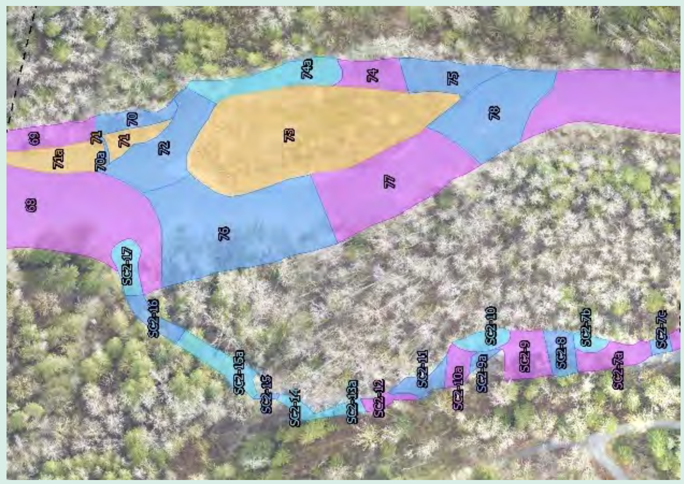
FINAL REPORT ◦ FEBRUARY 2021

Sultan River
Riverine Habitat Monitoring



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Cover graphics:

Upper left: View of a short cascade habitat unit in Operational Reach 2 near river-mile 8 (photo taken September 5, 2020 by Stillwater Sciences).

Top right: View of a low-gradient riffle habitat unit in Operational Reach near river-mile 15 (photo taken September 4, 2020 by Stillwater Sciences).

Bottom left: View of a large woody debris jam in Operational Reach 1 at Side channel 2 (photo taken September 3, 2020 by Stillwater Sciences).

Bottom right: Map excerpt of delineated habitat units in Operational Reach 1 and Side channel 2 near river-mile 1 (map by Stillwater Sciences).

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EXECUTIVE SUMMARY

Stillwater Sciences conducted a riverine habitat survey that entailed characterization and measurement of aquatic habitat features in the river corridor from Culmback Dam (river mile [RM] 16.5) to its confluence with the Skykomish River (RM 0). The study was separated into two efforts that included a survey of the lower 2.7 miles of the Sultan River and its four side channels ("Lower Reach") and a survey of the uppermost (RM 2.7-16.5) Sultan River (Upper Reach"). The Lower Reach habitat survey is required by the Comprehensive Settlement Agreement for the Henry M. Jackson Hydroelectric Project (Project), which includes Culmback Dam operated by the Snohomish Public Utility District (the District). The requirement for a habitat survey was triggered by a significant high-flow event that occurred in winter 2020. Additional tasks executed as part of this work included data synthesis, mapping, analysis, and reporting of all collected data.

Previous surveys were conducted in 2007 and 2010 to provide baseline data as part of the relicensing of the Project and to determine the effects of prior high-flow events that occurred in March 2014 (as reported in Stillwater 2015) and November 2015 (Stillwater 2016). Table ES-1 lists each reach and the year they were surveyed.

Riverine habitat attributes recorded for these studies include in-stream unit subtype (e.g., pools, riffles, glides, islands), measurements of wetted unit surface area dimensions (length and width), unit margin features (lengths of undercut banks and bar edges), and the distribution and characterization of large woody debris (LWD). Subsequent to the 2007 and 2010 surveys, habitat enhancements were made to the Lower Reach including the installation of engineered large wood jams along the margins of the mainstem and side channels, and side-channel enhancements including contouring, dredging, reconnection of historic channels as well as establishment of new channels in select locations.

Table ES-1. Reaches surveyed and the year the survey was conducted.

Reach	Surveyed in 2007?	Surveyed in 2010?	2012	Surveyed in 2014?	Surveyed in 2016?	Surveyed in 2020?
Mainstem (Lower Reach)	Yes	No	LWD installations	Yes	Yes	Yes
Mainstem (Upper Reach)	Yes	No		No	No	Yes
Side channel 1	No	Yes (partial)		Yes	Yes	Yes
Side channel 2	No	Yes		Yes	Yes	Yes
Side channel 3	Yes	No		Yes	Yes	Yes
Side channel 4	No	No		Yes	Yes	Yes
				↑ HIGH FLOW MARCH 2014	↑ HIGH FLOW NOVEMBER 2015	↑ HIGH FLOW JANUARY & FEBRUARY 2020

While it may not be possible to directly attribute habitat changes in the Sultan River system to the winter 2020 storm event, the 2020 study shows that habitat diversity continues to increase when comparisons are made between the 2020 study and studies conducted in 2007, 2010, 2014, and 2016. Habitat diversity, or number of habitat units within the Study Area, has increased between 2007 and 2020 with most of the changes occurring within the side channels in the lowermost Sultan River. Locally, changes in aquatic habitat within the side channels are often occurring near the inlets of these channels and in other reaches where large wood and jams are providing complexity and habitat formation. Overall, low-gradient riffles, pools, and glides are the most abundant habitat subtypes and are represented almost equally in terms of surface area across the Study Area.

Large wood continues to accumulate throughout the Study Area. When comparing the amount of LWD throughout the Sultan River system, the number of LWD jams increased by 186% from 2007 to 2020 and the overall density of LWD pieces and jams increased throughout the Study Area. Between 2016 and 2020, the number of LWD jams in the Lower Reach increased threefold. While much of the LWD is situated above the wetted channel during low flow conditions in the Lower Reach, the remainder of the wood lies within the channel and will likely provide habitat complexity and habitat formation during periods of low and high flow.

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1 STUDY OBJECTIVES AND DESCRIPTION

Stillwater Sciences was retained by Public Utility District No. 1 of Snohomish County (the District) to conduct a riverine habitat survey along the Sultan River during summer 2020. The study entailed characterization and measurement of aquatic habitat features in the river corridor from Culmback Dam (river mile [RM] 16.5) to its confluence with the Skykomish River (RM 0) (Figure 1-1). The study was separated into two efforts that included a survey of the lower 2.7 miles of the Sultan River and its four side channels (hereafter, the "Lower Reach") and a survey of the uppermost (RM 2.7-16.5) Sultan River (hereafter, the "Upper Reach"). The Lower Reach survey was conducted in accordance with FERC licensing requirements associated with the Comprehensive Settlement Agreement for the continued operation of the Jackson Hydroelectric Project, FERC No. 5127 (the Project). The requirement for a habitat survey was triggered by a significant high-flow event that occurred in winter 2020.

1.1 Previous Surveys

The entire mainstem and one of its lower-reach side channels (SC-3) were originally surveyed as part of the Project relicensing process in 2007 and reported in *Revised Study Plan 18: Riverine, Riparian, and Wetland Habitat Assessment* (hereafter referenced as RSP 18) by the District (Stillwater Sciences 2007). In 2010, habitat was surveyed in two of the lower-reach side channels (SC-1 and SC-2), and a geomorphic assessment was conducted to inform wood placement and channel enhancement feasibility (Stillwater Sciences 2010). Construction occurred in 2012 with inlet and outlet enhancements and boulder placement implemented in all four of the mapped side channels (SC-1, SC-2, SC-3, and SC-4). Enhancements also included multiple log structures and individual logs in the side channels and eight large engineered large woody debris (LWD) structures in the mainstem. In the Upper Reach, three engineered structures were installed at RMs 10.0, 9.4, and 5.4 since the previous survey.

Repeat habitat surveys of the Lower Reach occurred in summer 2014 and 2016 (and reported in Stillwater Sciences 2015 and 2016). The need for these two surveys was triggered by high-flow events (termed "process flows") required by the Fisheries and Habitat Monitoring Plan under Article 410 for the continued operation of the Project. A daily (24-hr) mean flow exceeding 4,100 cubic feet per second (cfs) is considered channel maintenance flow and flow exceeding 6,500 cfs is considered channel forming flow as summarized in the FERC license order. The primary objective of resurveying in 2014 and 2016 was to identify any significant changes that occurred following the March 2014 and November 2015 high-flow events that could affect fish habitat in the lower river. As recorded at the U.S. Geological Survey (USGS) streamflow gage below the Project powerplant near RM 4.5, these two high-flow events reached 4,940 and 7,320 cfs. These flows had estimated flood-frequency return periods of approximately 3.1 and 6.4 years, respectively (period of gage record is water years 1984–2020). The two resurveys also provided a means to identify changes associated with the habitat enhancements constructed in 2012 and later.

1.2 Present Survey Objectives

Need for the present study was triggered by the high-flow event of winter 2020, which peaked at approximately 13,900 cfs on February 1, 2020, corresponding to a flood return period of approximately 31 years. This event was the third largest flow recorded since the gage was established in 1984 and the largest event since Project relicensing in 2007. Given the flood's significance and potential for riverine habitat change, the present study entailed re-assessment of riverine habitat changes in the Lower Reach (RM 0–2.7) and the Upper Reach (RM 2.7–16.5) (Figure 1-1), the latter of which had not been surveyed since the 2007 baseline surveys. This study thus evaluates habitat changes in the preceding 13 years, with most presumably associated with the 2020 high flows. Changes resulting from the constructed habitat enhancements and their interaction with the high-flow event are also considered.

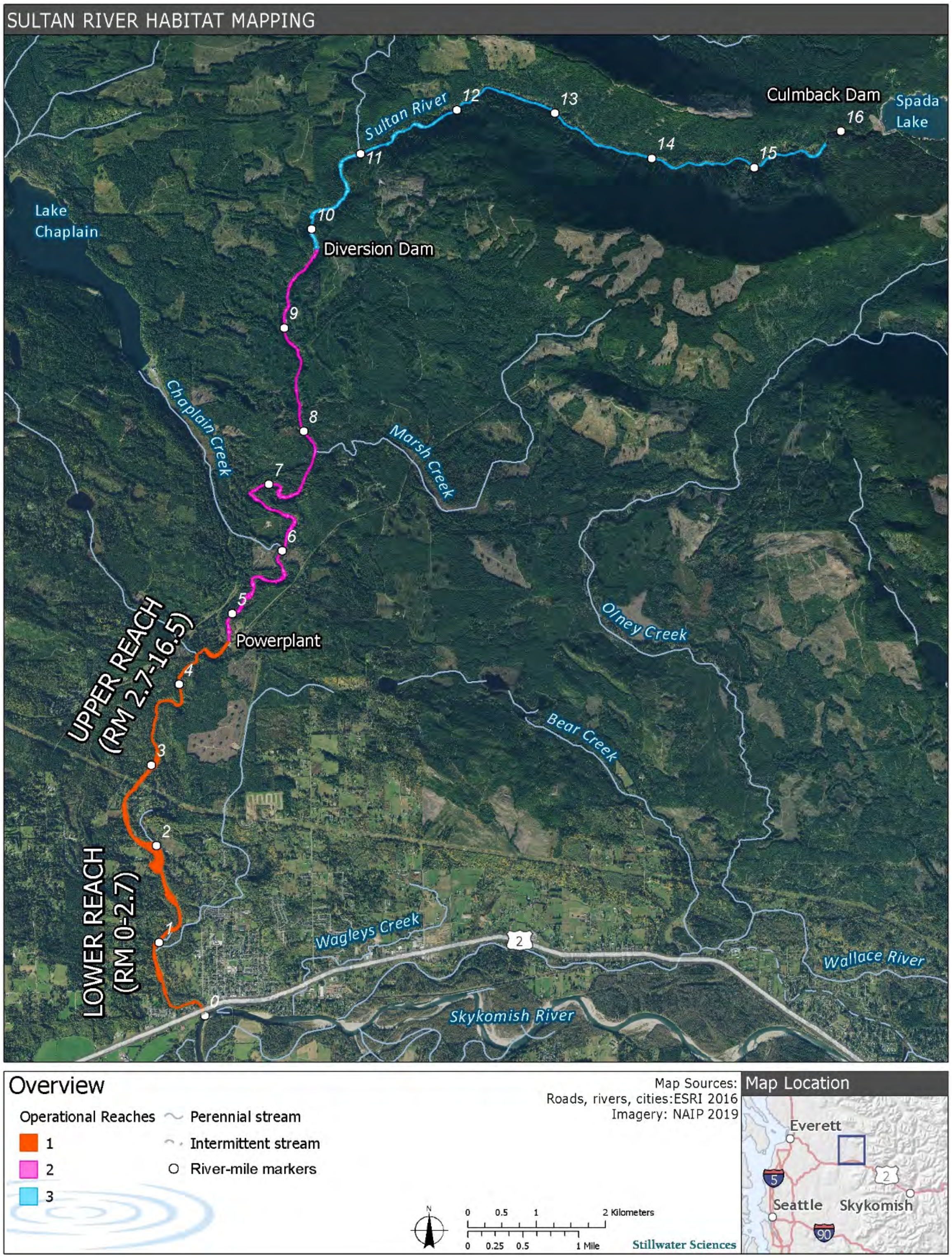

Figure 1-1. Overview map of the Sultan River, indicating locations of Project facilities, the extent of the three Operational Reaches, and the "Upper" and "Lower" habitat-mapping reaches.

1.3 Study Area

As part of the Project's relicensing process in 2007, RSP 18 was completed to address FERC requirements for a detailed description of aquatic and terrestrial resources between Culmback Dam and the mouth of the Sultan River. The Sultan River below Culmback Dam flows through a highly confined, steep channel for 13 of its 16.5-mile length to its confluence with the Skykomish River. The canyon that confines the river creates a high-energy environment that significantly affects the nature of instream habitats found within the river. At approximately RM 3.3, however, the river transitions into a less confined, alluvial valley where the channel widens and gravels from upstream sources deposit and accumulate. The river's longitudinal profile depicted in Figure 1-2 is based on Lidar elevation data collected in spring 2020 (details of the remote-sensing data are presented in Section 2). The Project's three Operational Reaches (ORs), distinguished by the locations of the main Project facilities, are shown and defined in Figures 1-1 and 1-2. For purposes of organizing and comparing past and present habitat-mapping activities, the river is separated into a "Lower Reach" (RM 0–2.7) and an "Upper Reach" (RM 2.7–16.5) that overlap the ORs (see Figures 1-1 and 1-2). At the RM 2.7 demarcation between the two mapping reaches, the river is crossed by Bonneville Power Administration (BPA) transmission lines (see Figure 1-1).

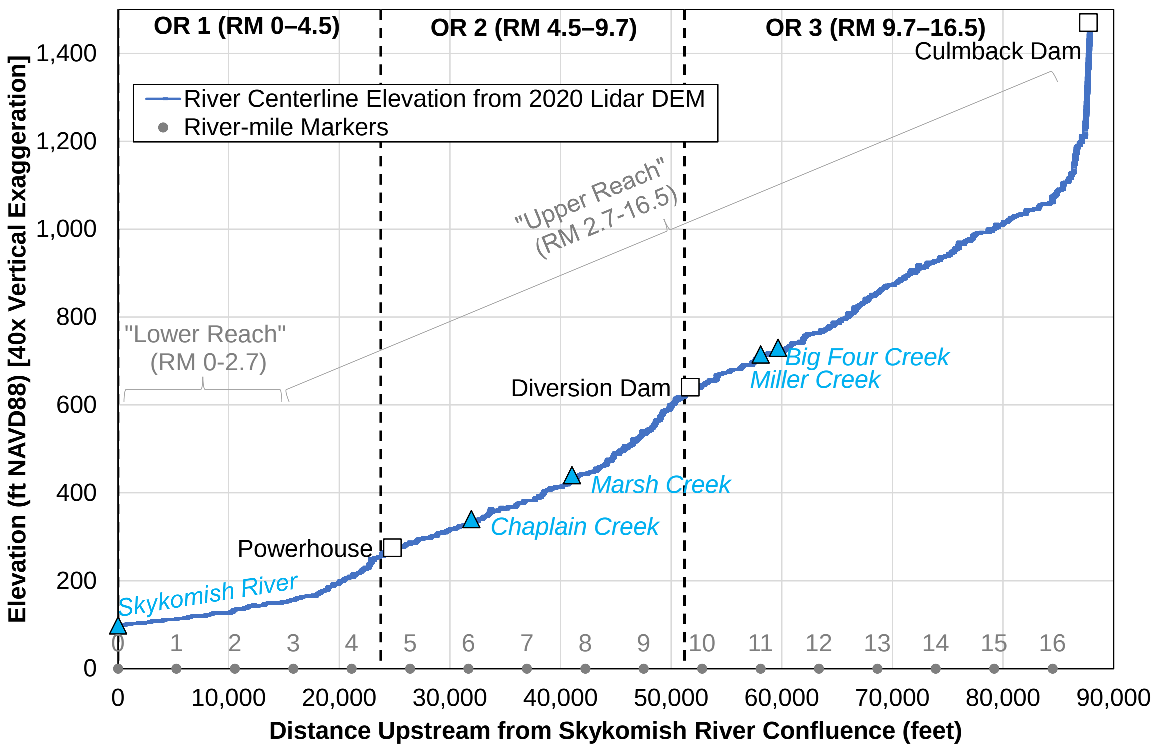

Figure 1-2. Longitudinal profile depiction of mainstem Sultan River channel elevations from the Skykomish River to Culmback Dam (source: Lidar data from GEO-1 and GIS Surveyors; analysis by Stillwater Sciences).

Several aquatic habitat changes in the Sultan River occurred in late 2020 after surveys conducted by Stillwater Sciences in August and September 2020 were completed. The first change involved the action of selectively dismantling a log jam impacting the property of several landowners along lower SC-2. The remaining changes involved actions where an array of logs were placed by helicopter at RM 5.4, 9.4, and 10.0 for habitat enhancement. Log placements were funded through the Fish Habitat Enhancement account established in the current license.

1.4 Fish Species

The river and its side channels currently provide spawning and rearing habitat for numerous species of resident and anadromous salmonids (Stillwater Sciences 2007). The reach between Culmback Dam and the Diversion Dam (RM 9.7) historically has supported self-sustaining stocks of resident rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*O. clarki*), and mountain whitefish (*Prosopium williamsoni*). Anadromous species, including Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), chum salmon *(O. keta*), coastal cutthroat trout (*O. clarki*), and steelhead trout (*O. mykiss*) have utilized spawning and rearing habitats within the river downstream of the Diversion Dam, which until recently was a barrier to upstream passage. Bull trout (*Salvelinus confluentus*) have not been observed spawning in the Sultan River but are known to opportunistically use the lower river as rearing/foraging habitat during odd years when the abundance of pink salmon is high and dislodged eggs are readily available. Each of these fish species depend on aquatic habitats affected by Project operations: it is therefore important to collect information on habitats within the affected reach on an ongoing basis.

Recent enhancements completed in 2016 improved upstream and downstream volitional fish passage at the Diversion Dam through the removal of a concrete sluiceway, excavation of the streambed to the historic channel elevation, and the addition of a new sluiceway gate to maintain structure function and enable unrestricted access to six miles of habitat upstream. These fish-passage improvements allow anadromous fish to freely migrate upstream, and for downstream access to be free from manmade obstructions. Within two weeks of completion of these fish passage improvements, coho salmon for the first time in 90 years were observed spawning five miles upstream of the Diversion Dam. In addition to improvements made for fish passage, a new water temperature conditioning structure at Culmback Dam was installed in 2018 to provide a seasonally appropriate temperature regime for targeted fish and macroinvertebrate species.

2 METHODS

Methods for the 2020 study adhered closely to those established in RSP 18 (Stillwater Sciences 2007) for the entire river extent, and to those studies repeated during the intervening years in the Lower Reach (Stillwater Sciences 2010, 2015, 2016). The survey and analytical methods described below relied primarily upon mapping of habitat units and inventorying of LWD using a combination of remote-sensing data and field-based observations conducted in summer 2020. Maps illustrating habitat units for the Lower Reach are included in Appendix A. Maps illustrating LWD by habitat unit are included in Appendix B. Maps illustrating habitat units for the Upper Reach are included in Appendix C.

2.1 Methods Established During the 2007 Habitat Mapping Survey

The Lower and Upper reaches were originally mapped, and their riverine habitat attributes quantified, in 2007 using a combination of remote-sensing data and a comprehensive field survey. A reach-wide field survey was necessary because available aerial imagery lacked sufficient resolution and unobstructed views of the river. The 2007 mapping of riverine habitat units and related features, including LWD, followed the field-based classification systems and inventory methodology adapted from those commonly used in Washington State (Pleus et al. 1999, Schuett-Hames et al. 1999). The data were synthesized in a geographical information system (GIS) and resulted in a comprehensive spatial data product consisting of delineated habitat units and inventoried LWD pieces and jams. Delineated units were identified by their Natural Sequence Order (NSO) number within the three ORs (e.g., unit 1-3 was the third unit delineated in OR1). An example of the habitat units mapped in 2007 is shown in Figure 2-1. Maps illustrating habitat units mapped in 2007 are included in Appendix D.

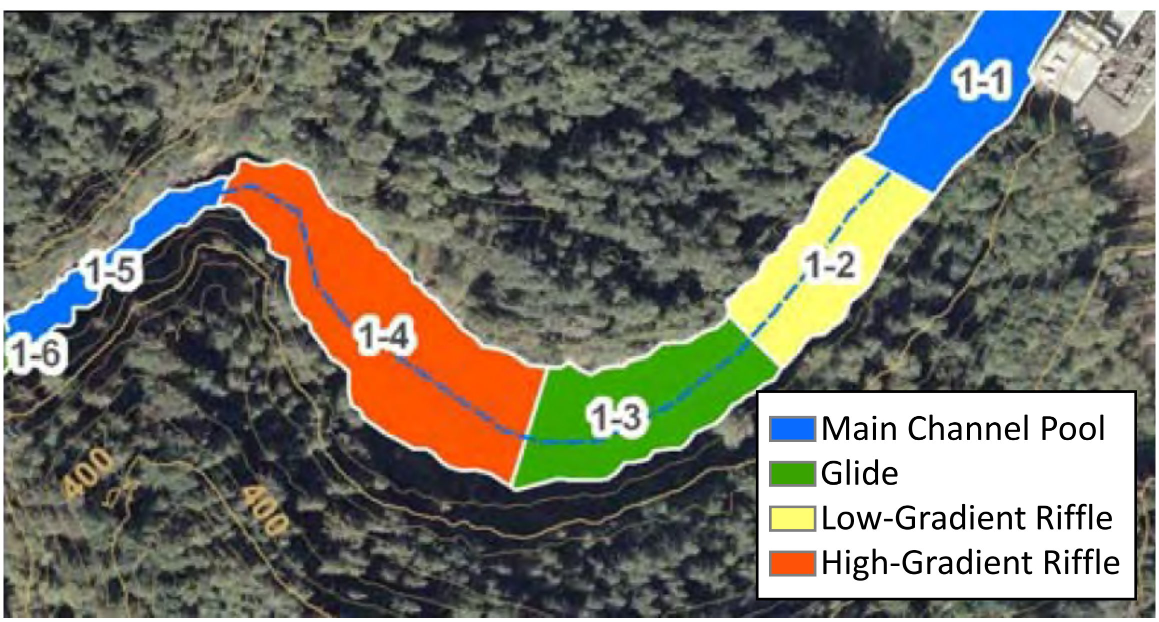

Figure 2-1. Example of riverine habitat distributions by habitat type classifications mapped in 2007 (excerpt from Figure 4-9 in Stillwater Sciences 2007).

The 2007 data were used to describe the dominant attributes of habitat-unit types and LWD occurrences at the scale of the Operational Reaches: OR 1 (RM 0–4.95), OR 2 (RM 4.95–10.07), and OR 3 (RM 10.07–16.17) (see Figures 1-1 and 1-2). The attributes included the relative proportions of habitat-unit types (e.g., pools vs. riffles), pool depths and pool-forming factors, LWD loading, and bar-edge and undercut-bank habitat. As was acknowledged in the accompanying technical report, the spatial accuracy of the unit transitions and wetted areas and LWD occurrences was limited due to the original mapping approach. Specifically, the field mapping entailed hand-drawing the observed features on printed maps, which were then scanned and digitized for subsequent analysis in a GIS. Thus, the spatial extent and positioning of the habitat-unit areas and LWD points contained an unknown degree of potential errors accrued from the initial visual interpretation in the field and subsequent digital translation in the GIS. These spatial errors did not affect the associated analyses presented in the 2007 report, however, because the unit-type areas and LWD occurrences were integrated at the scale of the river's operational reaches.

2.2 2020 Remote-Sensing Data Collection

Under a separate contract with the District, remote-sensing imagery and elevation data were collected in spring 2020 following the winter high-flow event to capture physical conditions along the entire river corridor between Culmback Dam and the Skykomish River. These data are described in Table 2-1. Graphical examples of the processed aerial imagery and Lidar bare-earth digital elevation model (DEM) surface are shown in Figure 2-2. Bathymetry point data were also collected in the Lower Reach (RM 0–2.7) but were not delivered as a compiled elevation surface that could be readily merged with the Lidar DEM, and so their utility for informing field crews of channel depths was limited.

Table 2-1. Remote-sensing data collected in spring 2020 for the District in the Lower and Upper reaches.

Data Type	Collection Method *	Location Collected	Collection Dates	Vendor	Delivered Product(s)	Processed Resolution of Elevation Surface
Aerial Imagery	Camera mounted to aircraft	Upper and Lower reaches (RMs 0–16.5)	March 26, 2020 and April 1, 2020	GEO-1 (collection) GIS Surveyors (processing)	4-band ortho-mosaic	1-foot
Topography	Lidar sensor mounted to aircraft				Point-cloud, bare-earth DTM surface, first-return DSM surface	1-foot (based on Lidar point density of 40–60 pts/m^2)
Bathymetry	Single-beam sonar transducer mounted to paddlecraft	Lower Reach (RMs 0–2.7)	June 22–27, 2020	David Evans and Assoc.	Point elevation data	No surface created

* Technical specifications of each dataset's collection and processing methods may be requested from the vendors.

a)

b)

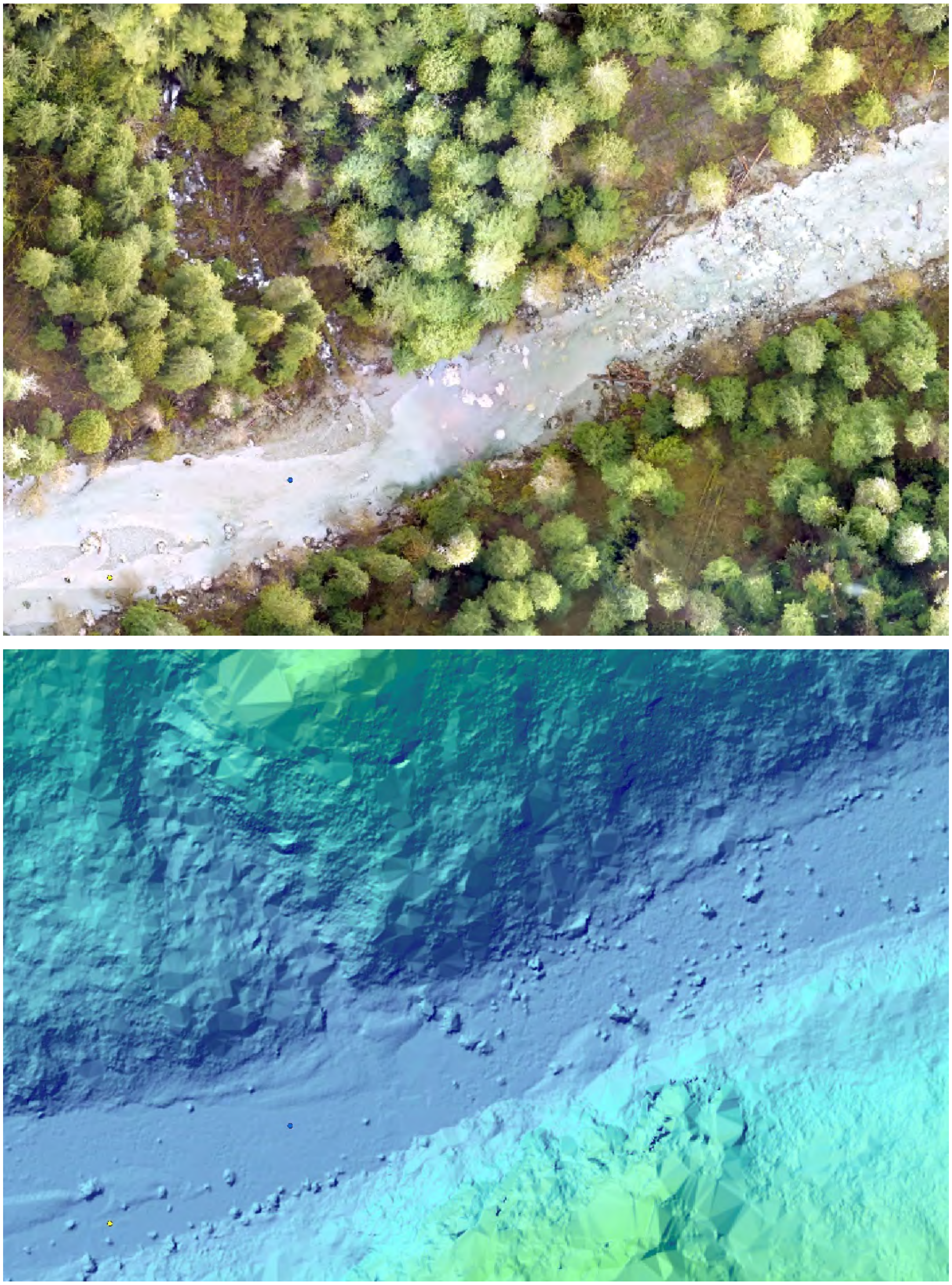

Figure 2-2. Examples of (a) processed aerial orthomosaic and (b) Lidar-acquired bare-earth topographic surface of the Sultan River at the same location near RM 11, collected by GEO-1 and processed by GIS Surveyors in spring 2020.

Stillwater Sciences received the spring 2020 remote-sensing data from the District and evaluated its suitability for aiding a new delineation of riverine habitat unit and inventory of LWD. The new imagery was found to be vastly superior to the ca. 2007 imagery in both resolution and coverage of the wetted channel, allowing for a high-resolution, mostly unobstructed view of the entire river corridor.

2.3 GIS Mapping of Habitat Units and LWD in the Upper Reach

While the methods for the Lower Reach survey relied entirely on field observations, the Upper Reach surveys relied on a hybrid GIS and field-survey approach. Thus, the mapping of habitat-unit areas and LWD pieces and jams in the Upper Reach in 2020 was primarily achieved in GIS (ESRI ArcMap 10.8) using the spring 2020 aerial imagery supplemented by the Lidar bare-earth DEM. Detailed description of field methods employed in both reaches are presented in Section 2.4 below.

GIS mapping of the Upper Reach started with delineation of the wetted channel edges (boundaries) visible in the spring 2020 aerial imagery, using heads-up digitizing at a scale of 1:500. The 2007 habitat units were then overlain upon the 2020 imagery and wetted channel boundaries, and a thorough review of the habitat units was performed to identify changed conditions since 2007. The habitat-unit criteria established in the 2007 study, originally adapted from Flosi et al. (1998) and Pleus et al. (1999), have been slightly refined in recent years based on re-mapping efforts in the Lower Reach and consideration of newer published literature (e.g., Beechie et al. 2005, Flosi et al. 2010, Bisson et al. 2017). Table 2-2 presents the updated criteria used to identify primary and sub-unit habitat types in the Lower and Upper reaches.

Table 2-2. Criteria used to identify primary and sub-unit habitat types in both reaches.

Core Habitat Unit Type (Code)	Sub-Habitat Unit Type (Code) *	Criteria				
		Description	Channel Position	Gradient	Relative Velocity	Relative Roughness
Riffle (R)	Glide (GLD)	Low-gradient, wide uniform channel bottom with sand, gravel, or cobble substrates, and having low to moderate flow velocities lacking pronounced turbulence.	Main, center	Very low (<<4%)	Low	Mixed (sand–cobbles)
	Low-Gradient Riffle (LGR)	Shallow, low-gradient (<4%) reaches with swiftly flowing, turbulent water with some partially exposed gravel to cobble-dominated substrate.	Main, center	Low (<4%)	Moderate	Coarse (gravels–cobbles)
	High-Gradient Riffle (HGR)	Steep (>4%) sections of moderately deep, swift, and very turbulent water with high exposure of cobble to boulder-dominated substrate. Formerly referred to as “Rapid (RPD).”	Main, center	High (>4%)	Fast	Coarser (cobbles–boulders)

Core Habitat Unit Type (Code)	Sub-Habitat Unit Type (Code) *	Criteria				
		Description	**Channel Position**	**Gradient**	**Relative Velocity**	**Relative Roughness**
Riffle (R)	Cascade (CAS)	The steepest riffle habitat, consisting of alternating small waterfalls and small shallow pools composed of boulders and bedrock.	Main, center	Very high (>>4%)	Very fast	Very coarse (boulders–bedrock)
Pool (P)	Main-channel Pool (MCP)	Scour-formed pool centered along the main-channel (>60% of channel width) with slow velocities and composed of variable substrates.	Main, center	Very low (<<4%)	Low	Mixed (sand–cobbles)
	Lateral (Scour) Pool (SCP)	Scour-formed pool along channel margin (<60% of channel width), typically formed by flow impinging against a partial channel-bank obstruction (e.g., bedrock, boulder, LWD), with slow velocities and composed of variable substrates.	Main, margin	Very low (<<4%)	Low	Mixed (sand–cobbles)
	Backwater Pool (BKW)	Shallow, eddy-scour formed pool within channel margin formed by obstruction (e.g., bedrock, boulder, LWD), with slow velocities and composed of finer substrates.	Main, margin	Very low (<<4%)	Very low	Fine (sand–gravels)
Other (OT)	Island (ISL)	Large bars within the stream channel that are relatively stable, usually vegetated, and surrounded by water. Minimum length of an island unit being at least two times the bankfull channel width with the terrestrial area vegetated by perennial plants two meters or greater in height.	Main, center	Very low (<<4%)	N/A	Mixed (sand–boulders)

* Subtype designations and definitions are adapted from Flosi et al. 1998 and Edelen 2005.

Consistent with the 2007 study, the minimum mapping unit size considered in both GIS and the field was set by the unit's wetted width, whereby only those habitat units whose apparent lengths equal or exceed their apparent wetted widths were delineated. Thus, undersized sub-units were either subsumed within their larger neighboring units or used to mark the boundary between two adjoining units. For example, two neighboring pool units separated by a low-gradient riffle that was shorter than its wetted width were mapped separately, with their border bisecting the short (and unmapped) riffle.

The stream gradient of riffle units was originally informed quantitatively during the 2007 study through generation of a classified centerline of the river segmented with assigned slope breaks based on the older Lidar dataset. In keeping with this approach, a new river centerline was generated in the GIS that accounted for the 2020 centerline position (interpreted from the aerial imagery) and slope (contoured from the Lidar topography) (see Figure 1-2).

To the extent possible, the pool-forming factors adapted from Pleus et al. (1999) and employed in the 2007 study were again attributed to the pool units, which included bedrock, boulders, streambanks, and LWD (see Section 2.4 below). However, the field surveys subsequently demonstrated that pool-forming factors could not be reliably identified in the GIS absent ground-truthing, due to the inability to visually discern boulders and bedrock in the aerial imagery (see results in Section 3.2.1 Habitat Unit Composition, below).

Mapping and basic characterization of LWD pieces and jams throughout the Upper Reach in the GIS analysis followed an efficient methodology given the challenges inherent in visually interpreting these often small and submerged features in the imagery. Observed LWD was classified into two categories: individual pieces or debris jams. The centerline and total apparent length of each individual LWD piece was digitized and attributed with its location within the river channel (bankfull channel, wetted mid-channel, or wetted channel). An LWD jam was defined as an accumulation of >10 downed trees/rootwads that each exceed 20 centimeters (cm) in diameter, exceed 1.8 meters (m; 6 feet [ft]), and are physically interlocked with one another (Schuett-Hames et al. 1999). The areal extent of each distinct LWD jam was digitized and attributed with its position in the river channel.

2.4 2020 Field Mapping

The field methods employed in the Lower and Upper reaches to characterize riverine habitat units and associated LWD generally followed the same methods from RSP 18. The entirety of the Lower Reach was surveyed, and approximately one-third (4.5 miles) of the Upper Reach was surveyed in the field. Surveys were conducted between August 31, 2020 and September 7, 2020. Flows during the survey were maintained by dam releases to approximate the discharge range experienced during the previous surveys (Table 2-3). Examples of field data collection forms and criteria are provided in Appendix E.

Table 2-3. Daily mean discharge during the previous and current field surveys.

Dates of Habitat Survey	Daily Mean Discharge (cfs)	
	USGS gage 12138160 below the Powerplant (at RM 4.5)	**USGS gage 12137800 below the Diversion Dam (at RM 9.7)**
2007: 6/19–7/10	310–608 A	98–208 A
2010: 5/26–5/28	571–642 A	189–207 A
2014: 7/28–7/31	331–543 A	103 A
2016: 7/11–7/14	322–336 A	117–121 A
2020: 8/31–9/7	330–442 A	109–123 P

Abbreviations: A=data value approved by the USGS; P=provisional data subject to refinement by the USGS.

2.4.1 Lower Reach survey

2.4.1.1 Habitat units

Habitat units in the mainstem river and its four side channels in the Lower Reach (RM 0–2.7) were surveyed during August 31, 2020 through September 3, 2020. Fieldwork involved a 2-person crew recording habitat attribute data in each NSO unit while walking and wading upstream along the river from the mouth to RM 2.7. Example field data collection forms and criteria are provided in Appendix E. Flows during the survey (330–345 cfs) were maintained by Project operations to match the discharge experienced during the previous surveys. Prior to enhancements, SC-1 and SC-2 were only activated at higher flows; therefore, the 2010 survey of these two side channels was conducted at a higher discharge (see Table 2-3).

The field crew surveyed each unit sequentially to identify habitat-unit boundaries and associated attributes. Mapping of habitat-unit boundary changes was conducted on printed base maps and datasheets or a handheld electronic tablet, depending on the degree of perceived unit change. Data were collected in a hierarchical manner to first identify or confirm previous habitat-unit boundaries, to verify or assign habitat subtype, and to define the unit's position within the lateral channel (see Table 2-2). These first-order, reach-scale data were recorded using the same alphanumeric coding system established in RSP 18 that assigned: (1) a unique numeric data identifier (NSO unit number); (2) a primary habitat unit type (e.g., pool, riffle, or other); (3) a habitat subtype (e.g., low-gradient riffle, main-channel pool); and (4) a ranking that defined the degree to which the unit occupied the wetted channel. The latter included primary main-channel units (Category 1), secondary main-channel habitat units (i.e., units that did not span the entire river channel) (Category 2), and side channel habitat units separated from the main channel by an island (Category 3). Islands (Category 3) were identified according to Schuett-Hames et al. (1999, who defined the minimum length of an island unit being at least two times the bankfull channel width with the terrestrial area vegetated by perennial plants taller than 2 m (6.6 ft).

Additional data, including photos and unit dimension measurements and lengths of undercut banks, were collected for each habitat unit. Length, average depth (except in pool habitat units), and three wetted-width measurements were either verified from the previous study or recorded for each habitat unit that were either newly delineated (as in the side channels) or re-delineated where habitat units had changed since the last survey. Additional information was recorded for pools, including maximum depth, residual pool depth, and the dominant factor forming the pool according to the criteria given in Pleus et al. (1999) (Table 2-4).

Table 2-4. Pool-forming factors and associated field codes.

Pool-forming factor	Field code
LWD log(s)	1
LWD rootwad(s)	2
LWD jam	3
Roots of standing tree(s) or stump(s)	4
Boulder(s)	5
Bedrock	6
Channel bedform	7
Resistant bank	8
Artificial bank	9
Beaver dam	10
Other/Unknown	11

The only deviation from previous survey methods established in the Lower Reach was the omission of estimating extent of bar edges due to variability and uncertainty encountered in previous bar-edge habitat estimates (Stillwater 2016).

2.4.1.2 LWD inventory

Survey methods to characterize and enumerate LWD within the Lower Reach followed methods refined for the Timber Fish and Wildlife Monitoring Program (Schuett-Hames et al. 1999). Deviations from survey methods included consolidating LWD into size categories and characterizing LWD in debris jams by tallying individual pieces and rootwads, as was done in 2007, 2014, and 2016. The LWD locations were surveyed using GPS. Example field data collection forms and criteria are provided in Appendix C.

The LWD categories and attributes are presented in Table 2-5. LWD was defined as dead logs, limbs, or rootwads partially or entirely located within the bankfull channel. LWD was enumerated according to minimum size and length criteria. Individually tallied downed logs and rootwads had a minimum length of 2 m (6.6 ft) and a minimum mid-point diameter of 20 cm (0.7 ft). The total length for each piece was recorded and a diameter class was assigned. Diameter classes were defined as 20–40 cm, 40–60 cm, and >60 cm. The position of LWD within the channel was recorded as either primarily (>50%) within the wetted channel (zone 1) or within the bankfull channel width (zone 2). Additional LWD data attributes recorded were:

- stability or anchor feature—root system, greater than 50% diameter buried at some point along length, pinned, or unstable (Schuett-Hames et al. 1999);
- species class—conifer, deciduous, or unknown;
- decay class—1–5 where 1 indicates the lowest state of decay and 5 indicates the highest (Robison and Beschta 1990, as cited in Schuett-Hames et al. 1999); and
- presence or absence of an intact rootwad.

Table 2-5. Large woody debris (LWD) attributes.

LWD Category	LWD Attribute
LWD piece	Length
	Diameter
	Decay Class
	Species Class (conifer, deciduous)
	Rootwad (yes, no)
	Anchoring (bed, bank)
	Channel Position (bank, mid-channel, bar)
LWD jam	Number of Pieces
	Dimension (length, width, height)
	Channel Position (bank, mid-channel, bar)
	Percent of Channel Width
	Largest Piece Size

In addition to individual pieces of LWD, debris jams were surveyed using GPS and their attributes were recorded on data collection forms (see Table 2-5). The criteria for identifying debris jams were the accumulation of ≥10 pieces of interlocked LWD pieces or rootwads were

≥20 cm in diameter and >1.8 m (6 ft) in length, and the majority of the debris jam was located within the wetted or bankfull channel (Schuett-Hames et al. 1999). Attribute data recorded for debris jams included a tally of all pieces and rootwads meeting the criteria, and approximate length, width, and height dimensions. Specific diameter and length measurements were recorded for the most prominent individual piece within each jam. All LWD locations were identified by recording the associated habitat unit NSO in addition to other data described above. The location and characteristics of engineered log jams, log structures, single placed logs, were noted separately from the naturally occurring LWD.

2.4.1.3 Channel substrate characterization

Particle-size distributions of channel bed substrates were assessed to help evaluate suitability of spawning habitat quality for anadromous fish known to inhabit the lower river. Sediment sizes are typically reported as percentiles of the intermediate diameter of sediment clasts on a bar or the bed of the river, notated as “D” with a subscript representing the percentage of particles smaller than that size (so, for example, D_{50} is the 50th percentile, or median substrate size) (Wolman 1954). Median particle sizes (D_{50}) ranging from 20 to 60 millimeters (mm), with less than 10% of particles smaller than 0.85 mm in diameter, are considered suitable substrate size for spawning of anadromous fish (Kondolf and Wolman 1993, Kondolf 2000, Riebe et al. 2014).

Field measurement of sediment character followed traditional pebble count methods (Wolman 1954, Bunte and Abt 2001) in one mainstem habitat unit (NSO 1-89) and three side channel units (SC-1 11I, SC-2 16, and SC-4 1P), each of which had been surveyed during previous studies. Pebble-count measurements recorded the intermediate-axis diameter of 100 particles at each site. Particle-size percentiles were computed from the cumulative distribution curve produced from the measurements recorded at each site.

2.4.2 Upper Reach methods

The goal of the field surveys in the Upper Reach (RM 2.7–16.5) was to supplement the GIS-based delineation of habitat units and LWD to create an updated account of conditions throughout the reach. The survey’s objectives were to: (1) verify, or “ground-truth,” the delineation of habitat units and LWD completed during the GIS analysis; and (2) collect detailed information on habitat units and LWD at the scale of the 2007 survey. A total of 4.6 RMs were field surveyed which represents 35% of the Upper Reach study area.

Fieldwork occurred on September 4–7, 2020 and involved a 2-person crew recording habitat-unit and LWD attribute data in each NSO unit while moving either upstream or downstream along the river in two segments in OR 2 (RM 4.7–5.8 and 7.5–8.8) and two segments in OR 3 (RM 9.8–10.9 and 14.4–15.5). Selection of these segments was based on several factors, including representation of multiple habitat-unit types, occurrence of known geomorphic change since the 2007 survey (e.g., debris flows), and safe access opportunities. Flow conditions were similar to those experienced during the 2007 surveys in the Upper Reach (see Table 2-3). The field crew utilized an electronic GPS-enabled data tablet pre-loaded with aerial imagery and the 2020 habitat unit and LWD shapefiles produced during the GIS analysis. Due to equipment malfunction with the tablet, back-up printed map tiles and datasheets presenting the same data layers were used during most of the field effort. The field crew assessed the units by walking, wading, and swimming through each NSO unit.

Within each unit, the following information was collected in a systematic manner:

- Habitat unit—unit identification number, core unit type, sub-unit type, dimensions (total length, average wetted width), pool depth, pool-forming factor, and dominant bed substrate size classes, or sediment facies (Buffington and Montgomery 1999) (see Tables 2-2 and 2-4);
- Individual LWD rootwad or piece—associated habitat unit identification number, diameter class, total length, position zone in wetted channel, rootwad retention, anchor feature, species class, decay class, and key piece quantity (see Table 2-5); and
- LWD jam—associated habitat unit identification number, jam identification number, position zone in wetted channel, presence in mid-channel, tally of rootwads and pieces, dimensions of key piece(s), and total jam dimensions (length, width, height) (see Table 2-5).

Where the GIS-mapped habitat units or LWD apparently differed from those observed in the field, the field crew re-mapped the subject features using the tablet or printed map tiles, and they identified any systematic errors in the mapping that could be applied to other areas that were not visited during the field survey.

All pools were accessed by field crews by swimming through most of the unit. Maximum pool depth recorded manually by field crews was set to 10 ft due to concerns with measurement accuracy at greater depths. Pool-forming factors were assessed in each pool unit. This work demonstrated that these factors had not been accurately identified in the GIS mapping to satisfactory levels, with the primary challenge being the inability to consistently differentiate bedrock and boulder pool-forming factors in GIS.

2.5 Data Transfer and QA/QC

Upon completion of the Lower Reach and Upper Reach field surveys, all recorded data, photos, and other field notes were transferred to local computer servers and organized with the other project data. All printed map tiles and datasheets were scanned, geo-referenced, digitized, and assigned classification attributes for use in the project’s GIS database. All spatial data compiled in the geodatabase were reviewed jointly by the field and GIS leads to ensure accuracy in the data transfer. The compiled data were then organized for use in the data analyses and reporting activities.

3 2020 RESULTS

This section presents the results from the habitat mapping and LWD inventory conducted in summer 2020. Results are presented separately for the Lower and Upper reaches, given the differences in their survey methods. Comparisons of the 2020 results to those from previous years are subsequently presented in the Discussion section.

3.1 Lower Reach Survey Results

3.1.1 Habitat unit composition

3.1.1.1 Primary units

Tables 3-1 through 3-5 present the results of habitat unit mapping in the Lower Reach (RM 0–2.7). A total of 206 in-river habitat units were surveyed within the Lower Reach (Table 3-1). Riffles were the most frequently observed primary habitat unit type (44%), with glides being the most frequently observed subtype (34%). There was only one high-gradient riffle observed: it was found in the mainstem channel. These proportions roughly corresponded to the relative amount of total surface area of the wetted riverine units (not including islands and dry channels), with glides accounting for approximately 41% of the total area (Table 3-2). The average wetted widths ranged from 10.3 ft for low-gradient riffles in SC-1 to 114.6 ft for glides in the main channel (Table 3-3). Habitat unit lengths ranged from 5 to 1,695 ft (Table 3-4). The total average lengths of each of the riffle subtypes were more than twice the total average length of the main-channel pool subtype. Average depths ranged from 0.3 ft in low-gradient riffles in SC-1 to 3.4 ft average maximum depths found in deep main-channel pools within the mainstem (Table 3-5). Across all habitat subtypes, average unit wetted depths in the Lower Reach were 1.0 ft during the survey.

Table 3-1. Composition of field surveyed riverine habitat units in the Lower Reach.

Habitat		Composition of habitat units by process reach ID and side channel						Total number of habitat units	Percent of total habitat units
Primary unit type	**Subtype**	**Main-stem (unit cat 1*)**	**Main-stem (unit cat 2 & 3*)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**		
Pool (P)	Main-channel pool (MCP)	2	2	40	9	5	12	70	29
Riffle (R)	Low-gradient riffle (LGR)	15	13	9	10	7	2	56	27
	High-gradient riffle (HGR)	1	0	0	0	0	0	1	<1
	Glide (GLD)	13	6	22	7	6	5	59	34
Other (OT)	Island (ISL)	5	7	4	1	1	0	18	9
	Dry channel (DRY)	0	0	2	0	0	0	2	1
Total		**36**	**28**	**77**	**27**	**19**	**19**	**206**	

* Mainstem (unit category 1) includes primary main-channel units. Mainstem (unit category 2 and 3) includes secondary main-channel habitat units (units that did not span the entire river channel) and side channel habitat units separated from the main channel by an island.

Table 3-2. Percent total surface area by riverine habitat unit in the Lower Reach.

Habitat		Percent total surface area of habitat units by process reach ID and side channel						Combined average % surface area
Primary unit type	**Sub-type**	**Mainstem (unit cat 1)**	**Mainstem (unit cat 2 & 3)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**	
Pool	Main-channel pool (MCP)	<1	14.4	42.0	45.1	21.0	52.0	29.1
Riffle	Low-gradient riffle (LGR)	27.9	56.8	14.9	32.3	37.1	10.8	30.0
	High-gradient riffle (HGR)	1.8	-	-	-	-	-	<1
	Glide (GLD)	70.0	28.8	43.0	22.6	41.9	37.2	40.6

Table 3-3. Average wetted width by riverine habitat unit in the Lower Reach.

Habitat		Average wetted width (ft) of habitat units by process reach ID and side channel						Total average wetted width (ft)
Primary unit type	**Subtype**	**Mainstem (unit cat 1)**	**Mainstem (unit cat 2 & 3)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**	
Pool	Main-channel pool (MCP)	14.7	36.3	10.3	23.2	38.3	17.5	16.4
Riffle	Low-gradient riffle (LGR)	88.1	36.7	10.3	23.2	43.3	18.6	44.1
	High-gradient riffle (HGR)	67.0	-	-	-	-	-	67.0
	Glide (GLD)	114.6	43.6	12.1	19.9	49.0	22.4	43.4

Table 3-4. Average unit length by riverine habitat unit in the Lower Reach.

Habitat		Average unit length (ft) of habitat units by process reach ID and side channel						Total average unit length (ft)
Primary unit type	**Subtype**	**Mainstem (unit cat 1)**	**Mainstem (unit cat 2 & 3)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**	
Pool	Main-channel pool (MCP)	145	330	60	95	112	63	79
Riffle	Low-gradient riffle (LGR)	329	167	90	61	145	77	173
	High-gradient riffle (HGR)	485	-	-	-	-	-	485
	Glide (GLD)	719	164	99	76	146	96	244
Other	Island (ISL)	477	254	50	149	230	77	173
	Dry channel (DRY)	-	-	269	-	-	-	269
Total average unit length		485	200	80	79	141	73	172

Table 3-5. Average unit depth by riverine habitat unit in the Lower Reach.

Habitat		Average depth (ft) of habitat units by process reach ID and side channel						Total average depth (ft)
Primary unit type	**Subtype**	**Mainstem (unit cat 1)**	**Mainstem (unit cat 2 & 3)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**	
Pool	Main-channel pool (MCP)*	3.4	2.0	0.8	1.0	2.6	1.0	1.1
Riffle	Low-gradient riffle (LGR)	1.7	0.7	0.3	0.4	0.8	0.4	0.9
	High-gradient riffle (HGR)	1.1	-	-	-	-	-	1.1
	Glide (GLD)	2.5	1.4	0.5	0.5	1.4	0.6	1.2
Total average unit depth (ft)		2.1	1.0	0.7	0.6	1.5	0.8	1.0

* Average main-channel pool depths represent average maximum depths.

3.1.1.2 Additional pool habitat unit attributes

Within the Lower Reach, 53% of the pools were either formed or constructed adjacent to engineered wood, large wood installations, or accumulated large woody debris (Table 3-6). Pools were observed above each of the eight large, engineered log jams. For the remaining pools, channel bedform (24%), roots of standing trees or stumps (11%), and boulders (10%) were the primary factors in their formation.

The unit-average maximum pool depths, shown in Table 3-7, were 4.0 and 3.0 ft in the mainstem for categories 1 and 2, respectively, and ranged from 1.7 to 4.0 ft in the side channels. Total average maximum pool depth for the Lower Reach was 2.0 ft.

Table 3-6. Primary pool-forming factors for riverine habitat units in the Lower Reach.

Pool-forming factor	Pool-forming factor by process reach ID and side channel						Total pool-forming factors
	Mainstem (cat 1)	**Mainstem (cat 2 & 3)**	**SC-1**	**SC-2**	**SC-3**	**SC-4**	
Roots of standing trees or stumps (Field code 4)	-	-	7	-	1	-	8
Boulder(s) (Field code 5)	-	-	4	-	-	3	**7**
Bedrock (Field code 6)	-	-	-	-	-	-	0
Channel Bedform (Field code 7)	-	1	8	5	3	-	17
Resistant Bank (Field code 8)	-	-	-	-	-	1	1
Artificial Bank (Field code 9)	-	-	-	-	-	-	0
LWD (logs) (Field Code 1)	-	-	16	4	1	7	28
Engineered Log Jam Associated	2	1	5	-	-	1	8
Total	**2**	**2**	**40**	**9**	**5**	**12**	**70**

Table 3-7. Average maximum pool depth for pools surveyed in the Lower Reach.

Habitat		Average maximum pool depth (ft) of pool habitat units by process reach ID and side channel						Total average maximum pool depth (ft)
Primary unit type	Subtype	Mainstem (cat 1)	Mainstem (cat 2 & 3)	SC-1	SC-2	SC-3	SC-4	
Pool (P)	Main-channel pool (MCP)	4.0	3.0	1.7	2.0	4.0	1.9	2.0
Total # of pools		2	2	40	9	5	12	

3.1.1.3 Undercut habitat attributes

Undercut bank habitats were estimated as the percent of the unit length on either the right or left edges of each habitat unit. The fraction of undercut habitat within each reach relative to twice the reach's total length (to account for the two banks) accounts for 26% of stream length in SC-2 and only 2% in the mainstem (Table 3-8). When comparing undercut habitat presence among the different habitat subtypes, results indicate that undercut habitat is present most often in glide habitat (42%) but also occurs in main-channel pool (32%), low-gradient riffles (26%), and island (<1%) (Table 3-9**)**. Average widths of undercut banks ranged from 0.30 ft in SC-1 to 2.5 ft in the mainstem.

Table 3-8. Cumulative length and fraction of bank with undercut habitat in the Lower Reach.

Process reach ID and side channel	Cumulative length of undercut left bank (ft)	Cumulative length of undercut right bank (ft)	Fraction of reach with undercut bank habitat
Mainstem (cat 1)	108.0	632.0	2%
Mainstem (cats 2 & 3)	175.8	462.6	6%
SC-1	911.5	941.5	15%
SC-2	890.3	242.5	26%
SC-3	7.4	212.8	4%
SC-4	373.8	162.4	19%

Table 3-9. Cumulative length and percent of habitat subtype with undercut habitat in the Lower Reach.

Habitat subtype	Cumulative length of undercut left bank (ft)	Cumulative length of undercut right bank (ft)	Total length of undercut bank (ft)	Percent of habitat subtype with undercut bank
Main-channel pool (MCP)	926.5	697.9	1,624.4	32%
Glide (GLD)	911.4	1,228.4	2,139.8	42%
Low-gradient riffle (LGR)	629.0	700.7	1,329.7	26%
Island (ISL)	-	26.8	26.8	<1%
Total	2,466.8	2,653.8	5,120.6	

3.1.2 Large woody debris survey

The density of LWD is presented in this report as pieces per mile of stream channel (Table 3-10). Both naturally occurring LWD and engineered wood structures are present. Efforts were made to tally naturally occurring wood separately from engineered wood structures. The assessment of pieces per mile of stream channel is limited to naturally occurring wood. It was common for naturally occurring LWD to become trapped by and incorporated into engineered structures. A total of 58 pieces of natural wood had accumulated at the engineered LWD jams on the mainstem. See Section 4.2.1 below for a discussion of the LWD in engineered wood structures. Maps showing the distribution of LWD by habitat unit are in Appendix B.

Table 3-10. LWD density per mile in the Lower Reach.

Process reach ID and side channel	Length (mi)	LWD density per mile including only individual pieces *	LWD density per mile including individual pieces and debris jam pieces *
Mainstem	2.7	60	191
SC-1	1.2	48	58
SC-2	0.4	35	135
SC-3	0.4	53	280
SC-4	0.3	60	127

* The field surveys also observed 31 rootwads and 184 logs between 10 and 20 cm in diameter, neither of which are included in this table for consistency with previous reports.

3.1.2.1 LWD individual pieces

Data collected for individual LWD pieces included categories of piece diameter, length estimates, species type, and decay class. For purposes of the survey, individual LWD pieces were tallied separate from pieces occurring within debris jams. Individual LWD pieces were tallied in four diameter size classes (10 to <20 cm; 20 to <40 cm; 40 to <60 cm; and ≥60 cm). However, the 10 to <20 cm size class was not included in Tables 3-11 and 3-12 for consistency with previous reports, which did not collect data on the 10 to <20 cm size class.

Over half (62%) of all individual LWD pieces greater than 20 cm were of a small-diameter class (20 to <40 cm); 29% were of medium diameter (40 to <60 cm); and 8% were of large diameter (≥60cm) (Table 3-11). An additional 184 individual pieces were tallied in the extra small diameter size class (10 to <20 cm), representing the most abundant of the four size classes. A total of 31 rootwads were also tallied during the survey.

The position of the LWD within the bankfull channel was also recorded. Wood was classified as occurring within the wetted channel (zone 1) or within the bankfull width (zone 2). LWD pieces were further differentiated if any part of the LWD extended into the mid-channel. The position of LWD within the channel is relevant to understanding how LWD contributes to habitat complexity by affecting channel hydraulics at different river discharges (Ralph et al. 1994, Montgomery et al. 1995). Within the Lower Reach Study Area, fewer than half (44%) of individual LWD pieces tallied were primarily within the wetted river channel (zone 1), with 56% of those extending into mid-channel. The remaining 56% of the individual LWD pieces were primarily in zone 2.

Tree species type and decay class were identified for all individual LWD pieces. Throughout the total surveyed Lower Reach Study Area, species composition was 75% unknown species (classified as such due to lack of bark or otherwise identifying features), 11% coniferous species, and 14% deciduous species. Using a decay class scale of 1 to 5, where 1 indicates the lowest state of decay and 5 indicates the highest state of decay, approximately one quarter (26%) were within decay classes 1 to 3, indicating that they were of fairly recent origin. LWD of older origin does not necessarily mean that it had been in that position for an extended period of time, as older wood could have been transported from upstream or upslope during prior high-flow events.

Table 3-11. Composition of individual LWD pieces in the Lower Reach.

LWD size category type	Total number of individual LWD pieces by process reach ID and side channel *						Total
	Mainstem (cat 1)	Mainstem (cat 2 & 3)	SC-1	SC-2	SC-3	SC-4	
Rootwad	6	1	18	0	0	6	31
Small (20–40 cm)	52	28	47	12	16	14	169
Medium (40–60 cm)	45	17	11	1	4	2	80
Large (>60 cm)	13	6	0	1	1	2	23
Total	116	52	76	14	21	24	303

* In addition, 184 logs were between 10 and 20 cm were tallied but not included in this table for consistency with previous reports.

3.1.2.2 LWD jams

Within the Lower Reach there were 15 natural debris jams within the river channel at the time of the survey (Table 3-12). There were ten natural debris jams documented on the mainstem and five on side channels. Nine of the mainstem jams are located adjacent to islands, with three of these at the head of islands and six along the narrow side of the mainstem adjacent to an island.

Table 3-12. Composition of LWD jams in the Lower Reach.

LWD jam category	Total number of LWD jams by process reach ID and side channel *						Total *
	Mainstem (cat 1)	Mainstem (cat 2 & 3)	SC-1	SC-2	SC-3	SC-4	
Total number of LWD jams	9	1	0	2	2	1	15
Total number of LWD pieces (including rootwads and key pieces)	264	33	0	40	91	20	448
Number of rootwads	33	3	0	9	11	5	61
Number of LWD key pieces	9	1	0	2	2	1	15

* This table does not include engineered LWD jams. A total of 145 additional pieces of wood are associated with engineered LWD jams.

3.1.2.3 Engineered wood installations

Since 2007, a large amount of engineered LWD was installed as bank-side jams in the mainstem, and as single-to multi-log structures in side channels. No new engineered LWD structures have been installed in the Lower Reach since the 2016 survey. However, the engineered LWD structures continue to influence channel morphology and habitat conditions. During the 2020 surveys, pool formation was noted upstream of six engineered jams where no pool formation had been documented in 2016. The engineered wood continues to recruit natural logs to varying degrees depending on location. A total of 145 LWD pieces, both natural and engineered, are associated with engineered jams.

3.1.3 Characterization of river channel substrate

Results from Wolman pebble counts are presented in Table 3-13. The sampled units included two glides (OR 1–89 and SC-4–1P), a low-gradient riffle (SC-2–16), and a dry channel (SC-1–11I). These habitat subunit types remained unchanged for all locations except for SC-1–11I, which was previously a small glide in 2016 (see additional discussion on comparisons with previous survey results in the Discussion section below). The results indicated that the median particle size in the Lower Reach ranged from 13 to 26 mm. Results also indicate side channels 1 and 4 contain similar -sized particles.

Table 3-13. Particle-size distribution of river substrate material from sample sites throughout the Lower Reach.

Reach	Unit number containing sample	Streambed substrate particle size by percentile class (mm)		
		D_{16}	D_{50}	D_{84}
OR 1	89	5	26	88
SC-1	11I	4	14	40
SC-2	16	5	24	96
SC-4	1P	3	13	36

3.2 Upper Reach Survey Results

3.2.1 Habitat unit composition

3.2.1.1 Primary units

Tables 3-14 through 3-17 present the results of habitat unit mapping in the Upper Reach (RM 2.7–16.5). Data are for ORs 2 and 3 in their entirety and from RM 2.7 and higher in OR 1. These results reflect conditions throughout the Upper Reach assessed via the hybrid GIS and field methods described above.

A total of 307 in-river habitat units were identified in the entire Upper Reach (Table 3-14), of which 115 habitat units were directly surveyed in the field. The three most frequently occurring subtypes were low-gradient riffles (34%), main-channel pools (33%), and glides (21%). Other subtypes included high-gradient riffles, cascades, lateral scour pools, backwater pools, and islands. These proportions closely translated to the relative amount of total surface area of the wetted riverine units (not including islands) (Table 3-15). The average width of all wetted riverine subtypes was approximately 62 ft, with the greatest average width by individual subtype found in low-gradient riffles (80 ft) and least average width in backwater pools (40 ft) (Table 3-16). The average length of all wetted riverine subtypes was approximately 180 ft, with the greatest average length in main-channel pools (250 ft) and least average in backwater pools (86 ft) (Table 3-17).

Table 3-14. Composition of GIS and field surveyed riverine habitat units in the Upper Reach.

Habitat		Composition of habitat units by Operational Reach			Total number of habitat units	Percent of total habitat units
Primary unit type	**Subtype**	**OR 1 [Upper Reach portion]**	**OR 2**	**OR 3**		
Riffle (R)	Glide (GLD)	10	16	38	64	21%
	Low-Gradient Riffle (LGR)	11	44	49	104	34%
	High-Gradient Riffle (HGR)	1	2	5	8	3%
	Cascade (CAS)	2	8	14	24	8%
Pool (P)	Main-channel Pool (MCP)	6	43	52	101	33%
	Lateral (Scour) Pool (SCP)	0	1	1	2	1%
	Backwater Pool (BKW)	0	1	0	1	0%
Other (OT)	Island (ISL)	1	2	0	3	1%

Table 3-15. Percent total surface area by riverine habitat unit in the Upper Reach.

Habitat		Percent total surface area of habitat units by Operational Reach			Combined average % surface area
Primary unit type	**Subtype**	**OR 1 [Upper Reach portion]**	**OR 2**	**OR 3**	
Riffle (R)	Glide (GLD)	26	11	29	21
	Low-Gradient Riffle (LGR)	38	39	35	37
	High-Gradient Riffle (HGR)	8	0	3	3
	Cascade (CAS)	5	6	5	5
Pool (P)	Main-channel Pool (MCP)	20	42	28	32
	Lateral (Scour) Pool (SCP)	0	0	0	0
	Backwater Pool (BKW)	0	0	0	0
Other (OT	Island (ISL)	3	1	0	1

Table 3-16. Average wetted width by riverine habitat unit in the Upper Reach.

Habitat		Average wetted width (ft) of habitat units by Operational Reach			Total average wetted width (ft)
Primary unit type	**Subtype**	**OR 1 [Upper Reach portion]**	**OR 2**	**OR 3**	
Riffle (R)	Glide (GLD)	91	80	66	74
	Low-Gradient Riffle (LGR)	104	86	70	80
	High-Gradient Riffle (HGR)	151	46	71	75
	Cascade (CAS)	85	61	55	59
Pool (P)	Main-channel Pool (MCP)	93	74	59	67
	Lateral (Scour) Pool (SCP)	0	42	42	42
	Backwater Pool (BKW)	0	40	0	40
Other (OT)	Island (ISL)	59	55	0	56

Table 3-17. Average unit length by riverine habitat unit in the Upper Reach.

Habitat		Average unit length (ft) of habitat units by Operational Reach			Total average unit length (ft)
Primary unit type	**Subtype**	**OR 1 [Upper Reach portion]**	**OR 2**	**OR 3**	
Riffle (R)	Glide (GLD)	320	185	228	232
	Low-Gradient Riffle (LGR)	377	222	199	228
	High-Gradient Riffle (HGR)	575	84	134	177
	Cascade (CAS)	336	230	147	190
Pool (P)	Main-channel Pool (MCP)	387	285	205	250
	Lateral (Scour) Pool (SCP)	0	132	104	118
	Backwater Pool (BKW)	0	86	0	86
Other (OT	Island (ISL)	526	275	0	358

3.2.1.2 Additional pool habitat unit attributes

The results of additional pool habitat unit attributes recorded during the field surveys are presented in Tables 3-18 and 3-19. Attempts to identify these pool attributes were initially made in the GIS using the remote-sensing data, but it was determined in the field that these attributes could not be reliably ascertained in the GIS absent ground-truthing and, therefore, only results from the field survey are presented.

Within the field-surveyed portions of the Upper Reach, most pools were formed by lateral and/or vertical outcrops of bedrock, with a smaller proportion of the pools formed by boulders (Table 3-18). Concrete walls were observed to influence pool formation near the Project's diversion dam and powerhouse.

Table 3-18. Primary pool-forming factors for field-surveyed riverine habitat units in the Upper Reach.

Pool-forming factor	Pool-forming factor of habitat units by Operational Reach		Total pool-forming factors
	OR 2 (where surveyed)	OR 3 (where surveyed)	
Roots of standing trees or stumps (Field code 4)	-	-	-
Boulder(s) (Field code 5)	-	5	**5**
Bedrock (Field code 6)	21	16	**37**
Channel Bedform (Field code 7)	-	-	-
Resistant Bank (Field code 8)	-	-	-
Artificial Bank (Field code 9)	1	2	**3**
LWD (logs) (Field Code 1)	-	-	-
Engineered Log Jam Associated	-	-	-
Total	**22**	**23**	**45**

Unit-average maximum depths of the field-surveyed pools were 8 and 4 ft for main-channel pools and lateral scour pools, respectively (Table 3-19). These results carry the caveat acknowledged in the Methods section, however, that the maximum recorded depth was 10 ft. Field crews observed, but were unable to accurately measure, several pools that exceeded 10 ft in maximum depth.

Table 3-19. Average maximum pool depth by field-surveyed riverine habitat unit in the Upper Reach.

Habitat		Average maximum pool depth (ft) of pool habitat units by Operational Reach		Total average maximum pool depth (ft)
Primary unit type	Subtype	OR 2 (where surveyed)	OR 3 (where surveyed)	
Pool (P)	Main-channel Pool (MCP)	8.1	7.9	8.0
	Lateral (Scour) Pool (SCP)	-	4.0	4.0
	Backwater Pool (BKW)	-	-	-
Total # of pools		22	23	-

3.2.2 Large woody debris survey

Within the Upper Reach, a total of 483 LWD pieces and 36 debris jams were tallied during GIS analysis (Table 3-20). Counts of individual pieces within the jams could not be reliably ascertained using GIS analysis due to limitations in the imagery resolution and obfuscation by overhanging tree canopy, shadows, and water turbidity. The greatest density of combined LWD pieces and jams per mile was found in OR 3.

Table 3-20. GIS-derived LWD pieces and jams and their combined density per mile in the Upper Reach.

Operational Reach	Length (mi)	Number of LWD individual pieces	Number of LWD jams	Total number of LWD pieces and jams	Combined LWD density of pieces and jams per mile
OR 1 [Upper Reach portion]	1.8	36	3	39	22
OR 2	5.2	148	15	163	31
OR 3	6.1	299	18	317	52
Total	13.1	483	36	519	40

In the field surveyed units in ORs 2 and 3, a total of 415 individual pieces and 34 debris jams were tallied, and a total of 1,567 LWD pieces were tallied as individuals and within jams (Table 3-21). Individual pieces accounted for 26% of surveyed LWD, with the remaining 74% present within the debris jams. The greatest density of combined LWD pieces and jams per mile was found in OR 2, which differs from the greater density per mile found in OR 3 by the GIS analysis due to differences in spatial extent and resolution of the GIS versus the field methods.

Table 3-21. Field-surveyed LWD density per mile in the Upper Reach.

Operational Reach	Length of surveyed segment (mi)	Number of LWD individual pieces	Number of LWD jams	Total number of pieces in LWD jams	Total number of LWD pieces as individual and in jams	Combined LWD density of pieces and jams per mile
OR 2 (where surveyed)	2.4	220	24	896	1,116	465
OR 3 (where surveyed)	2.2	195	10	256	451	205
Total	4.6	415	34	1,152	1,567	341

3.2.2.1 Field-surveyed LWD individual pieces

The composition of individual LWD pieces (not including pieces forming jams) in the field-surveyed units in the Upper Reach are presented in Table 3-22. Approximately 55% of all individual LWD pieces were downed trees of the small diameter class (20–40 cm).

Approximately 33% were of medium diameter (>40–60 cm) and 8% were of large diameter (>60 cm). Individual LWD pieces occurring as rootwads constituted approximately 3% of all field-surveyed LWD individual pieces within the Upper Reach. The presence of rootwads accounted for 64 of the 896 individual pieces of wood in OR 2 (7%) and 36 of the 256 (14%) of individual pieces found in OR 3.

Table 3-22. Composition of individual LWD pieces in the field-surveyed units in the Upper Reach.

LWD size category type	Total number of individual LWD pieces by Operational Reach		Total
	OR 2 (where surveyed)	OR 3 (where surveyed)	
Rootwad	3	8	11
Small (20–40 cm)	136	96	232
Medium (40–60 cm)	63	76	139
Large (>60 cm)	18	15	33
Total	220	195	415

The position of the LWD individual pieces within the bankfull channel was recorded. Within the field-surveyed units, 60% of individual pieces extended into the wetted channel (zone 1) with 18% of these pieces occurred mid-channel. The remaining 40% of individual pieces occurred within the bankfull channel and did not extend into the wetted channel (zone 2). In the field-surveyed units, the majority of the individual LWD pieces are either of decay class 3 (40%) or 4 (33%) (Table 3-23). While 53% of the pieces were an unknown species, 41% were determined to be coniferous and 6% were deciduous.

Table 3-23. Field-surveyed LWD by size and decay class in the Upper Reach.

Decay Class	Total number of LWD pieces by size category				Total	Percent Total
	Total number of small (20–40 cm)	Total number of medium (40–60 cm)	Total number of large (>60 cm)	Total number of rootwad > 20 cm		
1	20	6	3	5	34	8%
2	37	32	5	1	75	18%
3	77	67	19	3	166	40%
4	97	34	6	2	139	33%
5	1	0	0	0	1	<1%
Total	**232**	**139**	**33**	**11**	**415**	**100%**

3.2.2.2 Field-surveyed LWD jams

The composition of field-surveyed LWD jams in ORs 2 and 3 of the Upper Reach is presented in Table 3-24. The majority of the LWD jams (27 of 34) were positioned in zone 2 (outside of wetted area) and three were positioned vertically above the channel in zone 3 (Table 3-25). The remaining four jams were positioned within the wetted portion of the river channel.

Table 3-24. Composition of field-surveyed LWD jams in the Upper Reach.

LWD jam category	Total number of LWD jams by Operational Reach		Total
	OR 2 (where surveyed)	OR 3 (where surveyed)	
Total number of LWD jams field-surveyed	24	10	34
Total number of LWD pieces (including rootwads and key pieces)	896	256	1,152
Number of rootwads	64	36	100
Number of LWD key pieces	832	220	269

Table 3-25. Composition of field-surveyed LWD jams within the channel in the Upper Reach.

Operational Reach (where surveyed)	Total number of LWD jams per zone			Total
	Zone 1	Zone 2	Zone 3	
OR 2	1	22	1	24
OR 3	3	5	2	10
Total number of LWD jams	4	27	3	34

3.2.3 Characterization of river channel substrate

The majority of Upper Reach habitat units visited in the field were assessed for their dominant and subdominant bed substrate size classes, with deeper pool units being omitted from assessment due to their deep, turbid waters limiting visual inspection to an acceptable standard. The majority of habitat units visited in ORs 2 and 3 were found to be composed primarily of gravel, cobble, and boulder substrates, while very few units were found to be predominately composed of bedrock or sand (Table 3-26). A greater proportion of habitat units were predominately gravel-bedded in OR 2 than in OR 3, particularly in units located immediately upstream of the diversion dam. All units had minor (sub-dominant) proportions of gravel, cobble, and boulder, whereas bedrock and sand were not always present. Riffle units, including glides, low and high gradient riffles, and cascades, were predominately composed of cobble (35%) and boulder (46%); pool units, including main-channel and lateral scour pools, were predominately composed of sand (33%) and gravel (63%) (Table 3-27).

Table 3-26. Sediment composition of field-surveyed segments of the Upper Reach.

Dominant bed substrate size class *	Total number of habitat units by Operational Reach		Total
	OR 2 (where surveyed)	OR 3 (where surveyed)	
Bedrock	1	0	1
Boulder	18	11	29
Cobble	8	16	24
Gravel	20	10	30
Sand	7	3	10

* Sediment facies categories based on Buffington and Montgomery (1999).

Table 3-27. Sediment composition of field-surveyed habitat units in the Upper Reach.

Dominant bed substrate size class *	Total number of habitat units by habitat unit type						
	Riffle (R)				Pool (P)		Other (OT)
	Glide (GLD)	Low-Gradient Riffle (LGR)	High-Gradient Riffle (HGR)	Cascade (CAS)	Main-channel Pool (MCP)	Lateral (Scour) Pool (SCP)	Island (ISL)
Bedrock	-	-	-	1	-	-	-
Boulder	2	19	5	3	-	-	-
Cobble	6	16	-	-	1	-	1
Gravel	8	3	-	-	18	1	-
Sand	-	-	-	-	10	-	-

* Sediment facies categories based on Buffington and Montgomery (1999).

4 DISCUSSION

4.1 Riverine Habitat Characteristics

The primary objectives of this 2020 study were to identify any significant changes that have occurred in the Sultan River, and to evaluate any habitat changes that have occurred from the interaction between constructed habitat enhancements with multiple high-flow events.

4.1.1 Lower Reach

When comparing the 2020 results to those from 2007, 2010, 2014, and 2016 the following inferences can be made:

- A total of 206 in-river habitat units were found in the Lower Reach, which represents a decrease of 24 units from the previous 2016 survey. Diversity of habitat subtypes decreased, and some habitat units have merged, indicating that the lower Sultan River and its side channels continue to respond geomorphically and hydrologically. Many of these changes occurred in the side channels.
- Several previously observed habitat subtypes were not found in the 2020 survey: subsurface, marsh, alcove, and lateral scour pool.
- The average wetted width for pools in the side channels in 2020 ranged from 11.3 to 38.3 ft. In contrast, wetted widths in 2016 ranged from 5.6 to 31.2 ft.
- For riffles and glides in the mainstem and the four side channels, the average wetted width ranged from 10.3 ft for low-gradient riffles in SC-1 to 114.6 for glides in the main channel in 2020. These widths were largely unchanged from 2016, when average widths for riffles and glides were 10.3 and 109.5 ft, respectively.
- The percent of total surface area of each subtype in the Lower Reach did not greatly change in 2020 from what existed in 2016 and 2014. The lower Sultan River and its side channels continue to support complex habitat, particularly pool-riffle-glide complexes, and island habitat (Table 4-1).
- Total stream length of the Lower Reach in 2020 remained largely unchanged from 2016, while some updates were made to categorize previously reported mainstem stream length as side channel length. For example, a relatively long 91 ft main-channel pool had formed at the inlet of SC-2, increasing the side channel's total steam length while decreasing the mainstem stream length proportionally.
- Undercut bank habitat increased between 2016 and 2020 within the mainstem and all side channels (Table 4-2). For the Lower Reach, an increase of 1,099 ft of undercut bank habitat was observed along the left bank and 1,511 ft was gained along the right bank.

Table 4-1. Comparison of percent total surface area of habitat subtypes for 2007, 2014, 2016, 2020.

Year	Habitat subtype (all values in % of the year's total number of habitat units)			
	Glide	Low-gradient riffle	Islands	Pools
2007	66	29	6	<1
2014	55	25	16	4.3
2016	47	26	23	2.9
2020	49	23	23	4.2

Table 4-2. Comparison of length of undercut habitat in 2016 and 2020 in the Lower Reach.

Process reach ID or side channel	Left bank habitat (ft)			Right bank habitat (ft)		
	2016	2020	Difference (ft)	2016	2020	Difference (ft)
Mainstem	176	284	108	805	1,095	290
SC-1	243	912	669	183	942	758
SC-2	677	890	214	62	243	180
SC-3	0	7	7	30	213	183
SC-4	273	374	101	62	162	100
Total	**1,367**	**2,467**	**1,099**	**1,142**	**2,654**	**1,511**

4.1.1.1 Main channel

A decrease of 1,236 ft of stream channel length in the mainstem, from 24,277 ft in 2016 to 23,041 ft in 2020, does not represent a loss of habitat overall, it indicates that some habitat previously mapped as main channel was mapped as side channel habitat in the 2020 survey.

4.1.1.2 Side channels

Across all side channels, there has been a measurable loss of riffle habitat that is being converted to glides or pools (Table 4-3). While pool unit length and wetted width have increased, maximum depths in most pools outside of the mainstem have decreased, indicating that accretion of sediment could be occurring (Table 4-4). Across all side channels, undercut habitat has increased. The fraction of undercut habitat within each side channel relative to twice the reach's total length (to account for the two banks) ranged from 4% in SC-3 to 26% in SC-2.

While the mainstem remains largely unchanged (with a limited number of boundary shifts and unit merging), habitat changes and slight simplifications mainly occurred in the side channels and most notably in SC-1. One previously wetted stretch and small subchannel within SC-1 is now disconnected from the mainstem and therefore dry during low-flow conditions, while the lowermost section of SC-1 has transformed from a series of disconnected pool and dry channels as observed in 2016 into a continuous wetted stretch of glides, riffles, and pools. Other changes observed in habitat composition include some low-gradient riffles being converted to pools as additional wood accumulates in the channels.

Table 4-3. Comparison of side channel lengths in 2007/2010, 2014, 2016, and 2020.

Side channel	2007 and 2010 lengths (ft)	2014 digitized lengths (ft)	Difference	2016 digitized lengths (ft)	Difference	2020 digitized lengths (ft)	Difference
SC-1	2,512	5,744	3,232	5,995	251	6,169	174
SC-2	1,735	1,722	-13	1,802	80	2,144	342
SC-3	2,202	2,350	148	2,740	390	2,681	-59
SC-4	No Data	1,467		1,382	-85	1,393	11

Table 4-4. Comparison of maximum pool depths surveyed in 2016 and 2020.

Process reach ID or side channel	2016 average max pool depth (ft)	2020 average max pool depth (ft)	Difference
Mainstem (unit cat 1*)	3.1	4.0	0.9
Mainstem (unit cat 2 & 3*)	3.5	3.0	-0.50
SC-1	2.0	1.7	-0.30
SC-2	2.1	2.0	-0.10
SC-3	3.6	4.0	0.40
SC-4	2.5	1.9	-0.6
Total Average	**2.8**	**2.0**	**-0.8**

SC-1

Stream enhancements (e.g., dredging) were completed both pre- and post-survey to address stretches of dry channels and intermittent pools that were previously identified in 2016. Now, much of the side channel comprises a series of connected pools, riffles, and glides (Figure 4-1). The channel continues to exhibit habitat complexity with distribution of surface among habitat subtypes largely unchanged from 2016. Since 2014, glides and pool consistently account for over 75% of the channel's surface area with riffle habitat gradually decreasing slightly from 19% in 2014 to 14% in 2020.

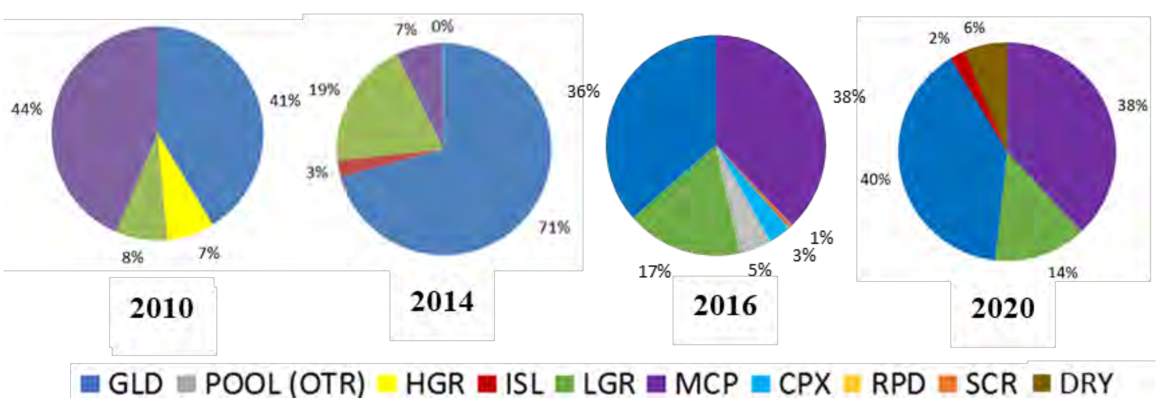

Figure 4-1. Comparison of SC-1 composition by surface area in 2010, 2014, 2016, and 2020. Habitat subtypes identified in 2020 and listed in Table 2-2 are Glide (GLD), high-gradient riffle (HGR), island (ISL), low-gradient riffle (LGR), main-channel pool (MCP), high-gradient riffle (HGR), and dry channel (DRY). Habitat subtypes identified in previous studies and included in the chart are intermittent and isolated pools POOL (OTR), pool complexes (CPX), and lateral scour pools (SCR).

An inlet near the upper end of SC-1 was disconnected from the mainstem during the 2020 study when flow measured between 330 and 345 cfs, resulting in a stretch that is now composed of a 515-ft-long dry channel. During similar flow conditions when flow measured between 322 and 336 cfs, this stretch was found to be a series of pool, riffles, and glides in 2016 (Figure 4-2).

Figure 4-2. Examples of stream changes that have occurred in SC-1 between 2016 and 2020 include a section that was a dry channel in 2016 and is now a connected stretch of small riffles, pool, and glides in 2020 (left) and also shown (right) is a dry channel in 2020 that was previously a wetted riffle in 2016.

Average side-channel depths decreased between 2014 and 2016. In this survey, however, SC-1 channel depths remained largely unchanged for habitat subtypes other than pools. Main-channel pools in this side channel were found to be generally shallower than 2016, which could affect the channel's ability to maintain cold-water refugia if the pools continue to become shallower. Shallower pools also may signify some accretion of sediment is still occurring due to morphological changes in the still-young channel or could be the result of channel-bottom morphology manipulation due to dredging in the channel.

Other changes include:

- stream length in the channel increased by 174 ft overall or a 3% increase; and
- undercut lengths increased significantly along both banks, with net gains of 669 ft on the left and 758 ft on the right. This increase can be attributed to much of the side channel being wetted throughout much of its extent compared to 2016 when stretches of the channel were dry.

SC-2

SC-2 is more structurally complex than SC-1, with generally smaller and less uniform habitat units. Since 2014, the channel has continued to evolve from a somewhat variable channel that contained 15 distinct subtype units to a more diverse stretch containing 27 in 2020, an increase of two units since 2016.

As in 2016, the changes in habitat mostly occurred in the side channel's upper stretch where LWD structures have accumulated additional large wood and retained spawning gravels. When comparing 2016 and 2020 by surface area, results show an increase in pool and island habitat and a decrease in glide and riffle habitat (Figure 4-3). Other changes include:

- stream length in the channel increased by 342 ft overall which is partially due to the addition of a main-channel pool at the inlet of the side channel;
- although mainstem discharges during the two survey periods were similar, average depths in the channel again decreased in 2020 from 0.82 ft in 2016 to 0.64 ft in 2020. Average depths in 2016 were on average half those observed in 2014, indicating reduced discharge through the channel or infilling;
- a new island has formed at the mouth of SC-2, increasing island habitat and complexity; and
- undercut lengths increased a combined 53% for both banks compared to the 2016 survey, with an additional 214 ft observed on the left and an additional 180 ft observed on the right.

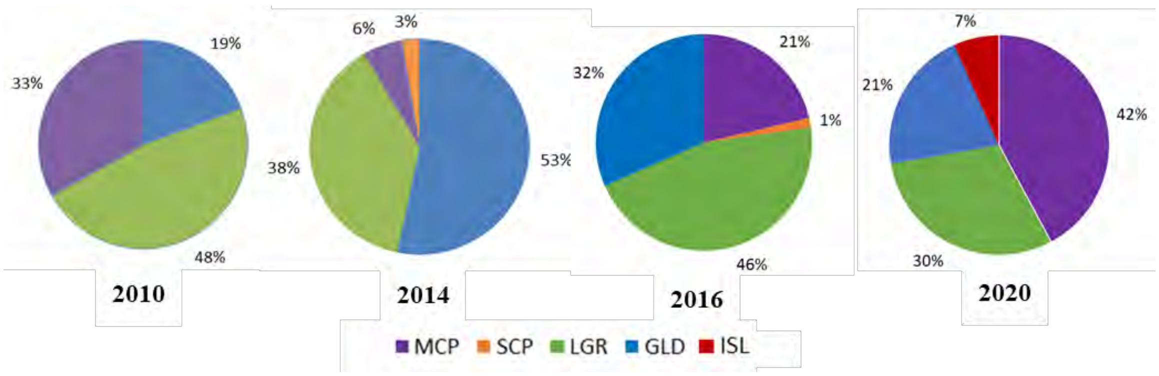

Figure 4-3. Comparison of SC-2 composition by surface area in 2010, 2014, 2016, and 2020. Habitat subtypes identified in 2020 and listed in Table 2-2 are Glide (GLD), island (ISL), low-gradient riffle (LGR), and main-channel pool (MCP). Habitat subtype identified in previous studies and included in the chart is lateral scour pools (SCR).

SC-3

Overall, SC-3 continues to respond geomorphically and evolve into a wider, deeper, increasingly complex channel composed mainly of glides and riffles with some main-channel pools and islands present (Figure 4-4). Average depths and wetted widths increased, and new habitat units were identified including a large pool that has been scoured out at the bend midway along the channel's length. The mouth of the side channel has undergone transition from a slower moving series of pool-riffle-glides to a faster moving stretch now mapped as a low-gradient riffle.

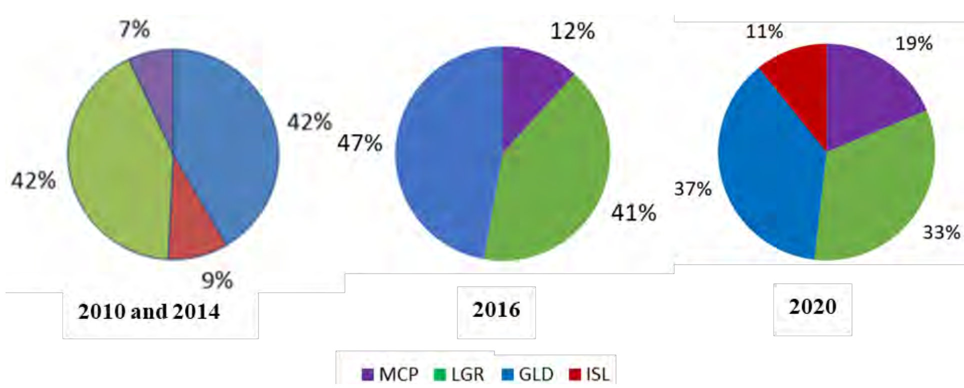

Figure 4-4. Comparison of SC-3 composition by surface area in 2010, 2014, 2016, and 2020. Habitat subtypes identified in 2020 and listed in Table 2-2 are Glide (GLD), island (ISL), low-gradient riffle (LGR), and main-channel pool (MCP). Habitat subtype identified in previous studies and included in the chart is lateral scour pools (SCR).

Additional changes in SC-3 since 2016 include:

- stream length decreased by 59 ft or 2%;
- average depths increased by .40 ft;
- average wetted width increased throughout the channel. Specifically, widths increased by over 7.0 ft for pool habitat units, 1.6 ft for riffles, and almost 3.0 ft for glides; and
- undercut bank habitat is found to a lesser degree in this side channel, compared to other side channels, with only 4% of stream length exhibiting undercut habitat. However, results indicate an increase compared to 2014 and 2016.

SC-4

Noticeable habitat changes have occurred since 2014 when the channel was composed of one long glide (with a small pool at its mouth and one riffle). Changes have occurred mainly at the inlet and the mouth of this side channel. Scour caused a new pool to form at the inlet, while a series of pool-riffle-glides that were identified in 2016 have been simplified into a series of pools with a long glide at the mouth. Overall, since 2016 there has been an increase in pool and glide habitat but a decrease in riffle habitat (Figure 4-5**)**.

SC-4 has become shallower by almost half a foot since it was first surveyed in 2014. Pools within the side channel also showed a decrease in average maximum depths, from 2.5 ft in 2016 to 1.9 ft in 2020. Depths ranged from 0.8 to 2.7 ft in 2016, but in 2020 they ranged from 0.3 to 2.0 ft. Accretion may be occurring and can be attributed to backwater flooding effects that can occur in the lowermost 0.7 miles of the Sultan River when the Skykomish River is at or above flood stage.

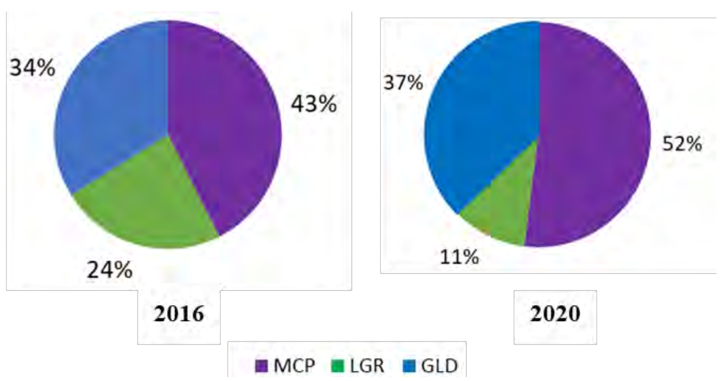

Figure 4-5. Comparison of SC-4 composition by surface area 2016, and 2020. Habitat subtypes identified in 2020 and listed in Table 2-2 are Glide (GLD), island (ISL), low-gradient riffle (LGR), and main-channel pool (MCP).

Additional changes in SC-4 since 2016 include:

- average wetted widths for pools and riffles decreased by 1.7 and 3.6 ft, respectively, but increased by 2.2 ft for glides; and
- undercut bank habitat, present mostly in glide habitat, increased by 60% with an additional 100 ft observed on the left and an additional 101 additional ft observed on the right bank.

4.1.2 Upper Reach

The Sultan River through the gorge (ORs 2 and 3) is a confined plane-bed channel, with step-pool to cascade sections that are frequently infused with landslide deposits. The uppermost section of ~0.7 miles below Culmback Dam is a slot canyon with steep falls and cascade drops over large boulders or bedrock chutes, as described by Ruggerone (2006). For most of its course from here downstream (~RM 16.2 to 2.7), the river flows through a highly confined canyon corridor that restricts channel migration or formation of side channels.

Geomorphic features and habitat units in both ORs 2 and 3 are characterized by long and relatively narrow pools, riffles, cascades or glides (i.e., plane bed, step pool, and cascade reaches). Whereas glides and main-channel pools were the dominant features in ORs 2 and 3 in 2007, habitat types are more evenly distributed across riffle, glides, and main-channel pools in 2020. When comparing surface area of primary unit types (riffles, pools, and other), the total percent surface areas were about equal in 2007 at ~55% for riffles and 45% pools within both ORs 2 and 3 (Table 4-5). While the same proportion remains largely unchanged in OR 2, the composition of OR 3 is now 71% riffle habitat and only 28% pools.

Table 4-5. Comparison of habitat units surveyed in 2007 and 2020.

Habitat		Percent total surface area by habitat subtype by Operational Reach in 2007 and 2020					
Primary unit type	Subtype	OR 1 *		OR 2		OR 3	
		2007	2020	2007	2020	2007	2020
Riffle (R)	Glide (GLD)	39%	47%	12%	11%	21%	29%
	Low-Gradient Riffle (LGR)	24%	24%	27%	39%	18%	35%
	High-Gradient Riffle (HGR)	8%	2%	10%	0%	11%	3%
	Cascade (CAS)	2%	0%	6%	6%	5%	5%
Pool (P)	Main-channel Pool (MCP)	6%	6%	36%	42%	40%	28%
	Lateral (Scour) Pool (SCP)	0%	0%	6%	0%	5%	0%
	Backwater Pool (BKW)	0%	0%	1%	0%	0%	0%
Other	Island (ISL)	22%	20%	2%	1%	0%	0%

* Data include OR 1 in its entirety from RM 0 to RM 4.9.

4.1.3 Study Area summary

Across the Study Area (OR 1, 2, and 3), there has been an increase of 153 habitat units (42% increase) from 2007 to 2020 (Table 4-6). The extent of the 2020 study is greater than the 2007 study due to three of the four side channels in OR 1 not having been surveyed in 2007. Other changes include the addition of 82 main-channel pools, low-gradient riffles have increased by 72, and glides increased by 39 between 2007 and 2020. These results indicate an increase in habitat complexity overall, with almost all of the changes occurring in OR 1 (particularly main-channel pools).

Table 4-6. Composition of habitat units in Study Area by Operational Reach in 2007.

Habitat		Composition of habitat units by Operational Reach					
Primary unit type	Subtype	OR 1 (RM 0–4.95)		OR 2 (RM 4.95–10.07)		OR 3 (RM 10.07–16.17	
		2007	2020	2007	2020	2007	2020
Riffle (R)	Glide (GLD)	34	69	17	16	33	38
	Low-Gradient Riffle (LGR)	37	67	28	44	23	49
	High-Gradient Riffle (HGR)	6	2	16	2	19	5
	Cascade (CAS)	2	2	10	8	14	14
Pool (P)	Main-channel Pool (MCP)	7	76	34	43	48	52
	Lateral (Scour) Pool (SCP)	0	1	6	1	6	0
	Backwater Pool (BKW)	0	0	4	1	3	0
Other (OT)	Island (ISL)	11	21	4	2	2	0
	Dry channel (DRY)	0	2	0	0	0	0
Total		97	240	119	118	148	159

4.2 Large Woody Debris Characteristics

4.2.1 Lower Reach

The total amount of naturally occurring LWD (number of individual logs) was similar between 2014 (216 pieces) to 2016 (214 pieces). Between 2016 and 2020, the number of logs increased approximately 27% to 272 pieces. The rootwad tally nearly doubled from 16 in 2016 to 31 in 2020 (Table 4-7). Evidence of new recruitment included logs that still had twigs and leaves. In addition to new recruitment, high flows likely washed some wood downstream and out of the assessment area. Tallied wood was more decayed in each subsequent survey between 2007 and 2020. The LWD classified in decay classes 4 or 5 in 2020 was 74% compared to 63% in 2016, 43% in 2014, and 22% in 2007.

The number of natural debris jams documented in 2020 was three times the number documented in 2016 (Table 4-8). The jams in habitat units 36 and 93 were also present in both 2014 and 2016. The jam in habitat unit 58 had formed after 2014 but was also present in 2016. Debris jams that were present in both 2016 and 2020 doubled the number of logs and grew in overall size. In addition, some of the engineered wood structures have recruited substantial amounts of additional natural wood, forming large debris jams. One example is in NSO 93, where the debris jam has grown to an estimated 70 pieces and now measures 120 ft wide, 110 ft long, and 22 ft high.

Table 4-7. Lower Reach LWD comparisons for 2014, 2016, and 2020.

LWD type	2014	2016	2020
LWD (individual pieces)*	216	214	272
Rootwads (individual pieces)*	11	16	31
LWD jams*	2	5	15

* Does not include engineered wood

The engineered log jams and LWD placed since 2007 were designed to provide habitat complexity, divert water into the side channels, retain gravel, provide bank habitat at varying flows, and roughen the flood plain. When scour forms at installed structures or natural LWD accumulates, the increased channel complexity can be utilized by juvenile salmonids. The engineered jams represent a significant increase in LWD in the mainstem over levels observed in 2007 and have begun to contribute to habitat complexity through the formation of pools and the accumulation and retention of natural LWD. The contribution to habitat complexity attributed to the engineered LWD was characterized during the 2016 surveys. During the 2020 surveys, evidence of the effects of engineered LWD on channel morphology and natural LWD retention was noted but not analyzed in detail. Additional pool formation had occurred in front of the engineered jams since 2016.

4.2.2 Upper Reach

In the Upper Reach, high stream power, confinement, and relatively small trees interact to leave most wood deposited well above the active channel and oftentimes perched above boulders. Results of the field-surveyed LWD jams indicate that 88% of the jams were positioned outside of the wetted channel. While 60% of individual large wood pieces were found at least partially within the low-flow wetted channel, only 47 of the 415 individual pieces of wood were found mid-channel. Field survey data in the Upper Reach also indicates that while the density per stream mile remains almost constant for individual pieces along the operational reaches, density of LWD jams per stream mile increases as one moves downstream towards a less confined, more alluvial channel.

Given that Culmback Dam blocks LWD from the upper watershed from entering the study reach, wood input sources in ORs 2 and 3 originate from young, streamside coniferous and deciduous trees falling into the river by storms (e.g., windthrow, icing) or landslides on adjacent hillslopes. Old-growth LWD is scarce in the surveyed units, with more than half of the individual wood pieces surveyed considered small (20–40 cm in diameter). Given the stream power, confined channels, and the abundance of smaller wood, the resulting low retention of wood in the Upper Reach channels is an expected outcome.

Decay level noted in 2020 was found to be slightly greater when compared to 2007 results, supporting a similar observation made in the Lower Reach that individual wood pieces found during the 2020 survey are of an older decay class compared with previous surveys. While 73% (306 of 415) of the individual pieces in the Upper Reach were of decay class 3 or more, where 1 indicates the lowest state of decay and 5 indicates the highest, this suggests that some of the wood originated as snags or is being retained in the system for ten years or more.

Due to the paucity of large wood being retained in the wetted channel, large wood has limited opportunity to interact with bedload and the existing LWD may not offer many benefits in terms of channel and habitat complexity during lower flows. None of the pools surveyed in the field were formed by LWD (logs, rootwads, or jams); the main pool-forming mechanism was lateral and/or vertical outcrops of bedrock, with a smaller proportion of the pools formed by boulders.

A full census of LWD found in the Upper Reach was not conducted therefore direct comparisons of LWD composition cannot be made between 2007 and 2020. However, when comparing 2007 results with LWD found in the units that were field-surveyed, the densities of combined LWD density of pieces and jams per mile are higher in 2020 compared to 2007 (Table 4-8). The number of LWD jams increased in 2020 in the Upper Reach field-surveyed units with the addition of 14 jams in OR 2 and two in OR 3 (Table 4-8). The number of jams identified during GIS-analysis was 35 which is similar to the number of jams identified during the field survey (34).

Table 4-8. LWD composition in 2007 and in field-surveyed units in 2020 for the Upper Reach.

LWD type	Operational reach			
	OR 2		OR 3	
	2007	2020*	2007	2020*
Number of LWD jams	10	24	8	10
Total number of LWD pieces and jams	1,006	1,116	628	451
Combined LWD density of pieces and jams per mile	80	465	196	205

* 2020 data represent LWD found only in field-surveyed units.

4.2.3 Study Area

In 2007, a total of 2,029 LWD pieces were tallied (including individual pieces, rootwads, and pieces found in jams). In 2020, within the field-surveyed units that represented 44% of the Study Area's 16.5 total miles, 593 LWD pieces were tallied in the Lower Reach (145 of these pieces were found in engineered jams) and 1,567 were tallied in the Upper Reach (Table 4-9). An additional 39 LWD individual pieces were tallied during GIS-analysis for the portion of OR 1 that was not field surveyed. Together, the total of LWD individual pieces tallied in 2020 is 2,199 and while this figure likely underrepresents the actual LWD pieces in the Study Area, it is also similar to the number of pieces tallied in 2007 (2,029).

Collectively, across the Study Area, there were 21 jams consisting of 330 LWD pieces in 2007. In 2020, 57 jams were tallied in the field-surveyed units and an additional three were identified using GIS-analysis in the Upper Reach portion of OR 1 that was not field-surveyed, representing a 186% increase overall in jams across the Study Area. Eight of the 23 jams in OR 1 are engineered.

Table 4-9. LWD comparison between 2007 and 2020 for the Study Area.

Operational Reach	Number of LWD jams		Total number of LWD pieces and jams	
	2007	2020	2007	2020
OR 1 [Lower Reach portion)	3	23	395	593 [A]
OR 1 [Upper Reach portion]		3[B]		39 [B]
OR 2	10	24	1,006	1,116
OR 3	8	10	628	451
Total	21	60	2,029	2,199

[A] Includes 145 individual pieces found in engineered jams.
[B] This reach was not field-surveyed therefore 2020 data are from GIS-analysis.

4.3 Sediment Characteristics

Sediment character along the river is a function of supply, transport capacity, and material properties (i.e., weak versus competent rock types). While the armor layer of the river's bed substrate has been assessed by various methods since 2007, there has not been a comprehensive and consistent methodology employed that would allow for a spatially explicit trends analysis over time. For example, sediment facies were assessed in select segments of the Upper Reach during 2020 but were not assessed in 2007. Thus, the following presents a brief comparison of repeat pebble-count data collected in the Lower Reach to the extent their spatial and temporal resolution provide.

One pebble count was conducted in 2007 in the Lower Reach mainstem, and its location was revisited in 2014, 2016, and 2020 (Table 4-10). Additional pebble counts were conducted in 2014 in side channels 1, 2, and 4, which were revisited in 2016 and 2020 (Table 4-11). Results indicate the D_{16}, D_{80}, and D_{84} percentiles decreased in the mainstem. The results also indicate that the assessed gravel patches were not suitable for spawning (i.e., D_{50} was not between 20 to 60 mm) in the side channels and were just marginally above the 20 mm lower range of suitable size in the mainstem. Similarly, a trend of decreasing particle size is evident across side channels 1, 2, and 4. The median particle size decreased by half or more for all side channels, and the D_{16} and D_{84} particle sizes either have remained unchanged (SC-4) or are now smaller (SC-1 and -2).

Table 4-10. Comparison of stream substrate particle-size percentiles in the Lower Reach mainstem in 2007, 2014, 2016, and 2020.

Year	Unit number	Stream substrate particle-size percentile (mm)		
		D_{16}	D_{50}	D_{84}
2007	89	23	39	63
2014	89	22	51	84
2016	89	10	53	96
2020	89	5	26	88

Table 4-11. Comparison of approximate size distribution of river substrate in the side channels for 2014, 2016, and 2020. Shaded cells indicate preferred spawning-size sediment.

Year	Unit number	Stream substrate particle-size percentile (mm)		
		D_{16}	D_{50}	D_{84}
SC-1				
2014	11	3	23	50
2016	11-I	4	27	83
2020	11-I	4	14	40
SC-2				
2014	16	25	62	129
2016	16	16	50	110
2020	16	5	24	96
SC-4				
2014	1	5	23	49
2016	1Q	10	31	70
2020	1P	3	13	36

Reported decreases in particle size were consistent across sampled units and likely indicate actual changes in particle size at these locations. However, there are some uncertainties in making direct comparisons, because the counts could have been conducted in slightly different locations (as unit boundaries have changed slightly in each of the side channels). Some variability is also likely an expression of the known inaccuracy of pebble counts (+/- 25% is a typical reported range of uncertainty; Bunte and Abt 2001). For future surveys, additional units could be selected for sediment sampling within each side channel to better evaluate variability and physical evolution of the side channel.

5 CONCLUSIONS

While it may not be possible to directly attribute habitat changes in the Sultan River system to the winter 2020 storm event, habitat diversity continues to increase when comparisons are made between the 2020 study and studies conducted in 2007, 2010, 2014, and 2016. Habitat diversity, or number of habitat units within the Study Area, has increased by 42% between 2007 and 2020 with most of the changes occurring in OR 1 and more specifically within the side channels. Though comparisons are made between 2007 and 2020, the spatial extent of the 2020 study is greater than the 2007 study namely in the Lower Reach where much of the side channel habitat had not been surveyed in 2007. These side channels have also had LWD jam and individual pieces installed within and along the channels and have undergone other enhancements like grading and dredging. Locally, changes in aquatic habitat within these side channels are often occurring near the inlets where many of the LWD jams and LWD pieces have been installed and where they are providing complexity and habitat formation.

The percent of total surface area of each habitat subtype in the Lower Reach did not greatly change in 2020 from what existed in 2016 and 2014. The lower Sultan River and its side channels continue to support complex habitat, particularly pool-riffle-glide complexes, and island habitat. In the Upper Reach, habitat types are more evenly distributed across riffle, glides, and main-channel pools in 2020 compared to 2007. Other changes across the Study Area between 2007 and 2020 include the addition of 82 main-channel pools, low-gradient riffles have increased by 72, and glides increased by 39.

Large wood continues to accumulate throughout the Study Area. When comparing the amount of LWD throughout the Sultan River system, the number of LWD jams increased by 186% from 2007 to 2020 and the overall density of LWD pieces and jams increased throughout the Study Area during the same period. In the Lower Reach, the number of LWD jams in the Lower Reach increased threefold between 2016 and 2020. While much of the LWD is situated above the wetted channel during low flow conditions in the Lower Reach, the remainder of the wood lies within the channel and will likely provide habitat complexity and habitat formation during periods of low and high flow.

The majority of the Upper Reach is composed primarily of gravel, cobble, and boulder substrates, while very few units were found to be predominately composed of bedrock or sand. In the Lower Reach, results of the pebble counts indicated that substrate size appears to be decreasing over time. Reported decreases in particle size were consistent across sampled units however the sample size is small. For future monitoring, additional units could be selected for sediment sampling within the mainstem and each side channel of the Lower Reach to better evaluate variability and physical evolution of those channels.

6 REFERENCES

Beechie, T.J., Liermann, M., Beamer, E.M., Henderson, R. 2005. A classification of habitat types in a large river and their use by juvenile salmonids. Transactions of the American Fisheries Society, 134 (3), pp. 717-729.

Bisson, P.A., Montgomery, D.R., Buffington, J.M. 2017. Valley segments, stream reaches, and channel units [Chapter 2]. In: Hauer, F. R.; Lamberti, G. A., eds. Methods in Stream Ecology - Volume 1: Ecosystem Structure (Third Edition). San Diego, CA: Academic Press. p. 21-47.

Buffington, J. M., and D. R. Montgomery. 1999. A procedure for classifying textural facies in gravel-bed rivers. Water Resources Research 35: 1903–1914.

Bunte, K. and S. R. Abt. 2001. Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. U.S. Forest Services, Rocky Mountain Research Station, General Technical Report RMRS-GTR-74. Available at: https://www.fs.fed.us/rm/pubs/rmrs_gtr074.pdf.

Edelen, W. J. 2005. A Technical glossary of stream & river stabilization, restoration, and bioengineering terms. https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/wapmctn6333.pdf.

Flosi, G., Downie, S., Hopelain, J., Bird, M., Coey, R. and Collins, B. 1998. California salmonid stream habitat restoration manual. 3rd ed. California Department of Fish and Game.

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 2010. California salmonid stream habitat restoration manual. 4th Edition. California Department of Fish and Game, Inland Fisheries Division, Sacramento, California.

Kondolf, G. M. and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29: 2275-2285.

Kondolf, G. M. 2000. Assessing salmonid spawning gravels. Transactions of the American Fisheries Society 129: 262–281.

Mongtomery, D. R., J. M. Buffington, R. D. Smith, K. M. Schmidt, and G. Pess. 1995. Pool spacing in forest channels. Water Resources Research 4: 1,097–1,105.

Pleus, A. E., D. Schuett-Hames, and L. Bullchild. 1999. TFW monitoring program method manual for the habitat unit survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish and Wildlife Agreement. TFW-AM9-99-003; DNR#105.

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of Western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51: 37–51.

Riebe, C. S., L. S. Sklar, B. T. Overstreet, and J. K. Wooster. 2014. Optimal reproduction in salmon spawning substrates linked to grain size and fish length. Water Resources Research 50: 898–918.

Robison, E. G., and R. L. Beschta. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 47: 1,684–1,693.

Ruggerone, G.T. 2006. Evaluation of salmon and steelhead migration through the upper Sultan River canyon prior to dam construction. Report to the City of Everett, pp. 48.

Schuett-Hames, D., A. E. Pleus, J. Ward, M. Fox, and J. Light. 1999. TFW monitoring program method manual for the large woody debris survey. Prepared for the Washington State Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-0004. DNR#106.

Stillwater Sciences. 2007. Study Plan 18: riverine, riparian, and wetland habitat assessment technical report. Prepared by Stillwater Sciences for Snohomish County Public Utility District No. 1.

Stillwater Sciences. 2010. Sultan River geomorphic assessment of side channel enhancement opportunities. Prepared by Stillwater Sciences for Snohomish County Public Utility District No.1.

Stillwater Sciences. 2015. Sultan River riverine habitat monitoring. Prepared by Stillwater Sciences, Portland, Oregon for Snohomish County Public Utility District No.1.

Stillwater Sciences. 2016. Sultan River riverine habitat monitoring. Prepared by Stillwater Sciences for Snohomish County Public Utility District No.1.

Wolman, G. M. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union 35, Number 6.