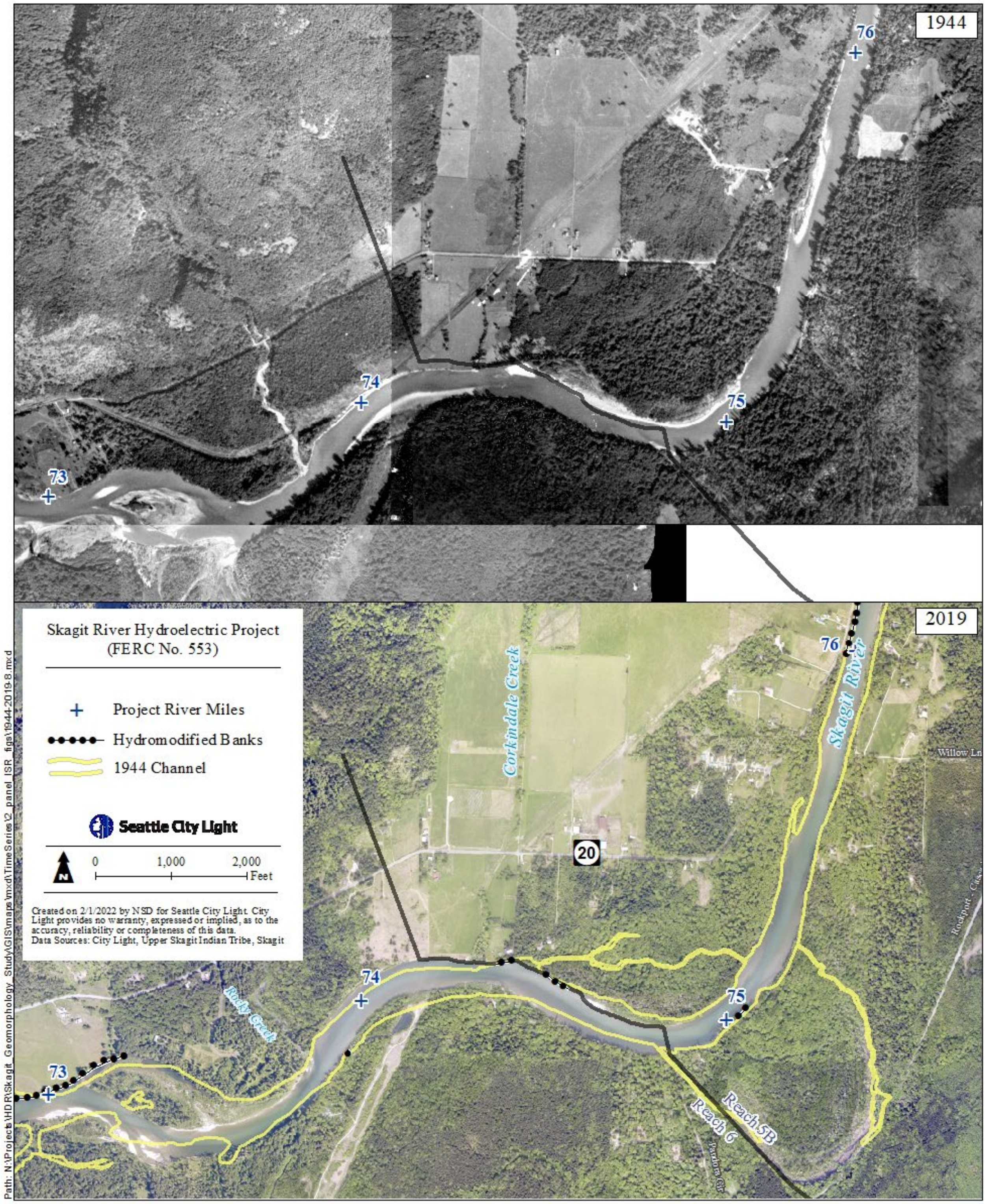

Figure 5.1-12. Comparison of 1944 and 2019 imagery in lower segment of Reach 5B and upper segment of Reach 6.

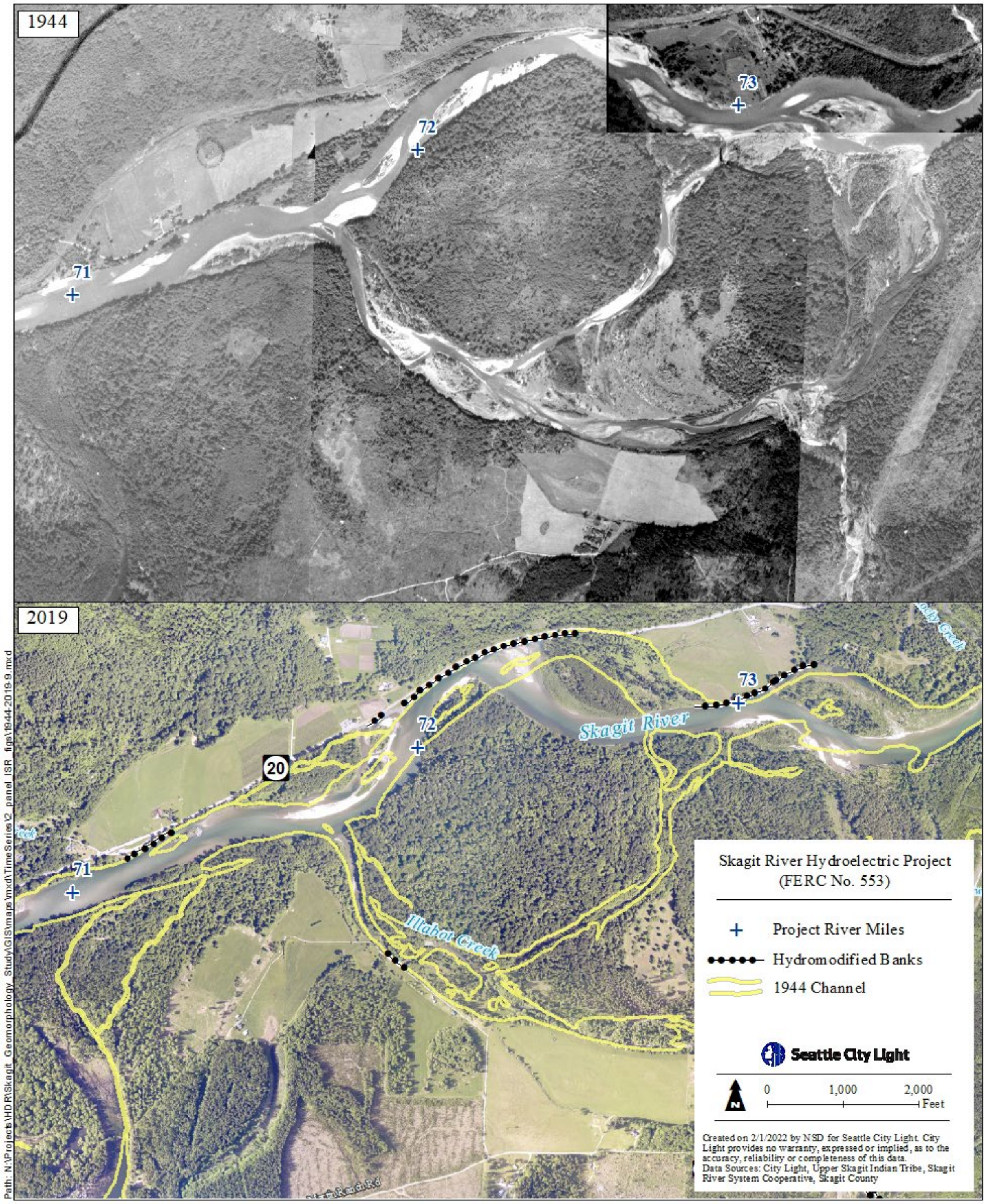

Figure 5.1-13. Comparison of 1944 and 2019 imagery in middle segment of Reach 6.

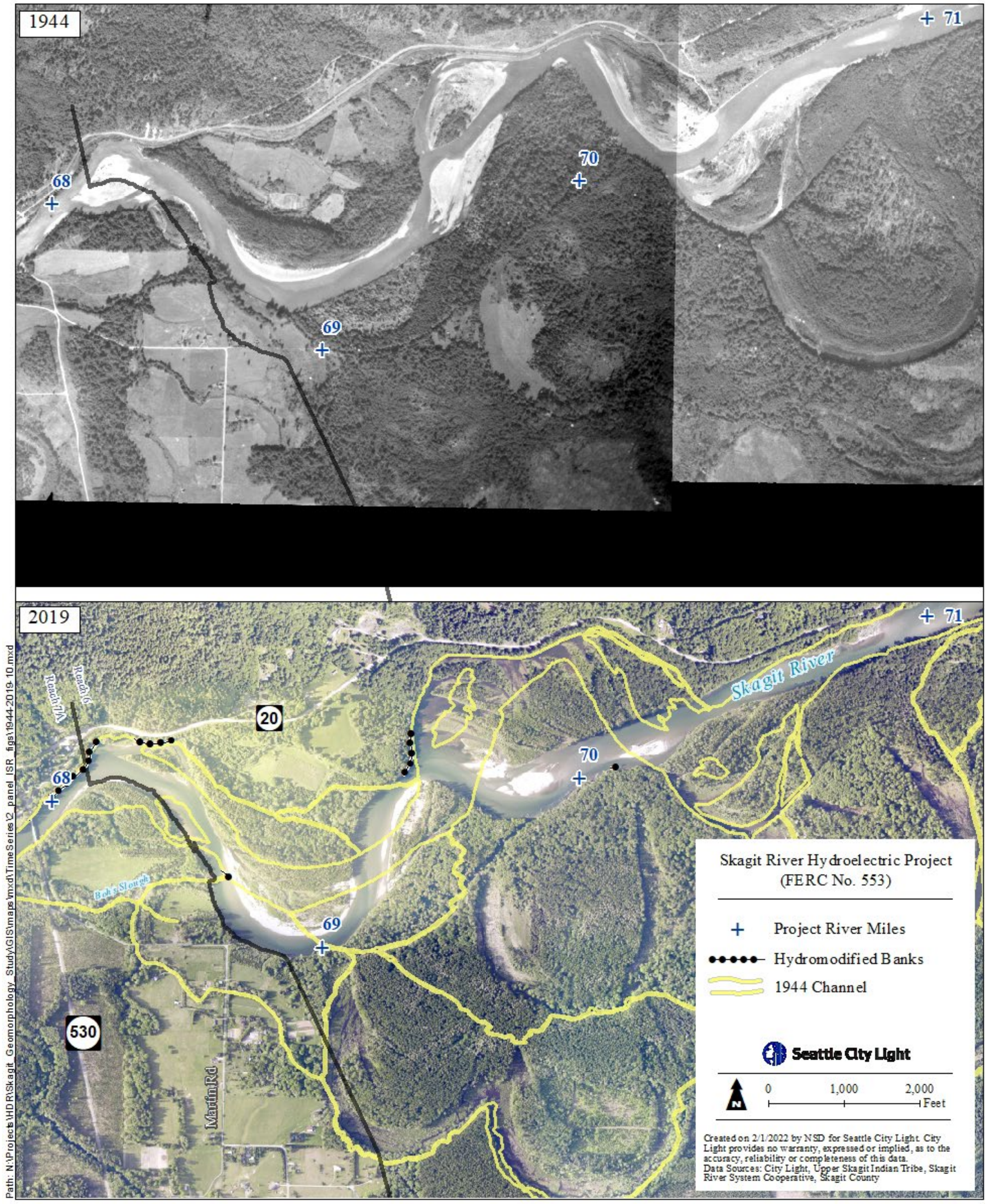

Figure 5.1-14. Comparison of 1944 and 2019 imagery in Reach 3A and lower segment of Reach 6.

Figure 5.1-15. Comparison of 1944 and 2019 imagery in Reach 7A.

5.2 Aquatic Habitat

5.2.1 Habitat Mapping

Habitat mapping results are presented by reach and subreach from upstream to downstream. The quantity and distribution of aquatic habitat provide a sense of availability and diversity of units between each reach. Channel unit areas including side channel and off-channel areas are based on the wetted extent polygon originally derived from the 2017 and 2018 LiDAR flights which were captured at 8,000 cfs and 6,000 to 7,500 cfs, respectively. Inundation areas will vary depending on river discharge, as will areas of individual channel units or side channels.

The amount of habitat and the relative proportion of habitat are presented in Figures 5.2-1 and 5.2-2. Data for reaches 2A through 7A are presented in the figures and tables below, respectively. Reach 1, the Gorge bypass reach, is not presented here as the FA-05 Bypass Instream Flow Model Development Study (City Light 2022b) is still being completed and will be used to map the habitat in that reach, the results of which will be reported in the USR. No data on Reach 1 will be included in this preliminary results section. Maps of all reaches with designated channel units are presented in Attachment F Aquatic Habitat Mapbook. Reach length and area normalized by length are presented in Table 5.2-1 to provide context for relative reach size and width. The number of channel units per mile, a measure of habitat diversity is presented in Table 5.2-2. Average depth, bankfull depth and bankfull width are reported in Table 5.2-3 and provide a relative comparison for reach cross-sectional area and channel capacity during channel forming flows. Bankfull widths are presented in Table 5.2-3; average and bankfull depth depend on the output from the hydraulic model and will be included in the USR once those data are available.

Reaches 6 and 2B are the largest, with Reach 6 containing more than twice the surface area as the next largest reach. Reach 6 is also the longest reach with about double the length of the next largest reach (Table 5.2-1), but even normalized by length, it provides the largest amount of habitat. As described in Section 3.0 of this study report, the reaches exhibit large differences in geomorphic characteristics. Reach 6 is lower in the watershed than most of the other reaches, carries more flow due to additional tributary inputs and flows through a less confined area, so has the potential for more side and off-channel habitat.

By far, the most common channel unit classification by area is glide habitat and, generally, this proportion increases in a downstream direction. This channel unit type represents the largest portion of habitat area for all the reaches shown in Figure 5.2-2, except for Reach 2A, which has large portions of both rapid and backwater habitat area. Reaches 2B and 6 also have the largest proportion of off-channel and side channel habitat and Reach 7A also has a larger portion of side channel habitat. The lower reaches (6 and 7A) have lower gradients and more flow, which results in less riffle and rapid habitat and more slow water habitat.

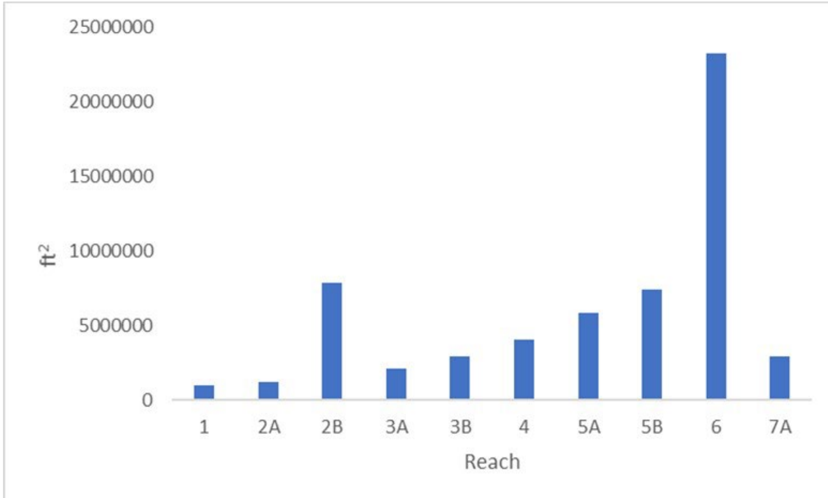

Figure 5.2-1. **Total area of aquatic habitat by reach.**

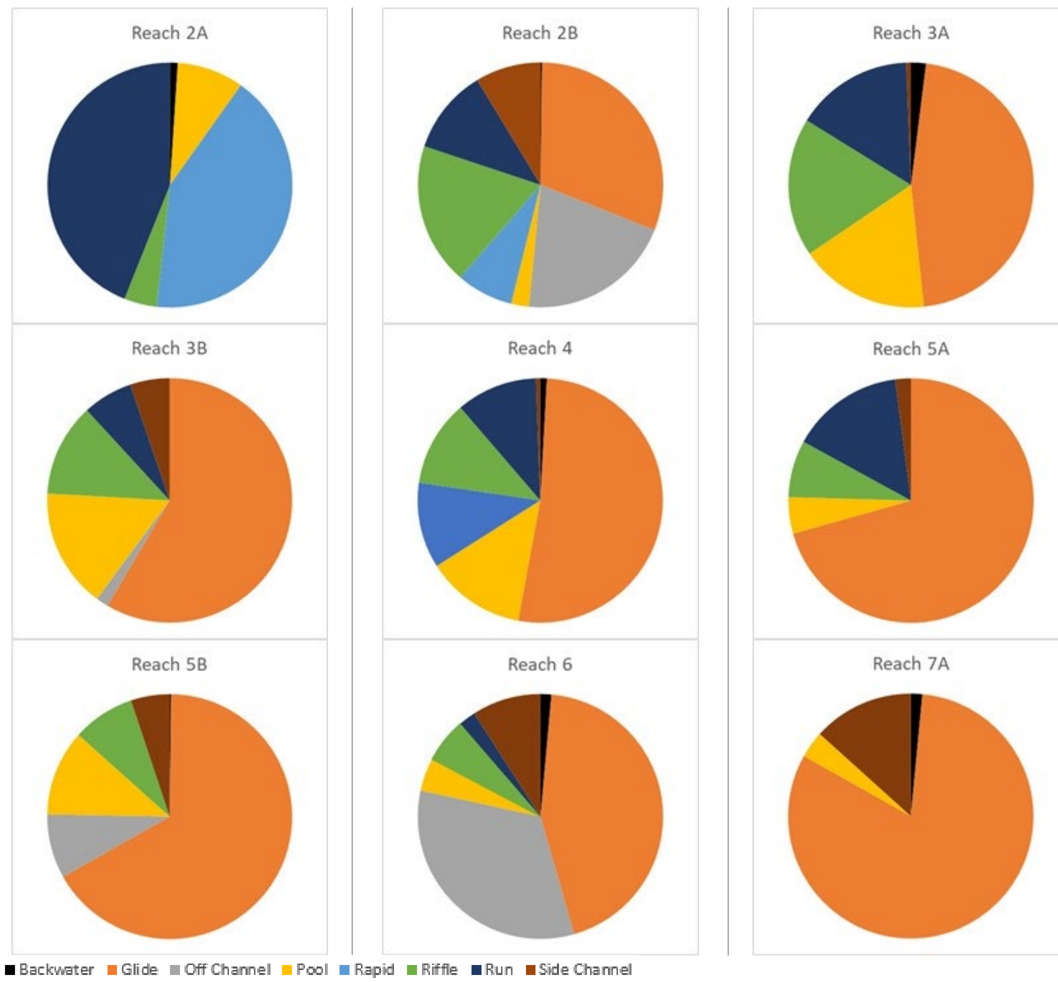

Figure 5.2-2. **Distribution of the area of channel unit classes by reach.**

Channel unit density in terms of channel unit total and channel units per mile are included in Table 5.2-3. The density and diversity of channel units can be seen by looking at both Table 5.2-2 and 5.2-3. In terms of the diversity (number of habitat types), Reach 2B is the most diverse and also has a relatively high density of channel units at 15 units per mile. Some of this diversity is attributed to the existence of off-channel habitat areas that are relics of past human alteration such as the aggregate ponds and the spawning channel. Reach 6 has the highest density of units but does not contain any rapid habitat, which is expected given its low gradient and the absence of bedrock in the reach. Reach 4 is also fairly diverse, but much smaller than Reaches 2B and 6, and with a lower density of habitat units. Reach 7A has both the least diversity and density of all the reaches mapped.

Table 5.2-1. Reach length and area normalized by length.

Reach[1]	Area (ft^2)	Length (miles)	Area Normalized by Length (ft^2/ft)
2A	1,259,521	1.16	206
2B	7,899,597	4.09	366
3A	2,126,914	1.92	210
3B	2,986,184	1.96	289
4	4,066,343	3.51	219
5A	5,844,664	3.52	315
5B	7,468,833	3.69	383
6	23,832,743	6.72	672
7A	2,981,566	1.27	443

1 Reach 1 data will be updated in the USR.

Table 5.2-2. Summary of area by channel unit classification by reach (ft^2).

Reach[1]	Backwater	Off-channel	Pool	Side Channel	Run	Glide	Rapid	Riffle
2A	12,880	0	110,897	0	553,475	0	527,933	54,337
2B	13,732	1,619,702	185,900	683,363	887,090	2,436,726	591,805	1,481,278
3A	41,700	0	365,571	13,215	330,427	986,309	0	389,691
3B	0	48,507	471,395	155,801	197,052	1,746,575	0	366,853
4	35,452	0	533,436	22,679	435,313	2,114,880	460,439	464,144
5A	0	0	281,459	121,635	873,328	4,128,236	0	440,096
5B	12,938	633,235	846,259	382,561	0	4,977,496	0	616,344
6	342,016	7,829,118	1,034,709	2,166,421	531,872	12,950,309	0	1,412,794
7A	45,184	0	105,385	396,501	0	2,434,496	0	0

1 Reach 1 data will be updated in the USR.

Table 5.2-3. Number of channel units by reach.

Reach[1]	Number of Channel Units	Length of Reach (miles)	Number of Channel Units per Mile
2A	12	1.16	10
2B	60	4.09	15
3A	27	1.92	14
3B	16	1.96	8
4	22	3.51	6
5A	16	3.52	5
5B	27	3.69	7
6	124	6.72	18
7A	5	1.27	4

1 Reach 1 data will be updated in the USR.

Average depth and bankfull width and depth provide a measure of channel capacity both during average flows and bankfull flows. These data also provide information on the relative size of each reach and the cross-sectional profile of the channel. Data on average depth and bankfull depth will be extracted from the FA-02 Instream Flow Model Development Study Upper Skagit Hydraulic Model (City Light 2022a) and included in the USR. Table 5.2-4 shows the bankfull width by reach as extracted from the composite surface used in the model development.

Table 5.2-4. Bankfull width, number of pools, pool frequency, and pools per channel width by reach.

Reach[1]	Bankfull Width (ft)	Number of Pools	Pool Frequency (number/mile)	Pools per Channel Width (Number)
2A	216	4	3.4	28.4
2B	324	6	1.5	66.6
3A	234	6	3.1	43.3
3B	233	5	2.6	43.3
4	325	4	1.1	57.1
5A	325	3	0.9	57.1
5B	382	8	2.2	51.1
6	537	16	2.4	66.0
7A	520	1	0.8	12.9

1 Reach 1 data will be updated in the USR.

Aquatic habitat quality is influenced by pool frequency, cover, key pieces of large wood and log jams, substrate characteristics, as well as the amount of edge habitat. Pool frequency is summarized by both pools per mile and pools per channel width. Pool frequency across reaches is relatively constant on a per mile basis with most reaches having 0.8 to 3.4 pools per mile (Table 5.2-4). On a per channel width basis, pool frequency ranges from 12.9 to 66.6 across reaches. Reaches 2A and 3A have the highest pool frequency while Reaches 2B and 6 have the highest number of pools scaled by bankfull width.

Large wood in the study area is an important contributor to pool creation, as well as providing cover and nutrient inputs for aquatic species. Substantial data on large wood distribution and characteristics are provided in Section 5.6 of this study report. The density of large wood jams as well as the presence of apex jams (a subset of log jams) and pool forming wood are indicators of structure and habitat quality for aquatic species, specifically Pacific salmon species. Selected wood metrics are presented in Table 5.2-5 summarizing the levels of large wood by reach. The majority of reaches have relatively low levels of functional wood as compared to the total number of pieces. Normalizing by reach length, Table 5.2-5 shows that in general, reaches farther downstream in the Skagit River (upstream of the Sauk River confluence in the primary study area) have more wood and more functional wood.

Table 5.2-5. Total Pieces, log jams, apex jams, and geomorphically functional wood by reach.

Reach[2]	Total Large Wood Pieces	Pieces (number / mile)	Log Jams (number)	Jam Density (number / mile)	Apex Jams[3] (number)	Pool Forming Wood[1] (number of pieces)	Pool Forming Wood (number / mile)
2A	52	44.8	2	1.7	0	0	0
2B	363	88.8	10	2.4	4	27	6.6
3A	57	29.7	1	0.5	0	0	0.0
3B	236	120.4	5	2.6	1	31	15.8
4	57	16.2	1	0.3	0	2	0.6
5A	150	42.6	2	0.6	1	0	0.0
5B	827	224.1	23	6.2	6	35	9.5
6	1908	283.9	27	4.0	7	60	8.9
7A	414	326.0	9	7.1	0	4	3.1

1 Pool presence was not observed for every piece; total count is an underestimate.
2 Reach 1 was not inventoried in August 2021.
3 Apex jams are a subset of log jams.

Similar to wood, cover also plays a role in the quality of rearing and spawning habitat for fish species. For the purposes of this study, cover includes the following: undercut banks, overhanging vegetation, rootwads, log jam/submerged brush pile, log(s) parallel to bank, aquatic vegetation, short (<1') terrestrial grass, tall (>3') dense grass (e.g., reed canary grass), vegetation > 3 vertical ft above stage zero flow (WDFW and Ecology 2016). Cover data, collected as part of the FA-02 Instream Flow Model Development Study (City Light 2022a), will be summarized in the USR and provides information regarding habitat available for rearing and hiding cover for juveniles and holding habitat for spawning fish. Cover metrics to be calculated include percent cover, pools per mile with cover, and area of edge habitat with cover.

Channel substrate also plays an important role in spawning habitat for adult salmonids and affects habitat use by juveniles. Specific substrate sizes are used by each species for spawning, so information on grain size can help to evaluate the quality of spawning habitat (see FA-02-Instream Flow Model Development Study for more detail). The combination of substrate and cover, especially in river margins and edge habitat, can also influence the rearing habitat capacity and the distribution of juvenile salmonids. Substrate data, collected as part of the FA-02 Instream Flow Model Development Study (City Light 2022a), will be summarized in the USR.

Edge habitat has been noted as a critical component for rearing juvenile Chinook as well as other salmon in the Skagit River (Beechie et al. 2005). Edge habitat is used by juvenile salmon to escape the main current of the river, hide from predators, and to rear and grow. The amount of cover, area of edge habitat, and area of edge habitat with cover are dependent on data from the FA-02 Instream Flow Model Development Study (City Light 2022a) and will be included in the USR.

Aquatic habitat conditions can be impacted by human modifications including banks that have been hydromodified or excessively eroding banks that are caused or affected by human actions on the landscape (Hartson and Shannahan 2015). Table 5.2-6 identifies the proportion of bank length in each reach that is hydromodified or actively eroding. There are some areas where banks have been hydromodified and are actively eroding, but those data are not included in the table below. See Attachment E for more detail on specific areas with both erosion and hydromodification. Substrate conditions downstream of actively eroding areas can also indicate whether and where erosion may be affecting fish habitat. As shown in the table, hydromodification is much more common on the right bank of the Skagit River, which may be due to higher levels of development and the presence of SR 20. Reaches 3A, 3B, 4 and 7A have the highest proportion of hydromodified banks on river right, followed by Reaches 6 and 5B. Reaches 2A, 2B and 5A have little to no hydromodifications as mapped using 2015 data (Hartson and Shannahan 2015). Active erosion is present on both banks mostly in Reach 6, which is also the longest reach. There is also active erosion noted in Reach 7A on the right bank and Reach 4 on the right bank. Reaches 6 and 7A are naturally less confined, from a geomorphic perspective, than some of the other reaches, so may be more prone to erosive processes.

Table 5.2-6. Percent of bank length hydromodified and percent of bank length actively eroding by reach.

Reach[1]	Percent Hydromodified (%)		Percent Actively Eroding (%)	
	Left Bank	Right Bank	Left Bank	Right Bank
2A	0%	0%	0%	0%
2B	0%	3%	1%	2%
3A	0%	37%	0%	0%
3B	0%	23%	0%	0%
4	6%	21%	0%	9%
5A	3%	0%	0%	0%
5B	1%	16%	0%	0%
6	1%	20%	32%	13%
7A	0%	21%	0%	14%

1 Reach 1 data will be updated in the USR.

5.2.2 Tributary Analysis

A summary of water depths, widths, and gradients found within each tributary that was explored for fish passage can be found in Table 5.2-7. Gradients are averaged across the entire approximate 500-linear ft reach. Widths are of the wetted channel unless the stream was dry, in which case bankfull width measurements were taken, as wetted width is a criterion of fish passability (WDFW 2019). Some tributaries were too deep or swift at time of survey (during the August 2021 field visit) for surveyors to cross or obtain true thalweg measurements. In these cases, water depth measurements were taken near the accessible bank and width measurements were estimated based on remote sensing data and visual verification in the field. In the case of Goodell Creek, a survey could not be completed due to deep, swift waters coupled with steep, erosive banks making the survey inaccessible. A full inventory of tributaries assessed, linear distance surveyed, water depth and relative elevation profiles, and field photos can be found in Attachment G, the Tributary Fish Passage Analysis Inventory.

Average negative slopes were recorded for three tributaries: Babcock Creek, Napolean Side Channel, and Sauk Side Channel 1. This occurred because each stream had very low overall gradients with sections of backwatering, leading to slightly negative overall slope values across the survey. Absolute gradients of these tributaries were less than one percent and are noted as approximately zero percent in Table 5.2-7.

Table 5.2-7. Summary of tributary water depth values and average widths.

Tributary	Avg. Gradient	Min. Water Depth (ft)	Max. Water Depth (ft)	Avg. Water Depth (ft)	Average Width (ft)
Alma Creek	5.25%	0.50	2.45	1.55	28[2]
Babcock Creek	~0%	0.00	3.17	1.04	5
Bacon Creek	1.17%	1.49	2.20	1.69	54
Barr Creek	4.25%	0.15	1.78	0.75	15
Copper Creek	6.37%	0.47	1.66	0.84	11
Corkindale Creek	2.07%	0.00	0.49	0.03	16[1]
Damnation Creek	5.16%	0.80	2.75	1.26	20
Diobsud Creek	0.14%	0.60	3.29	1.37	37
Goodell Creek	N/A	N/A	N/A	N/A	N/A
Illabot Creek	2.93%	0.50	3.70	1.73	17
Ladder Creek	2.68%	0.70	5.50	2.27	16
Martin Creek	0.86%	0.00	2.35	0.53	9
Napolean Side Channel	~0%	1.66	2.36	2.08	51
Newhalem Creek	2.90%	1.50	3.90	2.12	30[2]
Olsen Creek	1.67%	0.00	0.49	0.05	39[1]
Rocky Creek	2.83%	0.23	1.27	0.75	19
Sauk Side Channel 1	~0%	1.34	2.18	1.69	35
Sky Creek	18.65%	0.16	2.60	0.90	9[2]
Sutter Creek	4.33%	0.00	0.00	0.00	17
Thornton Creek	2.67%	0.38	2.74	1.31	33

1 Bankfull width measurement; bankfull widths were taken instead of wetted widths when stream channels were dry.
2 Estimated value.

5.3 Side Channels and Off-Channel Habitat

5.3.1 Current Side Channel Condition

Current side channel condition results are focused on side channels that were identified in a collaborative process with City Light and LPs during July 2021. Results are organized by geomorphic reach and include a summary of the side channels in each reach visited during August 2021 surveys. A more detailed narrative describing each side channel is available in Attachment H. Summary tables are provided at the end of each reach subsection and include side channel IDs, local side channel names, side channel type, approximate area, and inlet and outlet characteristics. Side channel areas presented in the summary tables are approximate and based on field observations and interpretation of REMs. Inlet and outlet connections are based on low flow field observations during August 2021 surveys. Maps showing side channels are presented below.

5.3.1.1 Reach summaries of side channel habitat

Reach 2A

Reach 2A begins at the Newhalem Powerhouse and extends down to the NPS Newhalem Visitor Center bridge and does not contain any side channels.

Reach 2B

Reach 2B spans from the NPS Newhalem Visitor Center bridge down to the County Line Ponds and contains ten side channels (Figures 5.3-1 and 5.3-2). At the time of the survey, six side channels are perennially connected, two seasonally connected, and two are inactive (Table 5.3-1). The largest side channel is the Thornton Side Channel at PRM 90.7, which has several inlets that converge into a single large side channel and an additional perennial side channel branching off at PRM 90.25. Three side channels in 2B have been enhanced as part of prior mitigation actions—Agg Ponds, County Line Ponds, and Park Slough. The Agg Ponds and County Line Ponds are two former aggregate mining sites with excavated side channels and off-channel areas formed by old mining pits. The Skagit River has eroded through portions of the County Line Ponds creating additional side channels and connections from two ponds to the river. Park Slough is a blind constructed Chum spawning channel created in the 1990s. The excavated channels in the Agg Ponds and Park Slough are ground water fed and provide rearing habitat due to cold water, slow water, and cover from large wood and overhanging vegetation, but spawning functionality in Park Slough has been reduced due to siltation and exacerbated by beaver dams that trap silt deposits. This statement is supported by the field observations of the Park Slough substrate in the summer of 2021 where extensive silt was observed throughout the slough. Since Park Slough was constructed as a spawning channel and presumably had spawning gravels in it when it was created in the 1990s, the extensive coverage of silt is an indication of loss of spawning habitat functionality in that area. Additional characterization of beaver activity at the Project's off-channel sites is provided in the TR-09 Beaver Habitat Assessment (City Light 2022f).

Table 5.3-1. Summary of side channels in Reach 2B.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Dominate Substrate	Outlet Connection and Dominate Substrate	Skagit R. Discharge During Survey[2] (cfs)
92.8-L	Unnamed	195,809	Side Channel, Inactive	Dry/Coarse Gravel	Dry/Sand and Fines	2,980
91.7-L	Unnamed	7,649	Side Channel, Inactive, backwater only	Dry/Vegetated	Wet/Sand and Fines	3,060
91.7-R	Unnamed	45,421	Side Channel, Seasonal	Wet/Cobble	Dry/Cobble	3,740
91.5-L	Park Slough	71,098	Side Channel, Perennial	Blind/Subsurface	Wet/Coarse Gravel	3,060
91-R	Agg Ponds[1]	174,429	Side Channel and Off-Channel, Perennial	Blind/Subsurface	Wet/Sand and Fines	3,710
90.7-L	Thornton Side Channel	392,807	Side Channel, Perennial	Wet/Cobble	Wet/Coarse Gravel	3,030
90.5-R	Unnamed	24,327	Side Channel, Seasonal	Blind/Subsurface	Dry/Coarse Gravel	3,710
90.25-L	Unnamed	114,505	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Coarse Gravel	3,030
90.1-R	Unnamed	25,677	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Cobble	3,030
89.5-R	County Line Ponds[1]	199,587	Side Channel and Off-Channel, Perennial	Wet/Cobble	Web/Coarse Gravel	2,900

1 Side channel area only; does not include ponds.
2 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

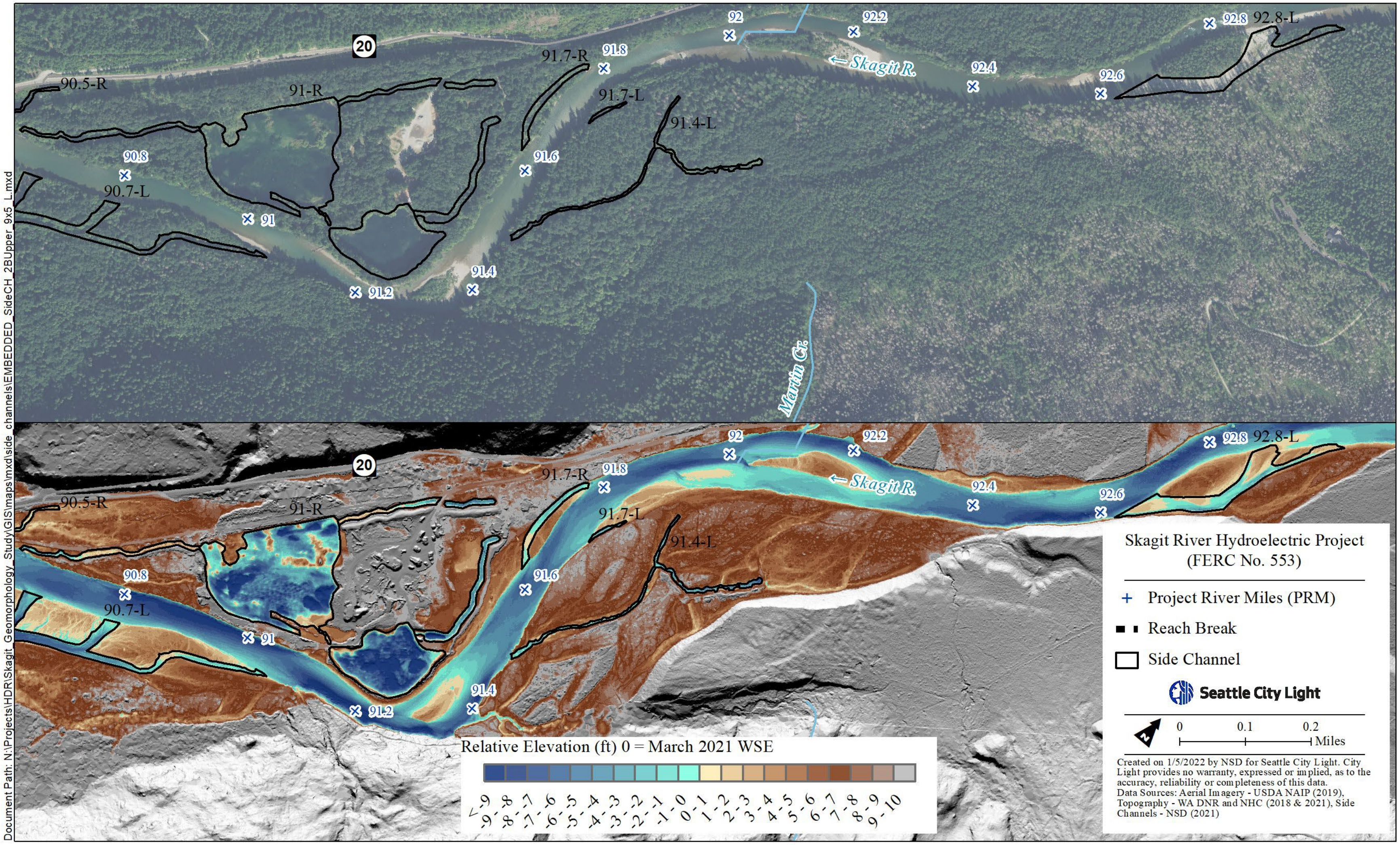

Figure 5.3-1. Map of Reach 2B upper side channels.

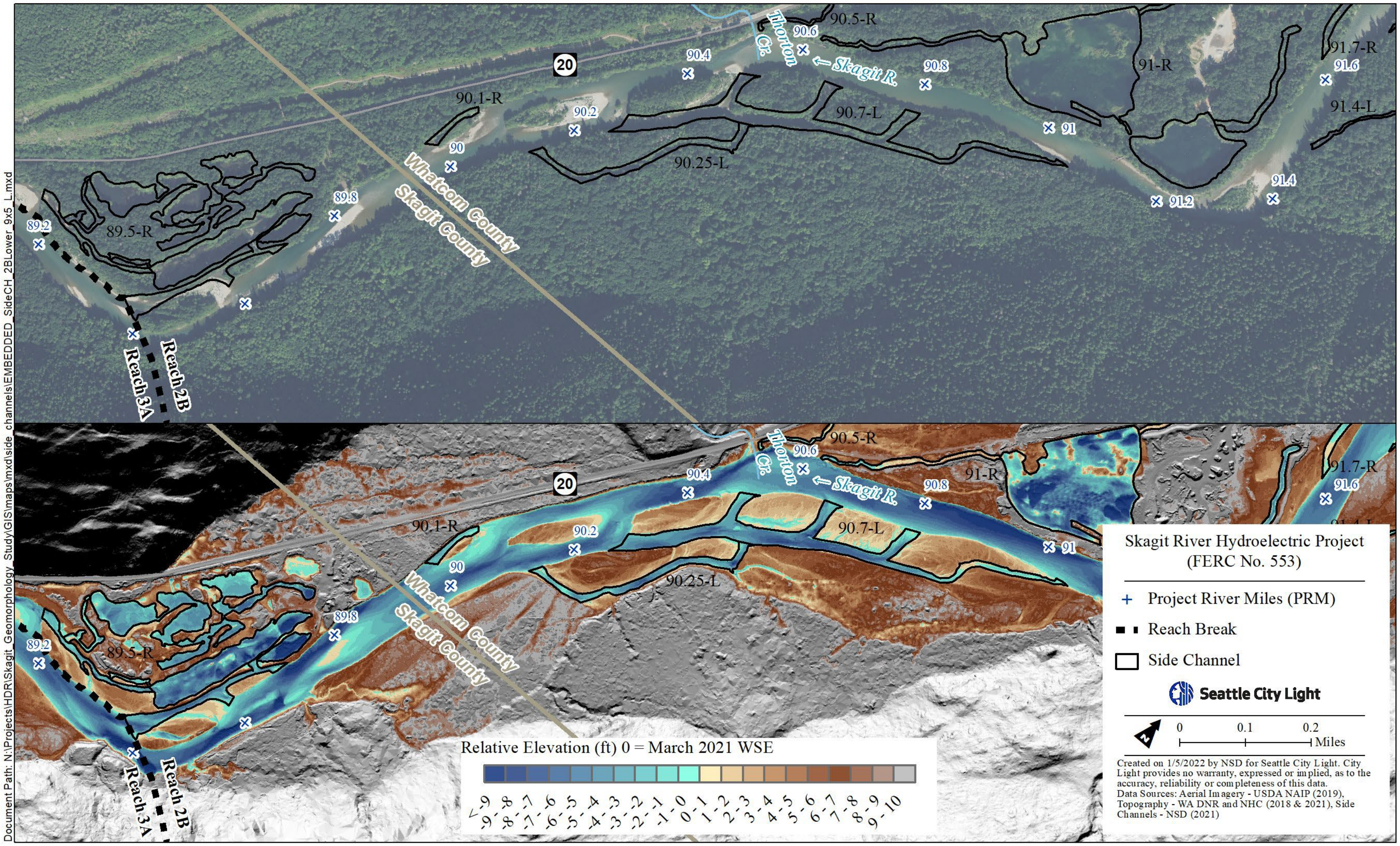

Figure 5.3-2. **Map of Reach 2B lower side channels.**

Reach 3A

Reach 3A is naturally confined with a narrow floodplain where the river steepens and begins to enter a long series of rapids. Only two side channels are present in 3A (Table 5.3-2 and Figure 5.3-3). The first side channel at PRM 88.8 is seasonal and backwaters from the river at higher flows. The second side channel at PRM 88.7 is a perennial feature that intersects the valley hillslope indicating a groundwater and hillslope fed channel. Both side channels have inactive vegetated inlets.

Table 5.3-2. Summary of side channels in Reach 3A.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Dominate Substrate	Outlet Connection and Dominate Substrate	Skagit R. Discharge During Survey[1] (cfs)
88.8-R	Unnamed	3,518	Side Channel, Seasonal	Dry/Vegetated	Dry/Sand and Fines	2,530
88.7-L	Unnamed	52,254	Side Channel, Perennial	Dry/Vegetated	Wet/Coarse Gravel	2,930

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

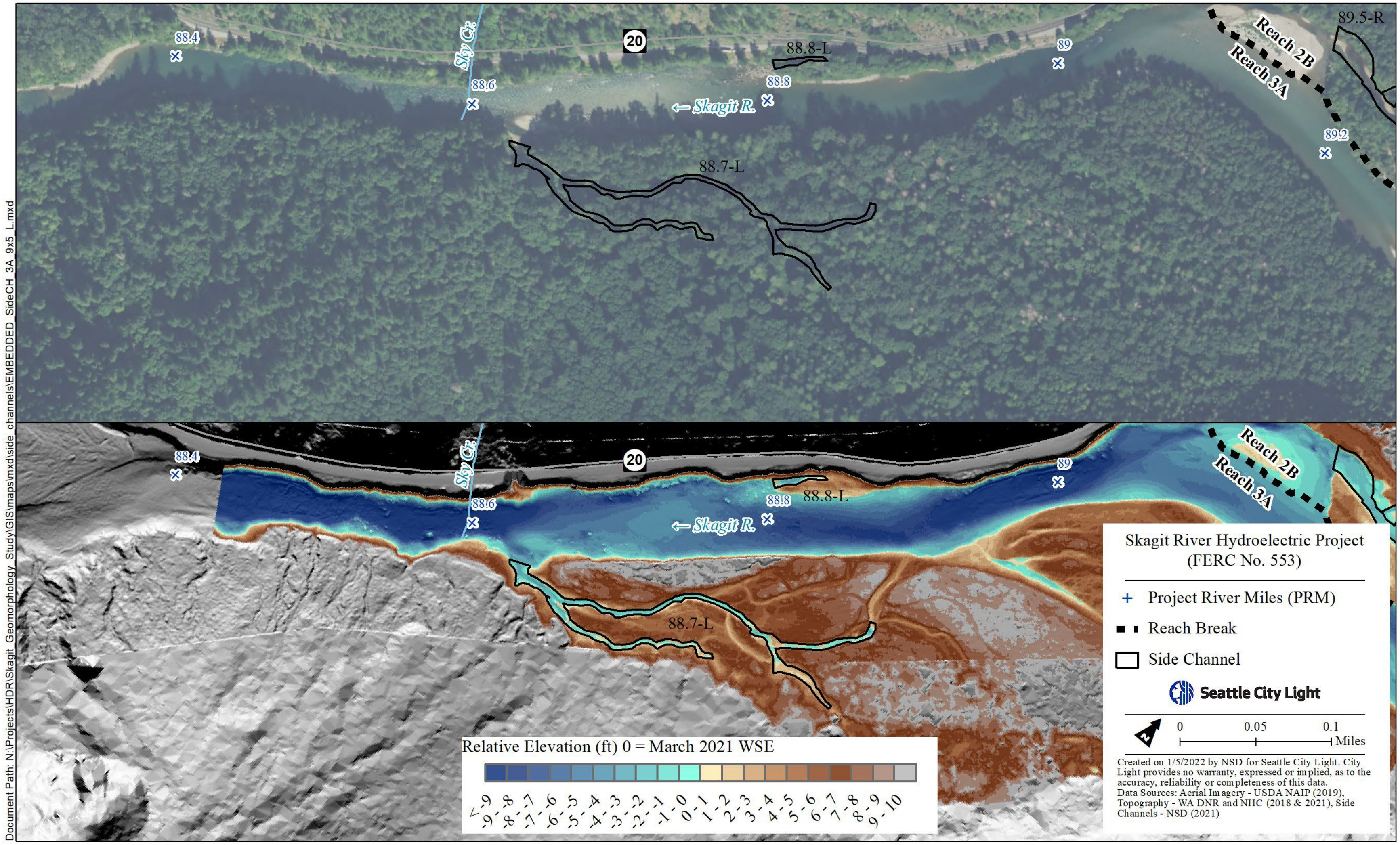

Figure 5.3-3. Map of Reach 3A side channels.

Reach 4

The river is confined to a narrow steep valley with several sections of rapids through Reach 4 and contains only 3 small side channels all near the downstream end of the reach (Table 5.3-3 and Figure 5.3-4). One channel is perennial, one is seasonal, and the third is inactive. The perennial channel at PRM 84.5 contains spawning gravel throughout and was <0.5 ft deep during the August 2021 survey. The seasonal channel at PRM 85.3 has a vegetated inactive inlet and backwaters at the outlet at higher flows. The inactive channel has matured woody shrubs growing within the channel indicating it has not had flow through recently.

Table 5.3-3. Summary of side channels in Reach 4.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Dominate Substrate	Outlet Connection and Dominate Substrate	Skagit R. Discharge During Survey[1] (cfs)
85.5-R	Unnamed	17,085	Side Channel, Seasonal	Dry/Vegetated	Dry/Sand and Fines	2,530
85.3-L	Unnamed	13,608	Side Channel, Inactive	Dry/Vegetated	Dry/Vegetated	3,510
84.5-L	Unnamed	14,553	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Coarse Gravel	3,510

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

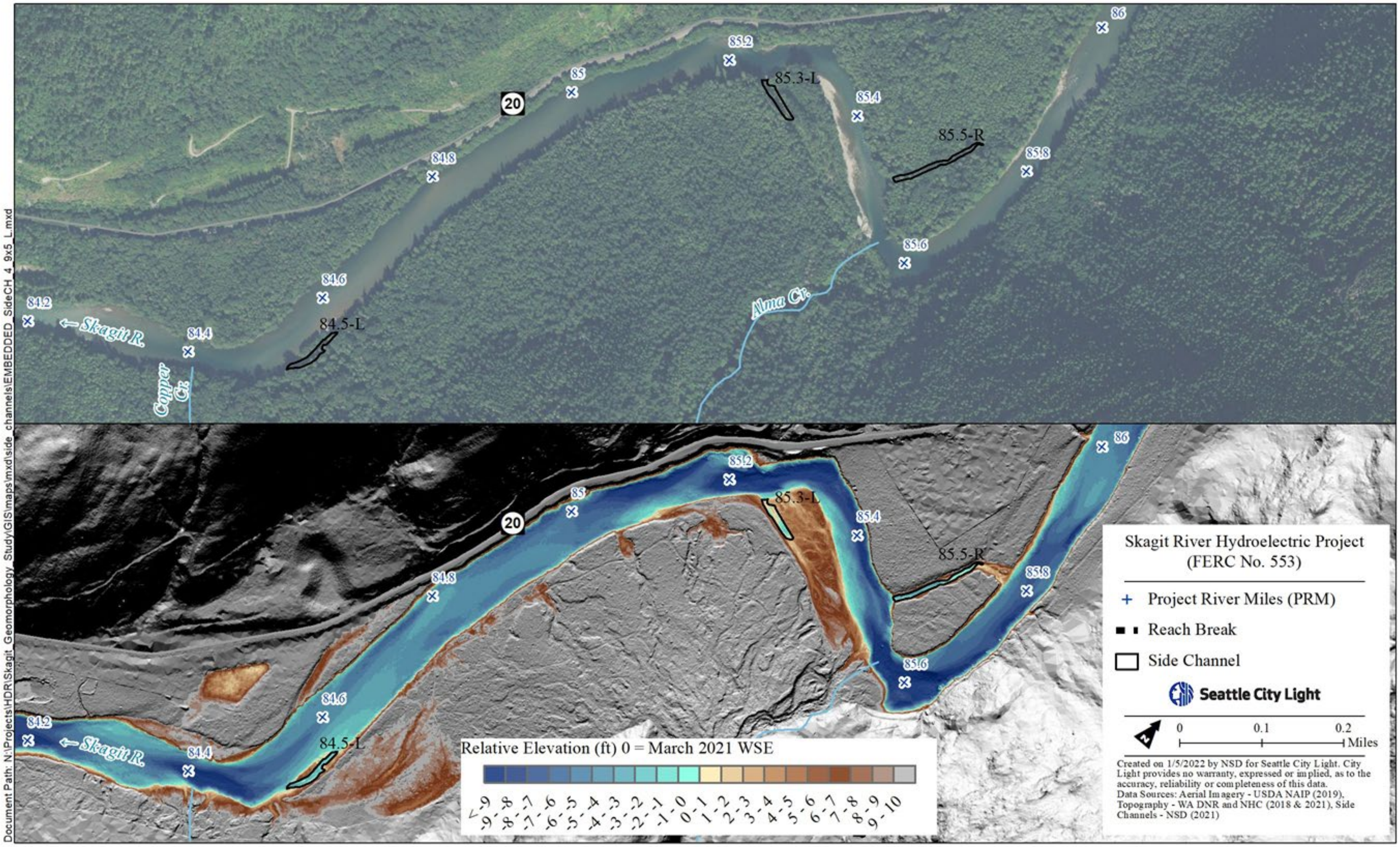

Figure 5.3-4. Map of Reach 4 side channels.

Reach 3B

Reach 3B is a short reach that begins just upstream of Bacon Creek and contains two side channels and one-off-channel area (Figure 5.3-5). The valley and floodplain begin to widen compared to Reach 4, but the river is still confined to a relatively narrow floodplain. The two side channels are perennial and off-channel feature is seasonal (Table 5.3-4). The two perennial channels at PRM 82.8 and 92.5 are flow through and provide spawning and rearing habitat due to spawning sized gravels found in both channels, and rearing habitat elements of pools, slow water, and cover provided by large wood. The off-channel area channel at PRM 82.9 is a pond connected to the Skagit River via an intermittently connected outlet. The pond contains aquatic vegetation and large wood, providing rearing habitat when connected to the river (Figure 5.3-6).

Table 5.3-4. Summary of side channels in Reach 3B.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Dominate Substrate	Skagit R. Discharge During Survey[1] (cfs)
82.9-L	Unnamed	117,001	Off-Channel, Seasonal	Dry/Vegetated	Dry/Sand and Fines	3,510
82.8-R	Moses Slough	136,231	Side Channel, Perennial	Dry/Cobble	Wet/Sand and Fines	3,880
82.5-L	Unnamed	61,202	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Coarse Gravel	3,510

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

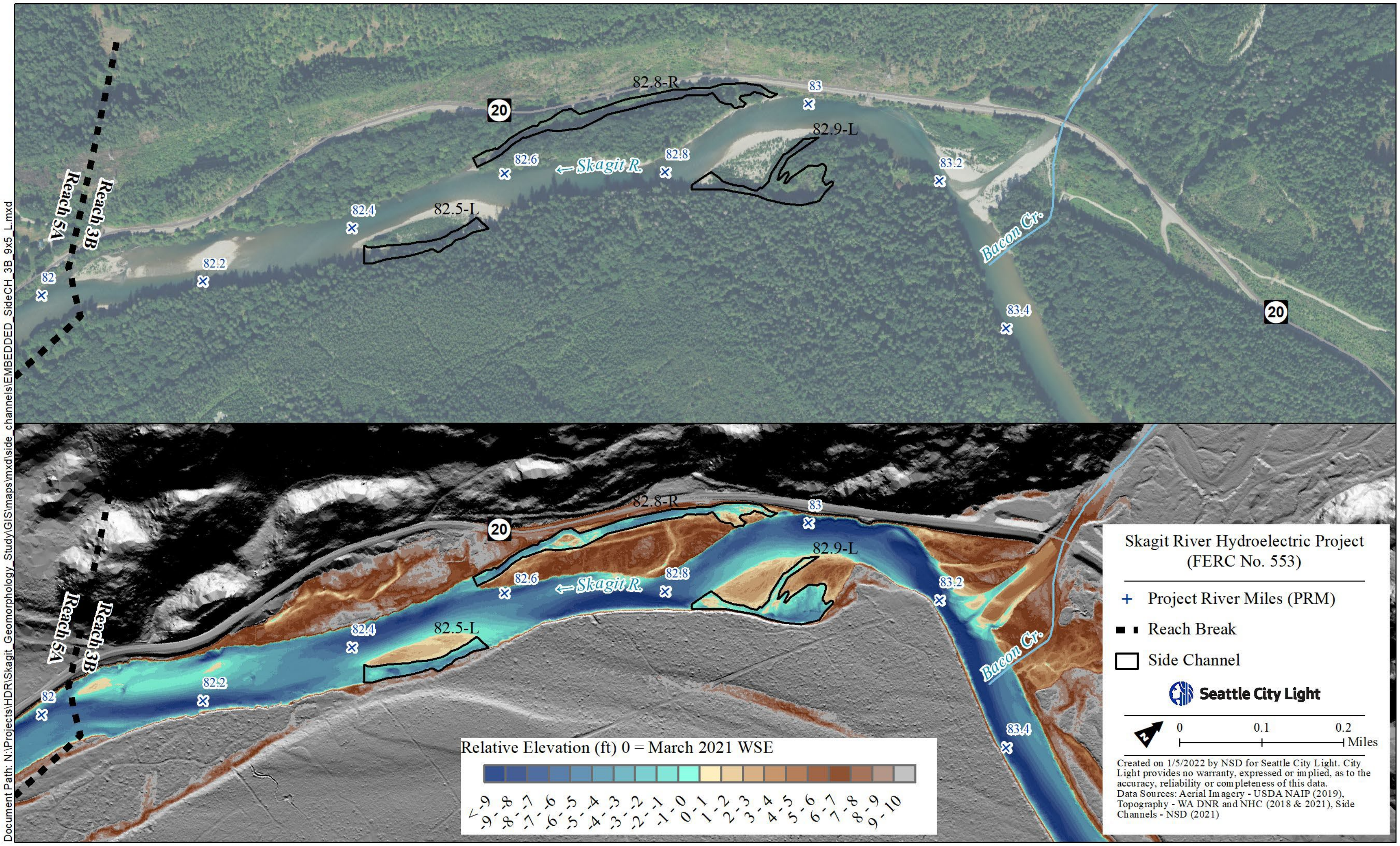

Figure 5.3-5. Map of Reach 3B side channels.

Figure 5.3-6. Off-channel pond in side channel PRM 82.9-L.

Reach 5A

Reach 5A begins upstream of Diobsud Creek and extends down to the Cascade Rockport Rd Bridge. Within Reach 5A the valley becomes wider, but the river channel is straight with a narrow active floodplain and contains three side channels (Figure 5.3-7). Two side channels are perennial, and one is inactive (Table 5.3-5). The perennial channel at PRM 81.4, known as Diobsud Slough, is a perennially connected backwater pool with a beaver ponded wetland above the backwater, but the inlet is inactive and vegetated. The perennial channel at PRM 80, known as Taylor Side Channel, is an excavated Chum spawning channel created in the 1990s. Taylor Side Channel is groundwater fed and provides rearing habitat due to cold water, slow water, and cover from large wood and overhanging vegetation, but spawning functionality has been reduced due to siltation and beaver colonization.

Table 5.3-5. Summary of side channels in Reach 5A.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
81.4-R	Diobsud Slough	73,138	Side Channel, Perennial	Dry/Vegetated	Wet/Sand and Fines	3,510
80.6-R	Unnamed	32,741	Side Channel, Inactive	Dry/Vegetated	Dry/Vegetated	3,510
80-L	Taylor Side Channel	171,393	Side Channel, Perennial	Blind/Subsurface	Wet/Fine Gravel	2,690

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

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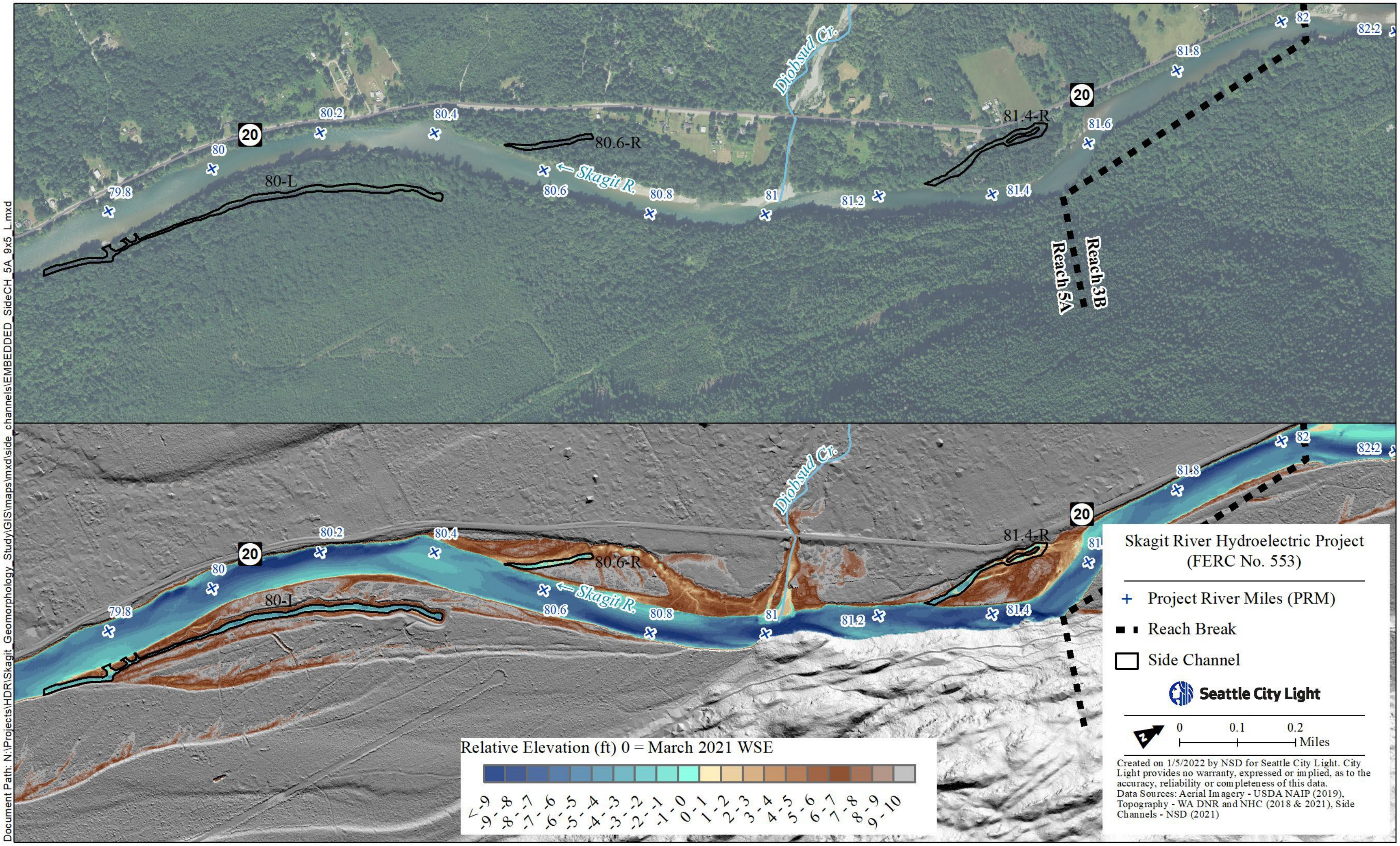

Figure 5.3-7. Map of Reach 5A side channels.

Reach 5B

Reach 5B begins at the Cascade Rockport Rd Bridge and continues down to PRM 74.8 and contains seven side channels (Figures 5.3-8 and 5.3-9). Four side channels are perennial and three are seasonal (Table 5.3-6). The upstream most and largest perennial channel is the Cascade River Distributary Channels at PRM 78.3, which contain several channels with similar characteristics—numerous log jams, pools, and spawning gravels. Marblemount Slough at PRM 78.1 is another large perennial channel and has plane bed morphology and few pieces of large wood. The remaining perennial channels are another plane bed channel devoid of large wood at PRM 76.6, and a channel at PRM 74.6 which used to be a flow through channel but has become mostly inactive aside from a backwater pool and shallow wetland formed by a beaver dam.

Seasonal channels in Reach 5B consist of Marblegate Slough, Clarks Cabin Side Channel, and an unnamed channel. Marblegate Slough at PRM 77 contains two wide long pools near the outlet that were isolated from the Skagit River during August 2021 surveys but appear to seasonally connect to the river and an inlet that is inactive and vegetated. Clarks Cabin Side Channel was not visited due to private property access. The unnamed seasonal channel at PRM 77 is a plane bed channel splitting around a forested island.

Table 5.3-6. Summary of side channels in Reach 5B.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
78.3-L	Cascade River Distributary Channels	317,281	Side Channel, Perennial	Wet/Variable: Cobble to Sand and Fines	Wet/Coarse Gravel and Cobble	3,620
78.1-R	Marblemount Slough	150,142	Side Channel, Perennial	Dry/Coarse Gravel	Wet/Sand and Fines	2.930
77.6-L	Unnamed	233,803	Side Channel, Seasonal	Dry/Coarse Gravel	Dry/Cobble	3,530
77-L	Marblegate Slough	106,661	Side Channel, Seasonal	Dry/Vegetated	Dry/Sand and Fines	3,530
76.6-R	Unnamed	54,413	Side Channel, Perennial	Wet/Cobble	Wet/Cobble	3,510
75.5-R	Clarks Cabin Side Channel	30,985	Side Channel, Seasonal	Not Surveyed	Not Surveyed	N/A
74.6-R	Unnamed	27,857	Side Channel, Perennial	Dry/Vegetated	Wet/Fine Gravel	3,510

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

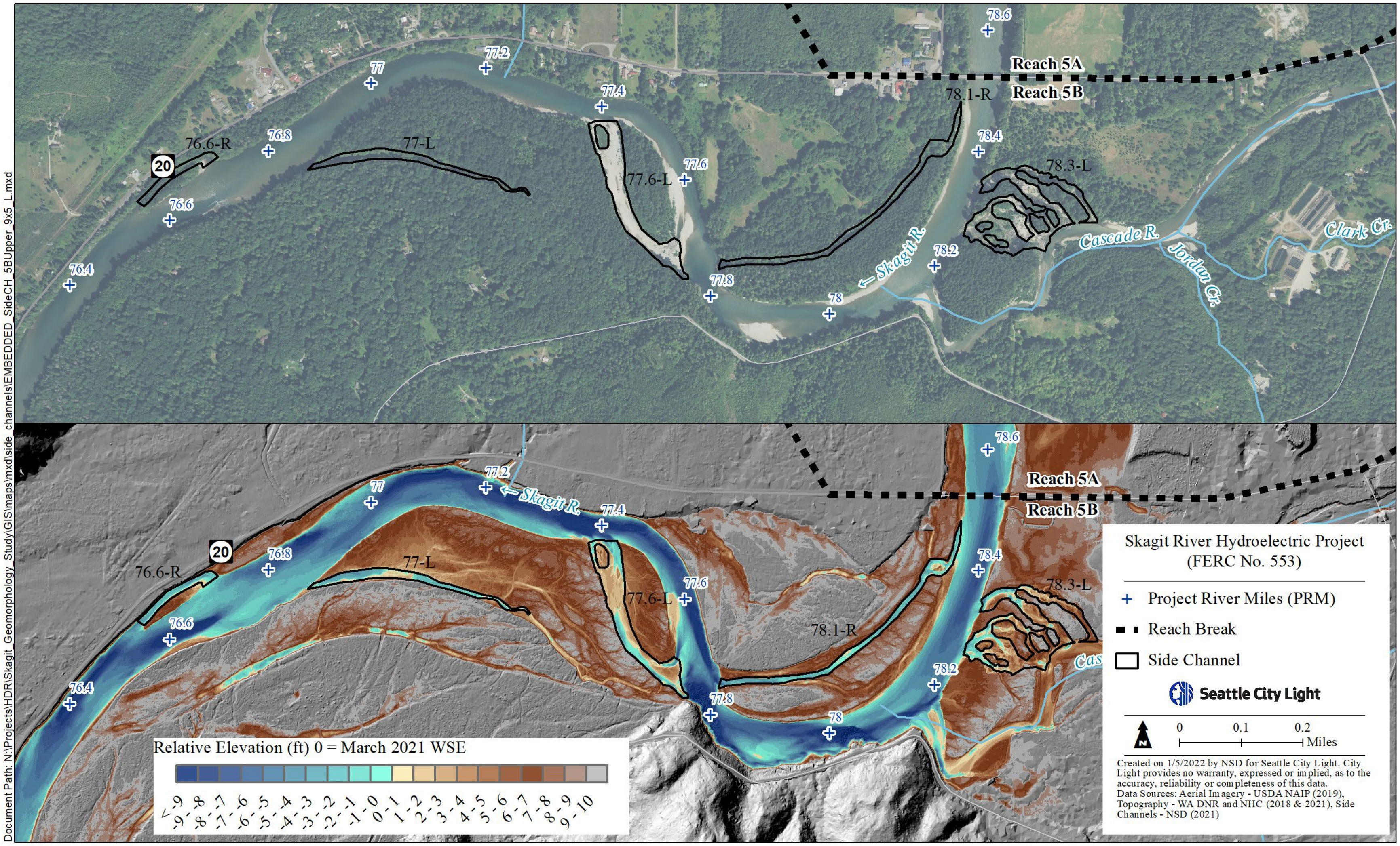

Figure 5.3-8. Map of upper Reach 5B side channels.

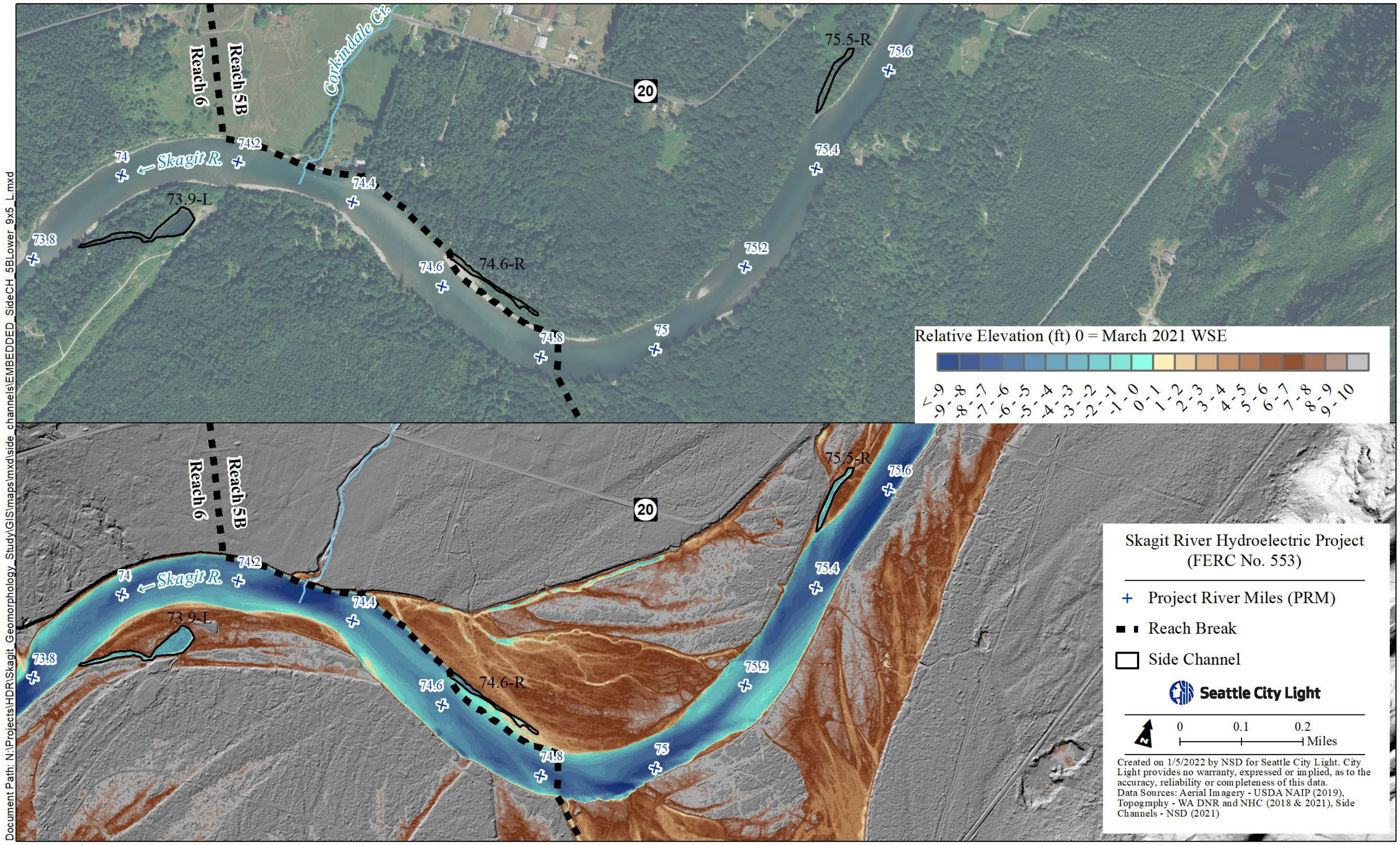

Figure 5.3-9. **Map of lower Reach 5B side channels.**

Reach 6

Reach 6 begins at PRM 74.8 and continues down to PRM 68.1 just upstream of the SR-530 bridge and contains 18 side channels and six off-channel areas, more than double the number of any other reach (Figures 5.3-10 and 5.3-11). Thirteen side channels are perennial and five are seasonal, and all six off-channel areas are perennial (Table 5.3-7). Powerline Pond at PRM 73.9 and Illabot Chum Channel at PRM 73.6 are both excavated Chum spawning channels created in the 1990's that currently function as off-channel areas. Similar to the other spawning channels both have reduced spawning functionality due to siltation but provide rearing habitat via protected channels with cover from large wood, overhanging vegetation, and aquatic vegetation. Powerline Pond has more extensive siltation and minimal spawning habitat.

Connecting the Illabot Chum Channel to the Skagit River is the Illabot Side Channel Complex at PRM 73.6. The Illabot Side Channel Complex is a series of side channels and an off-channel wetland occupying former Skagit River flow through channels. In present day the complex is fed by Illabot Creek and subsurface flow and contains a network of channels with large wood and log jams, pools, and vegetation cover that provide rearing and spawning habitat. Across the river at PRM 73.2 is Buller's Side Channel, also a relict flow-through channel that presently contains a large beaver ponded off-channel area at the upstream end and a side channel connecting to the Skagit River at the downstream end.

The remaining perennial off-channel features in Reach 6 include Hoopers Slough at PRM 72.3, Barnaby Outlet at PRM 70.2, Washington Eddy at PRM 69.6, and a smaller unnamed feature at PRM 68.6. Barnaby Outlet is an off-channel wetland that historically was connected to two large oxbow wetlands—Barnaby Slough and Harrison Pond. Both Barnaby and Harrison were disconnected from the Skagit River by dikes to build now derelict fish rearing ponds in the 1960's. Barnaby Slough was recently reconnected to the Barnaby Outlet, adjacent Lucas Slough, and the Skagit River by a restoration project which was under construction during August 2021.

Other larger side channels in Reach 6 include Timber Dolo Side Channel at PRM 71.9, Lucas Slough at PRM 69.9, an unnamed side channel at PRM 69.4, Johnson Side Channel at PRM 68.5, and Rockport Side Channel at PRM 68.3.

Table 5.3-7. Summary of side channels in Reach 6.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
73.9-L	Powerline Pond	75,082	Off-Channel, Perennial	Blind/Subsurface	Wet/Sand and Fines	3,510
73.6-L	Illabot Chum Channel	146,704	Off-Channel, Perennial	Blind/Subsurface	Wet/Sand and Fines	2,460
73.2-R	Buller's Side Channel	259,884	Side Channel and Off-Channel, Perennial	Dry/Vegetated	Fine Gravel	3,420

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
73-L	Unnamed	47,749	Side Channel, Seasonal, backwater only	Dry/Vegetated	Dry/Vegetated	4,060
72.8-L	Illabot Side Channel Complex	1,888,632	Side Channel and Off-Channel, Perennial	Wet/Variable	Wet/Coarse Gravel	2,820
72.5-R	Unnamed	84,585	Side Channel, Seasonal, backwater at low flow	Dry/Vegetated	Wet/Sand and Fines	3,510
72.3-R	Hoopers Slough	134, 827	Off-Channel, Perennial	Dry/Vegetated	Wet	4,303
72.2-L	Unnamed	51,615	Side Channel, Perennial	Wet/Sand and Fines	Wet/Sand and Fines	4,060
71.9-R	Timber Dolo Side Channel	274,451	Side Channel, Perennial	Wet/Cobble	Wet/Coarse Gravel	3,710
71.5-R	Unnamed	20,258	Side Channel, Seasonal	Dry/Vegetated	Wet/Sand and Fines	3,970
71.4-R	Unnamed	20,989	Side Channel, Perennial	Wet/Cobble	Wet/Coarse Gravel	3,970
71.2-L	Unnamed	38,534	Side Channel, Seasonal	Dry/Vegetated	Dry/Sand and Fines	4,030
70.8-R	Barr Creek Side Channel	38,407	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Coarse Gravel	3,360
70.2-L	Barnaby Outlet	330,823	Off-Channel, Perennial	Dry/Vegetated	Wet/Sand and Fines	3,880
70-L	Unnamed	32,428	Side Channel, Perennial	Wet/Sand and Fines	Wet/Sand and Fines	3,850
69.9-L	Lucas Slough	378,905	Side Channel, Perennial	Wet/Sand and Fines	Wet/Sand and Fines	2,460
69.7-R	Unnamed	54,277	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Sand and Fines	3,450
69.6-R	Washington Eddy	763,744	Off-Channel, Perennial	Dry/Vegetated	Wet/Sand and Fines	2,820
69.5-L	Unnamed	66,621	Side Channel, Perennial	Dry/Coarse Gravel	Wet/Sand and Fines	3,340
69.4-L	Unnamed (larger channel)	242,320	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Not visible due to deep water	2,460
68.6-R	Unnamed	117,740	Off-Channel, Perennial	Dry/Vegetated	Wet/Sand and Fines	3,140

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
68.5-R	Johnson Side Channel	196,038	Side Channel, Perennial	Wet/Coarse Gravel	Wet/Sand and Fines	3,450
68.3-R	Rockport Side Channel	179,901	Side Channel, Perennial	Wet/Cobble	Wet/Cobble	4,300
68.2-R	Unnamed	10,631	Side Channel, Seasonal	Dry/Sand and Fines	Dry/Sand and Fines	4,300

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

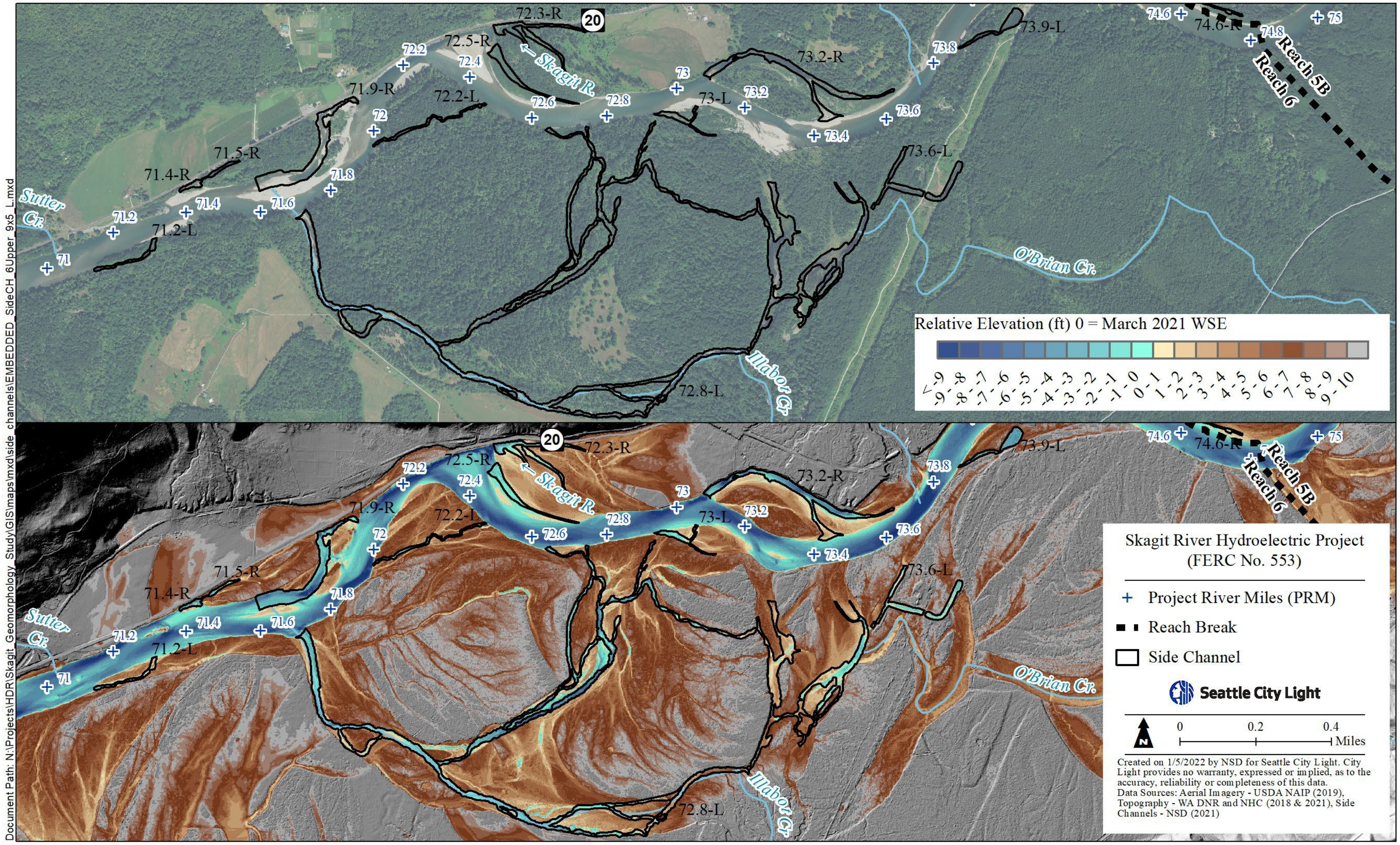

Figure 5.3-10. Map of Upper Reach 6 side channels with labels for Illabot Side Channel Complex channels.

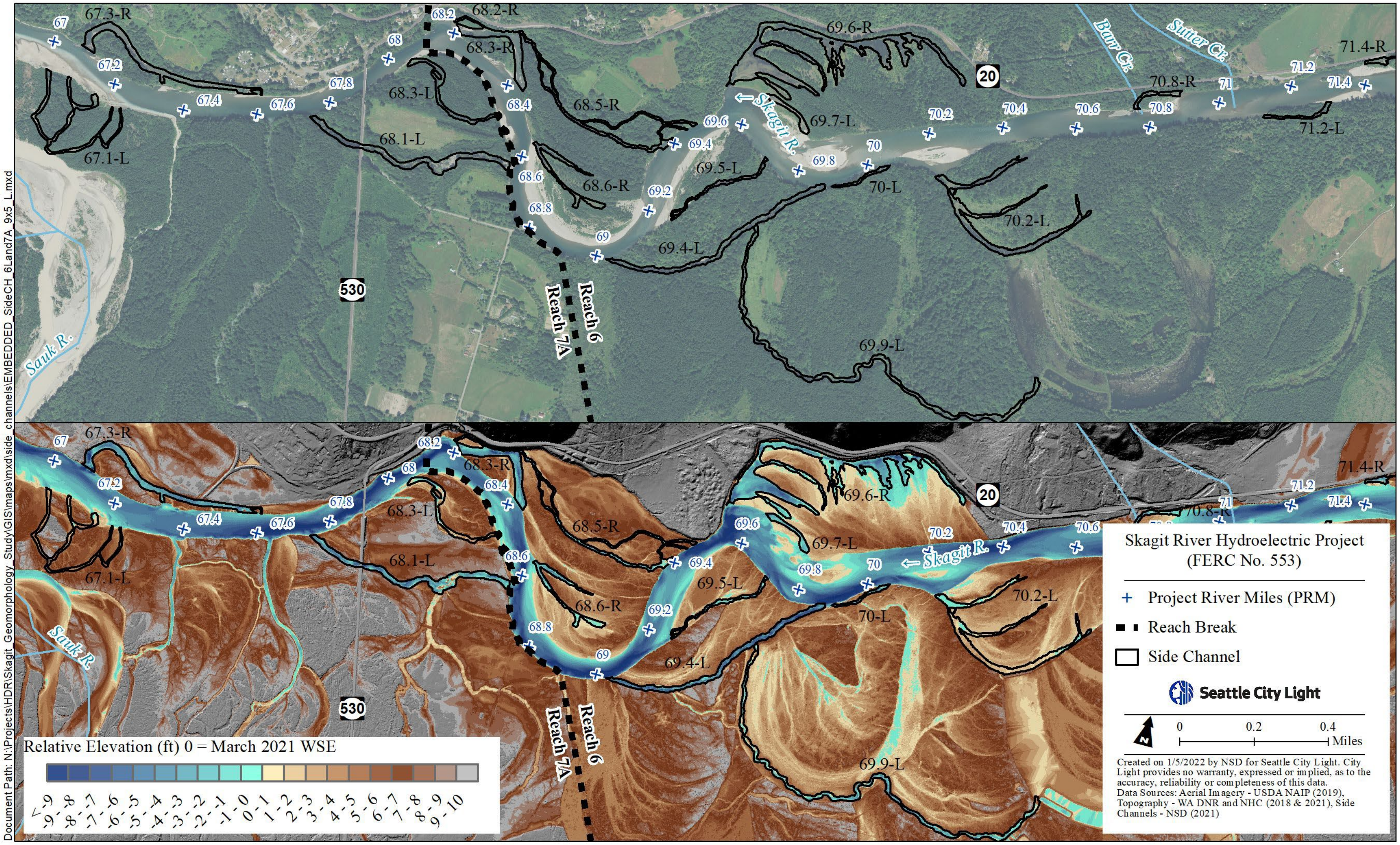

Figure 5.3-11. Map of side channels in Lower Reach 6 and Reach 7A.

Reach 7A

Reach 7A begins just upstream of the SR-530 bridge and extends down to the confluence with the Sauk River and contains four side channels (Figure 5.3-11). Two side channels are perennial and two are seasonal. (Table 5.3-8). Bohs Slough at PRM 68.1 is a perennial channel and flows under SR 530. Bohs Slough is mainly slower water habitat, glide, and pools, and contains channel spanning log jams and large wood pieces providing rearing habitat. Conversely the other perennial side channel Howard Miller Side Channel is a plane bed channel generally devoid of fish cover and contains less wood, aside from a log jam at the outlet that forms a pool with the mainstem Skagit River.

Table 5.3-8. Summary of side channels in Reach 7A.

Side Ch ID	Side Channel Name	Approx. Area (ft^2)	Type	Inlet Connection and Substrate	Outlet Connection and Substrate	Skagit R. Discharge During Survey[1] (cfs)
68.3-L	Unnamed	107,445	Side Channel, Seasonal	Dry/Sand and Fines	Dry/Sand and Fines	4,300
68.1-L	Bohs Slough	282,833	Side Channel, Perennial	Wet/Cobble	Wet/Sand and Fines	3,170
67.3-R	Howard Miller Side Channel	258,689	Side Channel, Perennial	Wet/Cobble	Wet/Fine Gravel	4,300
67.1-L	Sauk Waterfall	180,561	Side Channel, Seasonal	Dry/Sand and Fines	Dry/Sand and Fines	3,360

1 Discharge at USGS Gage 12181000 Skagit River at Marblemount, WA.

5.3.2 Time Series Analysis of Side Channel and Off-Channel Habitat

Results of the time series analysis of side channel and off-channel habitat indicate that the majority of the study area has been stable through time in terms of quality, area, and length of side channels with the exception of Reach 6, which has had some adjustments across the time series. Tables 5.3-9 through 5.3-15 include the data across reaches for each metric.

Visualization of the data in Table 5.3-9 through Table 5.3-15 is available in Attachment E. Table 5.3-9 and Figure 5.3-12 illustrate that the total length of side channels remained consistently low in most of the reaches except for Reach 6, and, to a lesser degree, Reach 2B. There is a notable increase in length for 2006-2007 in Reach 6, but this may be an artifact of the timing of the aerial photograph collection, as discussed in Section 4.3.2 of this study report. Removing Reach 6, Figure 5.3-13 shows a slight decrease in side channel length in Reach 5B over time with a notable dip in 2006-2007. More investigation of these data will be included in the USR.

Table 5.3-9. Length of side channels across time series (ft).

Reach	1944	1963 - 1964	Percent Change (1964-1944) (%)	1978 - 1979	Percent Change (1979-1964) (%)	1998	Percent Change (1988-1979) (%)	2006 - 2007	Percent Change (2007-1988) (%)	2019	Percent Change (2019-2007) (%)
2A	0	0	0	0	0	0	0	0	0	0	0
2B	9,113	6,062	-33	6,623	9	17,244	160	15,649	-9	16,507	5
3A	4,659	2,484	-47	2,419	-3	2,385	-1	2,349	-2	2,651	13
3B	2,747	2,190	-20	2,669	22	2,131	-20	2,957	39	4,195	42
4	868	425	-51	1,296	205	1,555	20	1,899	22	753	-60
5A	3,537	2,437	-31	2,354	-3	4,542	93	4,542	0	6,277	38
5B	24,740	19,619	-21	20,826	6	18,073	-13	13,345	-26	20,396	53
6	102,949	103,412	0	128,607	24	124,656	-3	163,470	31	120,355	-26
7A	10,733	5,858	-45	12,274	110	11,667	-5	12,551	8	7,148	-43
Total	159,346	142,487	-11	177,068	24	182,253	3	216,762	19	178,282	-18

Table 5.3-10. Areas of side channel and off-channel habitat across time series (ft^2).

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	0	0	0	0	0	0
2B	520,201	490,165	248,357	682,228	834,948	902,926
3A	190,291	52,251	49,846	51,626	50,386	53,908
3B	252,785	164,238	119,431	81,520	149,121	270,475
4	252,859	19,510	61,707	17,630	56,410	27,404
5A	91,637	73,680	69,804	284,770	284,770	299,805
5B	79,8874	1,197,941	721,670	589,065	697,968	937,210
6	6,308,362	9,673,719	9,681,557	8,372,980	11,949,160	12,628,932
7A	255,374	349,805	307,689	685,321	606,072	690,356
Total	8,670,383	12,021,309	11,260,061	10,765,140	14,628,835	15,811,016

Table 5.3-11. Braid ratio across time series.

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	0.000	0.000	0.000	0.000	0.000	0.000
2B	0.054	0.235	0.435	0.355	0.243	0.255
3A	0.000	0.086	0.170	0.174	0.193	0.178
3B	0.068	0.000	0.000	0.000	0.233	0.131
4	0.061	0.074	0.007	0.005	0.003	0.010
5A	0.000	0.000	0.000	0.000	0.014	0.068
5B	0.138	0.000	0.000	0.000	0.108	0.085
6	0.562	0.519	0.410	0.242	0.355	0.520
7A	0.814	0.724	0.977	0.000	0.000	0.000

Similarly, the ratio of side channel length to mainstem length (Table 5.3-12 and Figure 5.3-14) is relatively stable through time in most reaches, but changes are observed in Reaches 6 and 7A. Figure 5.3-15 shows the ratio through time with Reaches 6 and 7A removed. At this scale, Reach 2B shows an increase and Reach 5B shows a decrease while the remaining reaches are relatively constant through time. Patterns of change in these reaches as compared to the geomorphic setting, time steps, peak flows between time steps, and quality of remote sensing data will be further analyzed in 2022 and reported on in the USR.

Table 5.3-12. Ratio of the length of side channel to the length of mainstem across time series.

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	0.000	0.000	0.000	0.000	0.000	0.000
2B	0.431	0.289	0.313	0.803	0.723	0.774
3A	0.467	0.253	0.236	0.245	0.239	0.268
3B	0.266	0.218	0.264	0.211	0.291	0.413
4	0.047	0.023	0.070	0.084	0.103	0.041
5A	0.193	0.133	0.129	0.248	0.248	0.343
5B	1.267	1.034	1.086	0.941	0.696	1.065
6	2.902	2.909	3.611	3.626	4.699	3.419
7A	5.337	2.972	6.159	5.974	6.450	3.700

Table 5.3-13. Braid node density across time series (nodes/mile).

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	0.00	0.00	0.00	0.00	0.00	0.00
2B	0.50	1.76	2.75	2.95	2.44	1.98
3A	0.00	1.08	2.06	1.63	1.61	1.60
3B	1.02	0.00	0.00	0.00	1.56	1.56
4	0.57	0.87	0.29	0.29	0.29	0.29
5A	0.00	0.00	0.00	0.00	0.29	0.87
5B	1.35	0.00	0.00	0.00	0.55	0.55
6	3.57	2.97	2.08	1.23	2.43	2.70
7A	2.63	2.68	2.65	0.00	0.00	0.00

Table 5.3-14. Side channel node density across time series (nodes/mile).

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	0.00	0.00	0.00	0.00	0.00	0.00
2B	2.25	1.76	1.75	2.70	1.71	2.72
3A	2.12	0.54	0.52	1.09	1.07	1.60
3B	1.02	1.05	1.56	1.04	1.56	2.60
4	0.57	0.29	0.86	0.86	1.43	0.57
5A	1.73	0.58	0.87	0.58	0.58	0.87
5B	2.43	2.23	2.75	3.02	1.65	2.48
6	2.98	2.67	3.85	3.38	4.10	3.45
7A	2.63	2.68	2.65	8.11	8.14	5.47

The RCI (Brown 2002) integrates the sinuosity (or relative meander pattern) with the number of joins or junctions in the channel to summarize channel complexity. As shown in Figure 5.3-16, Reach 6 has the highest levels of complexity and the greatest amount of change over the time series. Reach 6 has the greatest amount of aquatic habitat, so the magnitude of the increase in the

RCI be magnified by the reach size, as well as be an artifact of differences in remote sensing data quality. With Reach 6 removed (Figure 5.3-17), Reach 2B shows an increase while Reach 5B shows a decrease, with all other reaches remaining relatively constant. As described in Section 2.6.3 of the RSP, additional investigation and analysis of these results will be included in the USR to provide insight into side channel formation, change, and response to peak flows.

Table 5.3-15. River Complexity Index across time series (Brown 2002).

Reach	1944	1963 - 1964	1978 - 1979	1998	2006 - 2007	2019
2A	1.13	1.14	1.14	1.14	1.13	1.14
2B	16.23	20.43	27.08	37.39	28.80	32.76
3A	8.27	6.97	9.70	9.21	9.33	10.54
3B	6.66	3.24	4.35	3.26	8.73	9.82
4	5.73	5.61	5.69	5.70	7.98	6.84
5A	7.27	3.11	4.15	1.04	3.12	8.31
5B	33.62	20.11	22.85	20.35	13.98	25.37
6	108.71	116.27	155.74	111.25	173.67	161.18
7A	2.52	1.23	3.74	2.14	3.35	2.11

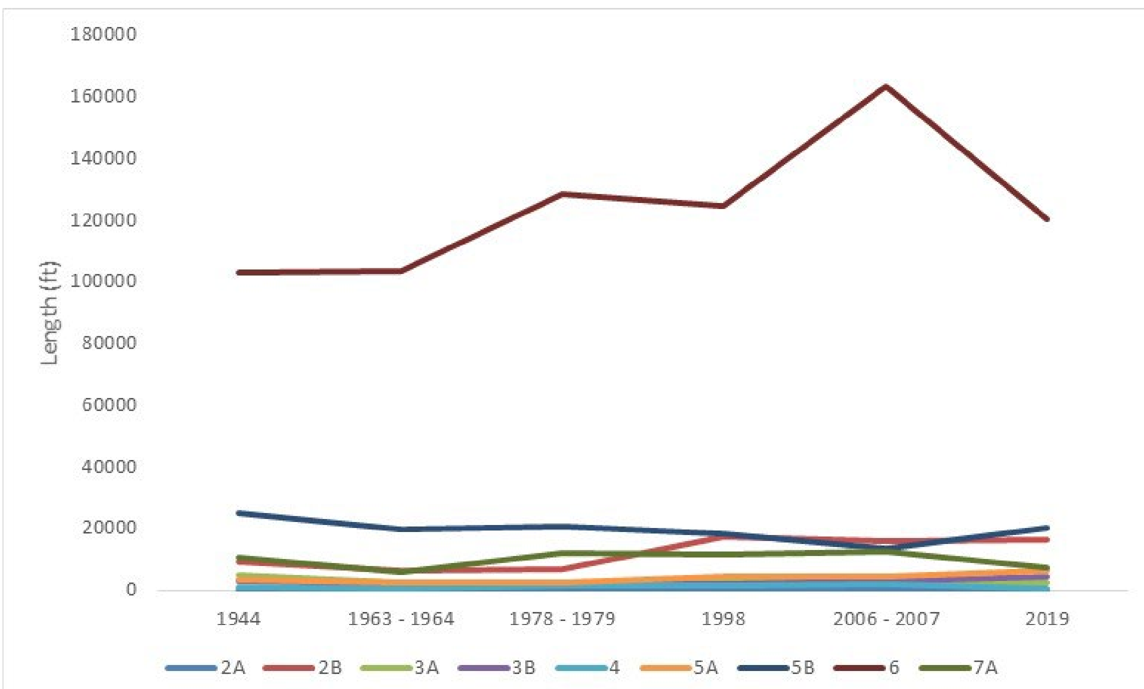

Figure 5.3-12. Length of side channels by reach across time series.

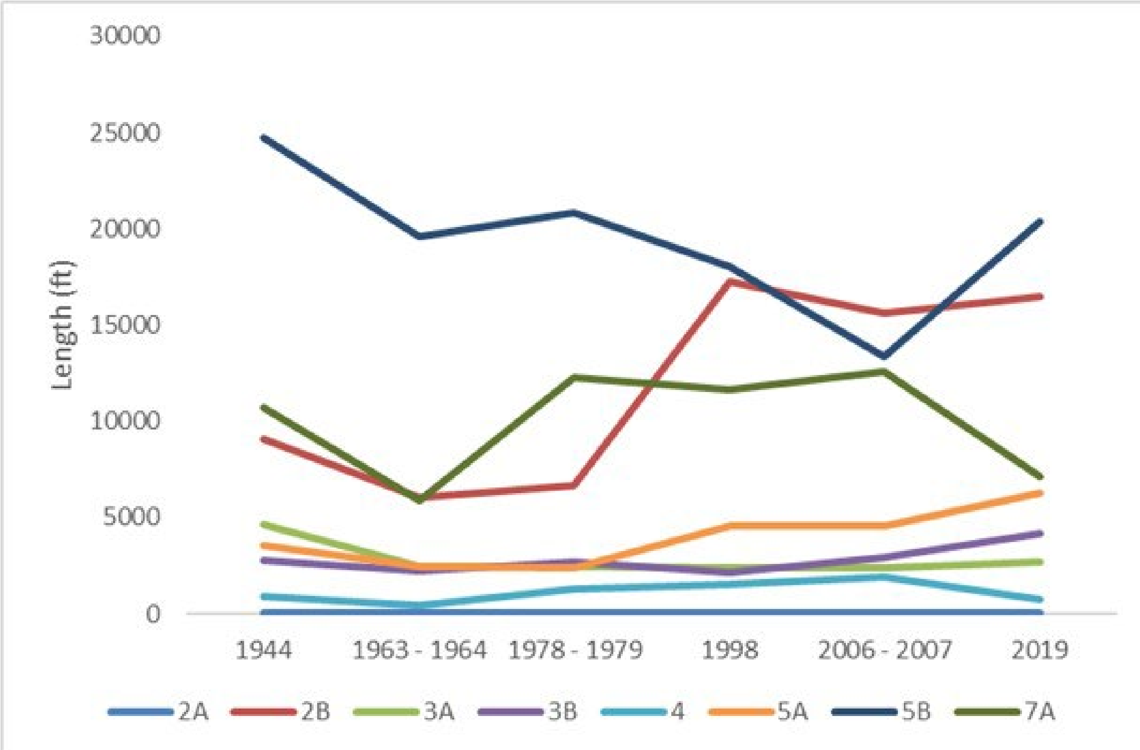

Figure 5.3-13. Length of side channels by reach across time series, removing Reach 6.

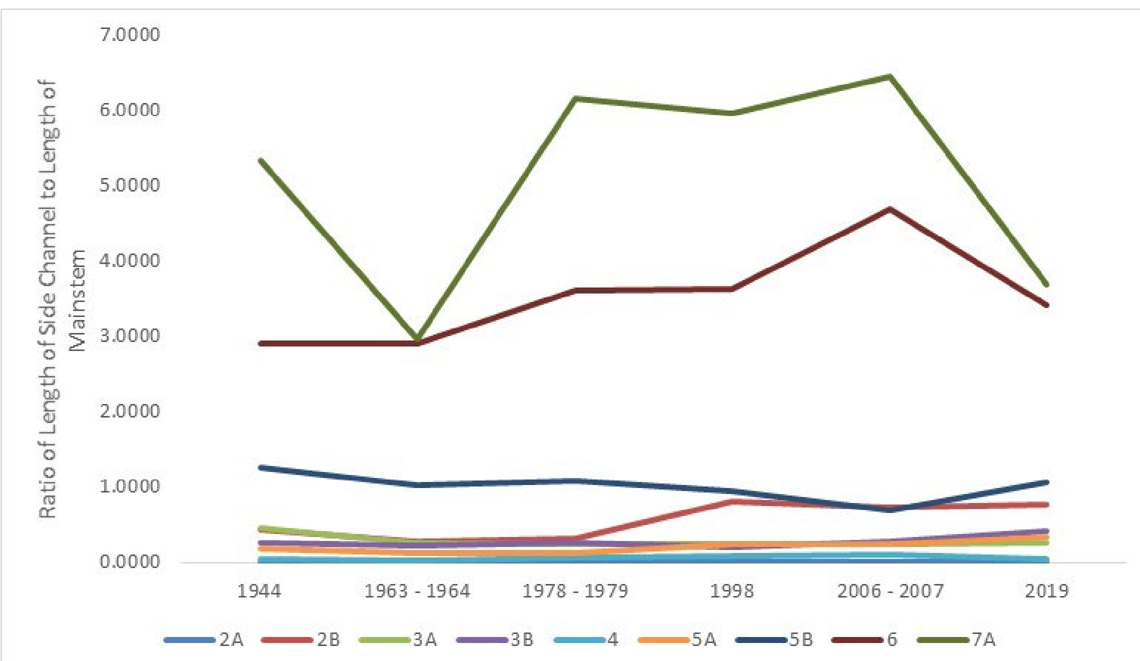

Figure 5.3-14. Ratio of length of side channel to length of mainstem across time series.

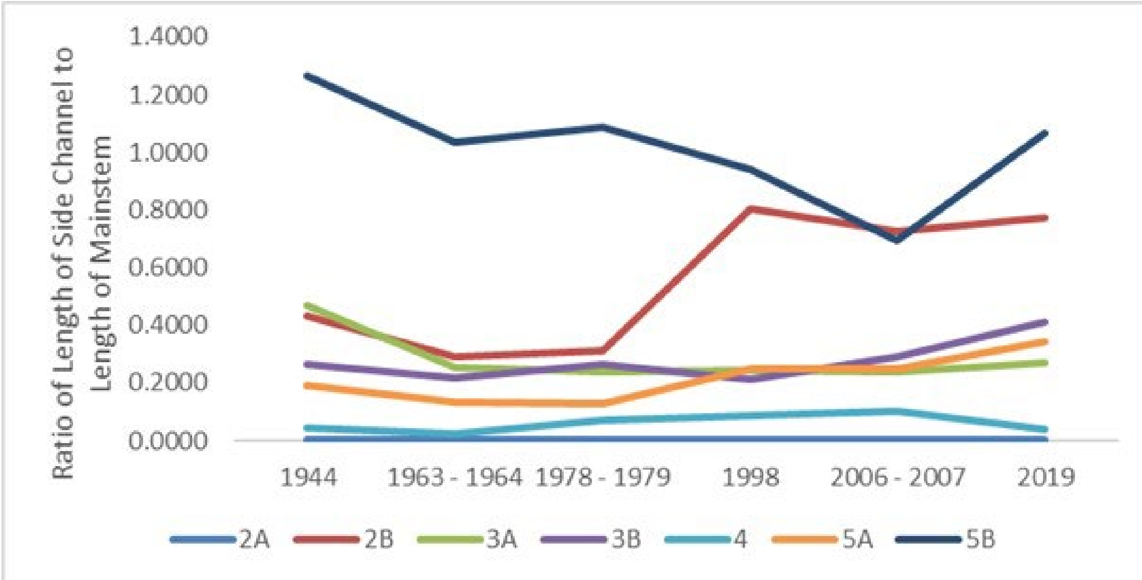

Figure 5.3-15. **Ratio of length of side channel to length of mainstem across time series with Reaches 6 and 7A removed.**

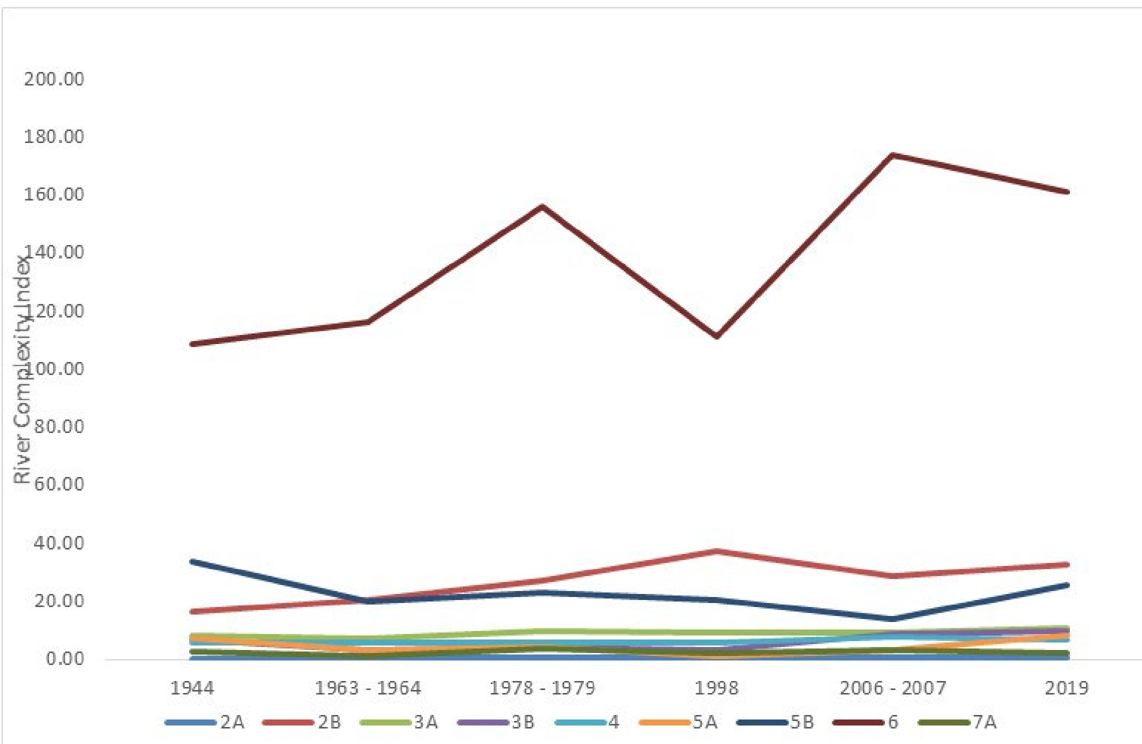

Figure 5.3-16. **River Complexity Index across time series.**

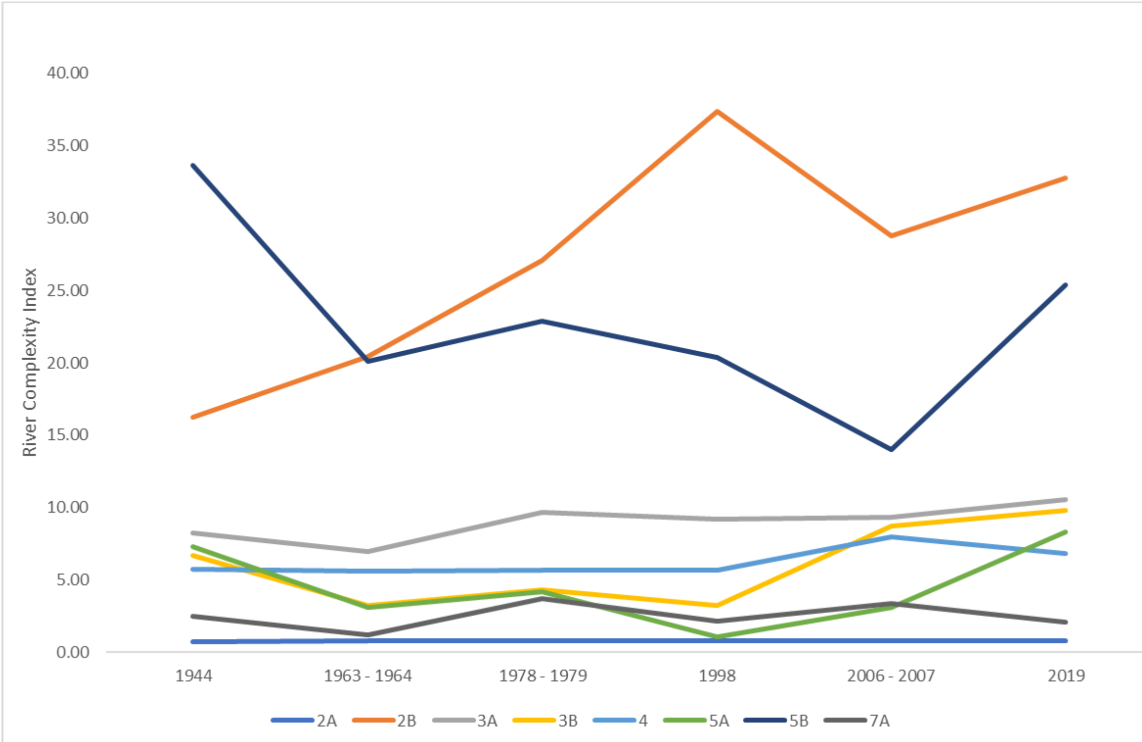

Figure 5.3-17. River Complexity Index across time series with Reach 6 removed.

5.4 Substrate/Sediment

Sediment at the bar-head locations sampled in this study is predominantly composed of cobble and gravel, with moderate spatial variability at the reach-scale. Surface pebble count results (Figure 5.4-1) indicate D_{50} values typically of 64-91 mm and D_{84} values generally toward the upper range of 91-128 mm. Two targeted sample sites (PRM 76.6 and 92.6) were notably coarser than typical conditions along the river. The surface grainsize distribution coarsens slightly from upstream to downstream at the Bacon Creek Confluence (PRM 83), fines to a local minimum above the Cascade River Confluence (PRM 78), increases below the Cascade River, and is higher through the remainder of Reach 5. The grainsizes generally fine from upstream to downstream across reach 6, suggesting that lower channel gradients above the Sauk River confluence (PRM 67) may be inducing a limitation on sediment transport competence of the cobble-sized material.

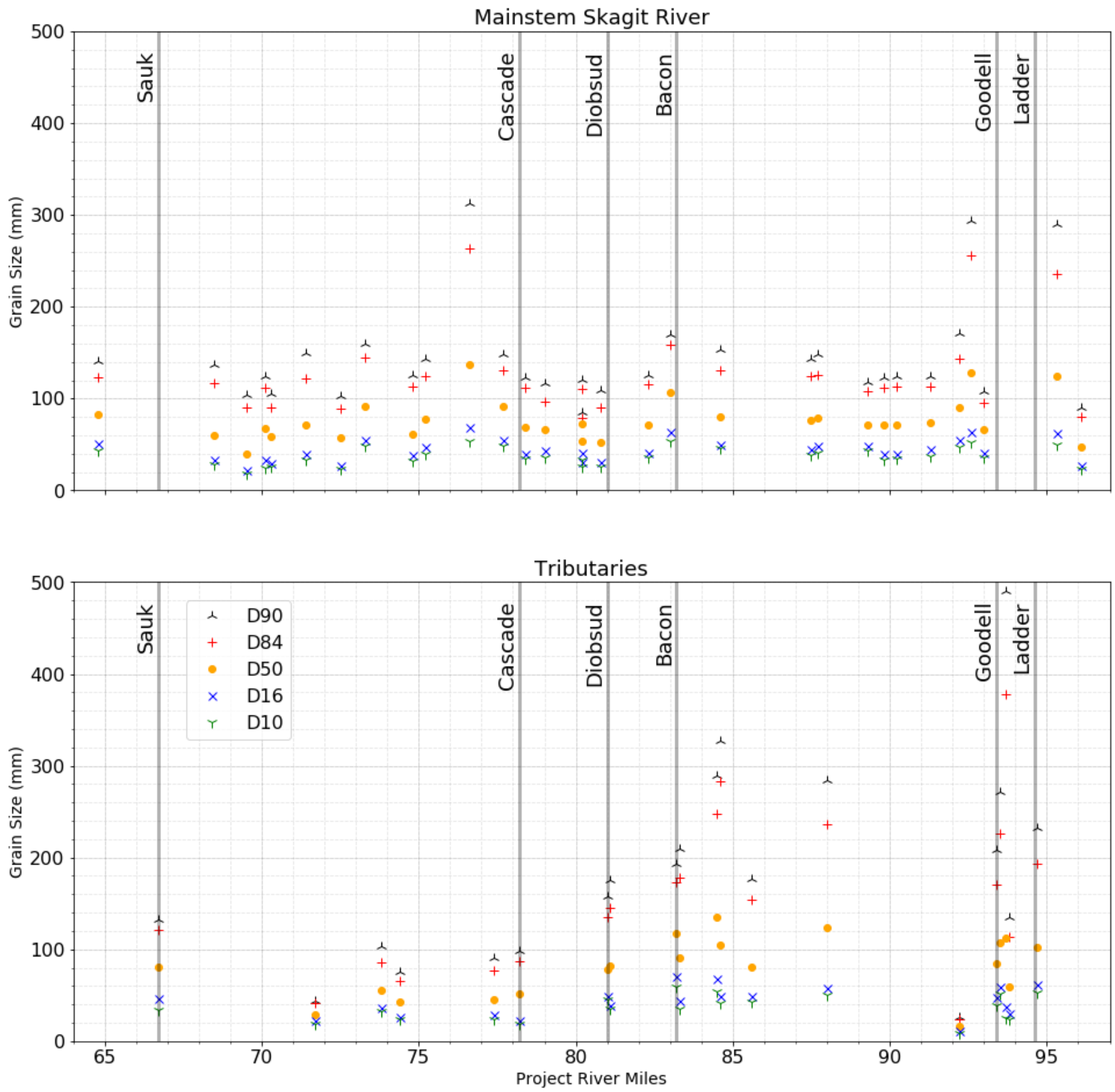

Figure 5.4-1. Summary grainsize statistics for all surface pebble count samples.

The grainsize distribution of the subsurface material is dominated by gravel-sized material and generally follows the same spatial patterns as the surface material. (Figure 5.4-2). The subsurface material only mildly fines in the downstream direction. Upstream from Bacon Creek the D_{50} has an average nearly at the 45 mm class size. From Bacon Creek to the Cascade River (PRM 78) the D_{50} decreases to an average of approximately the 32 mm class size. There is a notable increase in grain size below the Cascade River, despite the relatively smaller size fractions sampled upstream on the Cascade River. Downstream from the Cascade River the D_{50} continues to decrease to the bottom of Reach 5. Reach 6, above the Sauk River, has the smallest subsurface grainsizes observed, with D_{50} values between about 7 and 41 mm.

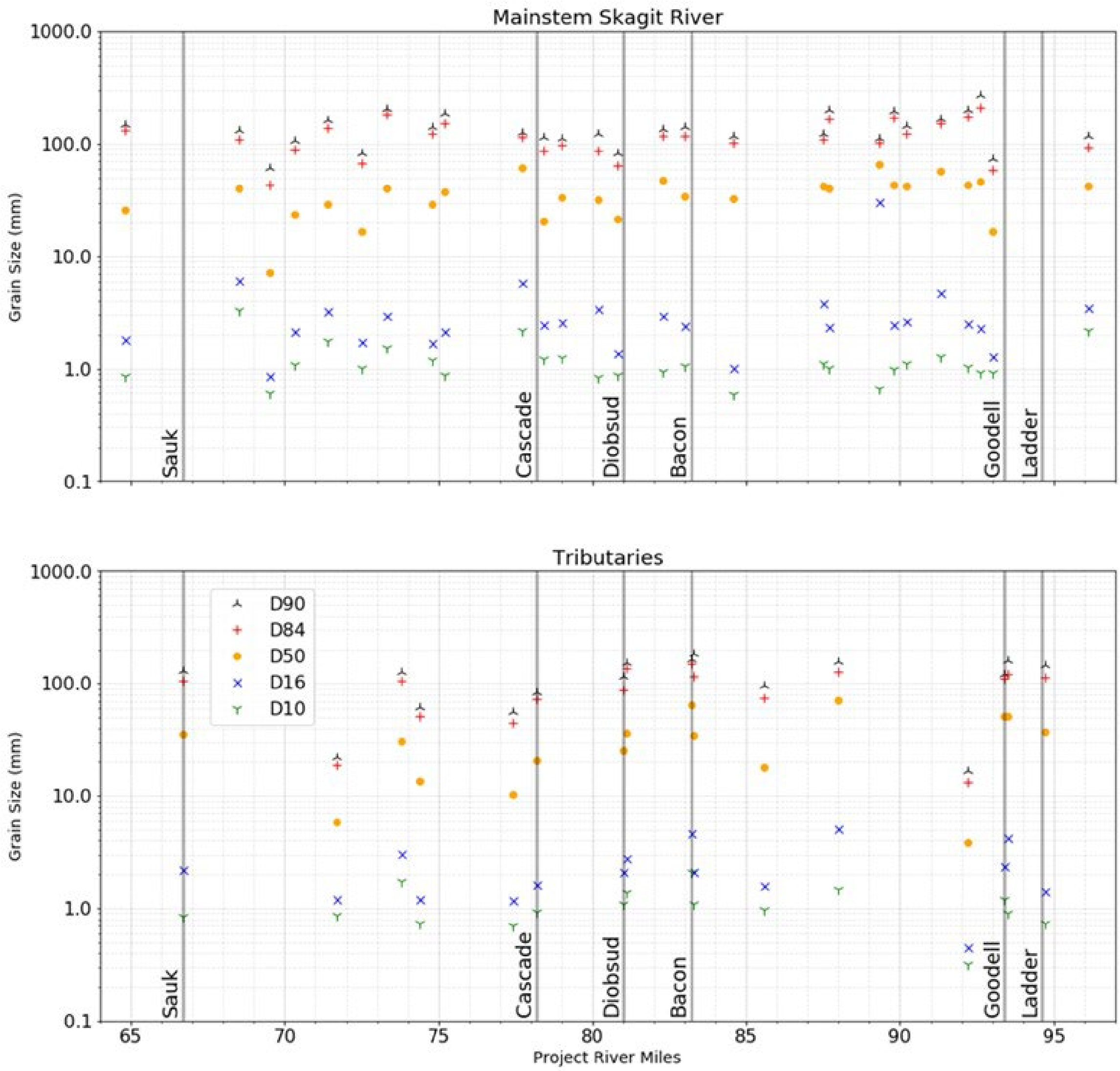

Figure 5.4-2. Summary grainsize statistics for all subsurface bulk sediment samples.

Similar to the pebble count and subsurface results, the grainsize distributions from the hybrid approach, produced following the approach of Rice and Haschenburger (2004), show little variation across the study reach, with a slight trend in fining in the downstream direction (Figure 5.4-3). An increase in grain size is noted directly below the Bacon Creek and Cascade River tributaries. Upstream from Bacon Creek the D_{50} has an average of approximately 33 mm. From Bacon Creek to the Cascade River (PRM 78) the D_{50} only slightly decreases to an average of approximately 32 mm. Downstream from the Cascade River the D_{50} has an average of 24 mm and drops from 62 mm to 18 mm from below the Cascade River to below the Sauk River.

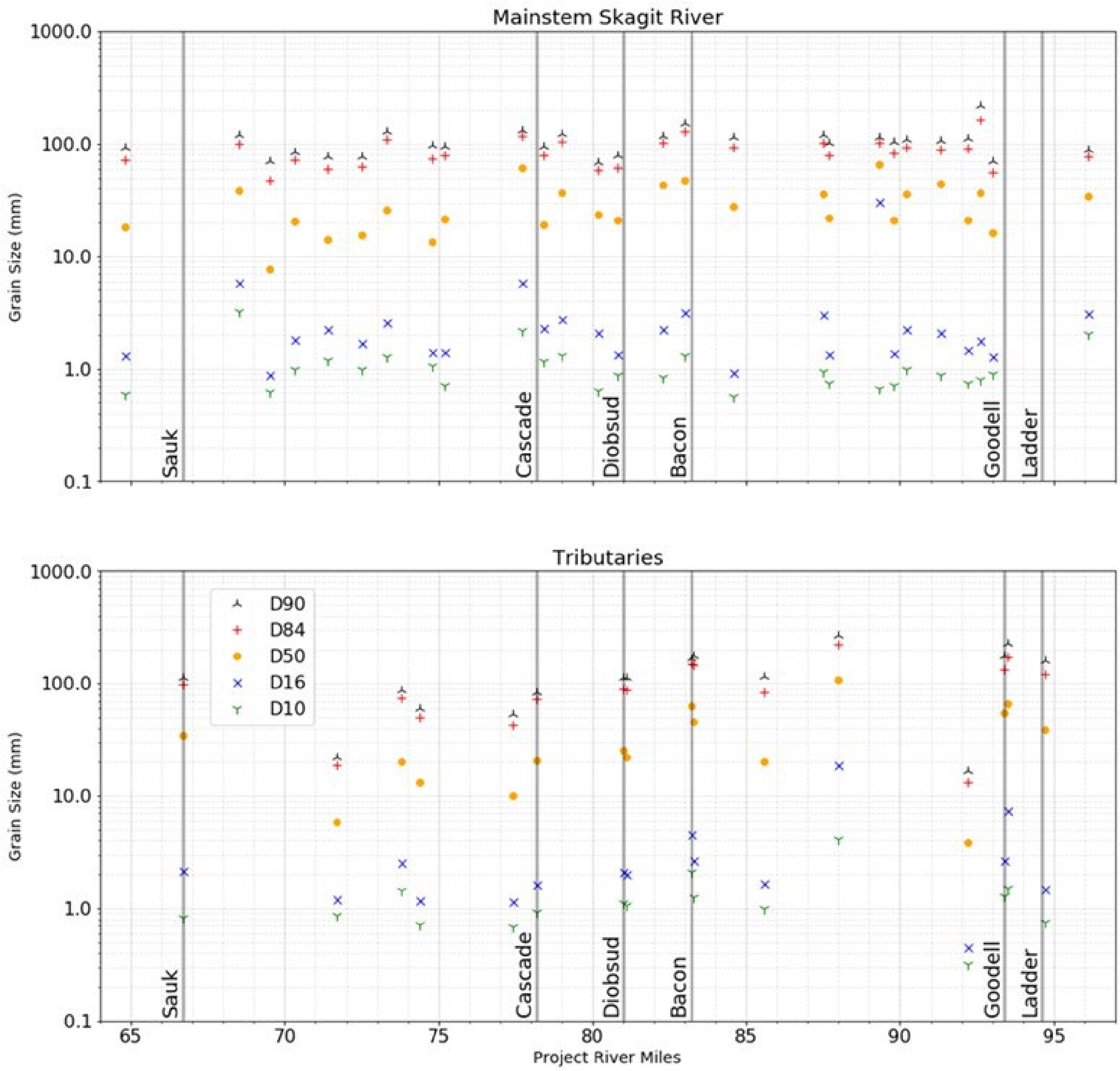

Figure 5.4-3. Summary grainsize statistics for all hybrid bulk sediment samples.

The selective removal of fine sediment through the process of winnowing results in bed-armoring, whereby the surface substrate is coarser than the subsurface substrate. Bed-armoring has important implications for understanding and predicting sediment transport rates, and inherently the geomorphology of rivers. Using the ratio of the D_{50} from the surface pebble counts to the D_{50} from the bulk subsurface samples, a relative sense of armoring shows that the surface layer in much of the study reach is twice as coarse as the subsurface (Figure 5.4-4).

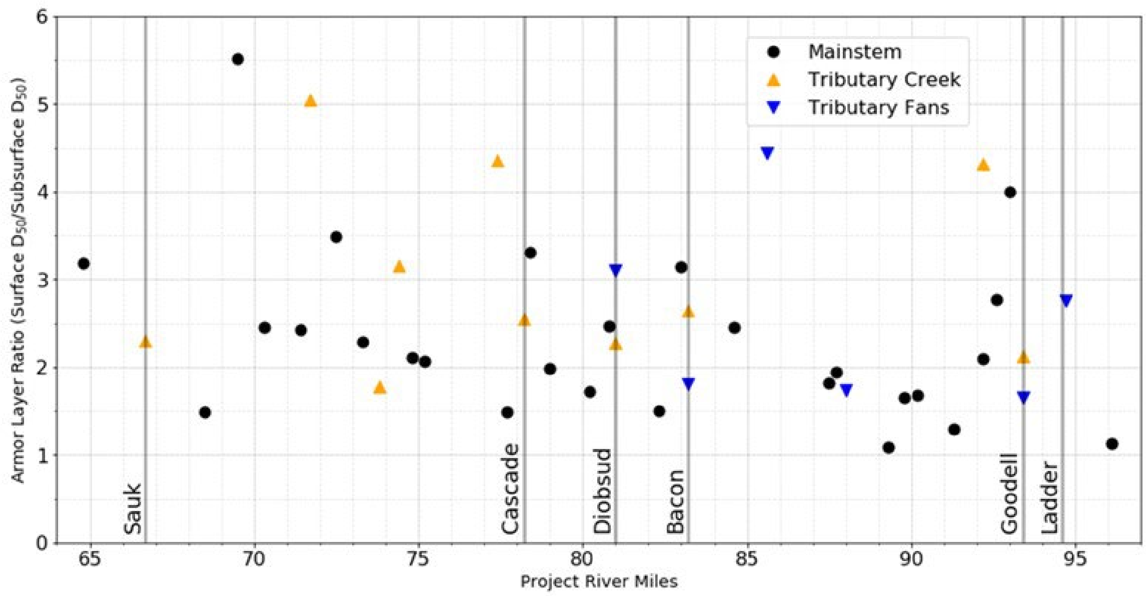

Figure 5.4-4. Armor layer ratio, as defined by the surface D_{50}/subsurface D_{50}

Evaluation of bed material mobility and further analysis of these grainsize data will be completed in conjunction with development of the sediment transport modeling program. Interpretation and analysis of pebble count lithology data are also ongoing and will be provided in the USR.

5.5 Sediment Transport and Sediment Augmentation

A comprehensive and nested modeling approach to evaluating sediment transport and sediment augmentation is ongoing and additional results will be included in the USR. This section reports results of observations from scour monitoring arrays indicating the degree of bed mobilization through the 2019-2020 and 2020-2021 winter seasons.

Analysis of the accelerometer data is ongoing and will provide insight into the timing and likely source of the scour, either from sediment transport or spawning salmon. Following the guidance of Gendaszek et al. (2013), changes in tilt that exceeded 15 degrees from the initial deployed orientation were inferred to be indicative of accelerometer disturbance. The source of scour will be determined by analyzing accelerometer activity in the context of both discharge and spawning season.

Overall, observations through summer 2021 suggest very little bed mobility occurred at the spawning site scour monitor installations installed in 2019 and 2020, with most locations showing no scour, most observations showing any scour indicating mobilization less than the thickness of the armor layer, and a maximum observed scour depth of 6.8 inches. Of the ten 2019-2020 monitoring arrays, possible scour of at least one of the four Golf Ball Scour Monitors was observed at eight arrays (Table 5.5-1). Scour was detected by observing an increase in the total number of balls floating in the scour chains compared to the previous monitoring year, with a scour depth of 1.7 inches for each floating ball added to the depth of the top ball at the time of installation. Observed scour was greatest at the 2019 Sites 1 and 2 with observed scour on three chains at each site and a maximum observed scour of ten inches.

While the timing of the bed movement is unknown, an analysis of the accelerometer data at this site does indicate some activity during low flow conditions in September and October 2020. As shown in Figure 5.5-1, Accelerometer 101 tilted more 15 degrees on September 22, 2020, at a discharge of approximately 5,000 cfs. The timing of this scour event within the average range of Chinook redd depths suggests that redd construction was possibly underway in the area.

Table 5.5-1. Summary of 2020-2021 scour monitoring results.

Site[1]	Chains with floating balls (out of 2) in 2020	Chains with floating balls (out of 4) in 2021	Name of monitors	Depth of scour indicated (in) 2019-2020	Depth of scour indicated (in) 2020-2021
BMM1		2	GBB		5.1
			GBC		4.7
BMM4		1	GBD		1.7
BMM6		0			<1.7
BMM7		1	GBD		5.7
Site 1 (2019)	1	3	GB1	1.7	3.4
			GB2	<0.4	6.8
			GBA	NA	6.9
Site 2 (2019)	1	3	GB4	4.7	10
			GBA	NA	3.4
			GBB	NA	1.7
Site 3 (2019)	1	3	GBA	NA	4.4
			GB5	<4	7.1
			GB6	1.7	<1.7
ABSS1		0			<1.7 to <5.5
ABSS2		0			<3 to <5
ABSS3		2	GBA		6.4

1 Site names reflect location and time of installation. 'Site' prefixes were installed in 2019, BMM were installed in 2020 Below Marblemount, ABSS were installed in 2020 upstream of (above) Shovel Spur; these are all located at spawning areas.

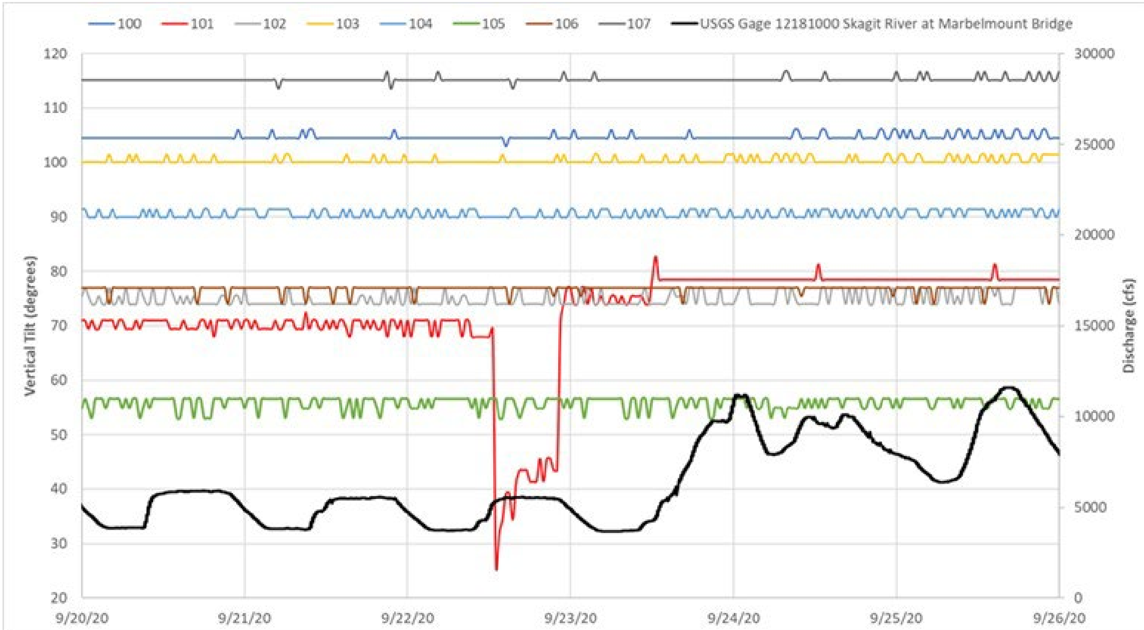

Figure 5.5-1. Example accelerometer data for Site 1 (first riffle upstream of Marblemount Bridge) showing timing of possible redd construction in Accelerometer 101 (red) relative to Skagit flows at Marblemount (black, USGS Gage 12181000).

5.6 Large Wood Inventory

5.6.1 Total Large Wood, Log Jams, and Spatial Distribution

Table 5.6-1 includes a summary of all large wood pieces and jams identified on aerial photographs from 1979-2019 and in the field in 2021 (a span of 42 years). Due to limitations in accessibility, the 2021 field survey only includes 26.5 of the 30.1 miles of the primary study area. The field survey was not conducted in the shovel spur rapids reach between PRM 86.7 and PRM 87.6 as well as the Gorge bypass reach (geomorphic reach 1; 2.7 miles length). As part of next steps, the Gorge bypass reach will be inventoried using high resolution drone imagery from 2021 collected by the FA-02 Instream Flow Model study team. Due to limitations in high resolution remote sensing data available, 1998 includes 11.8 miles, and 1979 includes 11.0 miles of the primary study area. The lesser number of pieces and jams identified prior to 2018 is likely due to the lower resolution of remote sensing imaging available.

Additionally, a much higher quantity of large wood was inventoried in the 2021 field survey, likely due to access to large wood that was hidden under canopy cover in the aerial imagery. This difference is especially pronounced when inventorying individual large wood pieces in side channels from aerial photos, as very few could be detected. The problem of canopy cover and low resolution in aerial photos makes it difficult to determine whether there were fewer large wood pieces and log jams historically, or if differences in methods and available data created the trend of large wood loading increasing in the Skagit since 1979.

Table 5.6-1. Large wood and log jams inventory from 1979 to 2021.

Year	Miles Surveyed	Large Wood Pieces[4]	Log Jams	Large Wood Per Surveyed Mile	Log Jams Per Surveyed Mile
1979[1]	11.0	65	17	5.9	1.5
1998[1]	11.8	27	14	2.3	1.2
2009[2]	27.5	90	46	3.3	1.7
2011[2]	27.5	99	59	3.6	2.1
2018/2019[2]	30.1	414	105	14	3.5
2021[3]	26.5	4,084	80	154	3.0

1 Aerial photographs.
2 Digital imagery.
3 Field.
4 Individual large wood pieces from 1979 to 2019 could not be detected under bank and side channel canopy cover, resulting in fewer inventoried large wood pieces.

Table 5.6-2 includes the total number of pieces of large wood inventoried individually and in jams during the field inventory in August 2021. Attachment I includes maps with all log jams, individual logs, and tallied large wood. Many log jams were estimated in the field as either 10-49 pieces, 50-99 pieces, or 100 plus pieces. A wood count value of 30, 75, and 100 pieces was assigned to each of these estimated log jams, respectively. Piece count defaulted to their exact value for log jams that were counted precisely in the field, this includes all log jams that were made of 5-9 pieces as well as some larger log jams.

Table 5.6-2. Total number of pieces of large wood inventoried individually and in jams during field work in August 2021.

Type	Mainstem Pieces	Mainstem Pieces Per Surveyed Mile	Tributary Pieces (500 ft surveyed)	Tributaries Pieces Per Surveyed Mile	Side Channel Pieces	Side Channels Pieces Per Surveyed Mile	Total Pieces
Single	760	29	63	33	858	25	1,681
In Jam	1,295[1]	49	79[1]	42	1,029[1]	30	2,403[1]
Total	**2,055**	**78**	**142**	**57**	**1,887**	**55**	**4,084**

1 Log jam wood counts are estimated.

Table 5.6-3 includes the total large number of large wood pieces distributed along the primary study area by geomorphic reach channel type. Details about geomorphic reaches are presented in Section 4.1 of this study report.

Table 5.6-3. Total number of pieces of large wood inventoried during field work in August 2021 by geomorphic reach and channel type.

Geomorphic Reach	Mainstem			Tributary			Side Channel		
	Total Pieces	Total Length (mi)	Pieces Per Mile	Total Pieces	Total Length (mi)	Pieces Per Mile	Total Pieces	Total Length (mi)	Pieces Per Mile
2A	43	1.2	43	8	0.3	31	0	0.0	N/A
2B	237	4.1	89	9	0.3	32	117	3.1	37
3A	23	1.9	30	33	0.2	174	1	0.5	2
3B	195	3.5	67	8	0.3	25	8	0.8	10
4	48	2	29	5	0.2	26	4	0.1	28
5A	72	3.5	43	41	0.2	216	37	1.2	31
5B	178	3.7	224	43	0.2	226	606	3.9	157
6	1156	6.7	285	52	0.9	60	700	22.8	31
7A	188	1.3	318	0	0.0	N/A	226	1.4	167
7B	20	0.3	67	0	0.0	N/A	0	0.0	N/A

Individual large wood pieces were distributed by dimensions and rootwad presence within the mainstem, tributaries, and side channels as follows.

5.6.1.1 Mainstem

Table 5.6-4 includes the length and diameter of individual pieces within the mainstem Skagit River. The majority of pieces counted in the mainstem were 25-49 ft long with a dbh of 1-1.9 ft. Table 5.6-5 includes the inventory of large wood pieces with and without rootwads present within the mainstem Skagit River.

Table 5.6-4. Diameter and length of measured pieces within the mainstem Skagit River.

Length (ft)	Diameter at Breast Height (ft)								Total	
	1-1.9		2-2.9		3-3.9		4 Plus			
25-49	293		35		12		2		**342**	**45%**
50-74	188		71		9		3		**271**	**36%**
75-99	26		65		15		4		**110**	**14%**
100 plus	8		11		7		11		**37**	**5%**
Total	**515**	**68%**	**182**	**24%**	**43**	**6%**	**20**	**3%**	**760**	

Table 5.6-5. Rootwad presence of individual pieces within the mainstem Skagit River.

Rootwad Presence	Diameter at Breast Height (ft)								Total	
	1.0-1.9		2.0-2.9		3.0-3.9		4.0-6.0			
Rootwad	229	44%	118	65%	37	86%	19	95%	**403**	**53%**
No Rootwad	286	56%	64	35%	6	14%	1	5%	**357**	**47%**
Total	**515**		**182**		**43**		**20**		**760**	

5.6.1.2 Tributaries

Table 5.6-6 includes the length and diameter of individual pieces within the 20 tributaries. The majority of pieces counted in the tributaries were 25-49 ft long with a dbh of 1-1.9 ft. Table 5.6-7 includes the inventory of large wood pieces with and without rootwads present within the tributaries.

Table 5.6-6. Diameter and length of individual pieces within tributaries.

Length (ft)	Diameter at Breast Height (ft)								Total	
	1.0-1.9		2.0-2.9		3.0-3.9		4.0-6.0			
25-49	18		9		1		2		**30**	**48%**
50-74	16		7		0		0		**23**	**37%**
75-99	2		4		2		1		**9**	**14%**
100 plus	0		0		1		0		**1**	**2%**
Total	**36**	**57%**	**20**	**32%**	**4**	**6%**	**3**	**5%**	**63**	

Table 5.6-7. Rootwad presence of individual pieces within tributaries.

Rootwad Presence	Diameter at Breast Height (ft)								Total	
	1.0-1.9		2.0-2.9		3.0-3.9		4.0-6.0			
Rootwad	6	17%	9	45%	2	50%	0	0%	**17**	**27%**
No Rootwad	30	83%	11	55%	2	50%	3	100%	**46**	**73%**
Total	**36**		**20**		**4**		**3**		**63**	

5.6.1.3 Side Channels

Table 5.6-8 includes the length and diameter of individual pieces within the side channels. The majority of pieces counted in the mainstem were 25-49 ft long with a dbh of 1-1.9 ft. Table 5.6-9 includes the inventory of large wood pieces with and without rootwads present within the side channel.

Table 5.6-8. Diameter and length of individual pieces within side channels.

Length (ft)	Diameter at Breast Height (ft)								Total	
	1.0-1.9		2.0-2.9		3.0-3.9		4.0-6.0			
25-49	475		93		12		5		**585**	**68%**
50-74	157		53		6		0		**216**	**25%**
75-99	19		33		0		1		**53**	**6%**
100 plus	0		2		0		2		**4**	**0%**
Total	**651**	**76%**	**181**	**21%**	**18**	**2%**	**8**	**1%**	**858**	

Table 5.6-9. Rootwad presence of individual pieces within side channels.

Rootwad Presence	Diameter at Breast Height (ft)								Total	
	1.0-1.9		2.0-2.9		3.0-3.9		4.0-6.0			
Rootwad	188	29%	80	44%	10	56%	5	63%	**283**	**33%**
No Rootwad	463	71%	101	56%	8	44%	3	38%	**575**	**67%**
Total	**651**		**181**		**18**		**8**		**858**	

5.6.2 Log Jam Persistence

Log jam presence was indicated in each year for which high-resolution aerial imagery was available as either present, not present, or unknown. Log jams were then tracked at specific locations in the river through time to determine the minimum length of time historically inventoried log jams persisted.

Table 5.6-10 includes the distribution of total lengths of time that individual log jams persisted from 1979 to 2021 within the mainstem, tributaries, and side channels. There was a total of 100 log jams that persisted between 1 and 3 years, 36 log jams that persisted between 8 and 12 years, 5 log jams that persisted between 13 and 23 years, and 4 log jams that persisted for a minimum of 42 years.

Table 5.6-10. Log jam persistence from 1979 to 2021.

Years Present	Total Jams
1	54
2	31
3	15
7	2
8	1
10	15
12	18
13	2
19	1
23	2
42	4

Inventoried historic log jams that were present in August 2021 were examined for recent changes in size. Changes were described as either growing, decaying, stable, variable, or unknown. Aerial imagery was used to ascertain recent trends in aerial change of log jams. Log jams that did not display a continuous trend in growth, decay, or stability were defined as variable. Log jams that were surveyed only in August 2021 were defined as unknown (Table 5.6-11).

Table 5.6-11. Historic change of log jams surveyed August 2021.

Growing	Decaying	Stable	Variable	Unknown	August 2021 Log Jams
9	3	46	2	20	80

5.6.3 Distribution by Habitat Units

Each individual piece of large wood and log jam inventoried during the August 2021 field inventory was spatially associated using GIS with channel units delineated from 2019 aerial photographs.

These channel units are defined as follows:

- Forested Island;
- Vegetated Bar;
- Main Channel Bar;
- Main Channel Wet; and
- Side Channel.

Large wood and log jam features that spanned more than one channel unit type were assigned to the channel unit type that contained the most length or area of the individual feature. An exception was made for large wood and log jam features that spanned a "Main Channel Wet" channel unit; in this case the feature defaulted to the "Main Channel Wet" classification. This was decided because it is geomorphically important to note if a large wood feature is interacting with the wetted channel even if it is not the majority of the wood feature. This analysis will be updated with 2021 aerials as part of work planned in 2022.

Large wood that was associated with wet channel units—"Main Channel Wet" or "Side Channel"—were spatially associated with aquatic habitat units in addition to the channel units. More information on these aquatic habitat units can be found in Section 4.2 of this study report. Wood that was inventoried in August 2021, but did not spatially correlate with a delineated channel unit or aquatic habitat unit, were defined as "unknown" and excluded. This instance occurred primarily in blind side channels that were surveyed entirely in August of 2021 based on pre-field REM data but were later excluded from the "side channel" classification. Total habitat unit area is smaller in Table 5.6-12 than in Section 5.2 of this study report. This is due to the large wood survey covering less area than the habitat unit survey. The large wood density values in Table 5.6-12 are preliminary and will be reported in the USR.

Table 5.6-12. Large wood inventory associated with aquatic habitat units.

Habitat Unit		Total Surveyed Area (acres)	Large Wood Pieces	Large Wood Density[1]
Wet	Side Channel	63.9	1,127	17.6
	Tributary	40.8	611	15.0
	Backwater	11.1	56	5.0
	Pool	91.7	235	2.6
	Riffle	122.1	161	1.3
	Rapid	25.7	26	1.0
	Glide	678.6	646	1.0
	Off-Channel	159.8	113	0.7
	Run	77.5	53	0.7
Dry	Bar	31.3	406	13.0
	Vegetated Bar	N/A	281	N/A
	Forested Island	N/A	132	N/A
Unknown		N/A	237	N/A
Total		**1,302.6**	**4,084**	**N/A**

1 wood density = pieces/surveyed acre.

5.6.4 Large Wood Inventory Detailed Areas

A more detailed large wood inventory was conducted in 10 half-mile areas as described in Section 4.6 of this study report. The distribution of various attributes collected within these detailed areas are as follows.

Tree species was collected for individual large wood pieces within detailed areas. Their distribution is presented in Table 5.6-13. When species was unable to be determined, the study team classified large wood as either a conifer or deciduous when possible. If a large wood piece could not be determined to be either a conifer or a deciduous species, the study team classified the large wood piece species as "Other."

Table 5.6-13. Distribution of tree species of large wood pieces inventoried within detailed areas.

Species	Large Wood Pieces
Alder *(Alnus rubra)*	79
Cottonwood *(Populus trichocarpa)*	68
Cedar *(Thuja plicata)*	58
Maple *(Acer macrophyllum)*	17
Fir *(Pseudotsuga menziesii)*	12
Conifer	12
Deciduous	2
Hemlock *(Tsuga heterophylla)*	2
Other	24

Decay class was collected for individual large wood pieces within detailed areas. Their distribution is presented in Table 5.6-14. Decay class is defined as either 1 (fresh), 2 (intermediate), or 3 (rotten). Class 1 refers to wood that is very firm and often has bark and limbs. Class 2 refers to wood that is firm and often has some bark and limbs. Class 3 refers to wood that is softer and has no or very little bark and limbs.

Table 5.6-14. Distribution of decay class of individual large wood pieces inventoried within detailed areas.

Decay Class	Large Wood Pieces
1	95
2	119
3	39

Residual pool depth was measured when present for individual large wood pieces within detailed areas. that were not a part of a log jam. Their distribution is presented in Table 5.6-15.

Table 5.6-15. Residual pool depths associated with individual large wood pieces within detailed areas.

Residual Pool Depth (ft)	Large Wood Pieces	Percentage of Total
8-12	6	28%
4-7.9	13	
1-3.9	25	
Present but not measured	16	
No Pool	151	72%

Individual large wood pieces that were inventoried in detailed areas contain attributes associated to rootwad diameter and associated pool depth. In Table 5.6-16 the correlation between rootwad presence and pool presence is summarized for individual large wood pieces that are not in log jams that were inventoried in detailed areas.

Table 5.6-16. Rootwad presence vs. pool presence for individual large wood pieces inventoried in detailed areas.

Rootwad Presence	Large Wood Pieces with Pool		Large Wood Pieces without Pool	
Rootwad Present	47	78%	94	62%
No Rootwad	13	22%	57	38%
Total	**60**		**151**	

Individual large wood pieces found in detailed areas that have a rootwad but are not in log jams were binned by their respective rootwad diameters. They were then associated with whether a pool was present in Table 5.6-17.

Table 5.6-17. Rootwad diameter vs. pool presence for individual large wood pieces inventories in detailed areas.

Rootwad Diameter (ft)	Pool Present		No Pool Present	
2-3.9	4	17%	20	83%
4-9.9	28	30%	65	70%
10-25	14	64%	8	36%

5.6.5 Distribution by Geomorphic Reaches

As shown in Section 3.0 of this study report, the primary study area was split into 7 geomorphic reaches; several of these geomorphic reaches were then subdivided into subreaches for a total of 11 geomorphic reaches and subreaches. Results relating to wood distribution in each subsequent geomorphic reach and subreach that was field inventoried are summarized below and in Attachment J.

5.6.5.1 Reach 2A

Large wood in Reach 2A has more pieces on the left bank then the right bank where it functions primarily as cover for aquatic habitat during high flows (Figure 5.6-1). In this reach the study team did not see wood forming pools or wood forming mid-channel bars. The total amount of large wood located in this reach was 52 large wood pieces. Of the 41 individual large wood pieces measured in this reach, nine pieces had rootwads. The rootwads ranged in diameter from 3-10 ft. Table 5.6-18 includes a summary of the large wood and rootwad count in mainstem, tributaries, and log jams within Geomorphic Reach 2A. In this reach, there were two small log jams located in the mainstem Skagit River (Figure 5.6-2).

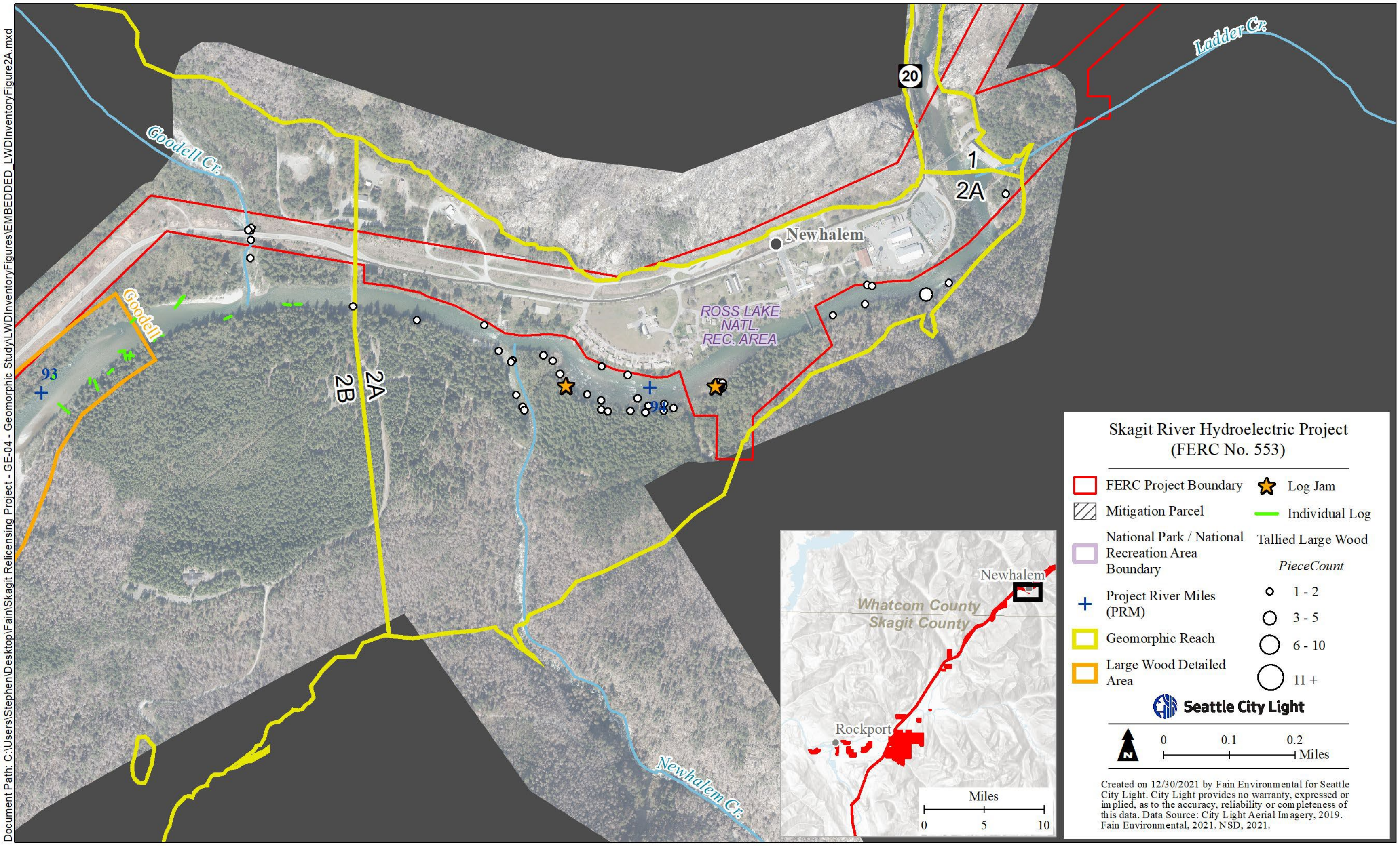

Figure 5.6-1. Large wood August 2021 field inventory for Reach 2A.

Table 5.6-18. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 2A.

Location	Large Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	33	7	21%
Ladder Creek	1	0	0%
Newhalem Creek	7	2	29%
In Log Jams	10	N/A	N/A
Total Count	**52**	**9**	17%

Figure 5.6-2. Small log jam located on left bank at PRM 93.9. Photo taken August 20, 2021.

5.6.5.2 Reach 2B

There were 363 total large wood pieces in Reach 2B, 234 of which were individual large wood pieces (Figures 5.6-3 and 5.6-4). Of these individual large wood pieces 96 of them had rootwads ranging in diameter from 3-20 ft. A summary of the large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 2B is shown in Table 5.6-19. There were nine small log jams in the mainstem and one small log jam in side channels in the August 2021 inventory. Example photos of an individual large wood piece and a log jam that are located in this reach can be seen in Figures 5.6-5 and 5.6-6.

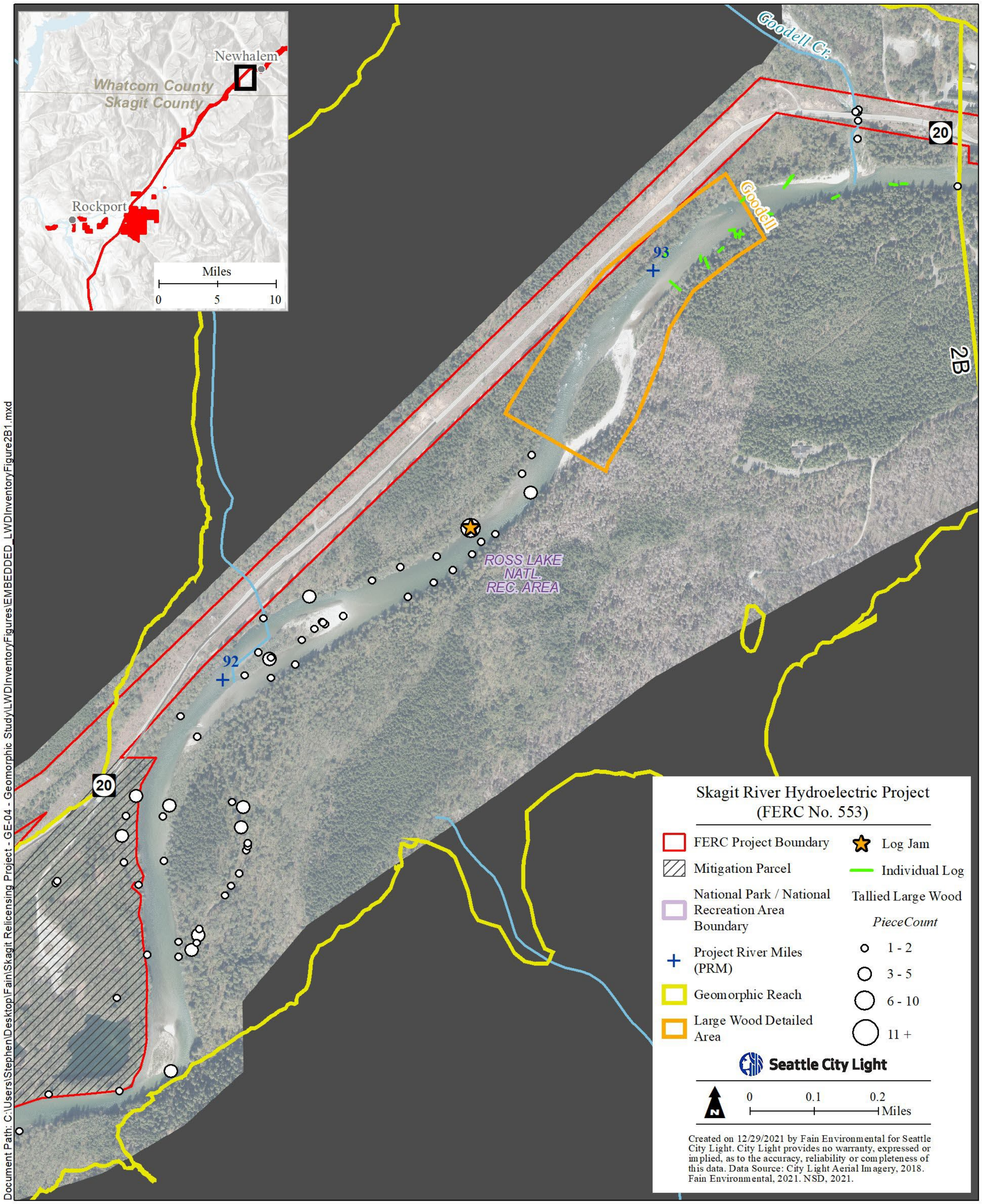

Figure 5.6-3. Large wood August 2021 field inventory for upper section of Reach 2B.

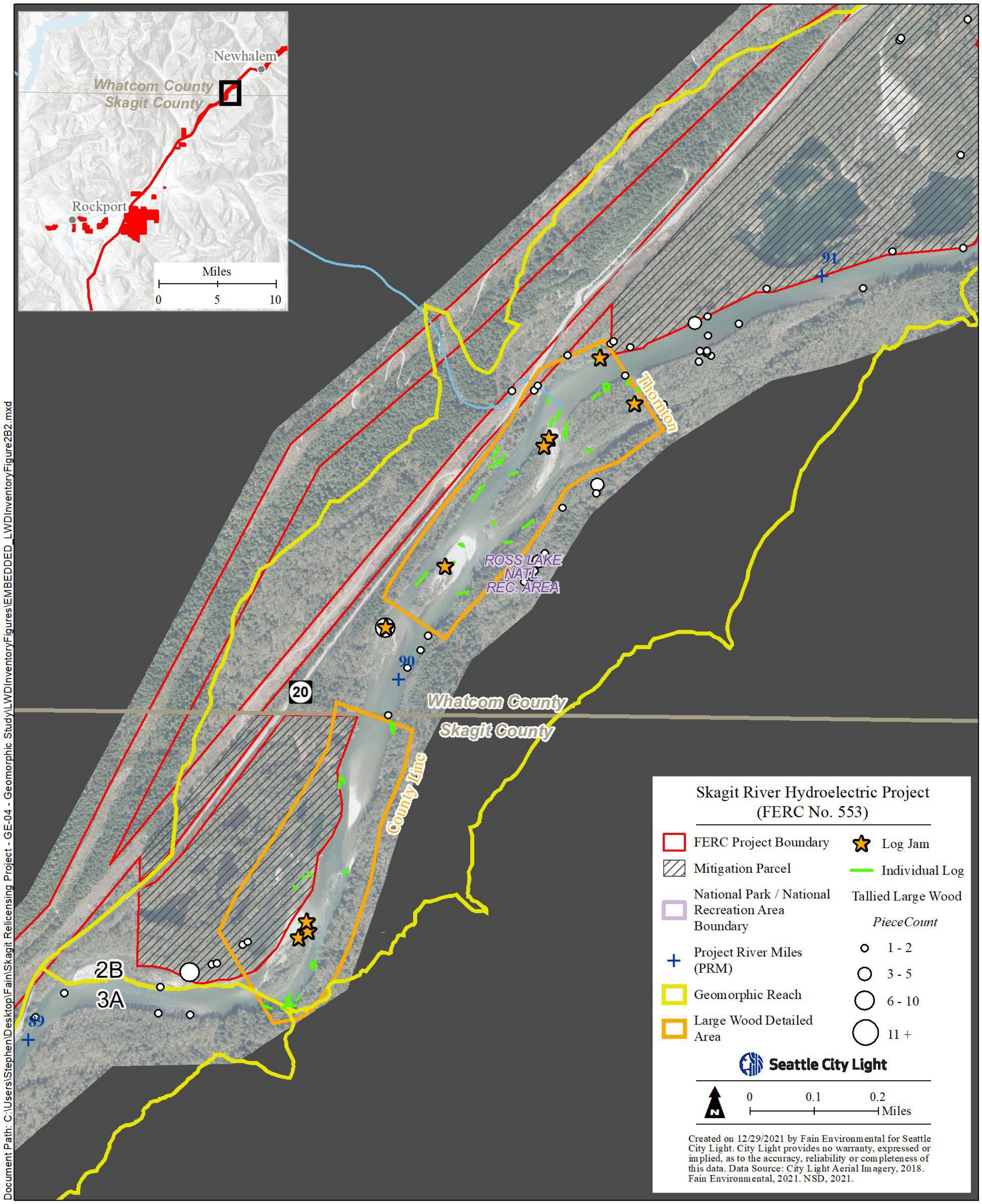

Figure 5.6-4. Large wood August 2021 field inventory for lower section of Reach 2B.

Table 5.6-19. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 2B.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	128	57	45%
Goodell Creek	6	0	0%
Thornton Creek	3	2	67%
Side Channels	97	37	38%
In Log Jams	129	N/A	N/A
Total	**363**	**96**	**26%**

Figure 5.6-5. A large wood Cedar piece (Tag ID 54) with a 6-ft dbh, 20-ft rootwad, and 70-ft length located at PRM 90.5 looking upstream. Piece forms a pool at rootwad. Photo taken on October 19, 2021.

Figure 5.6-6. Log jam on gravel bar at PRM 89.6. The key piece is an 11-ft rootwad, 67-ft long, 3-ft dbh cottonwood piece that is seen to the right racking a large Cedar piece. Flow is from left to right. Photo Taken on August 18, 2021.

5.6.5.3 Reach 3A

Reach 3A is a naturally confined reach with a narrow floodplain and a small amount of large wood pieces (Figure 5.6-7). In August 2021, the study team identified 57 pieces in this reach. A summary of the large wood count, rootwad count, and rootwad count for Geomorphic Reach 3A is shown in Table 5.6-20. In this reach the study team did not see individual pieces or log jams that formed pools.

Table 5.6-20. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 3A.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	23	6	26%
Sky Creek	1	1	100%
Damnation Creek	13	8	62%
Side Channels	1	0	0%
In Log Jams	19	N/A	N/A
Total	**57**	**15**	**26%**

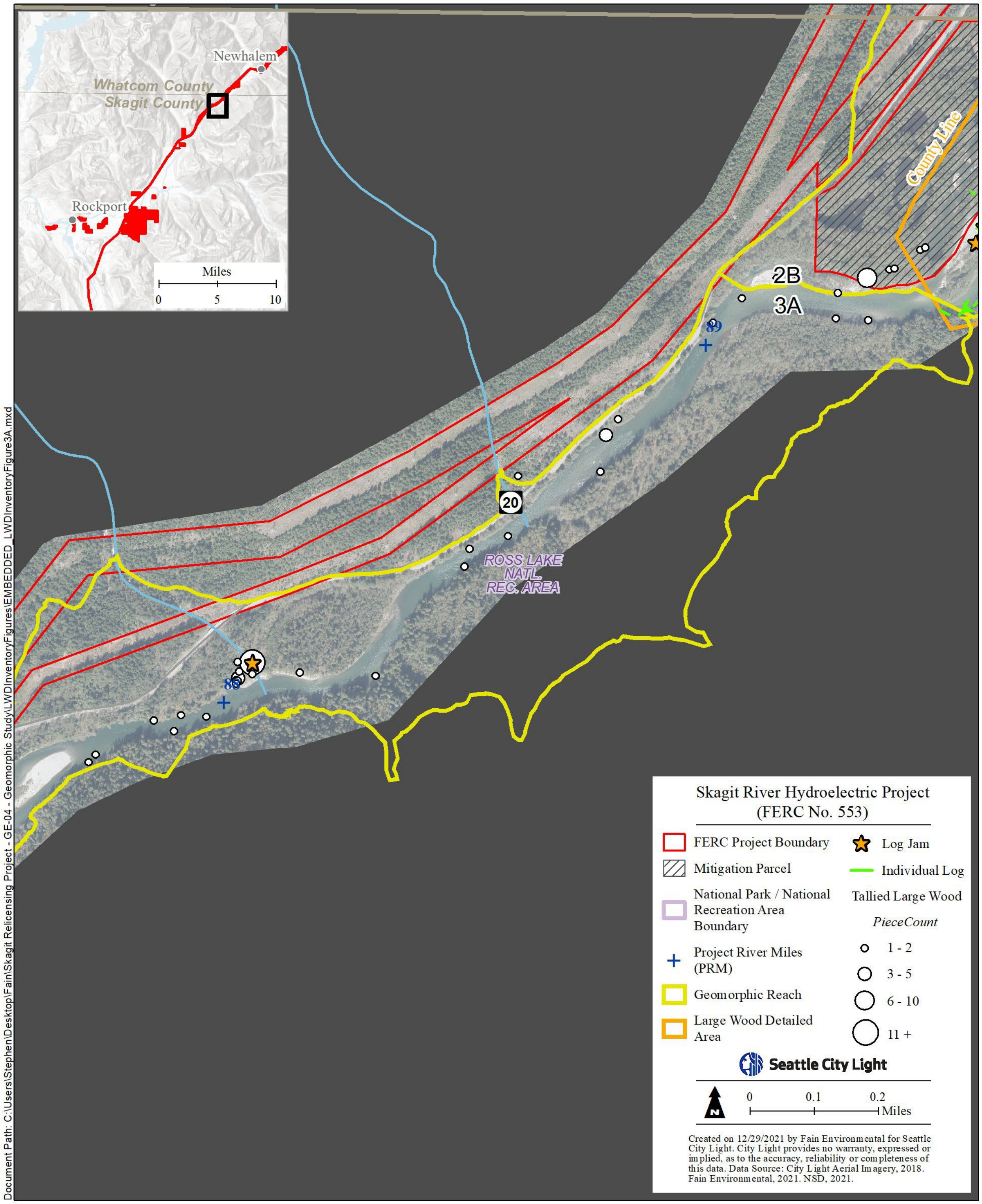

Figure 5.6-7. Large wood August 2021 field inventory for Reach 3A.

5.6.5.4 Reach 3B

Geomorphic Reach 3B is approximately 1.9 miles long. Table 5.6-21 presents a summary of the large wood inventory for Geomorphic Reach 3B (Figure 5.6-8). There was a total of approximately 236 pieces, with 71 rootwads counted in this reach (Table 5.6-21). Five of the small log jams were located in the mainstem and one was located in a side channel (Figures 5.6-9 and 5.6-10).

Table 5.6-21. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 3B.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	102	63	62%
Bacon Creek	8	6	75%
Side Channels	3	2	67%
In Log Jams	123	N/A	N/A
Total	**236**	**71**	**30%**

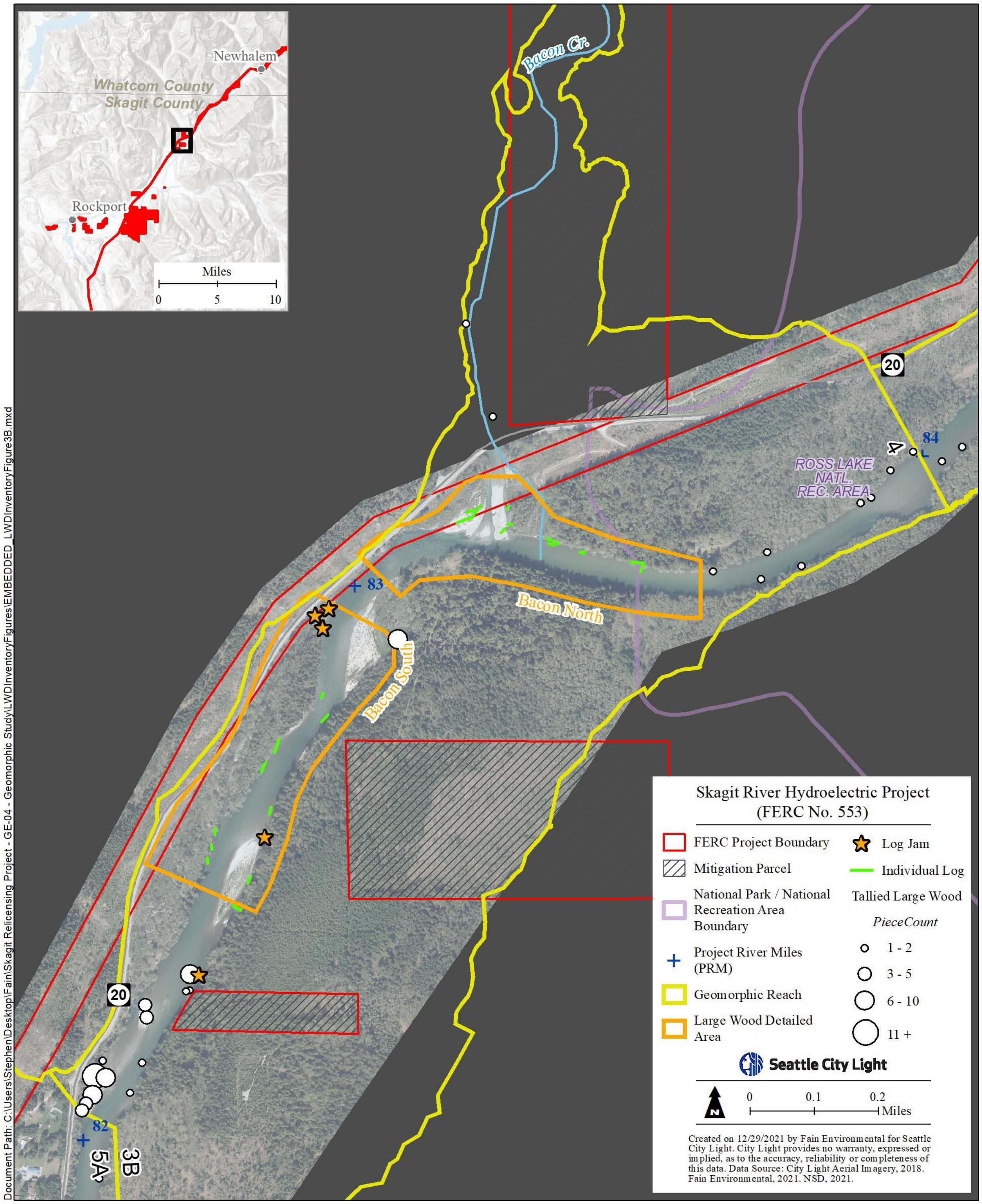

Figure 5.6-8. Large wood count, rootwad count, and percentage by location for Geomorphic Reach 3B.

Figure 5.6-9. Side channel inlet log jam located on left bank at PRM 82.6. Photo taken August 4, 2021.

Figure 5.6-10. Bar apex jam on right bank at PRM 82.9. Jam forms 8-ft pool at left side of photo. Flow is from left to right. Photo taken August 4, 2021.

5.6.5.5 Reach 4

Geomorphic Reach 4 is approximately 3.5 miles long. Reach 4 is located between Reach 3A and 3B and is referred to as the “landslide zone.” Table 5.6-22 presents a large wood count, rootwad count, and percentage by location for Geomorphic Reach 4. There was one log jam present in a side channel. Figures 5.6-11 and 5.6-12 includes the large wood field inventory from August 2021. There were approximately 57 pieces of wood counted in this reach. Intact rootwads were present for 23 of these pieces. In August 2021 the upper mile of this reach, PRM 86.5 to 87.5, was not inventoried because it was inaccessible to jet boats. An example photo of a large wood piece inventoried in this reach is seen in Figure 5.6-13.

Table 5.6-22. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 4.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	38	17	45%
Alma Creek	3	1	33%
Copper Creek	2	2	100%
Side Channels	4	3	75%
In Log Jams	10	N/A	N/A
Total	**57**	**23**	**40%**

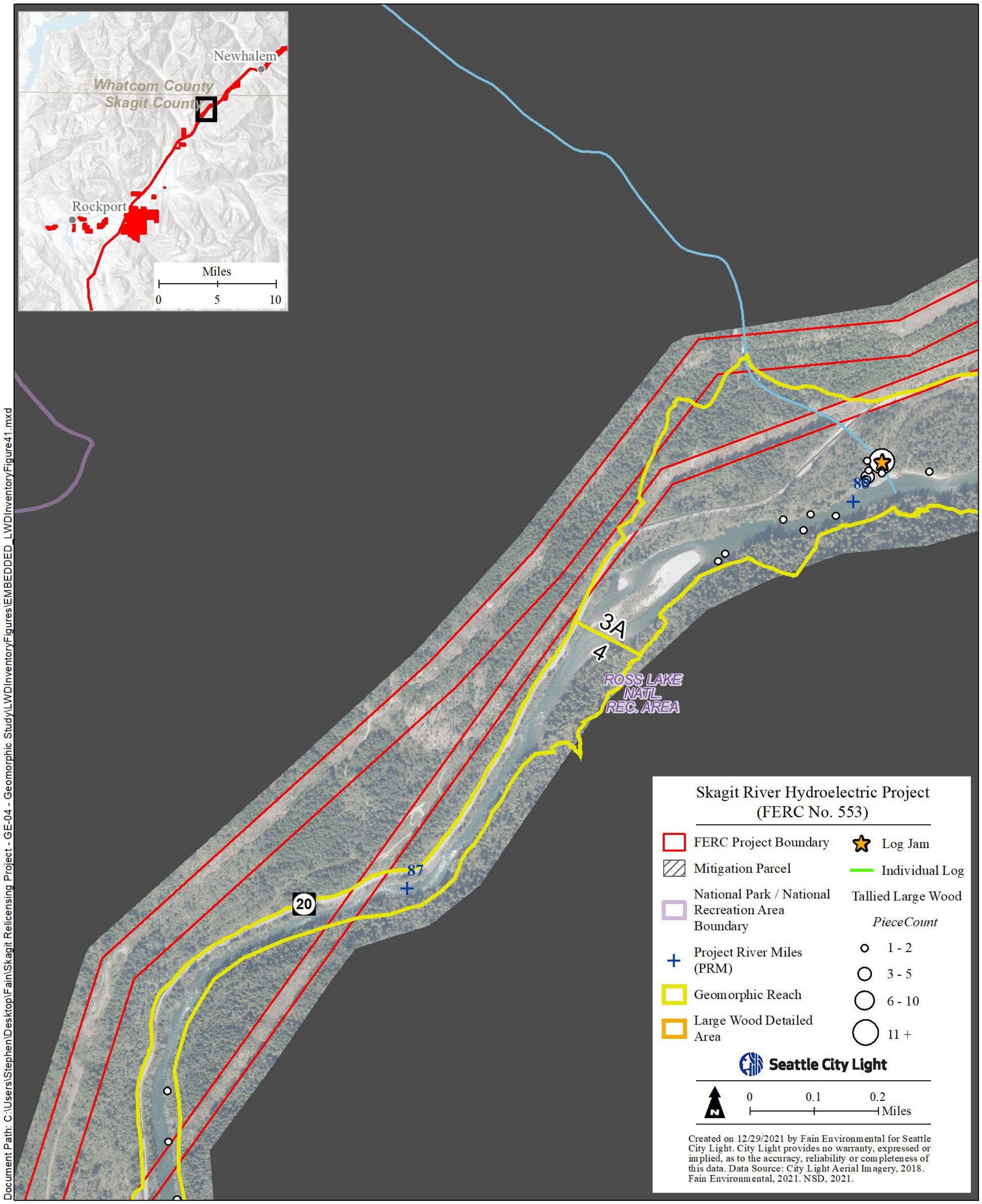

Figure 5.6-11. Large wood August 2021 field inventory for upper section of Reach 4.

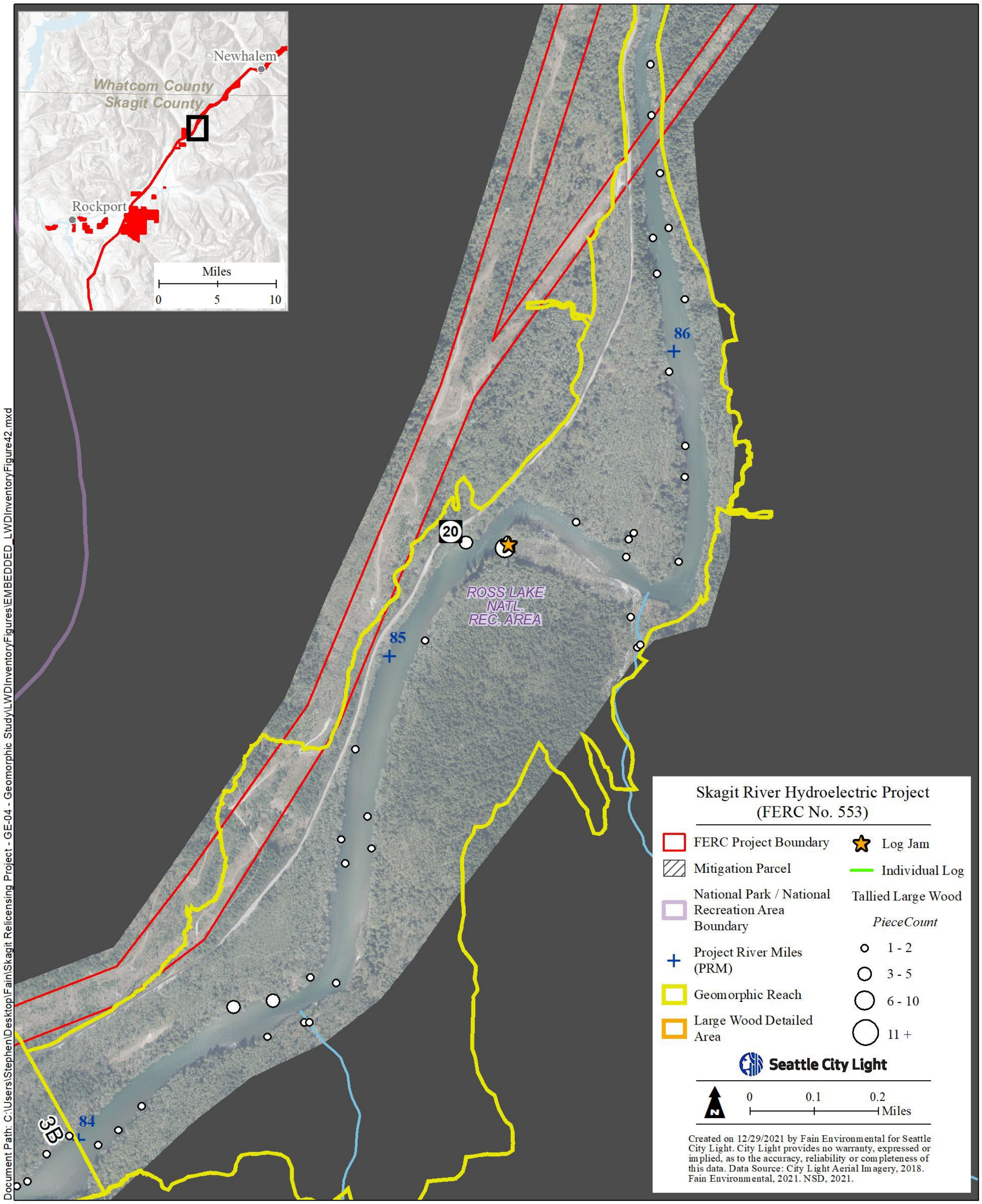

Figure 5.6-12. Large wood August 2021 field inventory for lower section of Reach 4.

Figure 5.6-13. A large wood Cedar piece (Tag ID 109) located at PRM 86.1 with a 12 ft diameter rootwad, a 5 ft dbh, and a 100 ft length. Looking downstream. Photo taken on October 19, 2021.

5.6.5.6 Reach 5A

There were 150 total pieces of large wood in Reach 5A of which 100 were individual pieces (Figures 5.6-14 and 5.6-15). Of these individual pieces, 38 of them have rootwads ranging in diameter from 2-10 ft. Table 5.6-23 presents a summary of the large wood count, rootwad count, and rootwad percentage for Geomorphic Reach 5A. This reach is relatively straight compared to the rest of the primary study area. One small log jam is located on the mainstem and one on Diobsud Creek (Figures 5.6-16 and 5.6-17).

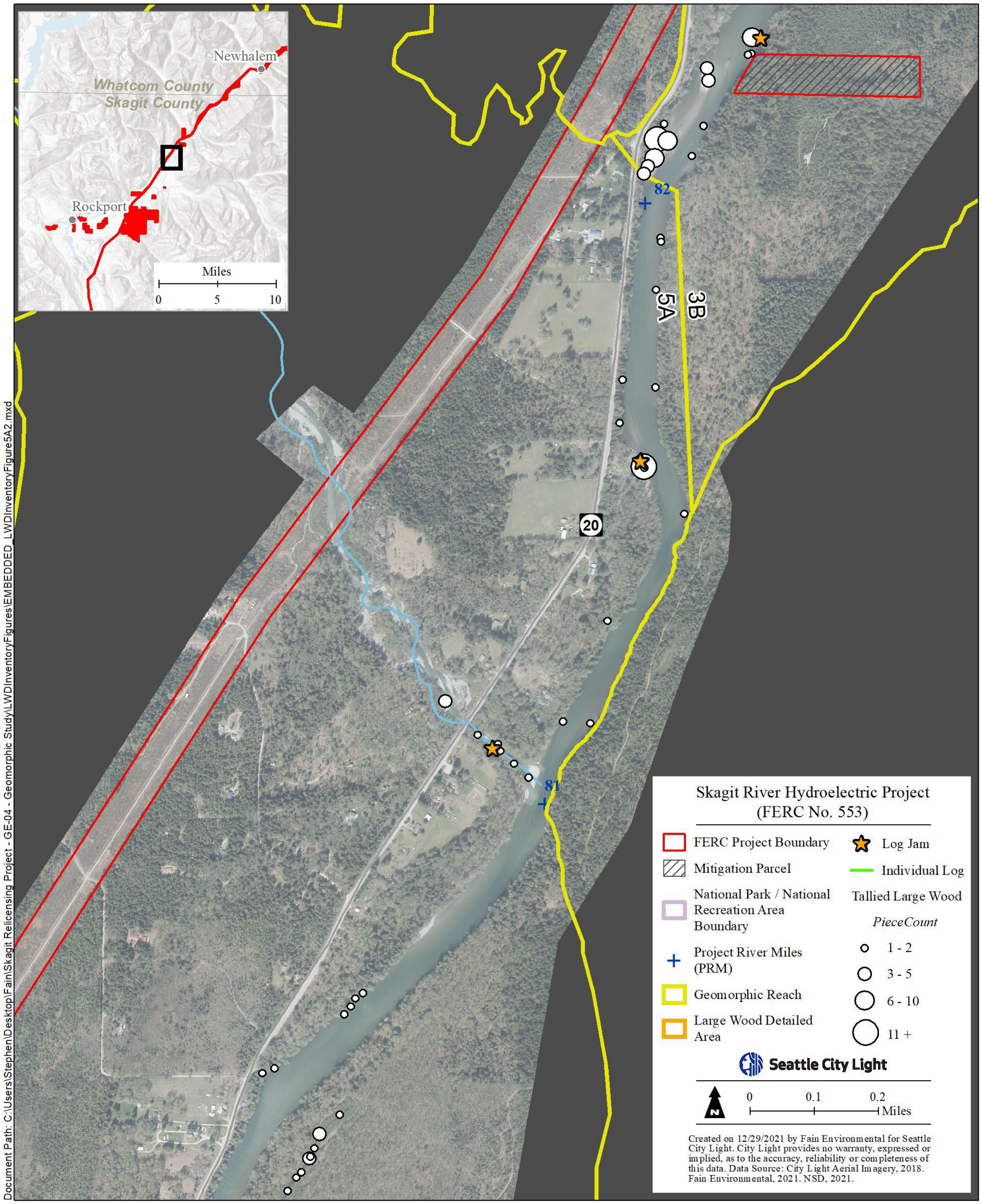

Figure 5.6-14. Large wood August 2021 field inventory for upper section of Reach 5A.

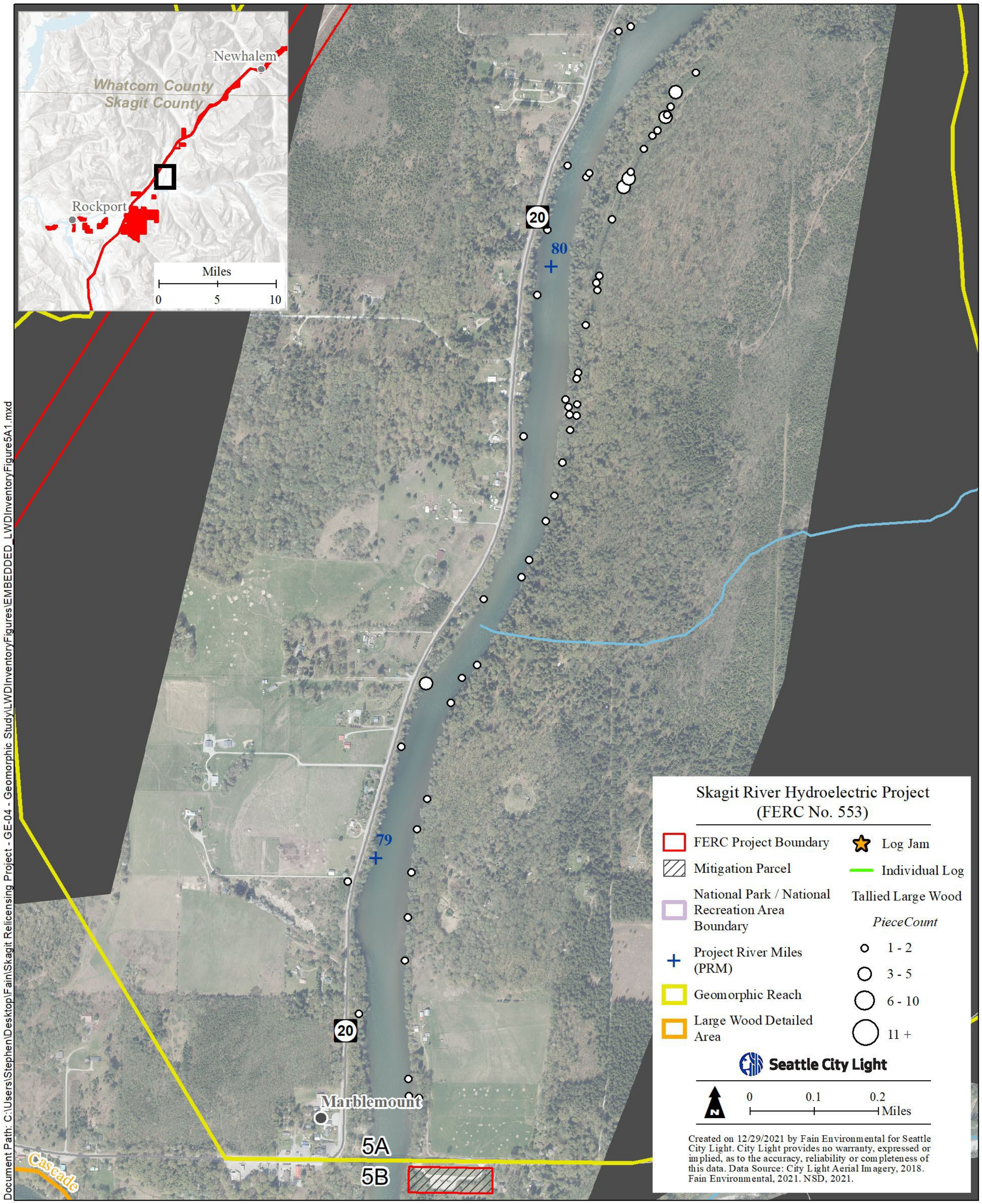

Figure 5.6-15. Large wood August 2021 field inventory for lower section of Reach 5A.

Table 5.6-23. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 5A.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	52	23	44%
Diobsud Creek	11	8	73%
Side Channels	37	7	19%
In Log Jams	50	N/A	N/A
Total	**150**	**38**	**25%**

Figure 5.6-16. Bar apex log jam located at PRM 81.6 on right bank. Looking from left bank to right bank, flow is from right to left. Photo taken August 4, 2021.

Figure 5.6-17. Apex jam located in Diobsud Creek forming 2-ft pool. Large wood Tag ID 82 is racked onto this jam. Photo taken looking downstream on August 25, 2021. Between PRM 80.6 and 81.0 there are no pieces of large wood in the mainstem of the channel.

5.6.5.7 Reach 5B

There were 827 total pieces of large wood inventoried in Reach 5B, of which 171 were individual pieces (Table 5.6-24; Figures 5.6-18 and 5.6-19). Of these individual pieces 81 of them have rootwads ranging in diameter from 1.5-30 ft (Table 5.6-24). The majority of the large wood in Reach 5B is in the Cascade River side channels as well as in a side channel located at PRM 77.7. Much of this wood is forming pools and functions as cover for aquatic habitat (Figure 5.6-20). Downstream of the side channel located at PRM 77.7 there is less large wood than upstream and the large wood that is present is primarily bank side pieces that function as cover but do not form pools for aquatic habitat. One large log jam was located in the mainstem (Figure 5.6-21). One small log jam was located in the Cascade River. The Cascade River Distributary side channels included 11 small log jams and one large jam. In the other side channels in this reach, there was a total of eight small and one medium-size jam.

Table 5.6-24. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 5B.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	71	25	35%
Cascade River	13	4	31%
Side Channels	87	52	60%
In Log Jams	656	N/A	N/A
Total	**827**	**81**	**10%**

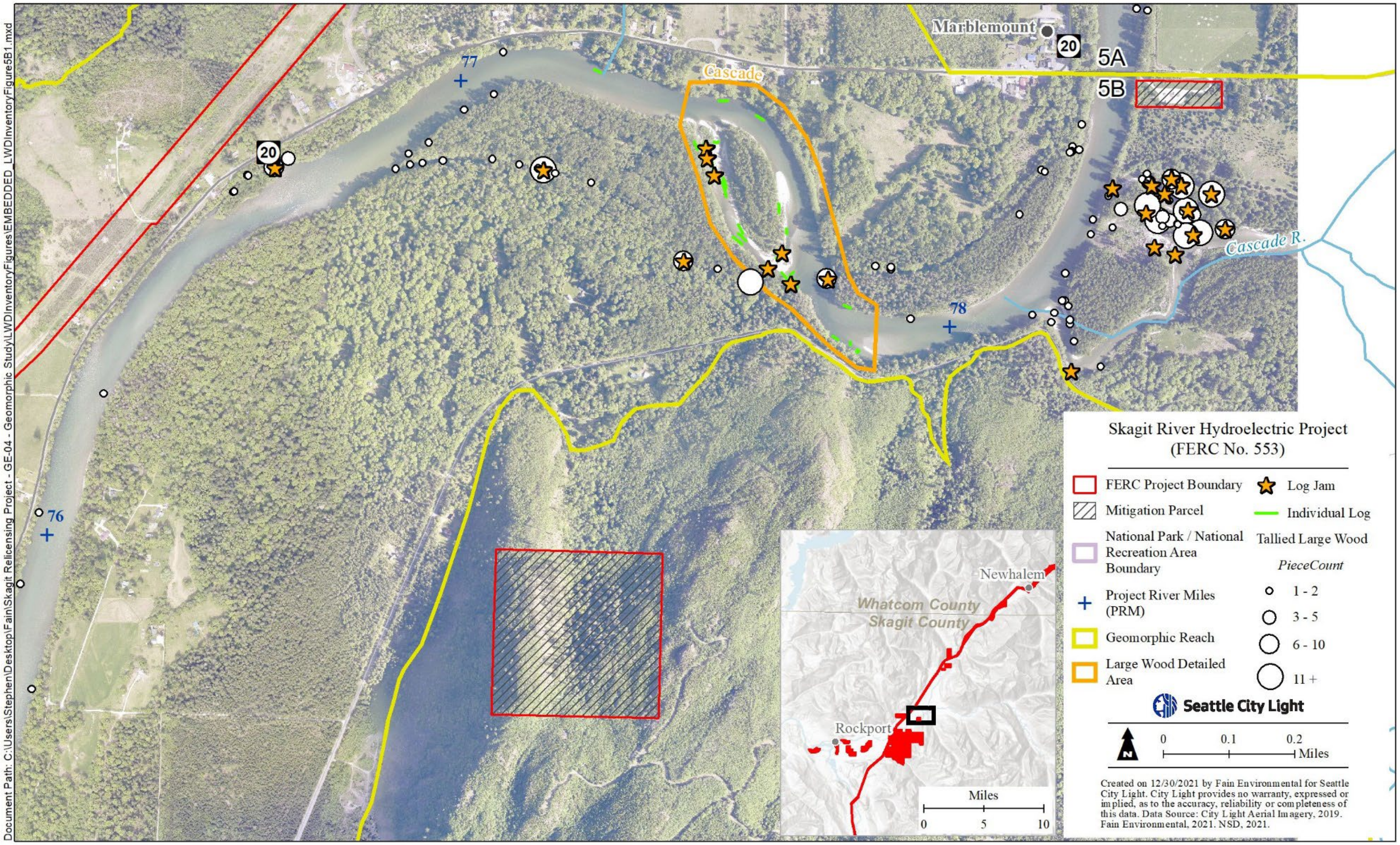

Figure 5.6-18. Large wood August 2021 field inventory for upper section of Reach 5B.

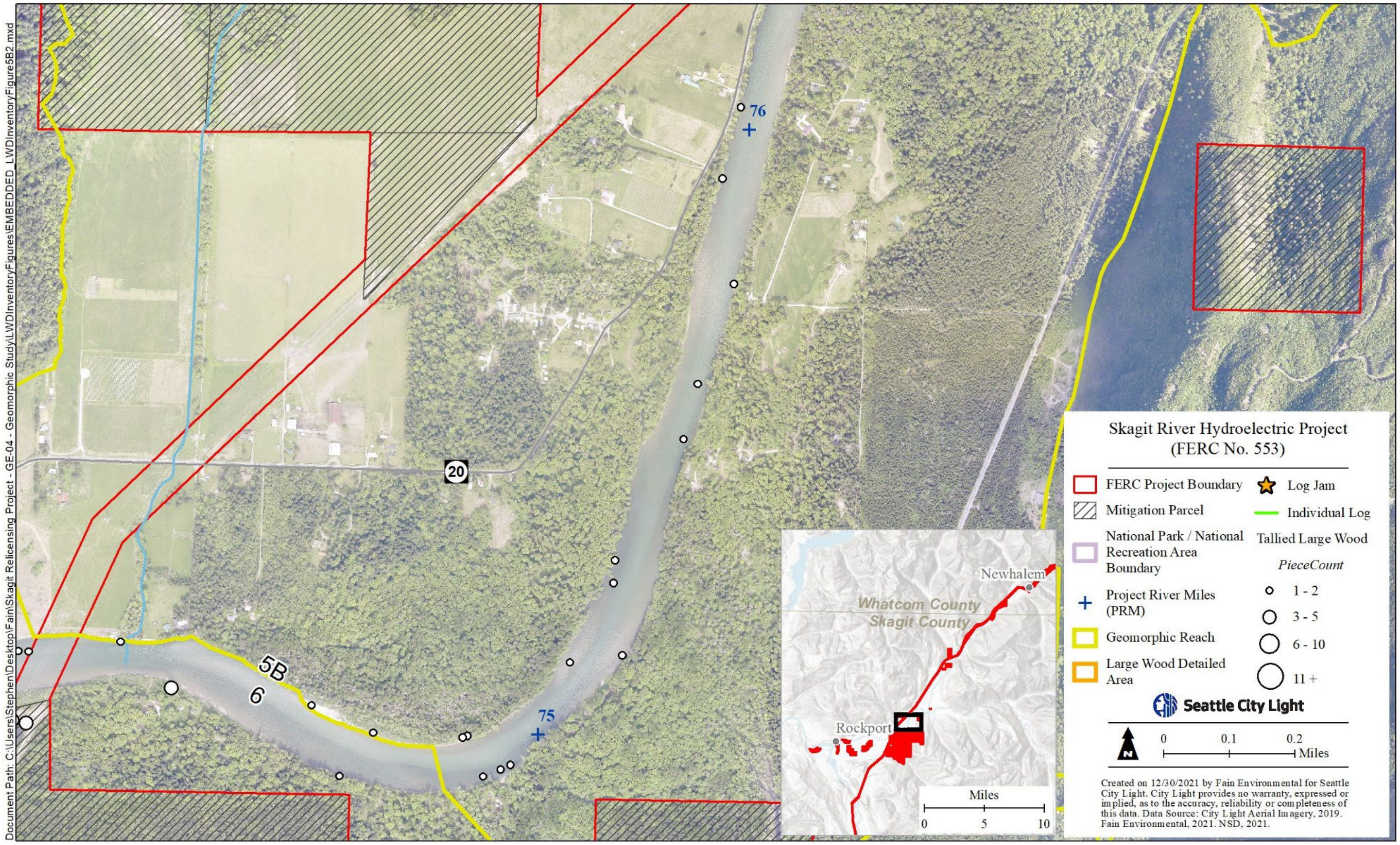

Figure 5.6-19. Large wood August 2021 field inventory for lower section of Reach 5B.

Figure 5.6-20. Individual large wood piece oriented parallel to flow with its rootwad upstream and forming a residual pool, located in PRM 77.7 ephemeral side channel (Tag ID 36). Flow is from right to left (looking upstream). Photo taken August 4, 2021.

Figure 5.6-21. Bar apex jam located at PRM 77.7 on left side of Skagit river, flow is from left to right. Large wood Tag ID 32 and 33 are racked on this jam. Tag ID 32 is a 115-ft long, 5-ft-dbh, 16-ft-rootwad cedar piece. Tag ID 33 is an 80-ft long, 3-ft-dbh, 10-ft-rootwad cedar piece. Photo taken August 4, 2021.

5.6.5.8 Reach 6

Geomorphic Reach 6 contained 1,908 total pieces of large wood of which 742 were individual pieces. Of these individual pieces 278 had rootwads (Table 5.6-25; Figures 5.6-22 through 5.6-24). This reach contained the most pieces of large wood in the primary study area. It also contained the most side channels and log jams. In the mainstem, there were eight small log jams, four medium log jams, and two large jams (Figures 5.6-25 through 5.6-27). Rocky Creek and Illabot Creek both had one small log jam (Figure 5.6-28). In the side channels, there were eleven small log jams.

This reach is characterized by a complex channel morphology and significant channel change over time. According to the historic aerial inventory, this reach has had a high concentration of large wood dating back to 1979.

Table 5.6-25. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 6.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	199	148	74%
Corkindale Creek	0	0	--
Rocky Creek	10	6	60%
Illabot Creek	0	0	--
Sutter Creek	0	0	--
Barr Creek	0	0	--
Side Channels	533	130	24%
In Log Jams	1166	N/A	N/A
Total	**1908**	**278**	**15%**

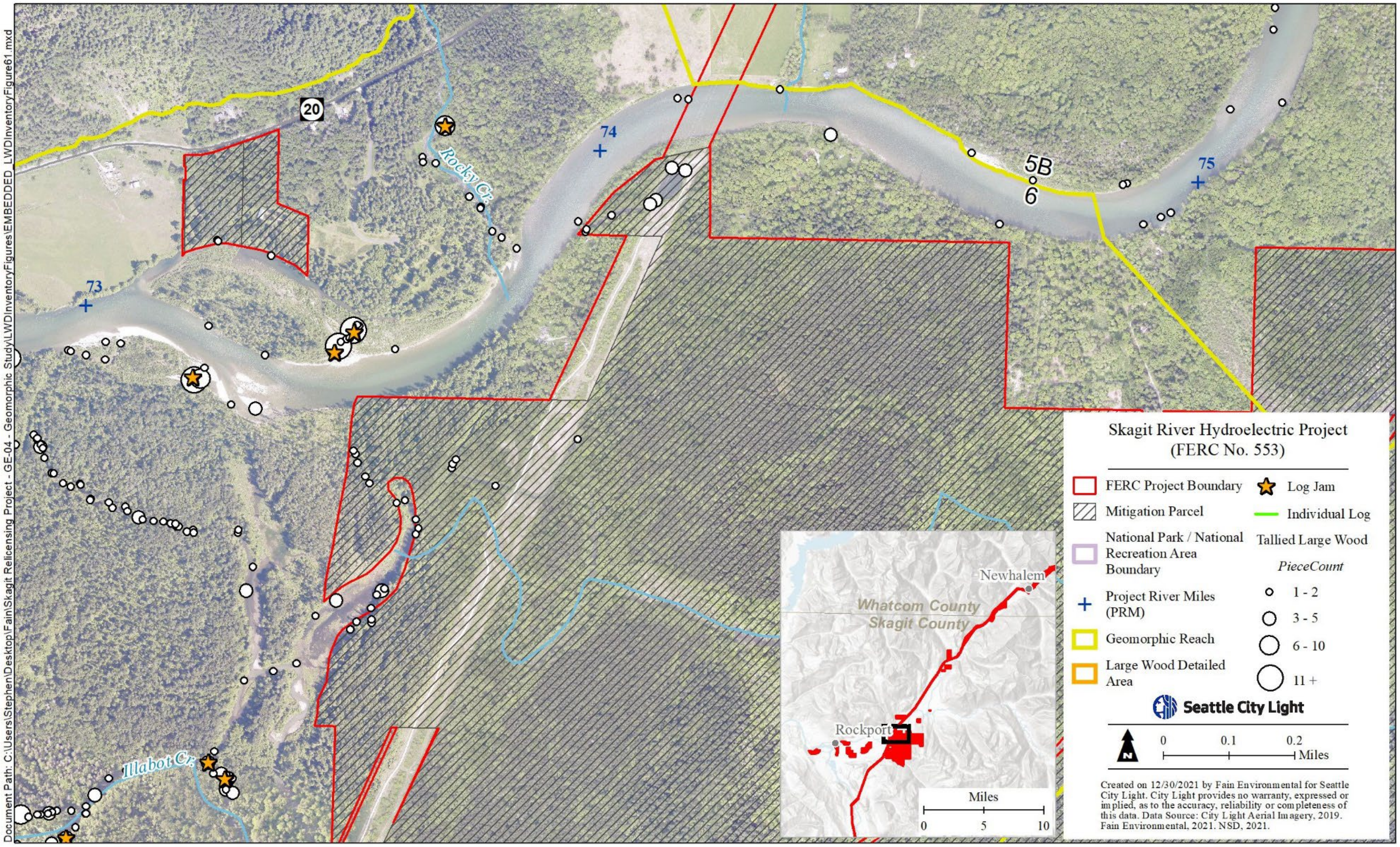

Figure 5.6-22. Large wood August 2021 field inventory for upper section of Reach 6.

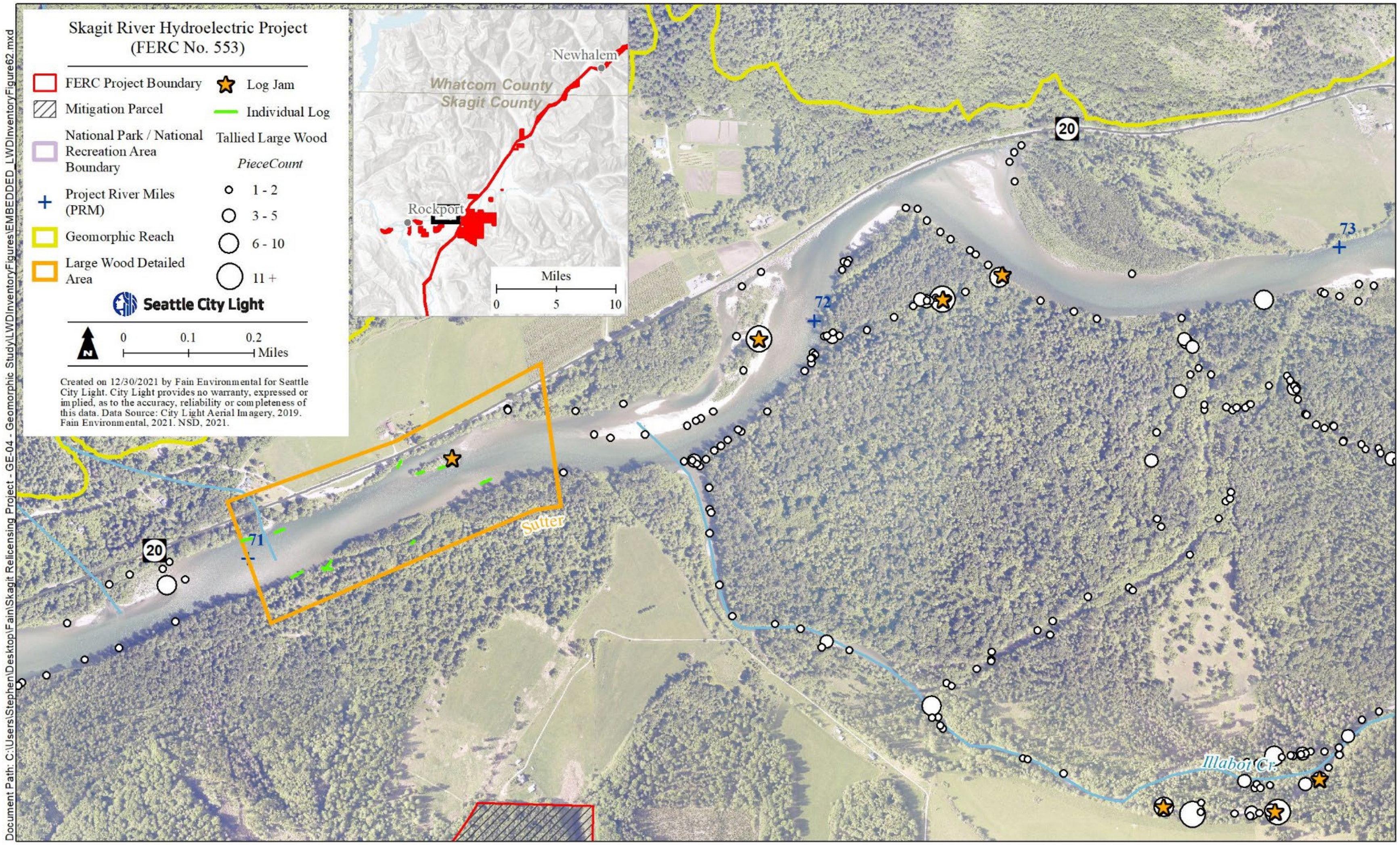

Figure 5.6-23. Large wood August 2021 field inventory for middle section of Reach 6.

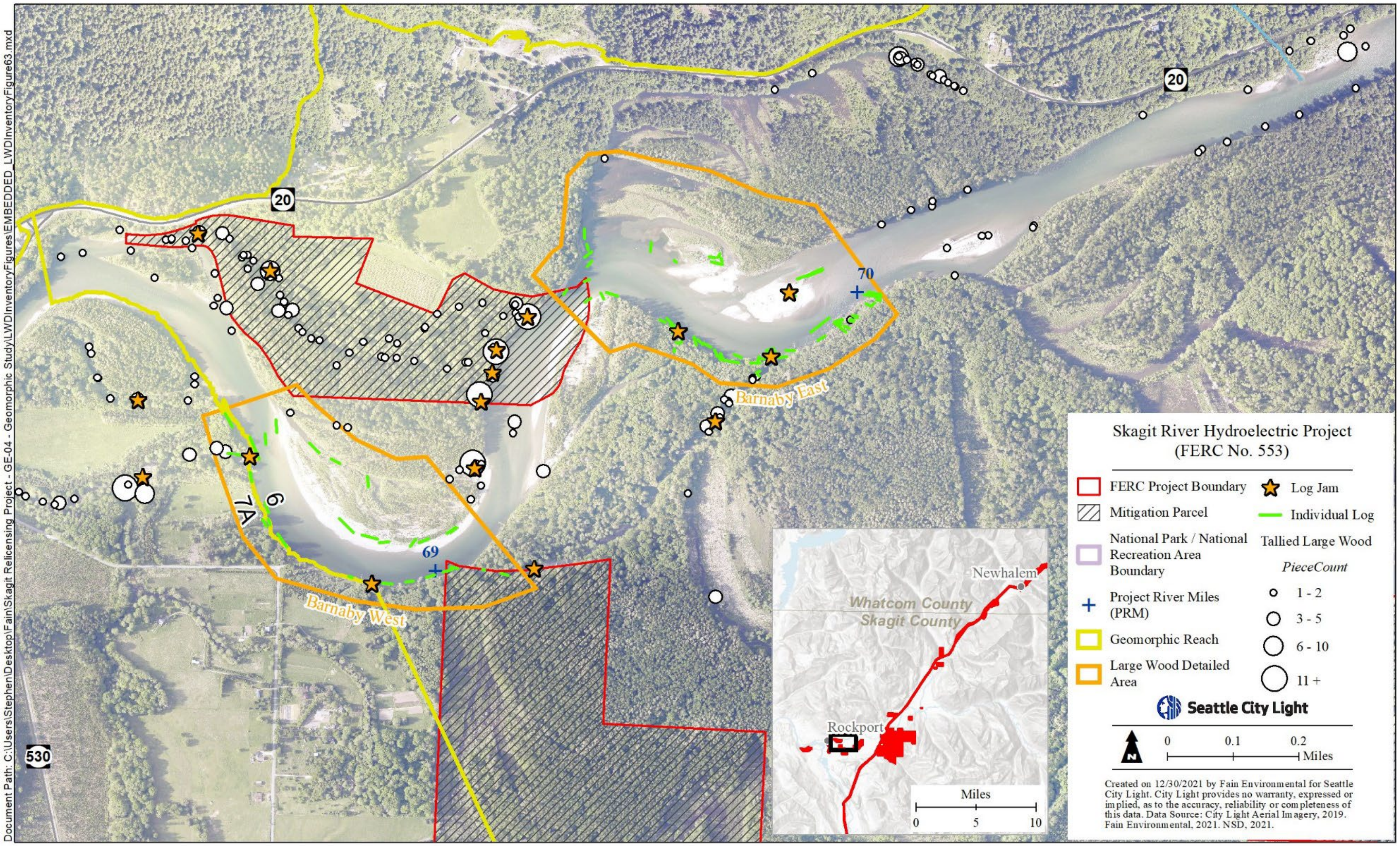

Figure 5.6-24. Large wood August 2021 field inventory for lower section of Reach 6.

Figure 5.6-25. Looking downstream at PRM 72.1. Right arrow is dolotimber revetment structure along roadside bank, center arrow is dolotimber apex jam, and left arrow is natural apex jam at PRM 72.0. Large wood Tag ID 65 is in the central dolotimber apex jam. Large wood Tag ID 67 is in the natural apex jam on the left. Photo is taken August 5, 2021.

Figure 5.6-26. Large apex jam that has persisted for 42 years at head of forested island at PRM 71.4, looking downstream. Forested island contains two large wood pieces on the left side that are tagged (Tag ID 16 and 17). Photo taken August 5, 2021.

Figure 5.6-27. Bar apex inlet jam at entrance to Bohs Slough side channel located at PRM 68.6 on river left. Flow is from left to right. Inlet jam contains tagged large wood pieces 159 and 160. Photo taken August 3, 2021.

Figure 5.6-28. Dispersed log jam located on Illabot Creek just upstream of confluence with Illabot side channel complex. Photo is looking upstream taken on August 26, 2021.

5.6.5.9 Reach 7A

Table 5.6-26 presents the wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 7A. Figure 5.6-29 includes Reach 7A and 7B. The study team identified approximately 414 pieces in Reach 7A of which 90 had rootwads (Table 5.6-26). There were six log jams in the mainstem and three jams in the side channel (Figure 5.6-30). Six of the nine log jams were forming pools.

Table 5.6-26. Large wood count, rootwad count, and percentage with rootwad by location for Geomorphic Reach 7A.

Location	Wood Count	Rootwad Count	Percentage with Rootwad
Mainstem	63	32	51%
Side Channels	110	58	53%
In Log Jams	241	N/A	N/A
Total	**414**	**90**	**22%**

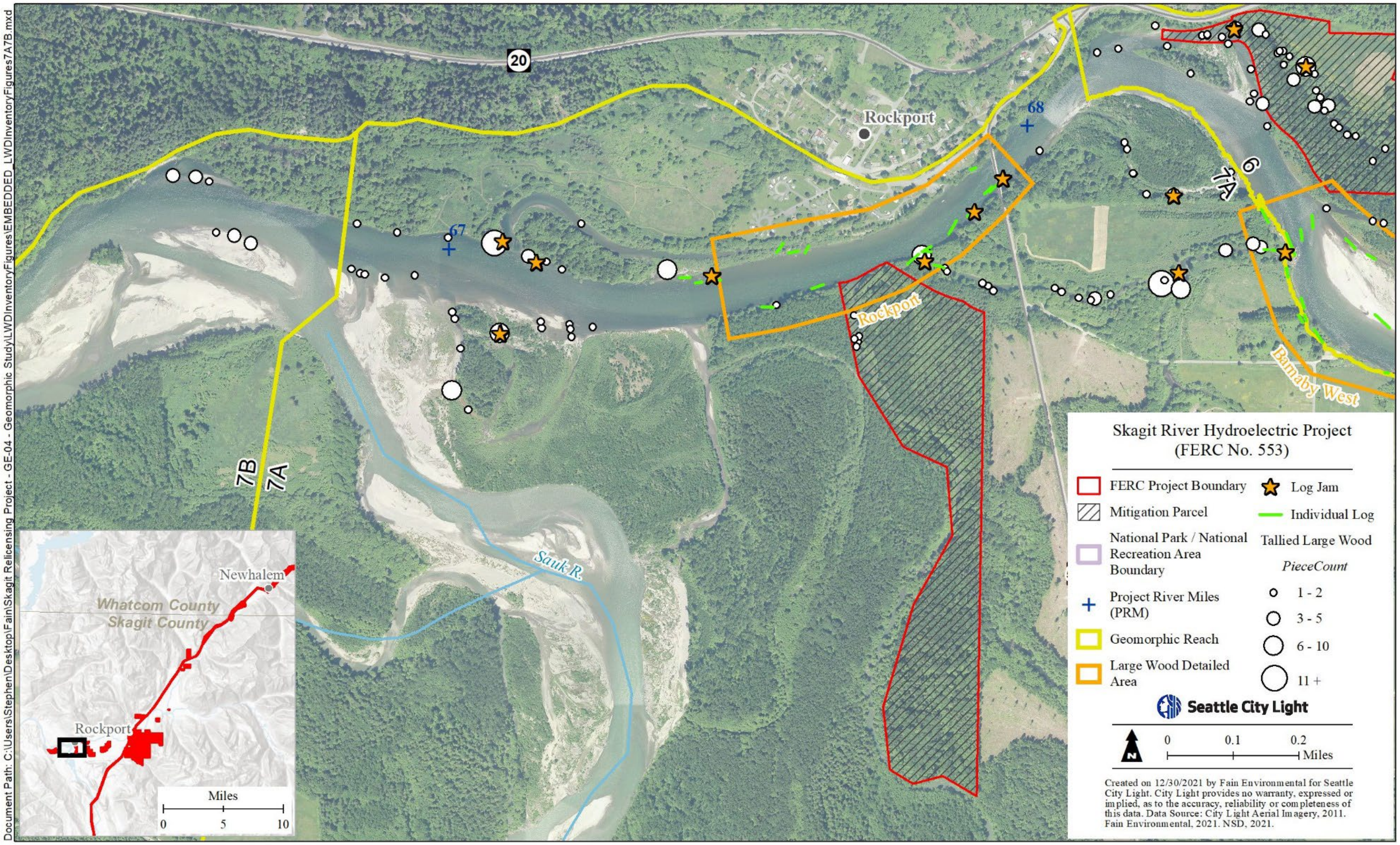

Figure 5.6-29. Large wood August 2021 field inventory for Reach 7A and 7B.

Figure 5.6-30. Medium log jam located in Bohs Slough between PRM 67.6 and 68.6. Photo is looking upstream and was taken on August 10, 2021.

5.6.5.10 Reach 7B

Fieldwork for LWD inventory only included approximately 0.3 miles of the upstream area in Reach 7B. Figure 5.6-29 includes Reach 7A and 7B. Historical LWD inventory using aerial photos (1979-2019) was not completed in reach 7B because it is downstream of the primary study area. The total number of pieces counted in August 2021 was 20 of which four had rootwads. Four large wood pieces in Reach 7B at PRM 66.6 are presented in Figure 5.6-31.

Figure 5.6-31. **Four large wood pieces in Reach 7B at PRM 66.6 on river right. Flow is from right to left. Photo taken August 5, 2021.**

5.7 Large Wood Transport

The large wood tracking, transport, and augmentation will be analyzed in combination with the Hydraulic Model results from the FA-02 Instream Flow Model Development Study during 2022 and results will be provided in the USR. The tracking results will be used to understand thresholds for motion of pieces by size and river discharge, transport distance, relationship between rootwads and mobility, jam stability, and potential recruitment areas.

5.7.1 Large Wood Tracking

Between October 13 and December 15, 2021, the study team installed radio tags and metal tags on 184 pieces of wood (Table 5.7-1). These tags were placed on large wood in the mainstem, tributaries, and side channels. A detailed table and map location of pieces of tagged wood is shown in Attachment K. Additionally, 37 pieces of wood being stored at the Agg pond site were tagged of the 184 total tagged pieces. A summary of the pieces that have been tagged by geomorphic reach is shown in Table 5.7-1. The wood being stored at the Agg Pond site was released into the mainstem river on December 9, 2021.

Table 5.7-1. Number of large wood pieces tagged between October 13 and December 15, 2021 by geomorphic reach.

Geomorphic Reach	Tagged Large Wood Pieces
2A	3
2B	64[1]
3A	0
3B	21
4	8
5A	15
5B	28
6	35
7A	8
7B	0
Total	182

1 Piece count includes 28 Ross Lake logs and 9 Agg Pond locally recruited logs.

The study team is monitoring flows and tracking large wood that has been tagged after flows greater than 15,000 cfs at the Marblemount Skagit River USGS Gage (1218100). On October 28-29, 2021, there was a large flow event in the Skagit River, Sauk River, and tributaries (Figure 5.7-1). The peak flows during this flow event are shown in Table 5.7-2.

Table 5.7-2. Peak flows in the Skagit River, Sauk River, and tributaries in October 2021.

Location	USGS Gage	Peak Flow (in cfs)	Date and Time
Skagit River at Newhalem	12178000	10,200	10/28/2021, 7:15pm
Newhalem Creek	12178100	2,650	10/28/2021, 8:30pm
Bacon Creek	12179900	4,640	10/28/2021, 8:45pm
Skagit River at Marblemount	12181000	29,100	10/28/2021, 9:45pm
Cascade River at Marblemount	12182500	9,170	10/28/2021, 11:30pm
Sauk River at Sauk	12189500	52,900	10/29/2021, 3:00am

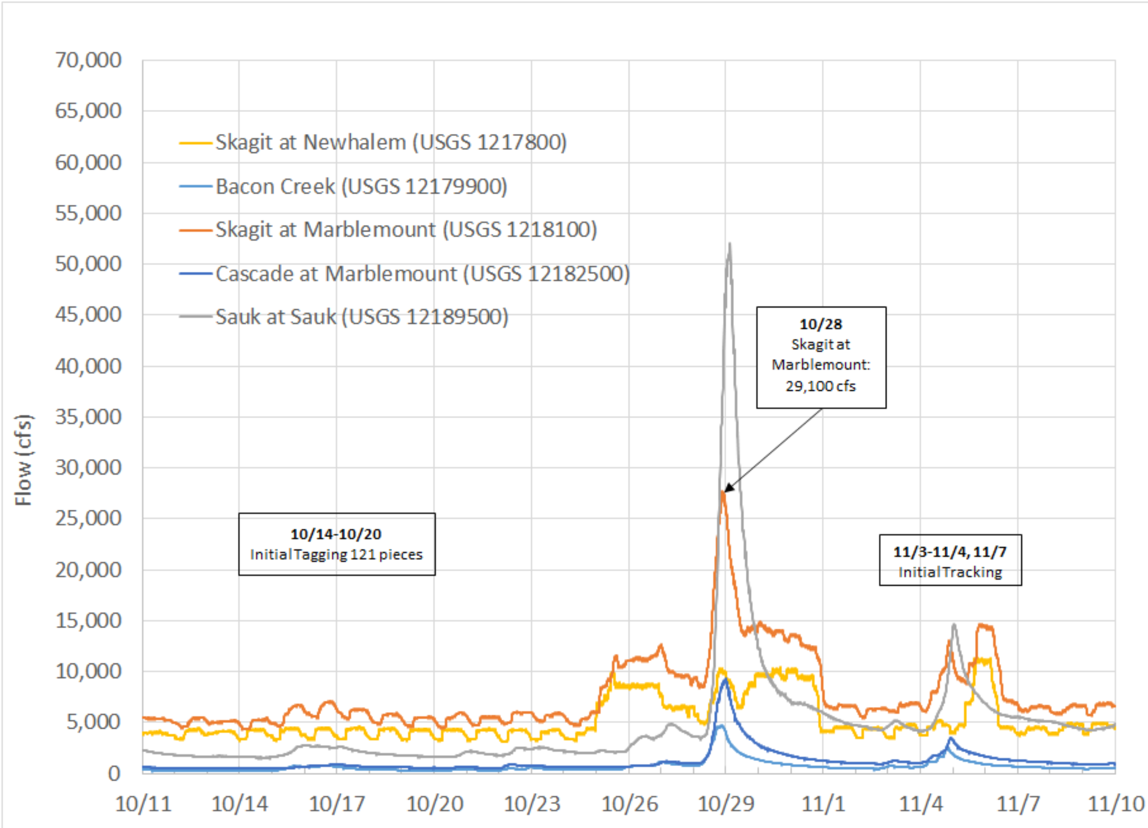

Figure 5.7-1. October 28, 2021 large flow event in the Skagit River, Sauk River, Bacon Creek, and Skagit River.

The study team completed tracking efforts in the primary study area on November 3, 4, and 11, 2021. Additionally, the team tracked wood downstream of the study area in some locations along the lower Skagit River from the shoreline between Concrete and Sedro Wooley on November 7 and 25, 2021. During the initial tracking efforts after the October large flow event, 39 of the 121 pieces that had been tagged up to that date had moved at least 100 ft. At least five of the pieces of large wood moved 10-60 miles and were transported downstream of the Sauk River, outside of the primary study area.

From November 12 to 15, 2021, there were two large flow events in the Skagit River, Sauk River, and tributaries (Figure 5.7-2). The peak flows during this flow event are shown in Table 5.7-3.

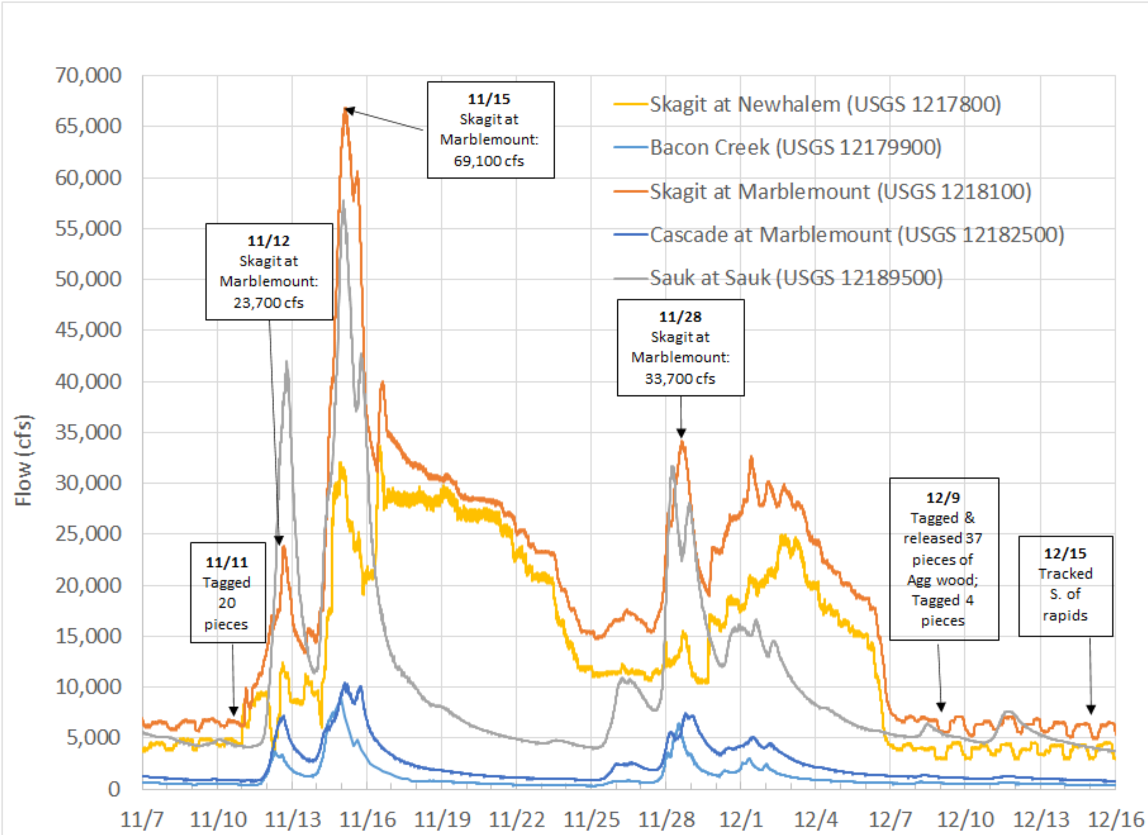

Figure 5.7-2. November large flow events in the Skagit River, Sauk River, Bacon Creek, and Cascade River.

Table 5.7-3. Peak flows in the Skagit River, Sauk River, and tributaries on November 15-16 2021.

Location	USGS Gage	Peak Flow (in cfs)	Date and Time
Skagit River at Newhalem	12178000	33,700	11/16/2021, 12:35pm
Newhalem Creek	12178100	5,110	11/15/2021, 12:30am
Bacon Creek	12179900	8,980[1]	11/15/2021, 12:00am
Skagit River at Marblemount	12181000	69,100	11/15/2021, 3:20am
Cascade River at Marblemount	12182500	10,500	11/15/2021, 3:00am
Sauk River at Sauk	12189500	57,800	11/15/2021, 1:15am

1 Peak flow at Bacon Creek Gage was estimated by USGS because it was not working from November 14, 2021 at 7pm, until November 18, 2021 at 12:30pm.

Tracking after the November 12 to December 6, 2021 large flow events occurred in the primary study area downstream of the rapids at PRM 86.5 on December 15, 2021 and upstream of the rapids in January 2022. The tracking efforts will continue throughout 2022, and additional results will be included in the USR.

5.7.2 Large Wood Transport

Large wood transport results have not been completed at this time.

5.7.3 Large Wood Recruitment

Large wood recruitment results have not been completed at this time.

5.7.4 Large Wood Augmentation

Large wood recruitment results have not been completed at this time.

5.8 Process Flows

As identified in Section 4.8 of this study report and Section 2.6.7 of the RSP, analyses for process flows will integrate data from the scour monitoring and sediment transport modeling, as well as the hydrophone and accelerometer data, with hydraulic model results and will be reported in the USR. This integration will help determine flows that initiate substrate movement across locations. Hydraulic model results will also be used to identify potential flows that connect various side channel and off-channel habitats with the mainstem flow.

Process flows include a range of flow levels and inputs of sediment and wood to the channel that provide for aquatic organism migration and spawning, flush the channel of small organic debris and fine sediment accumulation, and result in geomorphic change, sediment transport and redistribution, and aquatic habitat creation, change, and maintenance. Available guidance (Wald 2009) suggests that natural conditions (10 and 2-year flows) be used as the benchmark for channel forming and channel maintaining discharges. Preliminary evaluation of the pre-regulation hydrology at Newhalem indicates that the natural conditions 2-year recurrence interval flow at that location is about 30,000 cfs and that the 10-year recurrence interval discharge is about 50,000 ±10,000 cfs.

The Indicators of Hydraulic Alteration (IHA) software package will be used to estimate the timing and duration of high flow events under unmanaged conditions which will be used to inform the development of process flow scenarios. Process flows to meet objectives will be determined through an iterative series of 2022 workshops involving the Geomorphology Study team and the FA-02 Instream Flow Model Development Study team.

6.0 SUMMARY

6.1 Completed Work and Next Steps

A compilation of relevant studies describing Skagit River geomorphology downstream from the Sauk River confluence were reviewed and summarized in an annotated bibliography included in Attachment A. **Next steps** include completing a summary of Skagit River geomorphic conditions downstream from the Sauk River confluence, to be included in the USR, pending the completion of the Landform Mapping Study downstream of the Sauk River confluence being conducted by NPS.

6.1.1 Geomorphic Change

Preliminary results completed to date include delineation of active channel areas for a time series of historical images, identification of channel segments where dynamic channel processes have been observed over the period of historical maps and imagery, calculation of channel migration rates, and evaluation of change in channel width, sinuosity, and braiding intensity based on the active channel mapping. No lateral channel migration was recorded in Reach 2A (above Newhalem Creek) or in Reach 4 (the landslide zone). Only short segments of localized bank erosion (0.1 ft/yr, on average) were mapped in the geologically confined segments upstream (Reach 3A) and downstream (Reach 3B) of the landslide zone. Reach 5A (Straight Creek Fault to the Cascade River at Marblemount) also had limited channel migration with only localized areas of erosion and an average migration rate of 0.1 ft/yr, on average. Reach 2B (from Newhalem Creek down to the limit of alpine glaciation) and Reach 5B (Downstream of the Cascade River to Rocky Creek) both include segments where dynamic channel processes were observed in the historical record; however, rates of lateral channel migration remain low overall (0.4 ft/yr., on average). Reach 6 (Rocky Creek to the Sauk River alluvial fan) stands out as geomorphically distinct from other reaches in the primary study area and had an average lateral migration rate of 4 ft/yr over the period 1944-2019.

Ongoing work **as part of next steps** will include continued analysis of data produced from the active channel mapping based on the historic record of aerial imagery and integration of findings with other components of the study to address the study objectives. Focus areas for **next steps** include further discussion of streambank characteristics, estimating sediment inputs from channel migration, evaluating vertical channel changes at USGS gaging stations, and analyzing channel evolution based on findings of the analysis. Results of these ongoing investigations will be presented in the USR.

City Light will collect additional topobathymetric LiDAR in spring 2022 and will be used for assessing geomorphic change compared to previous 2017 and 2018 LiDAR data (QSI 2017, 2018). These data will provide information on geomorphic change resulting from the November 2021 floods, including change in sediment storage values that will be used in calibrating sediment transport models to be presented in the USR.

6.1.2 Aquatic Habitat

Aquatic habitat in the study area has been mapped and summarized in Section 5.0 of this study report for those data that are currently available. Reach 1 summary data are dependent on modeling results from the FA-05 Bypass Instream Flow Model Development Study (City Light 2022b). Metrics for Reaches 2A through 7A have been calculated and are available for review and initial comparison.

As part of next steps, additional data and information from the FA-02 Instream Flow Model Development Study (City Light 2022a) will be used to provide further detail on the amount and quality of habitat within the mainstem, side channels, off-channel habitat areas, and tributaries within the study area. Habitat mapping discussion topics will include a summary by reach of the relative quality of habitat for fish and other aquatic species. Specific habitat features that are known to be used by focal species and life stages will be identified as part of this discussion, although an extensive discussion of fish-habitat relationships will not be included here as that topic is covered in the FA-02 Instream Flow Model Development Study. References to the FA-02 Instream Flow Model Development Study will be made for information on life history timing for fish species and habitat suitability.

Next steps in the analysis include the inclusion of output from the FA-05 Bypass Instream Flow Model Development Study hydraulic model (City Light 2022b) and the FA-02 Instream Flow Model Development Study hydraulic model (City Light 2022a). Integration of this information will allow for a more detailed and complete description of habitat conditions and quality across the Project reaches.

6.1.2.1 Tributary Analysis

According to the Statewide Washington Integrated Fish Distribution (SWIFD 2021), all five species of Pacific salmon and steelhead exist throughout the mainstem Skagit River at each of the studied tributary mouths. As chum are the least athletic jumpers and burst swimmers (Reiser et al. 2006) and least able to swim up steepening grades (WDFW 2019), fish passability was primarily evaluated in terms of chum athleticism.

No fish passage issues were found based on water depth alone that appeared isolated to tributary mouths or caused by aggradation of the alluvial fan. While three dry channel beds were found, conditions at the tributary mouth were consistent throughout the surveyed reach and not isolated to the confluence or alluvial fan. As dry channel beds alone do not constitute a fish passage barrier since flow depths fluctuate seasonally (WDFW 2019; Reiser, et al. 2006), these were not considered barriers, even though at the time of the survey fish could not access the tributaries.

Common regulatory practice in Washington evaluates fish passability based on stream gradient, channel width, and hydraulic drops (WDFW 2019). Regarding stream gradient and width, impassable conditions must be sustained for 525 linear ft to be considered a barrier (WDFW 2019). While this is the generally accepted guidance, it should be noted that this is purposefully conservative, so as not to preclude fish presence in a given area, and is not intended to state a particular species is necessarily able to pass freely, which is influenced by additional factors such as boulder size, flow velocity, constriction, proximity to natal streams of particular populations (Reiser et al. 2006; WDFW 2019) and even individual athleticism (Meixler et al. 2009). While chum only utilize grades below 3 percent, they are able to pass through grades up to 5 percent freely and may pass even higher grades if the reach length is less than 525 linear ft (WDFW 2019).

Three streams had average gradients over 5 percent that did not also have natural fish passage barriers due to waterfalls: Alma Creek, Copper Creek, and Damnation Creek. Alma Creek most consistently had grades of 3-4 percent, with one 60-ft section that had a sustained gradient of 17 percent. According to WDFW fish passage criteria, this is not a barrier to chum. Copper Creek had fairly sustained gradients of approximately 6 percent, which appeared to continue past the surveyed reach and may preclude chum from this tributary; however, it is not steep enough to preclude the other salmonid species, which can swim freely in grades lower than 7 percent, and are able to pass grades up to 12 percent (WDFW 2019). Damnation Creek had consistent grades of approximately 4.2 percent, with a reach break of 8.3 percent for 57 linear ft, which is not considered a barrier due to grade (WDFW 2019).

In terms of hydraulic drops, fish passage barriers were found on Ladder Creek and Sky Creek within the surveyed reaches. Both tributaries have natural waterfalls with heights over 12.1 ft between pools of depths equal to or greater than fish body length, which is the minimum depth necessary for a fish to orient and prepare for a leap (Reiser et al. 2006; WDFW 2019).

While Goodell Creek could not be surveyed due to inaccessibility of the river as a result of deep, swift waters, and erosive banks, the mouth and area beneath the bridge were visually inspected, and it was determined that fish passability based on the above criteria was not an issue in this tributary due to both sufficient water depth and low gradient channel bed.

6.1.3 Side Channels and Off-Channel Habitat

6.1.3.1 Current Side Channel and Off-Channel Habitat

The current conditions of side channels and off-channel habitats of the Skagit River were evaluated using remote sensing data and field observations. In total, 56 side channel and off-channel features were evaluated: 45 side channels, seven off-channel features, and four features containing both side channel and off-channel habitat. Side and off-channel habitats were evaluated for connectivity with the Skagit River and inlet and outlet condition, as well as the presence of habitat features, such as large wood, fish cover, and spawning gravels. A detailed narrative describing each feature is available in Appendix H.

Based on initial analysis of connectivity using REMs and field observations, 26 side channels are perennial, 15 are seasonal, and four are inactive. Within off-channel features, five are perennial and two are seasonal. All four features containing side channel and off-channel habitat are perennial.

Side channel and off-channel habitat varies substantially by geomorphic reach. Generally, the greatest amount of side and off-channel habitats are found in the furthest downstream portions of the study area below the Cascade River, where the valley width is wider and the floodplain and geomorphology are more dynamic. The majority of side and off-channel habitat is found in three reaches. Reach 6 contains the greatest amount of side channel and off-channel habitat, followed by Reach 5B and Reach 2B. Other reaches contain relatively low amounts of side and off-channel habitat.

The field data collection and summary of conditions for current side channel and off-channel habitat is complete. Future analytical work will focus on incorporating additional data from other relicensing studies including large wood from this Geomorphology Study, fish cover, substrate data, and hydraulics from the FA-02 Instream Flow Model Development Study (City Light 2022a). Large wood, fish cover, and substrate data will be used to further evaluate and quantify habitat conditions for salmonid rearing and spawning. Hydraulic conditions will be used to evaluate the connectivity and availability of side and off-channel habitat at various flow recurrence intervals and the conditions (e.g., depth and velocity) within side and off-channel habitats.

The current side channel and off-channel habitat data will also be used to further inform the analysis of time series data for side channel and off-channel habitat, as well as the relative importance of the formation and maintenance of these habitats in various areas.

6.1.3.2 Time Series Analysis of Side channel and Off-Channel Habitat

Time series data are useful for detecting changes in habitat conditions. Since side channel and off-channel habitat are, by nature, generally transitory within the dynamics of river processes, using a time series of images or remote sensing data can provide a record of the trajectories of side channel and off-channel habitat formation and degradation in specific areas, reaches, and throughout the study area. Aerial images used in mapping geomorphic change for the period 1944-2019 were used to summarize the changes in side channel and off-channel habitats (Attachment E). Metrics for each time step were calculated to summarize status and trends of floodplain habitat through time. Results are presented in Section 5.3.2 of this study report and initial review of the data has been completed.

Next steps to be completed for the time series will involve further evaluation with comparisons to the hydrograph during that period between aerial images to evaluate the relationship between changes in amount and characteristics of side and off-channel habitat and changes in the flow regime through time. Additional factors such as changes in hydromodification, localized land use impacts, and erosion will also be considered in this further analysis.

Other analysis of time series data will include evaluation of focus areas identified as having changed substantially through time. Detailed investigation of these areas will allow better identification of conditions and flows that may encourage development of floodplain habitat within the Skagit River under the existing regime. These data will also allow identification of some of the conditions that may result in loss or degradation of side channel and off-channel habitat through time. Other factors in the primary study area that influence side channel and off-channel habitat connectivity include sediment transport, flow levels and velocities, influences from large wood, hydromodifications, erosion, and land used impacts.

6.1.4 Substrate/Sediment

A total of 43 bulk samples to characterize the subsurface material and 51 lithology-specific pebble counts to characterize the armor layer were collected from locations distributed along the river and distal reaches of tributaries (Figure 4.4-2). Ultimately, over 12,000 kg of sediment was handled in the process of collecting the bulk samples, and over five thousand grains were measured for the pebble counts. Samples targeted bar head locations that were believed to represent typical structural bed material in each reach. As discussed with LPs during the July 2021 Geomorphology Work Group meetings, the practical sampling limit of 200 kg determined for this project was below the recommended 1 percent criteria for many samples (Church 1987); therefore, the hybrid method of Rice and Haschenburger (2004) was applied to characterize the coarse tail of the bulk grainsize distribution.

Results of the grainsize analysis of the sediment samples are described in Section 5.4 of this study report. Sediment at the bar-head locations sampled in this study is predominantly composed of cobble and gravel, with moderate spatial variability at the reach-scale. Surface pebble count results (Figure 5.4-1) indicate D_{50} values typically of 64 to 91 mm and D_{84} values generally toward the upper range of 91 to 128 mm. The grainsize distribution of the subsurface material is dominated by gravel-sized material, with characteristic D_{50} values ranging from 20 to 50 mm.

The selective removal of fine sediment through the process of winnowing results in bed-armoring, whereby the surface substrate is coarser than the subsurface substrate. Bed-armoring has important implications for understanding and predicting sediment transport rates, and inherently the geomorphology of rivers. Using the ratio of the D_{50} from the surface pebble counts to the D_{50} from the bulk subsurface samples, a relative sense of armoring shows that much of the study reach is about twice as coarse in the surface as it is in the subsurface.

Sediment sampling for the primary study area is complete, but analysis of the substrate data is ongoing. Evaluation of bed material mobility and further analysis of these grainsize data will be completed in conjunction with development of the sediment transport modeling program and following completion of the FA-02 Instream Flow Model Development Study's Hydraulic Model (City Light 2022a). Interpretation and analysis of pebble count lithology data are also ongoing.

6.1.5 Sediment Transport

A scope for sediment transport modeling has been developed. Monitoring of sediment mobilization and transport to provide calibration data for these models is ongoing. This monitoring consists of installation of scour monitoring arrays and deployment of sediment tracer particles.

A total of nineteen scour monitoring arrays, each consisting of eight or more individual scour monitors have been installed along the Skagit River and lower reaches of select tributaries (Figure 4.5-2). These have been installed in three phases: a pilot redd scour monitoring project was initiated at three locations during August 2019; this was expanded to ten sites focused on areas of known important spawning activity in 2020; and an additional nine sites were installed in August 2021. The sites installed in August 2021 included two sites to study mobilization of tributary fans and seven sites (five in the Skagit River and one each in Bacon Creek and Cascade River) at riffle crest locations to study general bed scour associated with sediment transport.

Overall, scour observations through summer 2021 suggest very little bed mobility occurred at the spawning site scour monitor installations installed in 2019 and 2020, with most locations showing no scour, most observations showing any scour indicating mobilization less than the thickness of the armor layer, and a maximum observed scour depth of 6.8 inches. Preliminary interpretation of data from accelerometers suggests that most bed mobilization occurred during low flow conditions but concurrent with the spawning season, indicating that observed scour was most likely the result of spawning activity.

RFID-tagged tracer particles were deployed in early-November 2021 at six locations at and upstream of the Bacon Creek confluence. Tracer particles give information on the pattern of sediment particle displacement during floods and serve as a proxy for potential sediment movement following a theoretical addition of bed material to the river near Newhalem.

The sediment transport modeling program, described in Section 4.5 of this study report, is ongoing. Scour monitor arrays and particle tracer locations will be revisited during low-flow in summer 2022, which will provide information on bed mobilization during the large November 2021 flood flows.

6.1.6 Large Wood Inventory

6.1.6.1 Historic Inventory

The results of a historic large wood inventory from 1979 to 2019 are presented in Section 5.6 of this study report. Historic aerial analysis yielded a lower total large wood and log jam count for older years. This also coincides with a lower aerial image resolution. There is potential that the lower total large wood count in previous years is due to the decreased resolution. The magnitude of large wood in the primary study area could be similar in each year. Alternatively, aerial inventory of log jams is potentially a more reliable remote sensing technique than induvial large wood piece inventory as log jams are much larger features. Log jam density gradually increases from 1.7 log jams per mile to 3.5 log jams per mile between 1979 and 2019. Results from this analysis show that despite the potential variation in large wood and log jam magnitude the spatial distribution of large wood and log jams in the mainstem of the primary study area has remained similar on a geomorphic reach scale since 1979. Large wood and log jams have retained a higher concentration in Reach 5B and Reach 6 than the rest of the primary study area. Most individual large wood pieces located in side channels could not be inventoried using aerial images due to canopy cover unless they were located in the Cascade River distributary side channels. As a result conclusions on the variation of large wood loading in side channels from 1979 to 2019 cannot be made.

Historic analysis of large wood and log jams within geomorphic reaches has shown that large wood and log jam distribution changes most commonly within Reach 5B and Reach 6. These changes are often linked to channel migration. In other reaches where less channel migration is occurring, large wood and log jams often accumulate in the same location over time.

An analysis of log jam persistence over time shows that log jams located at the apex of forested islands or bars stay around the longest, followed by side channel inlet jams. Meander jams and bar top jams appears to be the least stable.

Next steps in this analysis will involve further evaluation of large wood and log jams with comparisons to the hydrograph during that period between aerial images to evaluate the relationship between changes in amount of wood and changes in the flow regime.

6.1.6.2 August 2021 Field Inventory

The results of a field inventory conducted in August 2021 are presented in Section 5.6 of this study report. This field inventory found 4,084 large wood pieces and 80 log jams in the primary study area. The majority of large wood was found in Geomorphic Reaches 5B and 6, totaling 2,735 total pieces of large wood. This is equal to 67 percent of the total wood count found both individually and in log jams. Most of the large wood that was inventoried was found within log jams totaling

2,403 pieces of large wood, or approximately 59 percent of the total count. Large wood in the primary study area is concentrated primarily downstream of the Cascade confluence and upstream of Rockport.

The large wood field inventory completed in tributaries show that Cascade River and Diobsud Creek have the highest abundance of large wood and log jams near their confluences with the Skagit River. This is followed by Bacon Creek, Goodell Creek, Rocky Creek, Damnation Creek, and Illabot Creek. The remaining tributaries had very little large wood to no large wood.

Large wood was found most densely in side channels and tributaries with a large wood density of 17.6 and 15.0 pieces per acre, respectively. In the mainstem, large wood pieces had a density of 1.1 pieces per acre in the wetted channel. Additionally, in the mainstem large wood pieces had a density of 13.0 pieces per acre on dry bars. This observation shows that a significant portion of large wood in the mainstem is bar top wood that does not interact with the wetted channel during low flows.

Large wood characteristics gathered in the field inventory show that large wood pieces that have a greater dbh are more likely to have a rootwad attached. This was seen in the mainstem and side channels. The inventory also showed that pool forming large wood is more often associated with large wood that has a rootwad attached. Additionally, this study found that large wood with a larger diameter rootwad is more likely to form a pool than large wood with a smaller diameter rootwad. Large wood with a 2-to-3.9-ft diameter rootwad formed a pool 17 percent of the time whereas large wood with a 10-to-25-ft rootwad formed a pool 64 percent of the time. Based on preliminary analysis, it appears the potential geomorphic importance of an individual large wood piece is directly related to its size and shape.

Some additional characteristics gathered about large wood in the study teams' field inventory is that most large wood has a decay class of either 1 or 2, 1 being the least decayed and 2 being an intermediate state of decay. Additionally, 73 percent of large wood inventoried was either a cedar, cottonwood, or alder tree species.

Next Steps to be completed in 2022 include large wood inventory of the Gorge bypass reach (geomorphic reach 1) using high resolution drone imagery collected by the FA-02 Instream Flow Model study team as well as to continue analysis of August 2021 field inventory results.

6.1.7 Large Wood Transport

6.1.7.1 Large Wood Tracking

Between October 13 and December 15, 2021, the study team installed radiotags and metal tags on 184 pieces of wood. These tags were placed on large wood in the mainstem, tributaries, and side channels. A detailed table and map location of pieces of tagged wood is shown in Attachment K. Additionally, 37 pieces of wood being stored at the Agg pond site were tagged of the 184 total tagged pieces. A summary of the pieces that have been tagged by geomorphic reach is shown in Table 5.7-1. The tagged wood being stored at the Agg Pond site was released into the mainstem river on December 9, 2021.

Next Steps to be completed in 2022 include analyzing the large wood tracking in combination with the Hydraulic Model results from the FA-02 Instream Flow Model Development Study (City

Light 2022a). The tracking results will be used to understand thresholds for motion of pieces by size and river discharge, transport distance, relationship between rootwads and mobility, and jam stability.

6.1.7.2 Large Wood Transport

Next Steps to be completed in 2022 include calculating large wood transport with the Hydraulic Model results from the FA-02 Instream Flow Model Development Study (City Light 2022a) and results from the large wood tracking described in the previous section. Large wood transport calculations based on tracking results will be evaluated as part of the license application.

6.1.7.3 Large Wood Recruitment

Next Steps to be completed in 2022 include determining large wood recruitment by utilizing the FA-02 Instream Flow Model Development Study Hydraulic Model results (City Light 2022a) and other data that is being analyzed to determine large wood recruitment potential. The recruitment potential is determined by whether there is large wood within the riparian zone that can be recruited by the stream and is large enough to remain stable (NSD 2017). The study team will utilize historical channel migration zones, current erosion rates, stability of wood, data collected by DNR, and data collected in the TR-01 Vegetation Mapping Study (City Light 2022d). Large wood will be digitized in the primary study area using 2021 aerial photographs.

6.1.7.4 Large Wood Augmentation

Next Steps include large wood augmentation analysis after the FA-02 Instream Flow Model Development Study Hydraulic Model results are completed (City Light 2022a). Per the June 9, 2021 Notice, City Light will determine locations and methods for wood augmentation within six months of the FA-02 Instream Flow Model Development Study Hydraulic Model being completed. City Light will implement an augmentation pilot program with input from the LPs in 2023, unless they mutually determine a pilot program is not necessary.

6.1.8 Process Flows

The evaluation of process flows described in Section 2.6.7 of the RSP was initiated in January 2022. Existing data were reviewed and summaries of some of those documents are available in Attachment A. Process flows include a range of flow levels and inputs of sediment and wood to the channel that result in geomorphic change, sediment transport and redistribution, and aquatic habitat creation, change, and maintenance. Process flows to be considered will be determined at a series of iterative workshops involving the Geomorphology Study team, the FA-02 Instream Flow Model Development Study team, City Light staff, and LPs.

This discussion has started with acknowledgement of the large magnitude of channel-forming and maintenance flows recommended by Wald (2009), which include natural hydrology 10 and 2-yr recurrence intervals, respectively, and the need to evaluate potential effects of these flows on rearing habitat availability, channel bed stability, floodplain connectivity, and egg-to-fry survival. Sediment transport modeling tools described in Section 4.5.1 will be applied to evaluate how the channel will be expected to respond to variability in water and sediment inputs.

Following these workshops, several products will be produced per the guidance in Section 2.6.9 of the RSP. A more detailed summary of geomorphic change over the term of the current license will be produced, including further investigation into the correlation with peak flows and geomorphic disturbances. This effort will also contribute to the analysis of side channel formation and maintenance processes, as well as an assessment of hydrologic connectivity at a variety of flows. As per the RSP, the process flows investigation will also include IHA results for unmanaged conditions to help inform the timing and duration of high flow processes, as well as a synthesis of the interactions among flow, sediment loading, large wood input, channel migration/side channel formation, floodplain connectivity and aquatic habitat.

6.2 Status of June 9, 2021 Notice

The June 9, 2021 Notice noted the following items of discussion related to the implementation of this Geomorphology Study. The status of each is summarized in Table 6.2-1.

Table 6.2-1. Status of the Geomorphology Study modifications identified in the June 9, 2021 Notice.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light will develop a 1-D HEC RAS model for stream flow from the Sauk to the estuary and work with technical experts and LPs to identify robust sampling of mutually agreed to measurement endpoints within reference reaches within major reach segments. City Light will incorporate Jon Riedel's (NPS) work and the full range of hydrology and operations will be modeled.	As described in Section 4.5.1 of the Geomorphology Study Report, City Light will implement a suite of modeling tools to address areas between Gorge Powerhouse and the estuary. The modeling approach and suite of models were defined in consultation with LPs in workshops in July, September, and October 2021, consultation and development of the tools is ongoing.
City Light will convene workshops to address the technical issues such as channel migration, LWD, suspended sediment transport and washload, and off-channel habitat associated with the modeling effort or other additional modeling efforts.	The geographic extent of each modeling tool is described in Section 4.5.1 of the Geomorphology Study Report. Tools for application downstream of the Sauk include UBCRM and MAST 1-D, which will extend to the gravel-sand transition at approximately PRM 21. The rational for using MAST 1-D in lieu of HEC-RAS 1-D is explained in Section 7.3 of the Geomorphology Study Report.
City Light will modify the study plan to include collaboration with the LPs to look for opportunities to incorporate sediment modeling in reference reaches below the Sauk to the estuary.	Project effects on fine sediment delivery to the estuary will be evaluated by combining watershed-scale sediment yield analysis (Section 4.5.3 of the Geomorphology Study Report) with evaluation of floodplain-channel sediment exchange using the MAST 1-D model.
Regarding LPs' comments regarding LWD inventory, this is a topic of the lower river synthesis study. To the extent the synthesis study identifies a data gap, City Light will work collaboratively with the LPs to address it (including but not limited to the Watershed Council) Middle Skagit River Restoration Plan, aerial photos, etc.).	This is a topic for discussion after the ISR (March 2022) to be informed by the outcomes of the SY-01 Synthesis and Integration of Available Information on Resources in the Lower Skagit River [downstream of the Sauk], which is currently underway.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light will provide LPs with its existing inventory of LWD in the three project reservoirs by no later than August 1, 2021 and conduct an annual inventory of inputs during the study period. City Light will convene a workshop with the LPs during the fourth quarter of 2021 to collaboratively develop strategies for short-term and long-term management of woody debris in the reservoirs and transport of woody debris to the lower river. Action item: LPs will work with City Light within the next 30 days to develop protocol for wood crew to enumerate woody debris coming into reservoir.	Reservoir wood data collection is ongoing and data from 2017 to present was provided to LPs in late June 2021 and raw data sheets were provided in December 2021. A memorandum report summarizing this task is included with the ISR. This topic was discussed at the November 2021 Geomorphology Work Group meeting and is a topic for further discussion in 2022. City Light provided the data form to LPs and collected additional wood data on Ross Lake in August with right-of-way crews responsible for corralling woody debris. These additional data are included as part of the ISR.
City Light will convene workgroup meetings to clarify expected capabilities of sediment transport and morpho-dynamic models for predicting changes to channel morphology.	This topic was discussed at the October 2021 Geomorphology Work Group meeting.
City Light will calibrate sediment transport models to at least the 10-year recurrence interval (subject to available data) and calibrate sediment transport model to help predict where sediment would be stored. If necessary, City Light will provide controlled releases to assist in calibrating the model. Such controlled releases will be designed in a manner as to not contribute to downstream property damage or risk to health and human safety.	Topic for on-going discussion at Geomorphology Work Group meetings, which began at July 2021 meeting. Discussions will continue into 2022. The sediment transport models will be calibrated to the November 2021 flood, which ranges from approximately a 2-yr natural flow condition recurrence interval event at the Newhalem Gage to approximately a 50-yr recurrence interval event at Marblemount. Repeat topobathymetric LiDAR bracketing this flood (2017/18 and 2022) and the empirical bed mobility observations described in Section 4.5.2 of the Geomorphology Study Report will provide that calibration information.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light will model to determine locations and methods for wood and sediment augmentation no later than 6 months following completion of the instream flow model. Based on the results of the modeling, City Light will implement a wood and sediment augmentation pilot program to be developed jointly by City Light and the LPs no later than 2023 (unless City Light and the LPs mutually determine that such a pilot program is unnecessary). City Light and the LPs expect that the augmentation pilot program will include monitoring, including monitoring downstream of the Sauk confluence, and will result in information to inform development of possible PM&E measures in the new license.	The development of the FA-02 Instream Flow Hydraulic Model is in process. The completed model may be used to inform discussions to explore a wood and sediment augmentation pilot; modeling of sediment and wood is being addressed in the Geomorphology Work Group meetings and this Geomorphology study, which is explicitly evaluating channel morphologic sensitivity to interactions between process flow inputs of water, sediment, and wood. Cross-coordination between the instream flow modeling and the geomorphology technical teams is underway. A GE-04/FA-02 coordination workshop was held on October 12, 2021 and these topics will continue to be discussed at Geomorphology Work Group meetings. Preliminary results of the sensitivity analysis (using UBCRM and mobile bed HEC-RAS 1-D, as explained in the Geomorphology Study Report) will be available in late Q3 2022 for consideration in the development of the pilot program in 2023.
City Light will continue current data collection/tagging of wood that is placed in the river under current programs and will disseminate data from these ongoing programs to the LPs as soon as practicable. The results of GE-04 and the other studies will be used to inform sediment and wood augmentation throughout the Skagit River system. City Light will provide LPs information about current data collection/tagging of wood as soon as practicable. The Federal and state resource agencies will consider what information and permitting is needed to implement the augmentation pilot program. City Light will work cooperatively with LPs to ensure timely implementation of the pilot program with all required permits in place.	LWD data tagging/tracking field effort of 37 reservoir wood pieces at the Agg pond is in progress and is described in this study report. Wood tagging topic has been an on-going discussion at Geomorphology Work Group Meetings. Future action item (2023) depending on the results of the relicensing studies. LWD data tagging/tracking field effort of natural large wood pieces and reservoir wood pieces is in progress and is described in this study report. Wood tagging topic has been an on-going discussion at Geomorphology Work Group Meetings. Topic for future discussions at Geomorphology Work Group meetings.
City Light will convene technical workshops with the purpose of expanding the scope, and changing and/or adding proposed tagging/monitoring of tributary sediment deposits to more tributaries, including downstream of Sauk Confluence.	Topic of ongoing and future discussions at Geomorphology Work Group meetings. City Light expanded the scope of particle tracing activity to include Ladder Creek, Newhalem Creek, Goodell Creek, one riffle crest near County Line, and Bacon Creek (including tracers on the fan and upstream of the SR 20 bridge).

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light will include continuous stage readers in selected off-channel habitats in the floodplain to validate floodplain connectivity. The location and placement of stage readers will be agreed upon by City Light and the LPs in a future workshop.	19 level logger sites were selected with LPs to build upon the existing network of six sites maintained by SRSC. Two sites were omitted due to results of cultural resource review and constraints with private property such that the revised plan calls for installation of 17 sites. Site 10 is tentative pending coordination with the Marblegate community. Eleven level logger sites were installed through February 1, 2022. Fieldwork planned for installation of six remaining sites in winter-spring 2022.
Action item: City Light will convene workshops to discuss the influence of groundwater and utility of FLIR on hyporheic exchange and in the selection of study reaches.	The initial workshop on FLIR occurred on October 21, 2021, with ongoing discussions on this topic occurring in subsequent work group meetings in 2022.
By relying upon focus areas in application of the 2-D transport model and using the instream flood model, City Light will assess floodplain flow conditions including shear stress and scour.	This issue was considered in the list of questions to be addressed by the proposed model suite being developed for the Geomorphology Study, presented at the October Geomorphology Work Group meeting.
As part of its FERC license application, City Light will integrate the results of GE-04 with the FA-02 hydraulic model and other available information to inform the impacts of process flows on anadromous salmon habitat and population productivities.	Future action item to be addressed as part of the license application (2023).
City Light will clarify the study plan to describe metrics available in the IHA software and will apply it to process flows. See Wald, A.R. 2009. Report of investigations in instream flow: High flows for fish and wildlife in Washington. Department of Fish and Wildlife, Olympia.	Potential metrics to be discussed at a work group meeting following LP review of the ISR (Q2 2022).
City Light and the LPs will develop in the workshop a suite of metrics to illustrate longitudinal disturbance regimes.	A GE-04/FA-02 workshop and data needs discussion was held on October 12, 2021 and discussions continue at the Geomorphology Work Group meetings.
City Light will modify the study plan to include flows necessary to inundate habitat features in the validation discharge data set (off-channel).	Once the FA-02 Instream Flow Model Development Study Hydraulic Model is developed and calibrated (first quarter of 2022), hydraulic model outputs for key floodplains (i.e., floodplains with stage and temperature monitoring are occurring) will be produced to support the topobathymetric field verification and validation in these areas. Level logger data can be compared against modeled water surface elevations to verify accuracy of the terrain in these key floodplains.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
City Light will quantify sediment supply into Ross Reservoir as an annual rate by using the existing DHSVM model and historical contours and bathymetry information.	Review of available information discussed at Fall 2021 work group meetings with further discussion in Q1 2022. During work group meetings in Fall 2021, DHSVM was determined to not be the preferred tool for this; rather, a regression relation to predict basin-scale fine sediment yield is being developed and will be compared to information on historical bathymetric changes.
This issue [process flows] has been resolved through commitments with respect to integration. That is, as part of its FERC license application, City Light will integrate the results of GE-04 with the FA-02 hydraulic model and other available information to inform the impacts of process flows on anadromous salmon habitat and population productivities.	Future action item (2022-2023). Development of alternative flow management scenarios, including process flows and associated sediment transport flows, will be analyzed as part of a series of proposed Geomorphology Work Group meetings to evaluate Project operations in late 2022.
As part of a Q3/4 workshop, City Light will address the simulation of added sediment, flow, and log jams in the model mesh via scenarios developed in coordination with the LPs. Otherwise, this issue is addressed by topic above and via scenarios implemented in the study plan.	Topic for ongoing Geomorphology Work Group meetings.
Issue: Adjust modeling focus areas so they are scaled to channel dimensions (e.g., 10-20x channel width) depending on process to be modeled June 9, 2021 Notice Modification: This issue will be resolved in a workshop.	As described in Section 4.5.1 of the Geomorphology Study Report, City Light is applying a suite of modeling tools to address areas below the Sauk confluence. The suite of models was discussed with LPs in workshops in July, September, and October 2021. The length of each model domain will be designed to capture the process of interest and minimize boundary condition effects on those processes. Given a characteristic channel width of 200 to 500 ft, the planned 1- to 2-mile model domain length will be 10 to 50 times the channel width.
Issue: Adjust study to characterize sediment supply from the Sauk so that we could assess the potential for bed aggradation in the Skagit at the confluence and the associated changes in dynamics from the upstream reach. June 9, 2021 Notice Modification: Action item: City Light to contact NPS, USIT, and Skagit River System Cooperative to resolve this outstanding issue.	City Light will reach out to NPS, Upper Skagit Indian Tribe and SRSC regarding this action item in 2022.
Issue: Link sediment modeling with the development of data on flows. June 9, 2021 Notice Modification: City Light will link sediment modeling with the development of data on flows.	As described in Section 4.5.1 of the Geomorphology Study Report, City Light is applying a suite of modeling tools to address areas below the Sauk confluence. A key input to these models will be estimated existing conditions and alternative process flow regimes.

Study Modifications identified in the June 9, 2021 Notice: As Written	Status
Issue: Explore use of 2-D Hec-Ras model in focus reaches to inform the 1-D model. June 9, 2021 Notice Modification: This issue will be addressed through workshops.	As described in Section 4.5.1 of the Geomorphology Study Report, City Light is applying a suite of modeling tools to address areas below the Sauk confluence. The suite of models was discussed with LPs in workshops in July, September, and October 2021 and will include six 2D focus reaches above the Sauk river.
City Light will hold workshop with those who have recent expertise in sediment and/or wood-transport modeling.	Susannah Erwin and Wes Lauer have participated in 2021 Geomorphology Work Group meetings. City Light expects they will continue to engage as available.
Issue: Need an empirical model to capture dynamic balance between floodplain formation on bars and destruction at eroding banks and avulsions. June 9, 2021 Notice Modification: Action item: City Light to contact NPS, USIT, and Skagit River System Cooperative to resolve this outstanding issue.	As described in Section 4.5.1, City Light is applying a suite of modeling tools to address areas below the Sauk confluence. The suite of models was discussed with LPs in workshops in July, September, and October 2021 and will include a MAST 1-D model intended to explicitly evaluate the dynamic balance between floodplain formation on bars and erosion by lateral channel migration.
City Light will map vegetation areas within the bank full from aerial photography and through a period of record.	Vegetated bars and forested islands were mapped from the time series of aerial imagery as described in Section 4.1.1. Evaluation of the potential for future large wood loading from bank erosion planned for 2022 (Section 6.1.7 of the Geomorphology Study Report).

7.0 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

To meet all study goals and objectives, as described in Section 6.0, some data collection and analysis will continue into a second year. Variances and proposed modifications to the study plan's methodology are described below.

7.1 Variances in Aquatic Habitat

The approach to measurement and analysis of aquatic habitat was largely directed by the FERC-approved study plan with a few additions as described in Section 4.2.2. For the tributary analysis, since the WDFW Fish Passage Manual (WDFW 2019) recommends using multiple metrics, rather than depth, to assess passage barriers, these metrics were collected and used (to the extent feasible) to supplement the assessment of fish passage at tributary mouths. Measurements of depth were still collected for the lowest 500 ft of the tributary consistent with the RSP, but additional information, such as gradient, was also gathered consistent with the WDFW Fish Passage Manual (WDFW 2019). This methodology ensured study goals and objectives were met.

7.2 Bulk Sample Volume and Hybrid Grainsize Classification Method

As described in Section 4.4.3 of this study report, in order to facilitate completion of the planned field program in the available time, the volume of bulk samples was reduced from the standard "maximum practicable" weight of 1,100 pounds suggested by Church et al (1987) to 440 pounds. In consultation with LPs, the hybrid approach of Rice and Haschenburger (2004) was added to ensure that bulk samples appropriately represent the grainsize distribution of coarse material. This approach better met the study objective to characterize the subsurface grainsize distribution of material along the river because it enabled better spatial coverage of the subsurface bulk grainsize sampling program while ensuring that the grainsize distributions defined by these samples appropriately represent the coarse (cobble and larger) fraction of the grainsize distribution that would have been systematically under-sampled following only the Church et al (1987) approach.

7.3 Sediment Transport Modeling Program

As described in Section 4.5.1, a modeling program to fulfill the RSP and the June 9, 2021 Notice was developed in collaboration with LPs during a series of workshops held on July 20, July 27, September 28, and November 9, 2021. Conversation at these meetings resulted in the following modifications relative to commitments in the June 9, 2021 Notice for evaluation of sediment transport downstream of the Sauk River.

- Rather than developing a HEC-RAS 1-D hydrodynamic model of this reach, which would not have explicitly simulated sediment transport, the modeling program is developing a MAST 1-D model of the reach. The MAST 1-D model will provide similar information on reach-scale hydraulic conditions relevant to processes governing channel morphodynamics and sediment transport to what would have been provided by a HEC-RAS 1-D model. It will also provide tools to quantify channel planform and profile sensitivity and sensitivity of bedload sediment transport patterns to variable inputs of flow and sediment. Thus, it provides a better tool with which to evaluate the magnitude and character of project effects on this reach of the river.

- The spatial extent of the sediment transport modeling program was revised to make the boundary of the model spatially consistent with the boundary of the process domain it was developed to simulate. Rather than extending downstream to the estuary, the downstream boundary of the model will be at the gravel to sand transition near Sedro Woolley where the character of the bed material, hydraulics, and mechanisms of bed material sediment transport fundamentally change relative to all reaches upstream from there to Newhalem. The study objective of understanding project effects on fine sediment delivery to the estuary will be evaluated by combining the sediment yield assessment described in Section 4.5.3 with results characterizing bank erosion sources of fine sediment in the MAST 1-D model.

7.4 Large Wood

The study objective of completing "An inventory of the current status of large wood in the Skagit River between Gorge Dam and the Sauk River…" using field methods mentioned in Section 2.6.6 of the RSP was not entirely met via 2021 efforts. Large wood in the Gorge bypass reach was not inventoried using field methods due to its lack of wetted aquatic habitat under regulated conditions. As a proposed modification, an inventory of large wood will be conducted in the Gorge bypass reach using high resolution drone imagery collected in 2021 by the FA-02 Instream Flow Model study team as opposed to a field study. High resolution drone imagery will meet the study objective of completing an inventory of this reach that is similar in precision to a field study.

Also, field inventory of the Shovel Spur rapids reach between PRM 86.7 and PRM 87.6 was not conducted due to safety concerns not allowing access to this reach. As a proposed modification, an inventory of large wood in the Shovel Spur reach using aerial imagery will be conducted. This modification will meet the RSP objective of capturing the current status of large wood in the Skagit River as the large wood historic inventory of this reach shows sparse wood loading. Although there is potential to miss large wood hidden under canopy cover, the quantity of large wood is likely to be negligible and will not impact the objective of capturing the current status of large wood in the Skagit River between the Gorge Dam and the Sauk River.

The proposed study objective of creating an initial inventory of large wood using current (2019) filtered LiDAR cross referenced to concurrent aerial photographs (similar to methods described in Abalharth et al. 2015), mentioned in Section 2.6.6 of the RSP, was not completed because the available 2019 LiDAR data was not high enough of a resolution to delineate large wood features. Instead, the study team achieved this objective by delineating large wood features in aerial imagery from 2018 and 2019.

8.0 REFERENCES

Abalharth, M., M.A. Hassan, B. Klinkenberg, V. Leung, and R. McCleary. 2015. Using LiDAR to characterize log jams in lowland rivers. Geomorphology 246: 531-541.

Bauer, S. B. and T. A. Burton. 1993. Monitoring protocols to evaluate water quality effects of grazing management on western rangeland streams. Environmental Protection Agency (EPA), Region 10. EPA 910/R-93-017, Seattle, Washington.

Beamer, E.R., T. Beechie, B. Perkowski, and J. Klochak. 2000. Application of the Skagit Watershed Council's Strategy. River basin analysis of the Skagit and Samish Basins: Tools for salmon habitat restoration and protection. Skagit Watershed Council. Mount Vernon, Washington. 86 pp.

Beechie, T.J., M. Leirmann, E.M. Beamer, and R. Henderson. 2005. Classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society 134: 717-719.

Beechie, T.J., O. Stefankiv, B. Timpane-Padgham, J.E. Hall, G.R. Pess, M. Rowse, M. Liermann, K. Fresh, and M.J. Ford. 2017. Monitoring Salmon habitat status and trends in the Puget Sound: Development of sample designs, monitoring metrics, and sampling protocols for large river, floodplain, delta, and nearshore environments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-137. [Online] URL: https://doi.org/10.7289/V5/TM/-NWFSC-137. Accessed January 5, 2022.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Brown, A.G. 2002. Learning from the past: paleohydrology and paleoecology. Freshwater Biology 47:817-829.

Church, M. A., D.G. McLean, and J.F. Wolcott. 1987. Riverbed gravels: sampling and analysis. In C.R. Thorne, J.C. Bathurst, and R.D. Hey (Eds.), Sediment Transport in Gravel-bed Rivers (pp. 43–88). John Wiley & Sons Ltd., Chichester, England.

Cluer, B.D. and C. Thorne. 2013. A stream evolution model integrating habitat and ecosystem benefits. river research and applications. John Wiley & Sons, Ltd. DOI: 10.1002/rra2631.

Collins, B.D. and A.J. Shiekh. 2002. Methods used to map the historical riverine landscape and habitats of the Skagit River. Report to the Skagit River System Cooperative.

Curran, C.A., E.E. Grossman, M.C., Mastin, and R.L. Huffman. 2016. Sediment load and distribution in the lower Skagit River, Skagit County, Washington. U.S. Geological Survey (USGS) Scientific Investigations Report 2016–5106. Available at: http://dx.doi.org/10.3133/sir20165106.

Eaton, B. 2007. The University of British Columbia Regime Model (UBCRM) - User's manual: Draft. University of British Columbia. Vancouver, BC pp.

Gendaszek, A.S., C.S. Magirl, C.R. Czuba, and C.P. Konrad. 2013. The timing of scour and fill in a gravel-bedded river measured with buried accelerometers. Journal of Hydrology, 495, 186–196. [Online] URL: https://doi:10.1016/j.jhydrol.2013.05.012. Accessed February 1, 2022.

Hartson R. and J. Shannahan. 2015. Inventory and assessment of hydromodified bank structures in the Skagit River Basin: Chinook bearing streams. Submitted to Northwest Indian Fisheries Commission and Environmental Protection Agency (PA-00J322-01).

Haugerud, R.A. and R.W. Tabor. 2009. Geologic map of the North Cascade Range, Washington. U.S. Department of the Interior, U.S. Geological Survey (USGS).

Hawkins, C.P., J.L. Kershner, P.A. Bisson, M.D. Bryant, L.M. Decker, S.V. Gregory, D.A. McCullough, G.H. Reeves, R.J. Steedman, and M.K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18:6, pp. 3-12.

Jaeger, K.L., C.A. Curran, S.W. Anderson, S.T. Morris, P.W. Moran, and K.A. Reams. 2017. Suspended sediment, turbidity, and stream water temperature in the Sauk River Basin, Washington, water years 2012–16. U.S. Geological Survey (USGS) Scientific Investigations Report 2017–5113. Available at https://doi.org/10.3133/sir20175113.

Legg, N.T., C. Heimburg, B.D. Collins, and P.L. Olson. 2014. The channel migration toolbox: ArcGIS tools for measuring stream. State of Washington Department of Ecology.

Meixler, Marcia, S., Mark B. Bain, M. Todd Walter, Predicting barrier passage and habitat suitability for migratory fish species, Ecological Modeling, Volume 220, Issue 20, 2009, Pages 2782-2791, ISSN 0304-3800, [Online] URL: https://doi.org/10.1016/j.ecolmodel.2009.07.014. Accessed January 5, 2022.

Millar, R., B. Eaton, and M. Church. 2014. UBC Regime Model. [Online] URL: http://blogs.ubc.ca/beaton/working-code. Accessed December 19, 2021.

Natural Systems Design (NSD). 2017. Skagit River Large Woody Debris Assessment, Connecting LWD to the 2005 Skagit Chinook Recovery Plan. Report prepared for Skagit Watershed Council. November 13, 2017.

Quantum Spatial, Inc. (QSI). 2017. Skagit Topobathy, Washington, Topobathymetric LiDAR Technical Data Report.

_____. 2018. Upper Skagit, Gorge Lake & Diablo Lake, Washington, Topobathymetric LiDAR & Orthoimagery Technical Data Report.

Reiser, D.W., C.M. Huang, S. Beck, M. Gagner, and E. Jeanes. 2006. Defining flow windows for upstream passage of adult anadromous salmonids at cascades and falls, Transactions of the American Fisheries Society, 135:3, 668-679, DOI: 10.1577/T05-169.1.

Rice, S., and J. Haschenburger. 2004. A hybrid method for size characterization of coarse subsurface fluvial sediments. Earth Surface Processes and Landforms, 29(3), 401–421.

Riedel, J. 1990. Skagit River Project FERC No. 553 Report on Existing Conditions of Reservoir and Streambank Erosion. Report prepared by National Park Service (NPS), Jon Riedel Project Manager. January 1990.

_____. 2007. Late Pleistocene Glacial and Environmental History of Skagit Valley, Washington and British Columbia. Ph.D. thesis, Simon Fraser University, Vancouver, BC.

_____. 2019. Barnaby Slough Restoration Project, Quaternary Geology Report.

Riedel, J., S. Sarrantonio, K. Ladig, and M. Larrabee. 2020. Draft Skagit River Geomorphology Inventory Report: Part I – Gorge Dam to Sauk River. Report to Seattle City Light by the U.S. National Park Service (NPS).

Rothleutner, A.D. 2017. Sediment Budget of the Middle Skagit River, Washington 1937-2015 Reveals Decadal Variations in Sediment Export and Storage. Western Washington University MS Thesis. November 17, 2017.

Seattle City Light (City Light). 2021a. Revised Study Plan (RSP) for the Skagit River Hydroelectric Project, FERC Project No. 553. April 2021.

_____. 2021b. Skagit River Hydroelectric Project – Woody Debris Management Summary of Activities to Date Memorandum. March 2022.

_____. 2022a. FA-02 Instream Flow Model Development Study, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Northwest Hydraulic Consultants, Inc. and HDR Engineering, Inc. March 2022.

_____. 2022b. FA-05 Skagit River Gorge Bypass Reach Hydraulic and Instream Flow Model Development Study, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Northwest Hydraulic Consultants, Inc. and HDR Engineering, Inc. March 2022.

_____. 2022c. GE-03 Sediment Deposition in Reservoirs Affecting Resource Areas of Concern Study, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Watershed GeoDynamics. March 2022.

_____. 2022d. TR-01 Vegetation Mapping Study, Draft Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Environmental Science Associates. March 2022.

_____. 2022e. TR-02 Wetland Assessment, Draft Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by Environmental Science Associates. March 2022.

_____. 2022f. TR-09 Beaver Habitat Assessment, Interim Report for the Skagit River Hydroelectric Project, FERC Project No. 553. Prepared by HDR Engineering, Inc. March 2022.

Skagit River System Cooperative (SRSC). 2019. Digitized geospatial data files for multiple years of imagery on the Skagit River between Sauk River confluence and Marblemount.

Skagit River System Cooperative (SRSC) and Natural Systems Design (NSD). 2019. Hydraulic and Geomorphic Assessment Barnaby Reach of the Skagit River. April 4, 2019.

Smith, C.J. 2003. Salmon and steelhead habitat limiting factors Water Resource Inventory Areas 3 & 4 Skagit Watershed. Washington State Conservation Commission, Olympia, Washington.

Smith, D., K. Ramsden, and S. Hinton. 2011. Reach Level Analysis for the Middle Skagit River Assessment. Report prepared for the Skagit Watershed Council. July 7, 2011.

Statewide Washington Integrated Fish Distribution (SWIFD). 2021. [Online] URL: https://geo.nwifc.org/swifd/. Accessed in August 2021.

Tabor, R.W. and R.A. Haugerud. 1999. Geology of the North Cascades: a mountain mosaic. The Mountaineers Books. Seattle, WA.

U.S. Army Corps of Engineers (USACE). 2008. Skagit River Flood Damage Reduction Feasibility Study Skagit River Basin Sediment Budget and Fluvial Geomorphology. Report prepared by the USACE Seattle District. June 2008.

Wald, A.R. 2009. High flow for fish and wildlife in Washington. Report of investigation in instream flow. Washington Department of Fish and Wildlife (WDFW). [Online] URL: https://wdfw.wa.gov/sites/default/files/publications/00578/wdfw00578.pdf. Accessed in February 2022.

Washington Department of Fish and Wildlife (WDFW) and Washington Department of Ecology (Ecology). 2016. Instream Flow Study Guidelines - Technical and Habitat Suitability Issues Including Fish Preference Curves. Updated March 9, 2016. Olympia, WA.

Washington Department of Fish and Wildlife (WDFW). 2019. Fish passage and surface water diversion screening assessment and prioritization manual. Olympia, Washington.

_____ 2021. Fish passage and diversion screening inventory (FPDSI), 2021. [Online] URL: https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html. Accessed in August 2021.

Wolman, M.G. 1954. A method of sampling coarse river-bed materials. Transactions of the American Geophysical Union, 35(6), 951–956.

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SKAGIT RIVER GEOMORPHOLOGY BETWEEN GORGE DAM AND THE SAUK RIVER STUDY INTERIM REPORT

ATTACHMENT A

ANNOTATED BIBLIOGRAPHY OF GEOMORPHOLOGY FROM SAUK RIVER CONFLUENCE TO SKAGIT ESTUARY

The following attachment provides an annotated bibliography for relevant geomorphic references for the GE-04 Skagit River Geomorphology Between Gorge Dam and the Sauk River Study. A template example, topics and keyword, and data flags is included below. This format is similar to the ones being used in the SY-01 Integration and Synthesis of Available Information on Resources in the Lower Skagit River Study (Synthesis Study). The Synthesis Study is developing an extensive annotated bibliography of aquatic habitat, water quality, and other topics of interest downstream of the Sauk.

Example format for annotated bibliography

Reference	AFS Style Guide for References: https://fisheries.org/wp-content/uploads/2016/01/References.pdf. Use the "References" style in the Home tab to get the style correct for the references section.									
Source Information	***Type***	Source Type	***Status***	Draft/ Final	***Quantitative Data***	Yes/ No	***Spatial Data***	Yes/ No		
Topics and Keywords	***Topic:*** keywords.									
Species and Life Stages	***Species:*** life stages.									
Reaches and Spatial extent	Reaches.									

Summary: Brief description of the study.

Relevant Information: Information specifically relevant to the GE-04 Study.

Topics and Key Words

A framework of topics and keywords was developed to attribute sources to indicate the type of information provided by each source. These attributes are intended to be added to a relational database during screening of identified sources, with attributes being linked to references in the reference database based on a citation ID. The following table provides the current list of topics and keywords being used to attribute sources during screening, with a description of each topic and keyword combination for both SY-01 and GE-04.

Table A-1 List of attributes for topics and keywords for sources.

Topic	Keyword	Notes
Geomorphology and Landforms	Change	Changes in geomorphology or processes over time
	History	Geological history and history of formation and processes
	Channel migration	Channel migration, including lateral channel migration, channel migration zones, or active channel zone
	Channel incision	Channel incision
	Sinuosity	Channel sinuosity
	Slope	Channel slope or gradient
	Floodplain	Information on floodplain width or flood prone width

Topic	Keyword	Notes
	Side and off-channels	Abundance, connectivity, diversity of secondary channel habitats including braids, off-channels, and side channels
	Floodplain connectivity	Connectivity to floodplains or floodplain habitats
	Substrate and sediment	Substrate or sediment composition
	Sediment transport and supply	Sediment transport or supply, including landslides and reservoir retention
	Shallow and deep surface processes	Hydrostatic rebound, compaction, subsidence
	Large wood	Large wood abundance, recruitment, transport, retention
	Log jam	Log jam abundance, growing, decay, stable, variable
	Aquatic habitats and landforms	Fluvial geomorphology, or riverine landforms
	Estuarine habitats and landforms	Tidally influenced or estuarine habitats and landforms
	Climate change	Impacts of climate change on geomorphology
	Data gaps	Data gaps are identified
Water Quality and Productivity	Temperature	Temperature, maximum, mean, 7-day averages
	Nutrients	Nitrate, phosphorous, ammonia, nitrite
	Dissolved oxygen	Dissolved oxygen concentration
	pH	pH, alkalinity, acidity
	Bacteria	Fecal coliform or other bacteria
	Contaminants	Heavy metals, hydrocarbons, pesticides
	Turbidity	Turbidity, NTU, secchi
	Salinity	Salinity and conductivity
	Primary productivity	Periphyton or algal abundance
	Secondary productivity	Invertebrate abundance or diversity
	Climate change	Impacts of climate change on water quality
	Data gaps	Data gaps are identified
Modeling Tools	Hydrology	Hydrodynamic, hydrologic or hydraulic models
	Sediment	Sediment models
	Life cycle	Life cycle models
	Bioenergetics	Bioenergetic models or food web models
	Adult returns	Forecasting models for adult returns
	Climate change	Models the predict effects of climate change or predict climate change
	Habitat	Models describing habitat, intrinsic potential
	Connectivity	Habitat connectivity, landscape connectivity
	Data gaps	Data gaps are identified
Land Use and Cover	Land cover	General land cover information
	Forestry	Forestry and logging information, extent, management
	Agriculture	Agriculture land use information, extent
	Commercial	Commercial and industrial land use extent and types

Topic	Keyword	Notes
	Urban	Urban land use information, extent
	Banks and shoreline	Levees/dikes, shoreline hardening, armoring
	Floodplain	Irrigation/diking, wetland losses/conversion
	Climate change	Climate change impacts on land cover
	Data gaps	Data gaps are identified
Fish and Habitat	Habitat, instream flow	Peak flows, flood recurrence intervals, mean flows
	Habitat, riparian	Riparian extent or condition, stand structure, buffers
	Habitat, wetlands	Wetland quantity, quality, or type
	Habitat, beaver	Beaver abundance, distribution, habitat effects, conflicts, BDAs, beaver deceiver
	Habitat, barriers	Fish passage barriers
	Habitat, invasive species	Aquatic or terrestrial invasive species
	Habitat, freshwater	Habitat quantity, quality, or type
	Habitat, estuary	Habitat quantity, quality, or type
	Habitat, pocket estuary	Habitat quantity, quality, or type
	Habitat, nearshore	Habitat quantity, quality, or type
	Habitat, ocean	Habitat quantity, quality, or type
	Habitat, connectivity	Patchiness, landscape connectivity, local connectivity, accessibility
	Habitat, capacity	Capacity of habitat to support fish
	Habitat, limiting factors	Identifies habitat limiting factors
	Habitat, status and trends	Habitat status and trends
	Habitat, restoration	Projects, plans, designs, targets
	Habitat, climate change	Climate change impacts on habitat
	Habitat, data gaps	Data gaps are identified
	Fish, abundance	Abundance estimates for fish
	Fish, diet	Diet composition, foraging behavior, preference
	Fish, condition	Measures of condition, condition factor, lipids, weight
	Fish, density dependence	Measures of density dependent processes or patterns
	Fish, competition	Interspecific or intraspecific competition, territory
	Fish, survival	Survival at different life stages (e.g., egg to fry, smolt to adult), size selective mortality, density dependence
	Fish, growth	Growth estimates from mark recapture, otolith or scales
	Fish, swimming speed	Swimming speeds, travel speeds, movement
	Fish, physiology	Physiological studies
	Fish, rearing	Fish rearing patterns or preferences
	Fish, predation	Predation on fish, avian, marine mammal, fish
	Fish, life history	Life history characterization, description, diversity, resilience
	Fish, age structure	Age structure information
	Fish, size structure	Size structure, length frequency
	Fish, sex structure	Sex structure, ratios
	Fish, periodicity	The timing and duration of life stages
	Fish, status and trends	Population status and trends information, extent, management

Topic	Keyword	Notes
	Fish, hatchery	Hatchery abundance, strategies, interactions
	Fish, harvest	Harvest rates, fisheries, exploitation rates
	Fish, climate change	Climate change impacts on fish (e.g., temperature or periodicity)
	Fish, data gaps	Data gaps are identified
	Monitoring, restoration	Monitoring restoration projects (e.g., response, effectiveness)
	Monitoring, climate change	Monitoring climate change impacts or climate change
	Monitoring, data gaps	Data gaps are identified
	Monitoring, habitat	Habitat status and trends, monitoring
	Monitoring, abundance	Smolt trap, electrofishing, seining, fyking, angling, carcass, redd, or other abundance monitoring methods
	Monitoring, biotelemetry	PIT, radio, acoustic tagging, mark recapture studies
	Monitoring, scale or otoliths	Age analysis, time of entry, residency/transition periods, growth
	Monitoring, genetics	GMR, population assignment, origin
	Monitoring, flow	Flow monitoring

Data Flags

Information and data for target species, life stages, and reaches will also be identified for sources using data flags, as well as flags to identify if quantitative data or spatial data are provided by the source. The following table provides a list of proposed data flags to support identification and classification of sources and data compiled. Note, topics and keywords are attributed with these data flags rather than the sources so that the flags can be associated with specific topics or information. For example, a source with information or data on juvenile Chinook survival from rearing to outmigration can be attributed as Topic = Fish and Habitat; Keyword = Fish, survival; Species = Chinook; Life Stage = rearing to outmigration. This approach allows us to associate specific data types to sources rather than a generic flag that could incorrectly suggest that a source contained survival information for other species or life stages. Note Reach flags may include ranges or combinations of reaches depending on the spatial extent of the study and available data. Geomorphic reach descriptions for mainstem Skagit River were quoted from Riedel et al. (2020).

Table A-2 Proposed data flags to support identification and classification of sources and compiled data.

Field	Values	Description
Species	Chinook	Contains information or data on Chinook Salmon
	Coho	Contains information on Coho Salmon
	Sockeye	Contains information on Sockeye Salmon
	Chum	Contains information on Chum Salmon
	Pink	Contains information on Pink Salmon
	Bull Trout	Contains information on Bull Trout
	Steelhead	Contains information on steelhead
	All	Contains information on all target anadromous species

Field	Values	Description
	NA	Data not associated with target species (used for topics and keywords not related to target species)
Life Stage	Migration	Adult migration, including holding
	Spawning	Adult spawning
	Incubation	Egg incubation in substrate
	Rearing	Juvenile rearing in freshwater habitats
	Outmigration	Juvenile emigration from freshwater habitats
	Estuary rearing and emigration	Juvenile rearing, transition, and emigration through estuary habitats
	Nearshore rearing and emigration	Juvenile rearing in nearshore habitats, including pocket estuaries
	Ocean	Ocean maturation
	Migration – spawning	Adult migration through spawning
	Incubation – rearing	Incubation through rearing
	Incubation – outmigration	Incubation through outmigration
	Rearing - outmigration	Rearing through outmigration
	Outmigration – migration	Juvenile outmigration to adult migration
	Full life cycle	Full life cycle
	NA	Does not contain information on species or life stages
Reach	US R7	Reaches upstream of R7
	Sauk River	Includes Sauk River, tributary to the mainstem Skagit River that confluences at R7.
	R7	R7-Sauk River Alluvial Fan – "Wide alluvial fan that forces Skagit to north side of valley. Influenced by Glacier Peak sediment, some from lahars." PRM 68-65.
	R8	R8-Sauk Alluvial fan to Baker Mouth – "Steep, narrowed channel because river is incised into 30-50m thick, over-consolidated glacial deposits (till, silt, sand, and gravel)." PRM 65-56.5.
	R9	R9-Baker to Finney Cr. – "Channel incised into glacial and lahar terraces, Baker Hydro influence on sediment, large wood, and channel pattern." PRM 56.5-49.
	R10	R10-Finney Cr. To Hamilton Moraine – "Sinuosity higher strong right bank ground water influence, extensive lahar terrace." PRM 49-36.5.
	R11	R11-HM to Sedro-Wooley – "High sinuosity in wide outwash valley wide meander loops. Extensive lahar terrace on right bank." PRM 36.5-NA.
	R12-13	R12 and R13-SW to Burlington Hill – "River leaves valley and enters Puget Lowland. Start of river levees transition to sand bed." PRM NA. Downstream extent of tidally influenced habitats.
	R14	R14-Delta (BH to Skagit Bay) – "Puget lowland river constrained by levees on delta, split into two distributary channels, very limited sediment and LWD." PRM NA. This is the delta extent and range of tidally influenced habitats.

Field	Values	Description
	Skagit Bay	Skagit Bay – Skagit Bay and nearshore shoreline, including neritic and embayment habitats from the Deception Pass outlet in the North to the mouth between Whidbey Island and Camano Island in the South
	Padilla Bay	Padilla Bay – northern outlet of Swinomish Channel that is included in the geomorphic delta boundary for the Skagit River.
Quantitative Data	Yes/No	Indicates whether the source provides quantitative data on the topic and keyword, and/or species and life stage
Spatial Data	Yes/No	Indicates whether the source provides spatial data on the topic and keyword, and/or species and life stage

Additional List of Acronyms and Abbreviations

CMZ	channel migration zone
DHSVM	Distributed Hydrology Soil Vegetation Model
FV-COM	Finite Volume Coastal Ocean Model
GCM	Global Climate Model
PNNL	Pacific Northwest National Laboratory
RCP	Representative Concentration Pathway
Tg	teragram
SSC	suspended sediment concentration
SSL	suspended sediment load
VIC	Variable Infiltration Capacity
VSP	viable salmonid population

Annotated Bibliography

Bandaragoda et al. 2015

<table>
<tr><td>Reference</td><td colspan="9">Bandaragoda, C., C. Frans, E. Istanbulluoglu, C. Raymond, and L Wasserman. 2015. Hydrologic Impacts of Climate Change in the Skagit River Basin. Final Report Prepared for Skagit Climate Science Consortium. Available at: http://www.skagitclimatescience.org/wp-content/uploads/2016/04/UW-SC2_SkagitDHSVM-glacierModel_FinalReport_2015.pdf</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td></td></tr>
<tr><td>Topics and Keywords</td><td colspan="9">Geomorphology: Climate change, change, aquatic habitats and landforms.
Modeling Tools: Hydrology, climate change.
Fish and Habitat: <u>Habitat</u>, climate change; <u>Fish</u>, climate change.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="9">None.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="9">Reach 1-13, Skagit River.</td></tr>
</table>

Summary: This final report includes projections of naturalized streamflow based on a coupled glacio-hydrology model (DHSVM) at Skagit River Hydroelectric Project reservoir locations (Ross, Diablo, Gorge) and at sixteen tributaries using future climate change scenarios. The future streamflow projections are a collaboration between Seattle City Light, Swinomish Indian Tribal community, and the Sauk-Suiattle Indian Tribe administered by the Skagit Climate Consortium (SC2) and the University of Washington (UW). The model domain included the entire Skagit River basin at 150 m (492 ft) digital elevation model (DEM) with nested models of 50 m (164 ft) resolution of selected basins (Thunder Creek and Cascade River) that have major glacier ice cover at their high elevations. The DHSVM model was calibrated using historical meteorological data and observed ice extent between 1960-2010 and corrections were conducted using empirical data, naturalized flows at reservoirs, and observed stream gauges. Future projects were calculated using Global Climate Models (GCMs) 30-year period starting from 2010 to 2099.

The authors highlight the changes applicable to 2050. In glaciated high elevation basins, the current conditions of approximately 100 km^2 (39 square miles) of glacier ice are projected to decrease to less than 50 km^2 (19 square miles) by 2050. Tributary contributions, as measured by the August 90 percent exceedance probability between Newhalem to Marblemount are currently approximately 350 cfs and by 2050 could decrease to approximately 230 cfs (35 percent decrease). The South Fork Sauk River is predicted to decrease by 80 percent, from 14 cfs to 3 cfs for the August 90% streamflow. This represents a significant change in salmon habitat during a critical period.

The Sauk River currently has a bimodal annual hydrograph and is projected to progressively lose the summer peak (from snowmelt) and increase winter peak (from rainfall); by 2099 the Sauk River annual hydrograph is projected to have a single peak consistent with hydrograph timing of rain-dominated systems. The impacts of this shift will be most apparent in the August change where the decrease would be approximately 60%.

The lowest flows are currently 2000 cfs at the Gorge dam and predicted to decrease approximately 500 cfs in each 30-year period, to lower than 500 cfs in August by the end of the century.

Relevant Information: The authors highlight the changes applicable to 2050. In glaciated high elevation basins, the current conditions of approximately 100 km^2 (39 square miles) of glacier ice are projected to decrease to less than 50 km^2 (19 square miles) by 2050. Tributary contributions, as measured by the August 90% exceedance probability between Newhalem to Marblemount are currently approximately 350 cfs and by 2050 could decrease to approximately 230 cfs (35% decrease). The South Fork Sauk River is predicted to decrease by 80%, from 14 cfs to 3 cfs for the August 90% streamflow. This represents a significant change in salmon habitat during a critical period.

The changes predicted throughout the system include less glacial coverage and more of a rain-dominated system throughout the entire basin. The decrease in August flows is concerning for salmon habitat. This underlines the need for climate change to be considered in all future flow and operational scenarios.

Bandaragoda et al. 2020

<table>
<tr><td>Reference</td><td colspan="10">Bandaragoda, C., S. Lee, E. Istanbulluoglu, and A. Hamlet. 2020. Hydrology, stream temperature, and sediment impacts of climate change in the Sauk River basin. Prepared by Hydroshare for Sauk-Suiattle Indian Tribe and Skagit Climate Science Consortium. Available at: http://www.hydroshare.org/resource/e5ad2935979647d6af5f1a9f6bdecdea</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td></td><td></td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology: Climate change, change, aquatic habitats and landforms.
Modeling Tools: Hydrology, climate change.
Fish and Habitat: Habitat, climate change; Fish, climate change.
Water Quality and Productivity: Temperature.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">None.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Sauk River.</td></tr>
</table>

Summary: The study explored how low streamflows and peak annual flood streamflow in the Sauk Basin and tributaries are projected to respond to climate change using a coupled glacio-hydrology model (Distributed Hydrology Soil Vegetation Model, DHSVM) with highlighted discussions on 20 model output locations. The two climate change models that were used include Representative Concentration Pathways (RCP) 4.5 Ensemble and RCP 8.5 Ensemble. The Sauk River near Sauk is projected to have significantly more increases in winter time (November-January) streamflow and decreases in summer time (July-September) streamflow. The Sauk River currently has a bimodal annual hydrograph, but is projected to lose the summer peak from snowmelt and increase the winter peak from rainfall. By the end of the century the Sauk River annual hydrograph is projected to have a single peak consistent with rain-dominated systems. The impact will be most apparent in the August flow changes as future scenarios consistently give from around 50 percent to 90 percent declines toward the end of the century. High flows and peak events are projects to substantially increase by 2050, with statistically significant peak events (e.g., 100-year flood) expected to increase 20-30 percent for a moderate warming climate change scenario (RCP 4.5) and increase by 40 percent for high warming scenarios (RCP 8.5).

Historic daily maximum temperature during summers were 17.8°C (64.0°F), 19.2°C (66.6°F), and 17.4°C (63.3°F) at the Sauk River above Suiattle, Sauk River near Darrington, and the White

Chuck River, respectively. Daily maximum temperature is projected to increase by 2-3°C for all scenarios and sites. The Sauk River near Darrington shows the largest increase in maximum temperature and the White Chuck River the least.

Mean annual suspended sediment load (SSL) estimates were obtained using historical (1960-2010) and future modeled streamflows in suspended sediment rating curve for lower and middle Sauk locations. Historical SSL was approximately 40% lower than the 5-year mean annual historic yield reported by the USGS study in the Sauk River, when stream streamflow is used directly without monthly bias correction. Monthly bias-corrected streamflow gave historical suspended load approximately 20 percent greater than the 5-year mean reported by USGS. The RCP 4.5 scenario models predict approximately twofold increase by the middle and much higher by end of the century. SSL gets consistently higher in the second half of the century in the worst-case RCP 8.5 scenario of climate change. Bias-corrected streamflow also results in consistent relative increases in SSL in lower Sauk for future climate scenarios. These results are limited by the assumption that sediment supply level does not vary and increases from the pro-glacial areas melting are not considered. Loss of snow and ice cover with climate and resulting exposure of unconsolidated and fine sediments to overland flow would also increase suspended sediment loads in the Sauk River.

Relevant Information: The Sauk River provides a large load of sediment to the Skagit River. The future changes in high flows and peak events will affect the Skagit River in terms of hydrology, temperature, and SSL. This report provides estimates of SSL and temperature that could enter the Skagit River in moderate to high warming climate change scenarios (RCP 4.5 and RCP 8.5). Although approximately 30 miles downstream of the Gorge, the confluence of the Sauk and Skagit River is an important area to understand. Both the Sauk and mainstem Skagit River are predicted to reduce in flow and increase in temperature over the century. This could be problematic to salmon that can be affected adversely by the August reduction in flows and increase in temperature.

Beamer et al. 2010

Reference	Beamer, E., J. Shannahan, K. Wolf, E. Lowery, and D. Pflug. 2010. Freshwater habitat rearing preferences for stream type juvenile Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) in the Skagit River basin: phase 1 study report. Report prepared for Skagit River System Cooperative, La Conner, Washington.									
Source Information	***Type***	Study	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Side and off-channels, large wood, log jam, aquatic habitats and landforms. ***Fish and Habitat:*** Habitat, status and trends; Fish, abundance.									
Species and Life Stages	Chinook-rearing, steelhead-rearing.									
Reaches and Spatial extent	R1-R14, Sauk River.									

Summary: This study was conducted to better understand the decline of Chinook and steelhead salmonoid species in the Skagit River basin. The study's purpose is to identify seasonal and habitat type preferences in the Skagit River basin for these salmonoid species in order to inform restoration efforts. This study is split into two parts. Phase 1 of this study is designed to assess the feasibility of the proposed sampling design. Results from Phase 1 informs Phase 2 which will implement a larger scale effort of this assessment that aims to identify seasonal and habitat type preferences. This document reports on Phase 1 of this study.

This study assembled a habitat database of the Skagit River basin in GIS. This habitat database was organized by a nested scale habitat classification scheme. These classifications began with large scale habitat definitions including “Large mainstem”, “Small mainstems or tributaries”, and “Floodplain channels”. The smaller unit scale definitions included “Pool”, “Riffle”, “Bar”, “Bank”, and more. These delineated habitat units then had representative reaches selected based on factors of space, time of year, and habitat type. These representative reaches were then assessed in the field and pilot level fish observation data was collected. This fish data was then used to conduct a statistical power analysis to inform Phase 2 of this study. The field methods implemented in Phase 1 of this study were then refined based on experience in the field as well as the results of the power analysis conducted to inform the minimum effort required for Phase two of this study.

The results of Phase 1 of this study found detectable differences in fish assemblage abundance for all three factors that were hypothesized to determine fish assemblage abundance. These three factors are space, season, and habitat type. The power analysis conducted in Phase 1 found that in general juvenile Chinook data is the limiting factor in making a robust enough sample size to be statistically significant. Overall, a doubling or tripling of efforts conducted in Phase 1 would be sufficient to create statistically significant results in Phase 2.

Relevant Information This study provides data on the location and distribution of habitat unit types in the Skagit River during 2007. These habitat unit types follow a nested scale habitat definition scheme that begins with channel type and fines down to individual habitat unit types. In addition to habitat unit delineations this study also delineated locations that large log jams were interacting with the low flow channel in 2007. This data will help inform changes in habitat unit type and large wood abundance and distribution that are being reported on in the GE-04 study report.

Beechie et al. 2017

Reference	Beechie, T. J., O. Stefankiv, B. Timpane-Padgham, J. E. Hall, G. R. Pess, M. Rowse, M. Liermann, K. Fresh, and M. J. Ford. 2017. Monitoring Salmon Habitat status and trends in Puget Sound: development of sample designs, monitoring metrics, and sampling protocols for large river, floodplain, delta, and nearshore environments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-137, Seattle.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology and Landforms:*** Aquatic habitats and landforms, Estuarine habitats and landforms. ***Land Use and Cover:*** Land cover, Banks and shoreline, Floodplain. ***Fish and Habitat:*** Habitat, freshwater, Habitat, nearshore, Habitat, status and trends, Monitoring, habitat									
Species and Life Stages	Chinook-rearing, chum-rearing, steelhead-rearing. Chinook-spawning, chum-spawning, steelhead-spawning.									
Reaches and Spatial extent	R1-R14, Sauk River, Skagit bay.									

Summary: This report addresses the first stage of development of a habitat monitoring program for four salmon and steelhead spawning and rearing environments across the Puget Sound: large rivers, floodplains, deltas, and the nearshore. This program will be used to provide data for assessing habitat changes across each environment.

The goals of the first year of this monitoring effort are as follows:

1) To develop a hierarchical sampling design to monitor habitat status and trends.

2) To identify habitat metrics that are cost-effective and related to viable salmonoid population parameters.

3) To develop protocols to measure those metrics.

4) To test the satellite, aerial photography, and field methods for repeatability and reliability.

5) To evaluate habitat status to assess the ability of each metric to detect habitat differences among our chosen land-cover strata.

These efforts will be used to refine the habitat monitoring program to ensure consistency and relevancy so that it may be used reliably in the future.

Results from the first year of monitoring are included in this report. These results include next steps on the refinement of the habitat monitoring program as well as the current status of habitat for the four salmon and steelhead spawning and rearing environments.

Relevant Information This report provides data on the 2017 status of salmon and steelhead habitat across Puget Sound basins which include the Skagit River. Additionally, it provides a guideline for a habitat monitoring program using remote sensing and field-based techniques that has been extensively reviewed and evaluated for improvements on consistency and reliability. This is relevant to City Light as this methodology can be used to inform current aquatic habitat monitoring practices.

Collins et al. 2002

Reference	Collins, B. D., D. R. Montgomery, and A. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland Rivers. Can. J. Fish Aquatic Science 59:66-76.									
Source Information	***Type***	Study	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Large wood, log jam, change.									
Species and Life Stages	None.									
Reaches and Spatial extent	R13.									

Summary: This study examines the historic change of large wood function and distribution in Puget lowland rivers. The purpose of this study is to examine the statement that the influence of large wood decreases with increasing channel size. The authors of this study hypothesize that historic stream cleaning has greatly decreased the abundance of large wood in Puget lowland rivers and levee construction and riparian forest clearing has diminished the potential for lowland rivers to recruit wood. This combined effect suggests that the current condition of large wood loading in Puget lowland rivers is not representative of their historical condition.

The authors of this study examine this hypothesis by comparing the current condition of large wood distribution and function in reaches across three Puget lowland rivers. Two of these rivers, the Snohomish and Stillaguamish, have been heavily leveed, cleared, and logged. They are meant to represent conditions in a Puget lowland river that has been subject to extensive European settlement impact. The other river examined, the Nisqually River, contains reaches that have been largely untouched since European settlement. The study reaches in the Nisqually are meant to represent historic conditions of other Puget lowland rivers pre-European settlement. Additionally, the authors examined archival materials of wood distribution and function of these three rivers as well as other Puget lowland rivers, including the Skagit River, to provide insight into their historical condition.

Results from this study show significant differences in wood distribution and function between the Nisqually River and the Snohomish and Stillaguamish Rivers.

Archival materials of the Nisqually River suggest that the study reach is relatively unchanged from its mid-19th century condition. Present day large wood distribution is similar to the size distribution in 1873. Additionally, the present-day anastomosing channel planform in the Nisqually is similar to what is seen in historic aerial photos and historic maps. The historic distribution and function of large wood in the Nisqually is comparable to the historic conditions in the Stillaguamish. The Stillaguamish had comparable wood sizes to the Nisqually, abundant log jams, and an anastomosing channel planform according to archival materials. The Snohomish was dissimilar in that it did not have as much wood as the Nisqually and Stillaguamish. Additionally, it exhibited a single meandering planform as opposed to anatomizing. The authors note that the Snohomish does exist in a broad low-gradient valley created by Pleistocene subglacial runoff as opposed to the post-glacial incision dominated valleys that the Nisqually and Stillaguamish exist in. This could be the cause for the variation in historic conditions of these channels.

There are strong contrasts in wood distribution and function when comparing the Nisqually with the Stillaguamish and Snohomish River current day conditions. The Nisqually has 8 and 21 times more wood than the Snohomish and Stillaguamish, respectively. This difference is accounted for primarily from wood jams in the Nisqually which are much more abundant than in the Snohomish and Stillaguamish. Additionally, large wood was shown to have a greater impact on the overall aquatic habitat in the Nisqually forming 61 percent of pools versus 12 percent and 6 percent in the Stillaguamish and Snohomish respectively. The large wood in the Snohomish and Stillaguamish was also shown to lack long, large-diameter, pieces with rootballs which function in the Nisqually to initiate and stabilize log jams as key pieces.

The authors concluded that the present-day large wood conditions seen in most Puget lowland rivers is not representative of historic conditions. Large wood historically was one to two orders of magnitude more abundant pre-European settlement. This loss of large wood has been driven by human interaction.

Relevant Information This study discusses historic conditions of large wood distribution in the Skagit river and provides comparison of present day and mid-19th century large wood distribution conditions in Puget lowland rivers comparable to the Skagit river. This study cites archival materials that describe a log raft on the Skagit river near Mt. Vernon as “nine meters deep, consisting of from five to eight tiers of logs, which generally ranged from three to eight feet in diameter and existed for at least a century”, this jam was reported to be “large enough to support live trees 0.6 to 1.2 meters in diameter”. This raft jam was greater than 1 kilometer long. Additional archival materials discuss the prevalence of tidal distributary channels that were reportedly characterized by “hundreds of miles of old channels that were choked with wood, filled with sediment, and abandoned”. The study also provides evidence that Puget lowland rivers had one to two orders of magnitude more wood abundance in the mid-19th century.

Curran et al. 2016

<table>
<tr><td>Reference</td><td colspan="10">Curran, C. A., E. E. Grossman, M. C., Mastin, and R. L. Huffman. 2016. Sediment load and distribution in the lower Skagit River, Skagit County, Washington. U.S. Geological Survey Scientific Investigations Report 2016–5106. Available at: http://dx.doi.org/10.3133/sir20165106.</td></tr>
<tr><td>Source Information</td><td>Type</td><td>Report</td><td>Status</td><td>Final</td><td>Quantitative Data</td><td>Yes</td><td>Spatial Data</td><td>Yes</td><td></td><td></td></tr>
<tr><td>Topics and Keywords</td><td colspan="10">Geomorphology: Change, sediment transport and supply, substrate or sediment, climate change.
Modeling Tools: Hydrology, sediment.</td></tr>
<tr><td>Species and Life Stages</td><td colspan="10">None.</td></tr>
<tr><td>Reaches and Spatial extent</td><td colspan="10">Reach 12 and 13, Skagit Bay.</td></tr>
</table>

Summary: The authors developed and evaluated regression models of sediment transport (sediment-rating curves) by utilizing 175 measurements of suspended-sediment load, made routinely from 1974 to 1993, and sporadically from 2006 to 2009. Five different regression models were evaluated. The five types of models they used were ordinary least squares, polynomial least squares, seasonal, time-interval, and flow-range. The flow-range model had the closest fit between estimated and measured suspended sediment concentrations (SSC). Using this regression model for 75 years of daily discharge (1941-2015), a mean annual suspended-sediment load in the Skagit River of 2.5 teragrams (1 Tg = 1 million metric tons) was estimated. Individual large floods accounted for as much as 40 percent of annual sediment delivery. In 2007, an extremely wet year an annual load of 4.5 Tg was measured from daily suspended-sediment samples collected with an automated sampler. For 2007, the flow-range rating curve overestimated the SSC by 6.7 percent, while the seasonal rating curve underestimated load by 11 percent.

A summer low-flow model showed poor correlation between SSC values estimated from discharge and measured SSC values. The poor correlation indicates that discharge is a poor surrogate for SSC during the summer low-flow period. A comparison of models for three-time intervals revealed an overall increase of 66 percent in the slope of the SSC to discharge relation between 1974-1976 and 2006-2009. The increase suggests changes in sediment supply, channel hydraulics, and/or basin hydrology.

Particle size was an important factor controlling sediment delivery and deposition. The percentage of fines generally increased with increasing discharge during the winter storm season. A continuous turbidity record from the Anacortes Water Treatment Plan from water year 1999-2013 was used as a surrogate for the concentration of fines. The turbidity record confirms that about one-half of the mean annual suspended-sediment load is composed of fines.

Relevant Information: Regression models were developed to relate SSC to discharge, turbidity, and flow distribution the 15-km stretch of lower river. The flow-range model has the closest fit between estimated and measured SSC. All the models have considerable variability and poor correlation during summer low-flow periods. The increase in SSC over time suggests changes in sediment supply, channel, hydraulics, and/or basin hydrology. These relationships can be used to estimate sediment delivery and relative particle-size distribution and inform proposed delta restoration design.

Grossman et al. 2020

Reference	Grossman, E. E., A. W. Stevens, P. Dartnell, D. George, and D. Finlayson. 2020. Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise, Skagit River Delta, Washington, USA. Marine Geology 430:106336.									
Source Information	**_Type_**	Journal	**_Status_**	Final	**_Quantitative Data_**	Yes	**_Spatial Data_**	Yes		
Topics and Keywords	**_Geomorphology:_** Change, history, channel migration, channel incision, sinuosity, floodplain, side- and off channels, floodplain connectivity, substrate and sediment, sediment transport and supply, aquatic habitats and landforms, estuarine habitats and landforms, climate change. **_Modeling Tools:_** Hydrology, climate change.									
Species and Life Stages	None.									
Reaches and Spatial extent	Reach 13, Skagit Bay.									

Summary: The study authors used bathymetric change, sediment cores, and modeling to show how an estimated 142 ± 28 M m^3 of sediment, of which 68 percent was sand deposits, accumulated across the Skagit River delta between 1890 and 2014 related to land uses. The amount stored in reservoirs represents approximately 39 percent of the fluvial sand fraction over this time period. However, accumulation of 83 percent of the fluvial sand fraction found near the river mouth make retention in the delta foreset and tide flats effective metrics to evaluate land use impacts on sediment dynamics and ecosystems. A higher ratio of sand retention during the period 1890-1939, coinciding with extensive deforestation, channel dredging, and channelization activities, was found relative to the period 1940-2014, which was characterized by improved forest practices, and sediment management to protect endangered species.

Comparable offshore sand retention over time and higher nearshore retention before 1940 after normalizing for the assumed reduction in sediment runoff associated with improved forest practices, suggests the channelization has continued to influence sediment export at a magnitude equal to the effects of early logging. Adverse impacts of the bypassing sediment regime to natural hazards risk and ecosystem management concerns are discussed. Sediment budget and coastal change analyses provide a framework for evaluating opportunities to achiever great resilience in low-lying deltas worldwide.

Relevant Information:

The amount of sediment estimated in this study is important to the GE-04 study. With changes in dam operations there could be changes propagated downstream. The sediment budget and historical change analyses provide a framework to assess coast responses to sediment delivery and routing to guide vulnerability assessments and resiliency planning.

Hartson and Shannahan 2015

Reference	Hartson, R. and J.P. Shannahan. 2015. Inventory and Assessment of Hydromodified Bank Structures in the Skagit River Basin Chinook Bearing Streams. Final report submitted to Northwest Indian Fisheries Commission and Environmental Protection Agency. Prepared for The Upper Skagit Indian Tribe Natural Resources Division.

Source Information	*Type*	Report	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes		
Topics and Keywords	*Land Use and Cover:* Banks and shoreline.									
Species and Life Stages	None.									
Reaches and Spatial extent	R1-R13, Sauk River.									

Summary: This document reports on a 2015 field inventory of hydromodified banks in the Skagit basin. The inventory's extent encompasses all recorded Chinook salmon bearing channels within the Skagit basin. This 2015 inventory was based on an initial inventory of hydromodified banks conducted in 1998 in the Skagit basin. The 2015 field inventory was conducted using Trimble GPS units and is being stored in a GIS database. In addition to capturing the spatial distribution of hydromodifications the 2015 inventory also defined modification by "hydromodification type", "size class of material", "levee association", "length of structure", "location in channel", and more. Photos were also taken of each hydromodification.

The results of this field inventory will be used to inform and prioritize restoration efforts in the Skagit basin.

Relevant Information: This report provides data on hydromodified banks within the entire Skagit basin. This includes information in the main project area from the Gorge Dam to the Sauk River.

Hood 2007

Reference	Hood, W. G. 2007. Large woody debris influences vegetation zonation in an oligohaline tidal marsh. Estuaries and Coasts, 30(3):441-450.									
Source Information	*Type*	Journal	*Status*	Final	*Quantitative Data*	Yes	*Spatial Data*	Yes		
Topics and Keywords	*Geomorphology:* Large wood, estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply. *Water Quality and Productivity:* Nutrients. *Fish and Habitat:* Habitat, estuary.									
Species and Life Stages	None.									
Reaches and Spatial extent	Reach 13, Skagit Bay.									

Summary: This study shows that LWD plays a role in the establishment of shrubs, particularly nitrogen-fixing *Myrica gale* L. (*M. gale;* sweetgale) in the Skagit Delta tidal marshes. LWD, sweetgale, and other shrubs were surveyed along line transects in an oligohaline tidal marsh and in abandoned agricultural land whose dikes failed over 50 years ago and has reverted to marsh. The results show a strong association between LWD and *M. gale*. Sweetgale was very rare on LWD < 30 cm (12 in), more common for LWD between 30-75 cm (12-30 in), and always present on LWD ≥ 75 cm (30 in). The marsh surface was generally 45 cm below mean higher high water (MHHW), suggesting LWD provides a growth platform at an elevation near MHHW and reduces flood stress. The largest and most abundant tree in the marsh averaged only 35.8 cm (14 in), which suggests LWD recruitment from upstream sources is necessary to sustain sweetgale populations in the geomorphologically dynamic Skagit marsh.

Relevant Information: *M. gale* dependence on estuarine LWD suggests upstream riparian management can affect LWD subsidies to estuaries with potentially cascading effects on estuarine ecology, particularly community structure and nitrogen dynamics. Long-term estuarine habitat management should include upstream riparian zone management to allow LWD recruitment to the estuary to sustain LWD-dependent estuarine ecosystem structures and processes.

Hood 2007b

Reference	Hood, W. G. 2007b. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process. Water Resources Research 43:W03409.									
Source Information	***Type***	Study	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Estuarine habitats and landforms ***Modeling Tools:*** Connectivity									
Species and Life Stages	None.									
Reaches and Spatial extent	Skagit Bay									

Summary: This study proposes an alternative approach to examining tidal channel geometry and evolution to inform marsh restoration. This approach relies on scaling relationships between marsh island surface area and various metrics of the set of tidal channels draining each marsh island. This study was conducted in the Skagit River delta.

Tide channel margins were digitized from aerial photos and used to measure marsh island and tide channel geometries. These geometries were then scaled with each other as a function of marsh island area for 7 tide channel metrics which include total channel length, total channel surface area, tributary count, and more. These scaled relationships were then analyzed for statistical significance. This process was done separately for five different marsh island groups in the Skagit delta, one of which was cut off from sediment inputs by anthropogenic processes in the 1950s.

Results from this analysis showed statistically significant scaling for 6 of 7 metrics. When comparing these scaling relationships between marsh island groups it was observed that slopes remained uniform, but the intercepts varied. The difference in scaling intercept between the marsh island group cut off from sediment inputs and the other marsh island groups was most pronounced.

This new approach to examining tidal marsh systems show promise as seen in the difference in scaling relationships of a sediment starved marsh island group and a sediment connected marsh island group. This difference could be used in identifying marsh restoration sites.

Relevant Information: This study examines an alternative process for examining tide channel geometries and evolution. This study was conducted in and reports on empirical data collected in the Skagit River delta. This data could be used to inform current status of tide channels in the Skagit delta.

Reference	Hood, W. G. 2010. Tidal channel meander formation by depositional rather than erosional processes: examples from the prograding Skagit River delta (Washington, USA). Earth Surface Processes and Landforms 25(3):319-330.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply, channel migration.									
Species and Life Stages	None.									
Reaches and Spatial extent	Skagit Bay.									

Summary: The author used geographic information system (GIS) analysis of historical aerial photographs of the Skagit Delta marshes. These provide examples of an alternative channel meander forming process in a rapidly prograding river delta. Parallel sequences of marsh ridges and swales indicate locations of historical distributary shoreline levees adjacent to filled former island/mainland gaps. The location of marsh islands within delta distributaries is not random. Islands are disproportionately associated with blind tical channel/distributary confluences. Additionally, blind tidal channel outlet width is positively correlated with the size of the marsh island that forms at the outlet and the time until island fusion occurs within mainland marsh. These observations suggest confluence hydrodynamics favor sandbar/marsh island development. The transition from confluence sandbar to tidal channel meander can take less than 10 years, but usually occurs over several decades. This channel meander formation process is part of a larger scale depositional process of delta progradation that includes distributary elongation, gradient reduction, flow-switching, shallowing, and narrowing

Relevant Information: The Skagit River provides 34-50% of Puget Sound’s freshwater and sediment inputs, depending on the season. Distinguishing systems in which depositional version erosional channel-forming processes predominate may provide useful guidance for further refinement of morphodynamic models and for land-use management affecting sediment supply or river discharge to deltaic systems.

Hood 2015

Reference	Hood, W. G. 2015. Geographic variation in Puget Sound tidal channel planform geometry. Geomorphology 230:98-108.									
Source Information	***Type***	Journal	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Large wood, estuarine habitats and landforms, change, substrate and sediment, sediment transport and supply, channel migration, change, aquatic habitat and landforms, sea level rise. ***Fish and Habitat:*** Habitat, estuary.									
Species and Life Stages	None.									
Reaches and	Reach 13, Skagit Bay.									

Spatial extent	

Summary: The author performed allometric models to predict the number and size of tidal channels that could develop following salt marsh restoration and channels were digitized. Channel size and complexity were positively related to tidal range and negatively related to wave height in tidal channels throughout Puget Sound. The apparent accretion deficit suggested by larger tidal channel in the South Fork (SF) Skagit delta compared to North Fork (NF) delta is consistent with greater declines in historical salt marsh progradation rates in the SF compare to the NF delta. The results of this study suggest that sediment-challenged salt marshes in Puget Sound are already showing impacts from 20th Century sea level rise.

Relevant Information:

The results of this study suggest restoration of system-scale natural processes through relaxation of anthropogenic constraints on sediment supply could likely change patterns within the affected deltas. Wave environments appear to affect channel geometry. Wave-sheltered areas experience relative sediment deficits, such that some salt marshes in Puget Sound, such as the SF Skagit delta, are suffering sea-level rise impacts.

Hood *No Date*

Reference	Hood, W. G. No date. Distribution of large woody debris in river delta tidal marshes: Preliminary Results. Skagit River System Cooperative.									
Source Information	***Type***	Unpublished	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** change, history, channel migration, channel incision, sinuosity, floodplain, floodplain connectivity, substrate and sediment, sediment transport and supply, aquatic habitats and landforms, estuarine habitats and landforms, side- and off-channel habitat.									
Species and Life Stages	None.									
Reaches and Spatial extent	Skagit Bay.									

Summary: The author present examples of how large wood moves in the Skagit River delta. Some of the factors that affect LWD include topography, fetch, elevation, proximity to distributaries and dikes. The marsh island size strongly correlates ($r^2 = 0.90$) with total LWD length and count in the SF Skagit. The tidal channel size affects wood density and size. There is more total wood on the marsh surface than in channels, but channel density is higher. The wood appears to get trapped in tidal channels, especially smaller channels.

Relevant Information: The LWD in the Skagit is affected by topography, fetch, elevation, proximity to distributaries, and dikes. The tidal channel and marsh island size affects wood density and size. This has implications for large wood movement and location.

Jaeger et al. 2017

Reference	Jaeger, K.L., C. A. Curran, S. W. Anderson, S. T. Morris, P.W. Moran, and K. A. Reams. 2017. Suspended sediment, turbidity, and stream water temperature in the Sauk River Basin, Washington, water years 2012–16. U.S. Geological Survey Scientific Investigations Report 2017–5113. Available at https://doi.org/10.3133/sir20175113.

Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Change, history, substrate and sediment, sediment transport and supply. ***Water Quality and Productivity:*** Temperature, turbidity. ***Fish and Habitat:*** Fish, survival.									
Species and Life Stages	Chinook.									
Reaches and Spatial extent	Sauk River.									

Summary: Suspended sediment, turbidity, and water temperature data was collected at two USGS streamgages in the upper and middle reaches of the Sauk River over a 4-year period, October 2011 to September 2015, and at a downstream location in the lower Sauk River for a 5-year period from October 2011 to September 2016. Over the 5-year period, mean annual suspended sediment loads (SSL) at the upper, middle, and lower Sauk River streamgages were 94,200 metric tons (t) (240 t/km^2), 203,000 t (270 t/km^2), and 940,000 t (510 t/km^2), respectively. The median daily SSL for the streamgages was 27 t at Upper Sauk, 34 t at Middle Sauk, and 242 t at Lower Sauk. At the upper, middle, and lower Sauk River streamgages the fine sediment (smaller than 0.0625 mm) was approximately 53 percent, 42 percent, and 34 percent, respectively, of the total SSL.

SSL in the Sauk River Basin exhibited seasonal trends and substantial inter-annual variability. Fall (September to December) SSL, on average, accounted for more than half of the total annual suspended sediment load at the three streamgages (55 percent in upper, 67 percent in middle, and 62 percent in lower. Summer suspended sediment load was the smallest at the upper and middle streamgages (6 and 7 percent, respectively) and was 16 percent at the lower streamgage. The higher suspended sediment load at the lower gage was attributed to a relatively high load associated with late summer glacial melt in the tributary river, the Suiattle River, which joins the Sauk River downstream of the middle streamgage. Sediment availability typically remained high during the first fall storms, which glacial sediment accumulated over the summer was flushed out of the watershed. During five fall floods in fall 2015, 1.5 million metric tons more sediment was transported than would have been expected based on typical relations between sediment load and discharge.

A mass-balance analysis indicates that the Suiattle River accounts for about 80 percent of the total suspended-sediment load in the lower Sauk streamgage. The remaining load was split evenly between the inputs from the Upper Sauk River and White Chuck River Basins (10 percent each). About 60 percent of the SSL from the Suiattle River is estimated to be from the eastern flank of Glacier Peak. Sediment from the eastern flank of Glacier Peak may contribute approximately 50 percent of the sediment load for the entire Sauk River Basin in any given year.

Less than 1 percent of the study period included elevated water temperature and turbidity values that could impair Chinook salmon at various life stages at the Sauk River streamgages. During the study, potential temperature stress to fish in the Sauk River usually occurred during late summer and early fall, compared to periods of concern of turbidity. The study provides an opportunity to effectively determine what the background level might be for this or other regional rivers with regards to Washington state water quality standards.

Relevant Information: The study provides information on sediment load of the Sauk River, which enters the Skagit at the downstream end of the main project area. The Sauk River supplies a large amount of sediment to the Skagit River each year. The authors measured SSL from 2011 to 2016 in the Sauk River and provide a budget that can be used to better understand the SSL contribution from the Sauk River to the Skagit River inter-annually and seasonally.

Lee et al. 2016

Reference	Lee, S-Y, A.F. Hamlet, and E.E. Grossman. 2016. Impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin. Northwest Science 90(1), 23-43.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** Change, sediment transport and supply, climate change. ***Water Quality and Productivity:*** Temperature, turbidity, climate change. ***Modeling Tools:*** Hydrology, climate change. ***Land Use and Cover:*** Banks and shoreline, floodplain. ***Fish and Habitat:*** Habitat – instream flow, estuary, freshwater; Fish – climate change.								
Species and Life Stages	None.								
Reaches and Spatial extent	R1 – R14, Sauk River, Baker River.								

Summary: To assess the hydrologic response of the Skagit River due to climate change an integrated daily-time-step reservoir operations model, SkagitSim, was created to simulate reservoir operation policies for historical flow conditions and projected flow conditions in the 2040s (2030–2059) and 2080s (2070–2099). Results show that climate change will cause substantial seasonal changes in both natural and regulated projected flow conditions. The Skagit River Basin will transition from a mixed rain and snow watershed with dual peaks in the winter and spring to a rain dominated watershed with a single peak in the winter for both natural and regulated flow conditions.

Projected flow conditions were calculated using five different global climate models (GCMs) forced by the A1B greenhouse gas emissions scenario. The Variable Infiltration Capacity (VIC) hydrologic model was implemented at 1/16 latitude and longitude resolution over the Pacific Northwest. The VIC model was used to generate a streamflow time series for this study.

The projected shift in seasonal timing of flow affects the magnitude and timing of hydropower production. Hydropower production will increase in the winter and decrease in the summer. This will be a benefit to the region in the winter but will present challenges in the summer with additional increases in energy demand due to an increase in population and an increase in cooling demand. Additionally, increasing pressure to use reservoir releases of cold water to sustain temperature sensitive fish downstream may present additional challenges.

There will be large changes in the magnitude and timing of sediment load at the Skagit River near Mount Vernon. The peak sediment load in December will increase from a historic average of 0.40 teragrams/month to a projected average of 1.74 teragrams/ month (+ 335%) by the 2080s. The December to February total sediment discharge is projected to increase by 376% for the 2080s. This will benefit the Skagit delta by potentially mitigating the projected loss of marsh and shallow water habitat due to rising sea levels. Although an increase in suspended sediment load may also negatively impact many aquatic species.

The 100-year flood is projected to increase relative to historic baselines for both a natural and regulated scenario in both the 2040s and 2080s. Additionally annual peak flows are projected to increase in magnitude and occur more frequently in the winter season. Alternative flood control operations that increase flood control storage were shown to be not effective in mitigating higher flood risks in future climate change scenarios.

Extreme low flows under regulated conditions are projected to decrease due to an increase in evapotranspiration and a decrease in summer precipitation. Although projected low flows under regulated conditions will still be higher than historic low flows under natural conditions. This suggests that ecosystem impacts from a changing low flow regime may be modest.

Relevant Information: The report provides insight on projected changes in seasonal hydropower generation, flood mitigation, and sediment loading in the Skagit River Basin. Annual hydropower generation will not change significantly based on projected hydrologic conditions but seasonal changes in hydropower production will be significant. By the 2080s hydropower generation in the Skagit basin is projected to increase by 19% in the winter and spring and decrease by 29% in the summer. Annual peak flows as well as 100-year interval flows are projected to increase in magnitude causing an increase in flood risks downstream. An alternative reservoir operation policy that allows for an increase in flood control storage was shown to be ineffective in mitigating flood risks. There is projected to be a dramatic increase in sediment load with the total sediment discharge from December to February at the Skagit River near Mount Vernon increasing by 376%.

Nichols & Ketcheson 2013

Reference	Nichols, R. A., and G. L. Ketcheson. 2013. A two-decade watershed approach to stream restoration log jam design and stream recovery monitoring: Finney Creek, Washington. Journal of the American Water Resources Association 49(6):1367-1384.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	***Project Impacts***	No
Topics and Keywords	***Geomorphology:*** change, history, large wood, substrate and sediment, log jam, data gaps, aquatic habitats and landforms. ***Fish and Habitat:*** Fish, survival.									
Species and Life Stages	Chinook, juvenile, rearing.									
Reaches and Spatial extent	Reach 9-10.									

Summary: This report synthesizes 12 years (1999-2010) of stream restoration log jam design and stream recovery monitoring on Finney Creek, tributary to the Skagit River downstream of the Sauk River. A total of 1881 pieces of large wood were placed in 181 log jams, including 60 floating log ballasted jams, were constructed along 12.2 km (7.6 miles) of the Finney Creek channel. The goal was to alter hydraulic processes that affect aquatic habitat formation along 39 km (24.4 miles) with emphases on 18.5 km (11.5 miles) of lower Finney Creek. Aquatic habitat surveys over a five-year period show an increase in the area of large pools and an increase in residual and maximum pool depth in the lower reach of Finney Creek. Channel cross-sections show a deeper channel at most log jams, better channel definition in the gravel deposits at the head of the log jams, and improved riffle and thalweg development below the log jams. Stream temperature in the upper creek decrease by 1.0 degrees F in the first three years, and 1.1 degrees F in the lowest treated reach over nine

years. Photo points over the restoration time period show that riparian vegetation is recolonizing gravel bars.

Relevant Information: Log jams alter local hydraulics and sediment transport and storage processes that contribute to creation and maintenance of high-quality habitat features. A total of 1881 logs were imported and placed in 181 log jams covering 7.6 miles (12.2 km) of stream. The log jam number density went from 4.2 per mile to 39.3 per mile. In August 2021, the main project area from Gorge Dam to the Sauk River had a density of 2.7 log jams per mile.

NSD 2017

Reference	NSD (Natural Systems Design). 2017. Skagit River large woody debris assessment: connecting LWD to the 2005 Skagit Chinook recovery plan. Report prepared for Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	No		
Topics and Keywords	***Geomorphology:*** change, history, large wood, substrate and sediment. ***Fish and Habitat:*** Fish, survival.									
Species and Life Stages	Chinook.									
Reaches and Spatial extent	Reach 1-13.									

Summary: This report presents a method for developing a set of descriptive conceptual models that explain how large wood in the Skagit River Basin functions to achieve the goals of the 2005 Skagit Chinook Recovery Plan, as well as a method for a comprehensive assessment of large wood resources across Chinook habitat in the Skagit Basin. The seven limiting factors that influence the presence of large woody debris (LWD) include seeding levels, degraded riparian zones, dam operations, sediment and mass wasting, flooding, high water temperatures, and hydromodification. Throughout the Skagit River Basin, LWD forms key riverine habitat features that have a significant impact on hydraulic processes, geomorphology, and salmonid habitat quality. The depletion of LWD has led to extensive degradation of fish habitats throughout the Skagit Basin and region.

NSD presents a conceptual model for four distinct geomorphic sections of the Skagit River:

1) In narrow, high-gradient, headwater Skagit River reaches individual LWD can span the channel and dominate stream bedform and hydraulics.

2) Wider, intermediate-gradient reaches in the middle of the Skagit River system, LWD no longer spans the channel and is often is lodged on the bank, on bars, or in the channel bed.

3) In low-gradient tributaries, single pieces of wood usually do not span channel, but can form snags in the channel that can cause large LWD jams and obstruct large portions of the channel.

4) In wide, low-gradient Skagit River reaches surrounded by historic floodplain, single pieces of wood can lead to the formation of massive LWD jams that can change the course of the river, block river channels, and induce massive floods. In lower reaches of the Skagit River system, LWD jams and jam-related river features have the highest densities of juvenile Chinook across multiple seasons.

NSD presents a metrics matrix for the seven limiting factors that include processes affected and characteristics to measure to better understand the interaction between limiting factors and LWD. Additionally, the report identifies methods for wood inventory and assessment on large and small rivers. This includes using high resolution LiDAR, Green LIDAR, imagery, field verification, and modeling. The report provides recommended metrics for LWD assessment in the Skagit Basin. This included number of jams, number of key members, number of nodes, river complexity index, volume of wood, and number of pools greater than 1 meter depth by reach.

Relevant Information: The report provides guidelines for a comprehensive assessment of large wood in the Skagit Basin. Many of the recommended metrics were measured by the GE-04 Study Team in August 2021. Additionally, available LiDAR, green LiDAR, and aerial photography was used to identify historic location of jams and individual pieces, when the imagery hade high resolution. The conceptual model for four distinct geomorphic sections provides some patterns and trends that were verified as part of the GE-04 study. The model can be refined based on the additional data collected.

Riedel et al. 2020 – Summarized in SY-01 ISR.

Riedel et al. TBD – Skagit River geomorphology inventory report: part 2 – Sauk River to Skagit Estuary. This report will be summarized in the GE-04 USR.

Rothleutner 2017

Reference	Rothleutner, A. D. 2017. Sediment budget of the middle Skagit River, Washington 1937-2015 reveals decadal variations in sediment export and storage. Master's thesis. Western Washington University, Bellingham.								
Source Information	***Type***	Thesis	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** change, history, substrate and sediment, sediment transport and supply.								
Species and Life Stages	None.								
Reaches and Spatial extent	Reach 7-12.								

Summary: The thesis includes an evaluation of historical channel meandering since 1937 of the middle reach Skagit River between Rockport and Sedro-Wooley, Washington (Geomorphic Reach 7-12). The active floodplain has periodically been a significant source of sediment to the lower Skagit River and delta. She examined the geomorphic change and potential sediment production of the middle reach to test whether it is a significant source to the lower river. ArcGIS was used to calculate sediment volume produced by bank erosion versus stored in bars, island, and side channels through time. The results show changes in net sediment production through time, between 2006 through 2015, recruitment of floodplain sediment from the middle reach to the active channel produced approximately 27 percent of the annual sediment mean load measured in Mount Vernon. The sediment source was dominated by lateral incision at rates of 3-8 m/yr in several areas of high-relief (3-15 m) banks characterized by unconsolidated deposits. The results help quantify recent channel dynamics, rates of change, and sources of sediment that influence sediment transport and aggradation patterns, that are important to flood risk and salmon habitat.

Channel width consistently decrease through time along the entire mainstem middle Skagit reach. The overall width decreased from an average of 221.2 m in 1937 to 178.8 m in 2015. Channel widths were generally wider in the confined reach. There is an increase in the amount of erosion in comparison to aggradation in the more recent time periods of 2003-2006 and from 2006-2015. There will likely be a much more seasonal pattern of aggradation and erosion in the future. Erosion will likely be much higher during the winter months with periods of higher flow and more precipitation falling as rain.

Between 2006-2015 the mean annual sediment load from the middle reaches was 630,000 Mg. This accounts for approximately 25 percent of the estimated 2,500,000 Mg annual sediment load calculated from sediment rating curves. However, this value is probably an underestimate because most of the changes identified by the 2D Model for Aggradation and Erosion are large scale. Smaller changes are less likely to be captured. The estimated sediment contributions from the Sauk River are 950,000 Mg.

Relevant Information: Between 1937 and 2015, the overall channel width has decreased by approximately 42 m (138 feet) in the middle Skagit. There has been an increase in the amount of erosion in recent years. The mean annual sediment load for the middle reaches between 2006-2015 was approximately 63,000 Mg. This account for approximately 25 percent of the estimated 2,500,000 Mg annual sediment load calculated from sediment rating curves. Climate change and dam operations can potentially change the amount of sediment being discharged. Therefore, this study provides important information that can be used to understand how the sediment load could change in the future.

Seixas and Veldhuisen 2019

Reference	Seixas, G. B., and C. N. Veldhuisen. 2019. Forest practices and regulatory channel migration zones in the Skagit River basin since the forests and fish report. Report prepared for Skagit River System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** Channel migration, Channel incision, Side and off-channels, Floodplain connectivity, log jam. ***Land Use and Cover:*** Forestry.								
Species and Life Stages	None.								
Reaches and Spatial extent	R9-R11, Sauk River.								

Summary: In Washington State, riparian corridors along fish bearing streams are protected from forest practices. Rivers that show potential for channel migration face additional protections. Channel migration zones (CMZs) are recognized areas adjacent to streams and rivers that are deemed susceptible to channel migration within the next 140 years. Land managers are required to begin their riparian buffers at the outer edge of the CMZ. This protects critical riparian processes for future migrating channels such as large wood recruitment and streamside shading. These protections were put into practice in 2001 under the updated Forest Practice Rules document.

This report assesses the implementation of recognized CMZ zones within the Skagit River basin since the 2001 update. Additionally, CMZs within the basin that were missed are included in this assessment. "Missed" CMZs are sites where channel migration occurred since 2001 or occurred prior to 2001 in aerial photographs that were not analyzed in the original forest practice application. This assessment was done through an analysis of a compiled dataset of aerial photographs, LiDAR derived digital elevation models, and data from forest practice applications.

The results of this assessment found that of the 25 sites that were assessed, 11 sites were recognized as a CMZ and migration occurred, 3 sites were not recognized as a CMZ and migration occurred, 7 sites were not recognized as a CMZ and migration did not occur, and 4 sites were not recognized as a CMZ and migration did not occur. Additionally of the 14 sites that experienced migration only one avulsed and the other 13 migrated due to bank erosion. The authors of this paper propose four possible reasons as to why bank erosion is a more common process than avulsion among study sites. Reason one is that landowners may preferentially avoid avulsion-prone reaches due to easily identifiable risks. Reason two is that the historical removal of large wood may have increased channel incision and disconnected side channels and low-lying floodplains. Reason three, a reduction in sediment supply increased relative incision which again would disconnect side channels and low-lying floodplains. Reason four, it's possible the authors methods of identifying avulsion prone reaches may have overestimated the number of avulsion-prone reaches.

Several conclusions could be drawn from this estimate. Channel migration occurs most commonly at the outer edges of meander bends and along unconfined channels. Additionally, bank erosion was the most common migration process affecting the sites in the dataset.

Relevant Information: Bank erosion appears to be the most common channel migration processes that occurs at recognized CMZ sites within the Skagit River Basin, avulsion is much less common. There are several geomorphic factors that may have led to this observed condition. 1) riparian logging practices that historically removed old growth trees along channel banks decreased the overall rooting depth of floodplain vegetation and increased the likelihood for undercutting of banks. 2) historic removal of log jams disabled their ability to increase the upstream water surface elevation during floods and thus disconnected side channels and low-lying floodplains. Lastly, a decrease in sediment supply could have increase relative incision of the bed and further disconnected side channels and low-lying floodplains.

This is relevant to GE-04 as the lack of CMZs that experienced avulsion provides evidence that the Skagit River system is being impacted by the historic removal of log jams, harvest of trees from the riparian zone, and a decrease in sediment supply.

Seixas et al. 2020

Reference	Seixas, G. B., C. N. Veldhuisen, and M. Olis. 2020. Wood controls on pool spacing, step characteristics and sediment storage in headwater streams of the northwestern Cascade Mountains. Geomorphology 348:106898.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** Large wood, Aquatic habitat and landforms.								
Species and Life Stages	None.								
Reaches and Spatial extent	Headwater streams in Skagit River watershed.								

Summary: This report investigates the relationships between wood, pools, steps, and sediment storage characteristics in northwest Cascade headwater streams. The authors of this paper aim specifically to test three hypotheses.

1) Larger diameter classes of large wood are critical step-keying materials in headwater channels despite narrow channel widths.
2) Wood-keyed steps trap more sediment than clast- and root-keyed steps.
3) The negative relationship between LW frequency and the distance between pools observed elsewhere in large streams extends to headwater streams.

These hypotheses were investigated through a field analysis of 32 sites. These sites spanned a range of channel widths less than 4 meters, covered a range of gradients, were in unlogged and logged forests, and contained either sandstone or phyllite bedrock. Each site was studied across a reach length 30 to 50 times the active channel width. At each site a channel survey was completed which includes a longitudinal profile along with the width of the active channel every 10 meters. Additionally, a wood inventory was completed at every site and all pools exceeding 10 centimeters in height were documented.

The authors classified wood into categories of 2-5, 5-10, 10-20, 20-40, and 40-100 centimeters in diameter. The results of this study showed wood within the 40-100 centimeter (16-39 inches) diameter class has the greatest potential to form key pieces relative to the total piece count associated with step formation in that diameter class. Additionally, the authors note that wood smaller than 10 centimeters (4 inches) diameter plays a significant role in key-step formation within channels that are less than 2 meters (6.6 feet) wide but drops off sharply on wider channels. These findings show that wood in larger size classes are particularly effective at anchoring steps and are critical for step formation in small headwater channels. The observation that smaller wood in channels less than 2 meters wide play a more significant role in key-step formation than in wider channels shows that potential wood function depends on channel size even within a small range of 1- to 4-meter (3.3- to 13.1-feet) width channels.

This report found that wood-keyed steps are significantly more likely to trap sediment than clast- and root-keyed steps. The authors of this report suspect this effect is due to the geometry of most wood pieces having a much larger length compared to their diameter. This increases the likelihood of jamming in between channel banks which thus creates stable structures that accumulates sediment.

This report found that there is a significant correlation between large wood frequency and distance between pools, similar to what has been observed in larger streams. As the frequency of large wood increase the average distance between pools decreases. This emphasizes the importance of large wood in headwater streams to form pools.

Relevant Information: This report gives information on the importance of wood in forming pools, steps, and trapping sediment in small headwater stream in the Cascade region. This is relevant to the project as it provides insight on wood in small width side channels and tributaries. One particularly important finding from this report is that wood smaller than 10 centimeters (4 inches) in diameter plays a significant role in step-pool formation within channels that are less than 2 meters (6.6 ft) wide. This highlights that wood that may not be geomorphically important in the main stem of the Skagit could be geomorphically important in side channels and tributaries.

Smith et al. 2011

Reference	Smith, D., K. Ramsden, and S. Hinton. 2011. Reach level analysis for the middle Skagit River assessment. Report prepared by Skagit River System Cooperative for Skagit Watershed Council, Mount Vernon, Washington.									
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	Yes	***Spatial Data***	Yes		
Topics and Keywords	***Geomorphology:*** Change, History, Floodplain, Side- and off-channel, floodplain connectivity, aquatic habitats and landforms, data gaps. ***Land Use and Cover:*** Land cover, Banks and shoreline. ***Fish and Habitat:*** Habitat, freshwater. ***Modeling Tools:*** Hydrologic.									
Species and Life Stages	Chinook, rearing, spawning.									
Reaches and Spatial extent	R8-11.									

Summary: This report identifies priority reaches within the Middle Skagit River, from Sedro-Wooley upstream to the confluence of the Sauk River. A conceptual model for rating reaches included geomorphic potential, existing habitat function, and floodplain impairment. Skagit Watershed Council contracted with Pacific Northwest National Laboratory (PNNL) to develop a three-dimensional hydrodynamic model covering all of the Middle Skagit study area except the Rockport reach. The model was developed with the Finite Volume Coastal Ocean Model (FV-COM) software to estimate water depth, velocity, and shear stress across the channel and floodplain for the 2-year, 5-year, and 25-year flow.

In order to estimate juvenile Chinook capacity for each reach, the surface area for banks and bars was estimated by measuring lengths from aerial photography. The measured length was multiplied by an average width which was based on field measurements. The area of remaining habitat types was measured in GIS. Then assumed fish capacity was calculated for each habitat type. The highest density of juvenile Chinook were found in natural backwater, natural bank, hydromodified backwater, and natural bars. The most fish were found in Skiyou, Ross Island, Savage, and Cockreham reaches (NPS R10-11, Smith Reach 1-4).

The geomorphic potential refers to potential of the channel within the reach to migrate across its floodplain and create or maintain abundant side-channel, off-channel, and complex mainstem edge habitats. The reaches with the least confinement, largest floodplain areas, and widest floodplain widths occur in the downstream end of the study area and include Skiyou, Ross Island, and Cockreham (NPS R11, Smith Reach 1-3). Baker and Aldon (NPS Reach 6 and 8) reaches had the least floodplain inundation and Rockport reach was not measured.

The Cockreham reach has the highest floodplain impairment based on forest conditions, followed by Skiyou, Cape Horn, Ross Island, and Savage. Aldon and Rockport rated the lowest.

The top three reaches for geomorphic potential, Skiyou, Ross Island, and Cockreham were rated high for both restoration and protection actions. Skiyou was rated “Med/High” for protection because current habitat function was rated as medium, and Ross Island was rated “Med/High” for restoration because floodplain impairment was rated as medium. Savage was also rated "Med/High" for protection because even though it was rated medium for geomorphic function it was rated high for current habitat function.

The report recommends additional modeling, vegetation, habitat, and floodplain impairment data be collected. For specific sites additional data may be useful for understanding project feasibility, field check for existing habitat features, hydrodynamic modeling for individual hydromodifications, photo survey to identify historic channels and migration, and fish modeling of potential new habitat.

Relevant Information The reaches in this study (Smith) roughly match the NPS reaches as follows: NPS R8 (Smith Reach 7,8, and 9), NPS R9 (Smith Reach 5&6), NPS R10 (Smith Reach 3&4), NPS R11 (Smith Reach 1, 2, and 3). The report provides a conceptual model for geomorphic potential, existing habitat function, and floodplain impairment. This can be used to characterize the reaches from Rockport to Sedro Wooley.

Todd et al. 2009

Reference	Todd, S., O. Odum, M. Koschak, and A. McBride. 2009. Quality assurance and methodology for mapping marine shoreline geomorphology. Report by Skagit System Cooperative, La Conner, Washington.								
Source Information	***Type***	Report	***Status***	Final	***Quantitative Data***	No	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** Estuarine habitats and landforms. ***Land Use and Cover:*** Land cover, Banks and shoreline.								
Species and Life Stages	None.								
Reaches and Spatial extent	Skagit Bay.								

Summary: This report describes the methodology implemented for mapping marine shoreline geomorphology in the Puget Sound region. This work was completed by the Salmon and Steelhead Habitat Inventory and Assessment Program. The first draft of this work used a dataset that composed of DNR (Washington Department of Natural Resources) Geology, 10-meter DEMs, ecology drift cells, and DNR hydrography data. The updated quality assurance version of this work relied on a systematic evaluation of recent aerial photos. The intent of this work was to capture a "present day" shoreline geomorphology dataset that could be compared with a "historic" shoreline geomorphology dataset being developed by Puget Sound Nearshore Ecosystem Restoration Program. This could be used to help identify potential nearshore restoration sites.

Relevant Information This dataset maps "present day" shoreline geomorphology at a high level of precision and accuracy within the Puget Sound region, including the Skagit Bay. This dataset could be helpful to inform potential geomorphic changes that have occurred along the Skagit Bay.

USACE 2008

Reference	USACE (U.S. Army Corps of Engineers). 2008. Skagit River flood damage reduction feasibility study, Skagit River basin, sediment budget and fluvial geomorphology. DRAFT. CENWS-ED-TB-HE 6/11/2008. Report prepared by USACE, Seattle District, Washington.								
Source Information	***Type***	Report	***Status***	Draft	***Quantitative Data***	Yes	***Spatial Data***	Yes	
Topics and Keywords	***Geomorphology:*** change, history, climate change, substrate and sediment, sediment transport and supply, data gaps.								
Species and Life Stages	None.								
Reaches and Spatial extent	Reach 1-14, Skagit Bay.								

Summary: This report includes a description of the Skagit River's sediment budget and fluvial geomorphology. The Skagit River channel is fairly stable with the most migration occurring the middle reach. Channel alignment in the upper basin is predominately controlled by geology and the lower river and estuary are primarily controlled by levees and bank protection, The middle reach has intermittent bank protection and the active migration zone is up to 2 miles wide.

The average annual sediment yield at Mount Vernon is in the range of 0.6 to 2.8 mcy (0.5 to 2.1 Tg). The major sources of sediment are the Cascade and Sauk rivers. Approximately half the basin does not contribute sediment because the sediment is stored in reservoirs. Storms with daily discharges greater than 50,000 cfs are a major factor in sediment production. These large discharge events can cause upper basin land disturbances and produce an estimated 21 percent of the average annual sediment yield.

Upstream of PRM 17, the Skagit River bed is composed of gravel, cobble, and boulders. Downstream of PRM 17, the riverbed and nearshore delta bottom are mainly sand. The 2.8 mcy (2.1 Tg) annual suspended sediment (SSC) yield at Mount Vernon is composed of approximately 50 percent sand, 50 percent silt and clay are transported through the lower river and into Skagit Bay.

Since 1931, there has been a long-term trend of sediment deposition in the channels downstream of Sedro-Wooley. There has been an overall averaged bed elevation increase of approximately 2.25 ft since 1931. The bed upstream of PRM 15.8 appears to be rising slightly faster than the overall average. Sand deposition has also been occurring in the estuary and on the delta.

Relevant Information

The study determines an average annual sediment yield at Mount Vernon of 0.5 to 2.1 Tg. Subsequent studies, such as Curran et al. 2016, have reported higher annual sediment yields (2.5 Tg). There has been a long-term trend of sediment deposition in the channels downstream of Sedro-Wooley. If there was more sediment being transported in the Skagit River, the amount of sediment deposition could increase more in the future.

References

Bandaragoda, C., C. Frans, E. Istanbulluoglu, C. Raymond, and L Wasserman. 2015. Hydrologic Impacts of Climate Change in the Skagit River Basin. Final Report Prepared for Skagit Climate Science Consortium. Available at: http://www.skagitclimatescience.org/wp-content/uploads/2016/04/UW-SC2_SkagitDHSVM-glacierModel_FinalReport_2015.pdf

Bandaragoda, C., S. Lee, E. Istanbulluoglu, and A. Hamlet. 2020. Hydrology, stream temperature, and sediment impacts of climate change in the Sauk River basin. Prepared by Hydroshare for Sauk-Suiattle Indian Tribe and Skagit Climate Science Consortium. Abstract available at: http://www.hydroshare.org/resource/e5ad2935979647d6af5f1a9f6bdecdea

Beamer, E., J. Shannahan, K. Wolf, E. Lowery, and D. Pflug. 2010. Freshwater habitat rearing preferences for stream type juvenile Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) in the Skagit River basin: phase 1 study report. Report prepared for Skagit River System Cooperative, La Conner, Washington.

Beechie, T. J., O. Stefankiv, B. Timpane-Padgham, J. E. Hall, G. R. Pess, M. Rowse, M. Liermann, K. Fresh, and M. J. Ford. 2017. Monitoring Salmon Habitat status and trends in Puget Sound: development of sample designs, monitoring metrics, and sampling protocols for large river, floodplain, delta, and nearshore environments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-137, Seattle.

Collins, B. D., D. R. Montgomery, and A. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland Rivers. Can. J. Fish Aquatic Science 59:66-76.

Curran, C. A., E. E. Grossman, M. C., Mastin, and R. L. Huffman. 2016. Sediment load and distribution in the lower Skagit River, Skagit County, Washington. U.S. Geological Survey Scientific Investigations Report 2016–5106. Available at: http://dx.doi.org/10.3133/sir20165106.

Grossman, E. E., A. W. Stevens, P. Dartnell, D. George, and D. Finlayson. 2020. Sediment export and impacts associated with river delta channelization compound estuary vulnerability to sea-level rise, Skagit River Delta, Washington, USA. Marine Geology 430:106336.

Hartson, R. and J.P. Shannahan. 2015. Inventory and Assessment of Hydromodified Bank Structures in the Skagit River Basin Chinook Bearing Streams. Final report submitted to Northwest Indian Fisheries Commission and Environmental Protection Agency. Prepared for The Upper Skagit Indian Tribe Natural Resources Division.

Hood, W. G. 2007a. Large woody debris influences vegetation zonation in an oligohaline tidal marsh. Estuaries and Coasts, 30(3):441-450.

Hood, W. G. 2007b. Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process. Water Resources Research 43: W03409.

Hood, W. G. 2010. Tidal channel meander formation by depositional rather than erosional processes: examples from the prograding Skagit River delta (Washington, USA). Earth Surface Processes and Landforms 25(3):319-330.

Hood, W. G. 2015. Geographic variation in Puget Sound tidal channel planform geometry. Geomorphology 230:98-108.

Hood, W. G. No date. Distribution of large woody debris in river delta tidal marshes: implications for habitat restoration.

Jaeger, K.L., C. A. Curran, S. W. Anderson, S. T. Morris, P.W. Moran, and K. A. Reams. 2017. Suspended sediment, turbidity, and stream water temperature in the Sauk River Basin, Washington, water years 2012–16. U.S. Geological Survey Scientific Investigations Report 2017–5113. Available at https://doi.org/10.3133/sir20175113.

Lee, S-Y, A.F. Hamlet, and E.E. Grossman. 2016. Impacts of Climate Change on Regulated Streamflow, Hydrologic Extremes, Hydropower Production, and Sediment Discharge in the Skagit River Basin. Northwest Science 90(1), 23-43.

Nichols, R. A., and G. L. Ketcheson. 2013. A two-decade watershed approach to stream restoration log jam design and stream recovery monitoring: Finney Creek, Washington. Journal of the American Water Resources Association 49(6):1367-1384.

NSD (Natural Systems Design). 2017. Skagit River large woody debris assessment: connecting LWD to the 2005 Skagit Chinook recovery plan. Report prepared for Skagit Watershed Council, Mount Vernon, Washington.

Riedel, J., S. Sarrantonio, K. Ladig, and M. Larrabee. 2020. DRAFT Skagit River geomorphology inventory report: part I – Gorge Dam to Sauk River. Report prepared by the National Park Service for Seattle City Light.

Riedel, J., S. Sarrantonio, K. Ladig, and M. Larrabee. TBD. DRAFT Skagit River geomorphology inventory report: part 2 – Sauk River to Skagit Estuary. Report prepared by the National Park Service for Seattle City Light.

Rothleutner, A. D. 2017. Sediment budget of the middle Skagit River, Washington 1937-2015 reveals decadal variations in sediment export and storage. Master's thesis. Western Washington University, Bellingham.

Seixas, G. B., and C. N. Veldhuisen. 2019. Forest practices and regulatory channel migration zones in the Skagit River basin since the forests and fish report. Report prepared for Skagit River System Cooperative, La Conner, Washington.

Seixas, G. B., C. N. Veldhuisen, and M. Olis. 2019. Wood controls on pool spacing, step characteristics and sediment storage in headwater streams of the northwestern Cascade Mountains. Geomorphology 348:106898.

Smith, D., K. Ramsden, and S. Hinton. 2011. Reach level analysis for the middle Skagit River assessment. Report prepared by Skagit River System Cooperative for Skagit Watershed Council, Mount Vernon, Washington.

Todd, S., O. Odum, M. Koschak, and A. McBride. 2009. Quality assurance and methodology for mapping marine shoreline geomorphology. Report by Skagit System Cooperative, La Conner, Washington.

USACE (U.S. Army Corps of Engineers). 2008. Skagit River flood damage reduction feasibility study, Skagit River basin, sediment budget and fluvial geomorphology. CENWS-ED-TB-HE 6/11/2008. Report prepared by USACE, Seattle District, Washington.