Eklutna Hydroelectric Project

Geomorphology and Sediment Transport

Year 2 Report

DRAFT

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Terms, Acronyms, and Abbreviations

1991 Agreement	1991 Fish and Wildlife Agreement
ADFG	Alaska Department of Fish and Game
ASTM	American Society for Testing and Materials
AWWU	Anchorage Water and Wastewater Utility
cfs	cubic feet per second
FSP	Final Study Plans
GIS	Geographic Information System
GPS	Geographic Positioning System
HEC-RAS	U.S. Army Corps of Engineers River Analysis System (HEC-RAS) developed by the Hydrologic Engineering Center
LiDAR	Light Detecting and Ranging
mm	millimeter
NAD	North American Datum
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NMFS	National Marine Fisheries Service
NVE	Native Village of Eklutna
PIT	Passive Integrated Responder
PME	protection, mitigation, and enhancement
PMP	probable maximum precipitation
PVC	polyvinyl chloride
RM	River Mile
RTK	real time kinematics
TWG	Technical Work Group
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

1 INTRODUCTION

The 1991 Fish and Wildlife Agreement (1991 Agreement) was executed amongst the Municipality of Anchorage, Chugach Electric Association, Inc., Matanuska Electric Association, Inc. (collectively "Project Owners"), U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), and the State of Alaska as part of the sale of the Eklutna Hydroelectric Project (Project) from the Federal government to the now Project Owners. The 1991 Agreement requires that the Project Owners conduct studies that examine and quantify, if possible, the impacts to fish and wildlife from the Project. The studies must also examine and develop protection, mitigation, and enhancement (PME) measures for fish and wildlife affected by such hydroelectric development. This examination shall consider the impact of fish and wildlife measures on other resources, including geomorphology and sediment transport, as well as available means to mitigate these impacts. The Project Owners initiated consultation in 2019 and have implemented studies to inform the development of the future Fish and Wildlife Program for the Project. As part of these studies, the Project Owners contracted Watershed GeoDynamics to describe and evaluate geomorphology and sediment transport in the Project area.

This Geomorphology and Sediment Transport Study was initiated in 2021 in accordance with Section 3.2 of the May 2021 Final Study Plans (FSP) (McMillen Jacobs Associates 2021). As noted in the FSP, and based on early outreach efforts, the main goal of the agencies and interested parties is to find a new balance amongst the uses of water in the Eklutna River basin, including power production, potable water supply, and fish habitat. Potential flow related PME measures include providing a flow regime into the Eklutna River that would accomplish habitat restoration and increase the anadromous fish assemblage of the river.

Geomorphology and sediment transport processes in the Eklutna River downstream from Eklutna Lake have been altered by several management actions over the past century including water withdrawals, retention of sediment within constructed reservoirs, removal of the lower dam at River Mile (RM) 4, gravel removal from the river and floodplain, construction of the Anchorage Water and Wastewater Utility (AWWU) pipeline and access road, and channel confinement by roads and bridges. Sediment input, transport, and deposition are important processes that help to provide high quality aquatic habitat. An understanding of current substrate conditions and current and potential future sediment input and transport rates will help to provide information that can be used to assess potential future flow releases and aquatic habitat improvement measures.

This Year 2 Report includes geomorphology and sediment transport data collected in 2020, 2021, and 2022 as well as development of a sediment transport model and integration with the fisheries and hydraulic modeling studies. The sediment transport model is available for use as a tool to help assess potential effects of various flow regimes on the Eklutna River.

2 STUDY OBJECTIVES

The goal of the Geomorphology and Sediment Transport Study is to gain an understanding of how sediment supply, transport, and deposition within the Eklutna River downstream of Eklutna

Lake are influenced by current and potential future Project operations, particularly related to aquatic habitat conditions. Specific objectives include:

- document current substrate conditions (surficial and subsurface);
- identify and estimate input from major sediment sources; and
- estimate sediment transport rates under the current flow regime and provide tools for estimating sediment transport rates under potential alternative flow regimes to help assess the effects of potential future flow regimes on substrate, channel forming processes, and aquatic habitat conditions.

3 STUDY AREA

The study area includes the Eklutna River and associated major sediment sources between the outlet of Eklutna Lake and the mouth of the Eklutna River. Sediment monitoring transects included in the study are shown in Figure 3.0-1.

4 METHODS

The Geomorphology and Sediment Transport Study includes five components:

- review existing information and pre-field analysis;
- conduct field inventory and scour/sediment monitoring;
- estimate historic/current sediment sources and input rates;
- map channel position changes through time; and
- develop a sediment transport model.

4.1. Pre-field Work

Pre-field work included compiling and summarizing existing information including reports, recent and historical aerial photographs, and LiDAR data. Information collected includes:

- Aerial photographs (historic and recent)
- LiDAR (2015 Municipality of Anchorage LiDAR, 2020 and 2022 Eklutna Project LiDAR)
- USFWS cross section and fish flow assessment (Hanson 2019)
- Alaska Department of Fish and Game (ADFG) sediment monitoring (ADFG 2019)
- Habitat mapping – Prince of Wales Consortium 2007 and Native Village of Eklutna (NVE) 2020
- An existing HEC-RAS model of the lower Eklutna River (HDR 2016)
- Eklutna Inc. sediment monitoring at the railroad and highway bridges

Geomorphic reaches were delineated based on channel confinement (e.g., bedrock canyon vs. alluvial reaches), and major flow or sediment sources (e.g., Thunderbird Creek, lower dam deposits, large valley wall sediment sources).

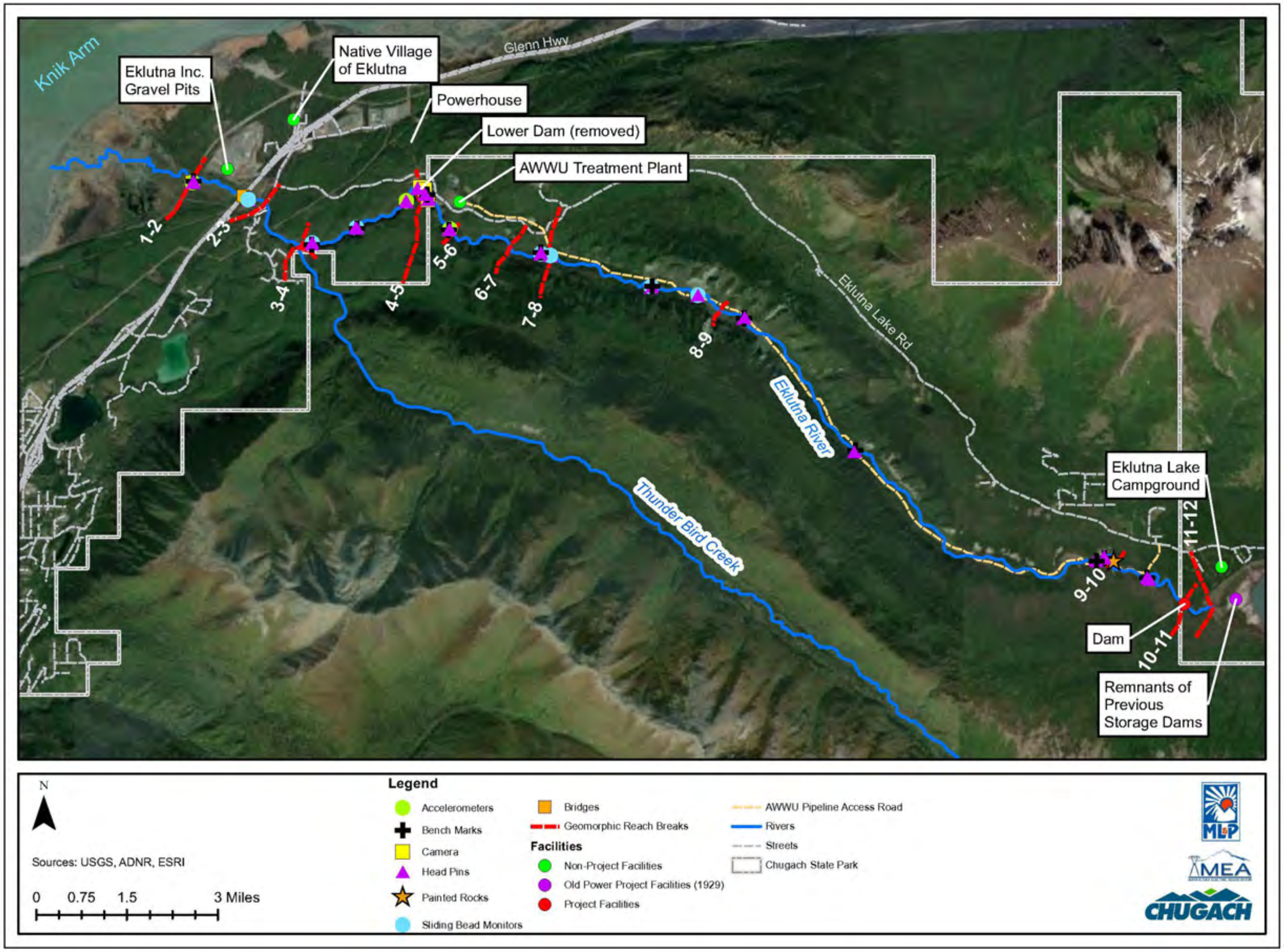


Figure 3.0-1. Study area and sediment monitoring transects.

4.2. Field Inventory and Scour/Sediment Monitoring

Field work included several site reconnaissance trips to view existing substrate, aquatic flow, and sediment source conditions as well as establish monitoring transects to measure any geomorphic changes resulting from the 2021 study flow releases. The 2021 study flow releases were intended to allow study teams to measure changes in hydraulic parameters (see Reiser et al. 2023), water quality (see Sauvageau and Schult 2023), and geomorphology (as described in this report) during different flow levels. The study flow releases started on September 13 and ended on October 6, 2021. The complete flow releases schedule is shown below.

- Monday, September 13 – Initiated flow releases at 150 cfs
- Friday, September 24 – Down-ramped to 75 cfs
- Wednesday, September 29 – Down-ramped to 25 cfs
- Wednesday, October 6 – Down-ramped to 0 cfs

Overall, the flow release schedule encompassed a 23-day period; 11 days high flow; 5 days mid-flow; 7 days low flow. Flow adjustments are described in more detail in the Instream Flow Study Year 2 Report (Reiser et al. 2023).

4.2.1. Selection of Sediment Monitoring Transect Locations

Nineteen sediment monitoring transects were established between Eklutna Lake and the railroad bridge, including eight transects that were previously established in August 2020, four transects that were established by ADFG and NMFS for the aquatic habitat monitoring effort after the lower dam removal, and two transects that are at or near transects established for the Instream Flow Study (Table 4.2-1 and Figure 4.2-1). The eight transects established in 2020 were established in case there was an unanticipated spill event in the fall of 2020. These sites were reviewed with the Aquatics Technical Work Group (TWG) during a June 9-10, 2021 site visit. The remaining transects were also selected in coordination with the Aquatics TWG during the site visit.

Sliding bead monitors were installed at 10 transects and accelerometers were installed at 5 transects. It was not possible to install scour monitoring devices in geomorphic reaches 9 or 10 due to large substrate size. Therefore, in addition to the 19 geomorphology transects, painted rocks were deployed across the channel at one additional location near RM 11.3 to provide information on gravel movement.

Table 4.2-1. Sediment monitoring transects.

Transect ID	River Mile (RM)	Geomorphic Reach[2]	ADFG Monitoring Transect?	Instream Flow Study Site Nearby?	2020?	Scour Monitoring Equipment
101	1.6	2				Sliding Bead, Accelerometer
G	2.15	2			Y	Sliding Bead, Accelerometer
ADFG 8 Down	2.9	4	Y		Y	Sliding Bead
ADFG 6 Down	3.3	4	Y		Y	Sliding Bead
ADFG 2 Down	3.8	4	Y			Sliding Bead, Accelerometer
204	4.0	5				
203	4.05	5				
202	4.1	5				
201	4.15	5				
ADFG 4 Up	4.4	5	Y			Sliding Bead, Accelerometer
102	5.3	7		Y		Sliding Bead
F	5.4	7/8			Y	Sliding Bead
103	6.3	8		Y		Sliding Bead, Accelerometer
E	6.6	8			Y	Sliding Bead
D	7.1	9				
105	10.5	9				
C	11.15	9			Y	
B	11.2	9			Y	Painted Rocks on alluvial fan
Painted Rocks[1]	11.3	9/10				Painted Rocks in stream
A	11.8	10			Y	

Notes:

[1] The Painted Rocks transect is an informal transect installed to help determine movement of specific particle sizes in the stream during the flow release.

[2] See Section 5.2 for discussion of geomorphic reaches.

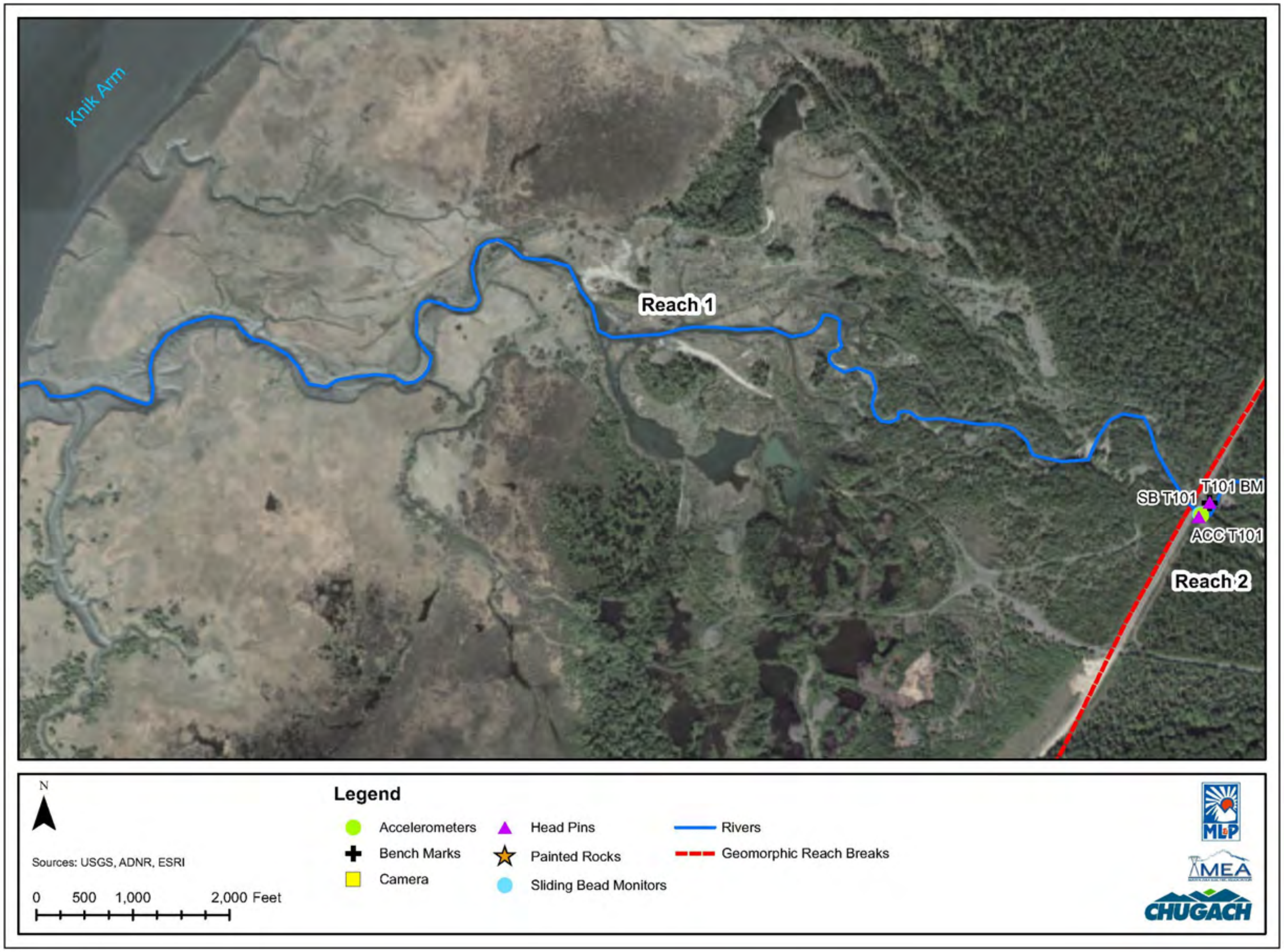


Figure 4.2-1. Sediment monitoring transect locations Map 1 of 10.

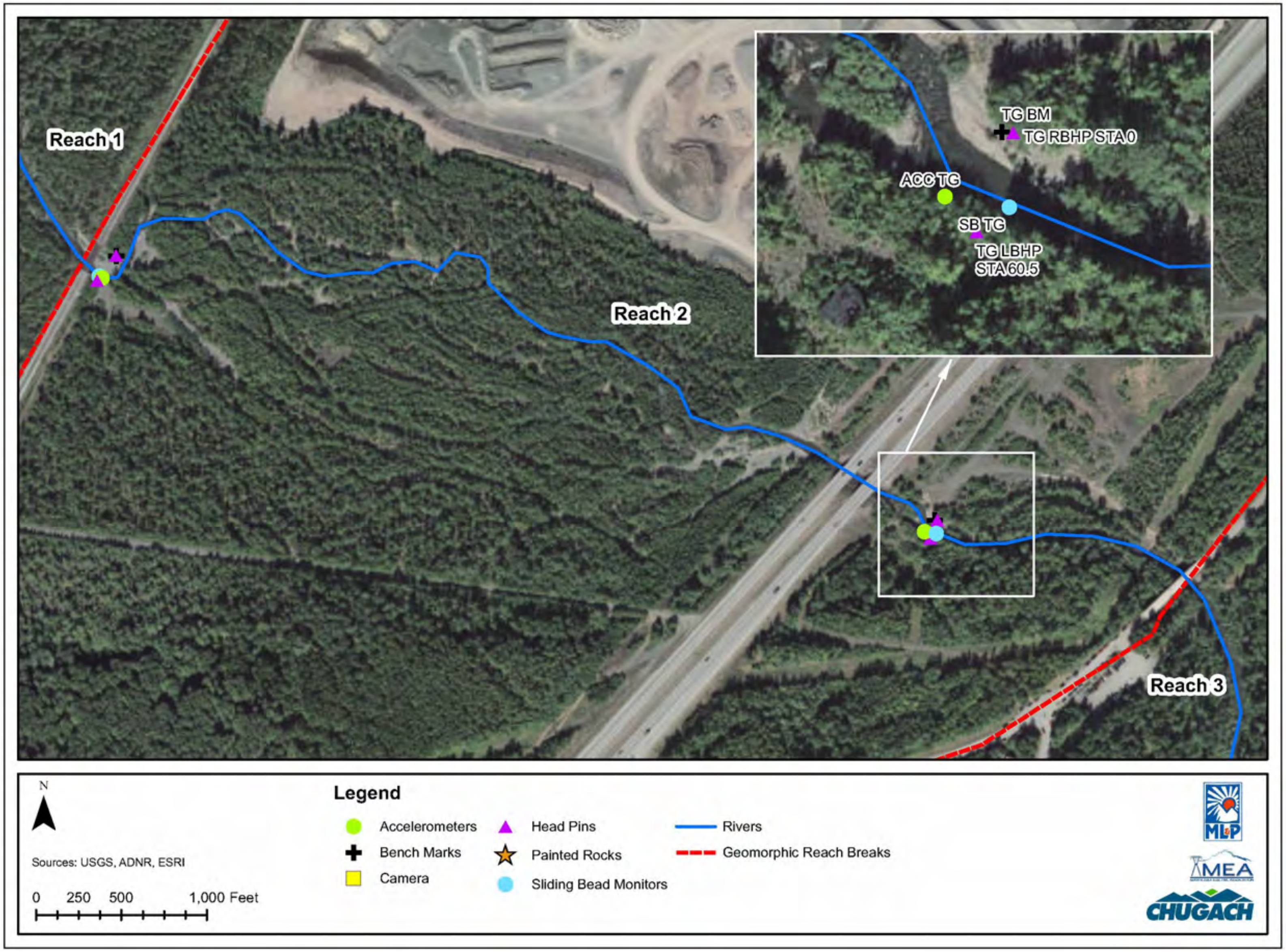


Figure 4.2-2. Sediment monitoring transect locations Map 2 of 10.

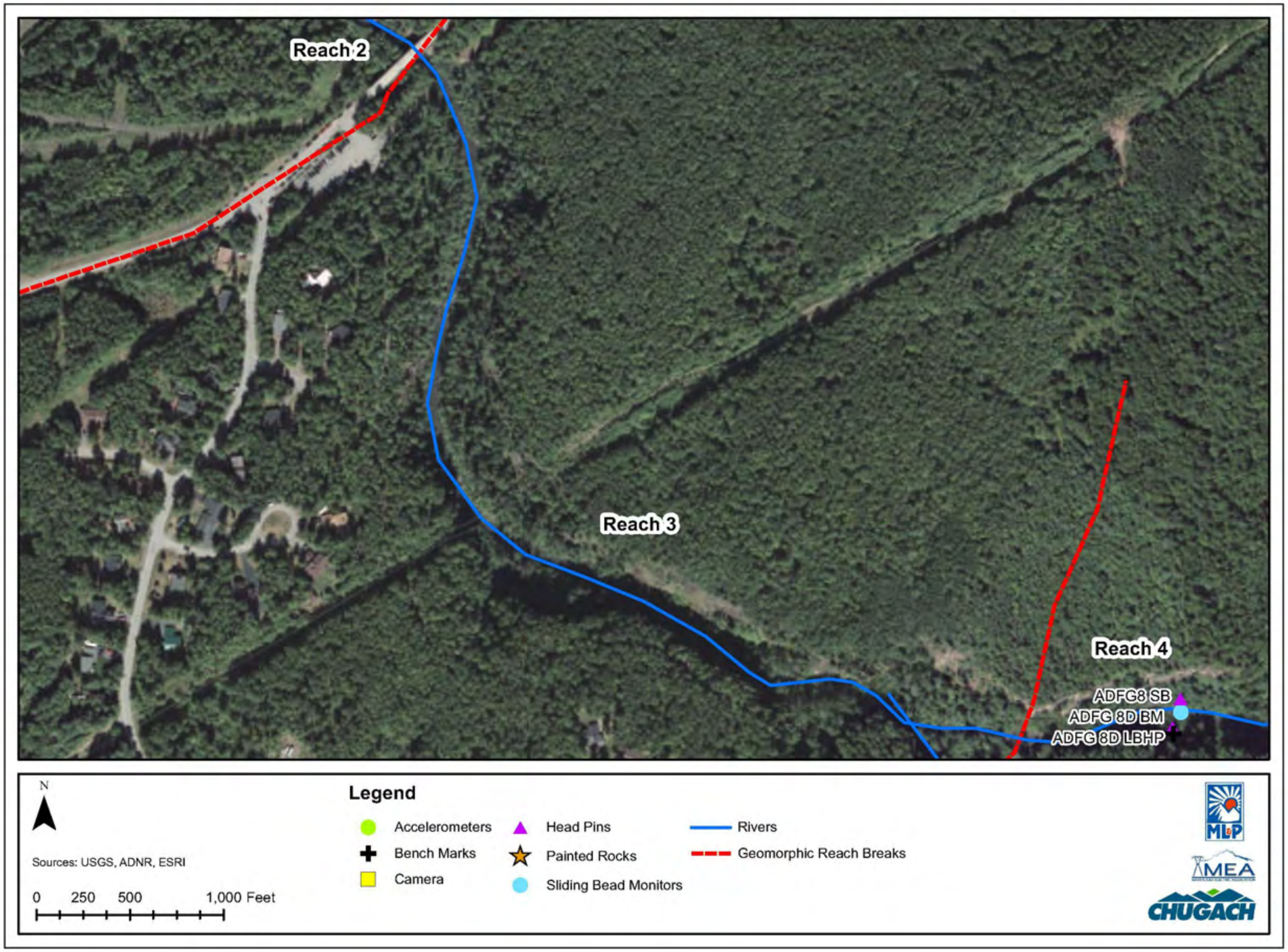


Figure 4.2-3. Sediment monitoring transect locations Map 3 of 10.

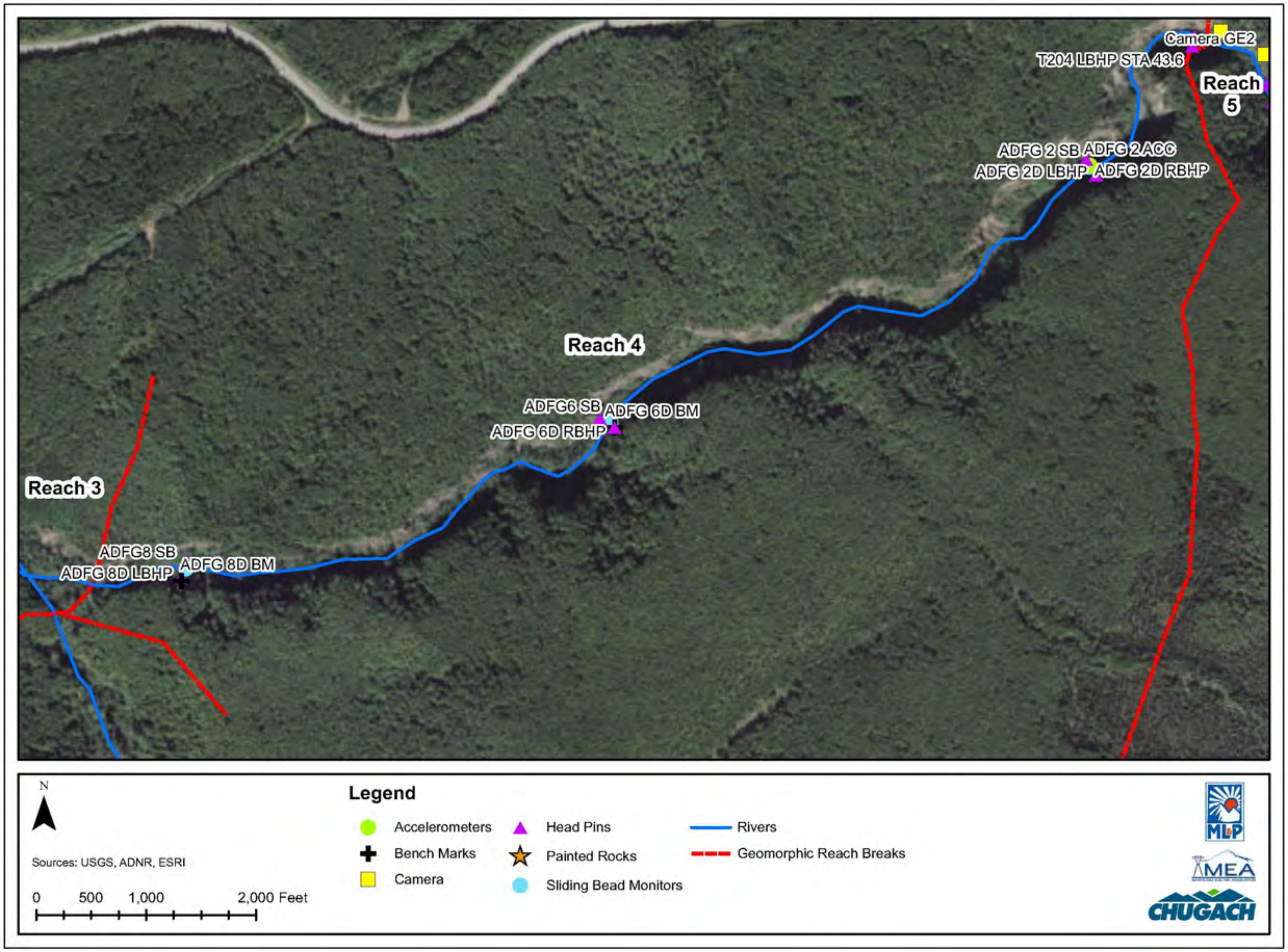


Figure 4.2-4. Sediment monitoring transect locations Map 4 of 10.

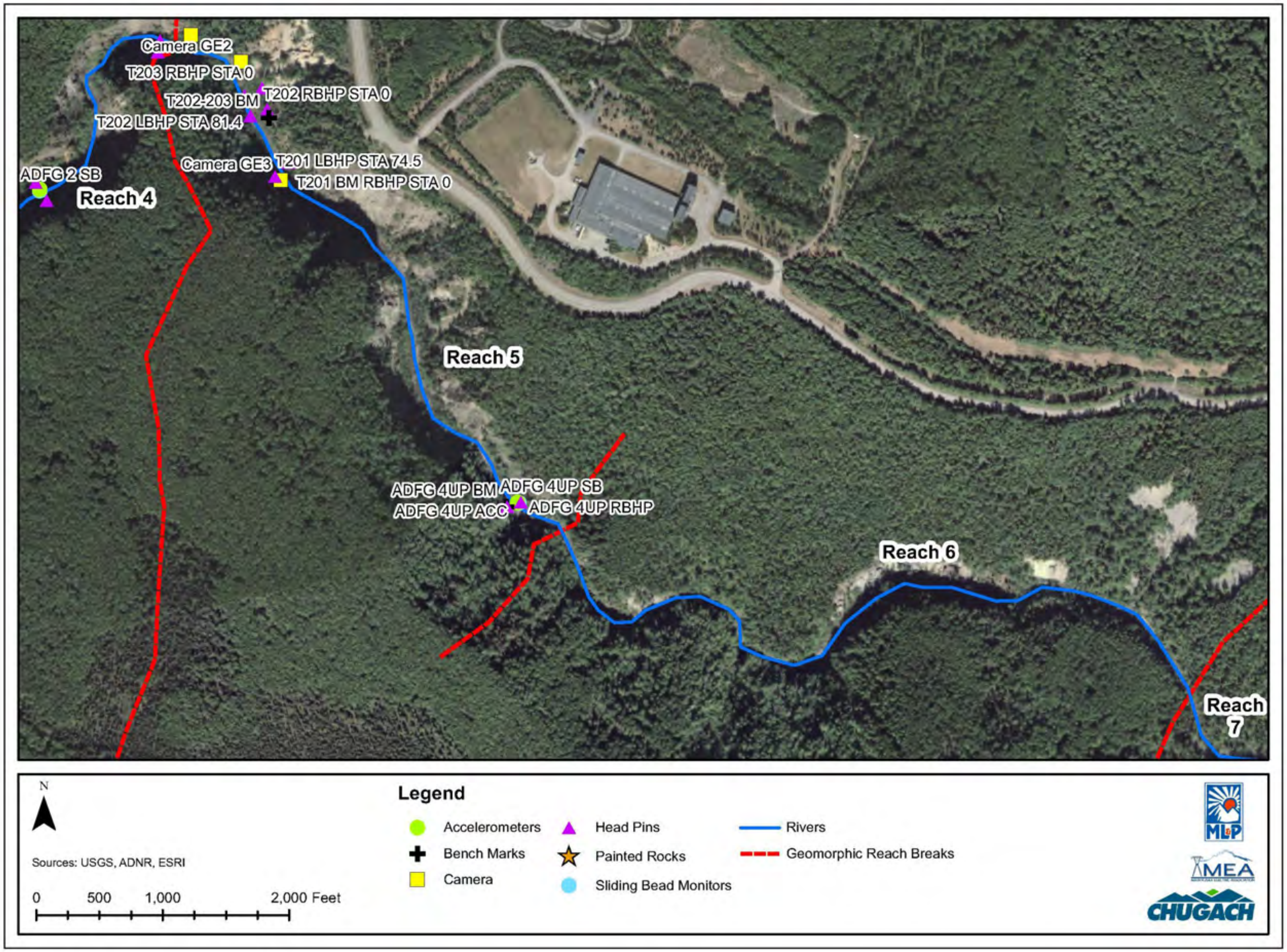


Figure 4.2-5. Sediment monitoring transect locations Map 5 of 10.

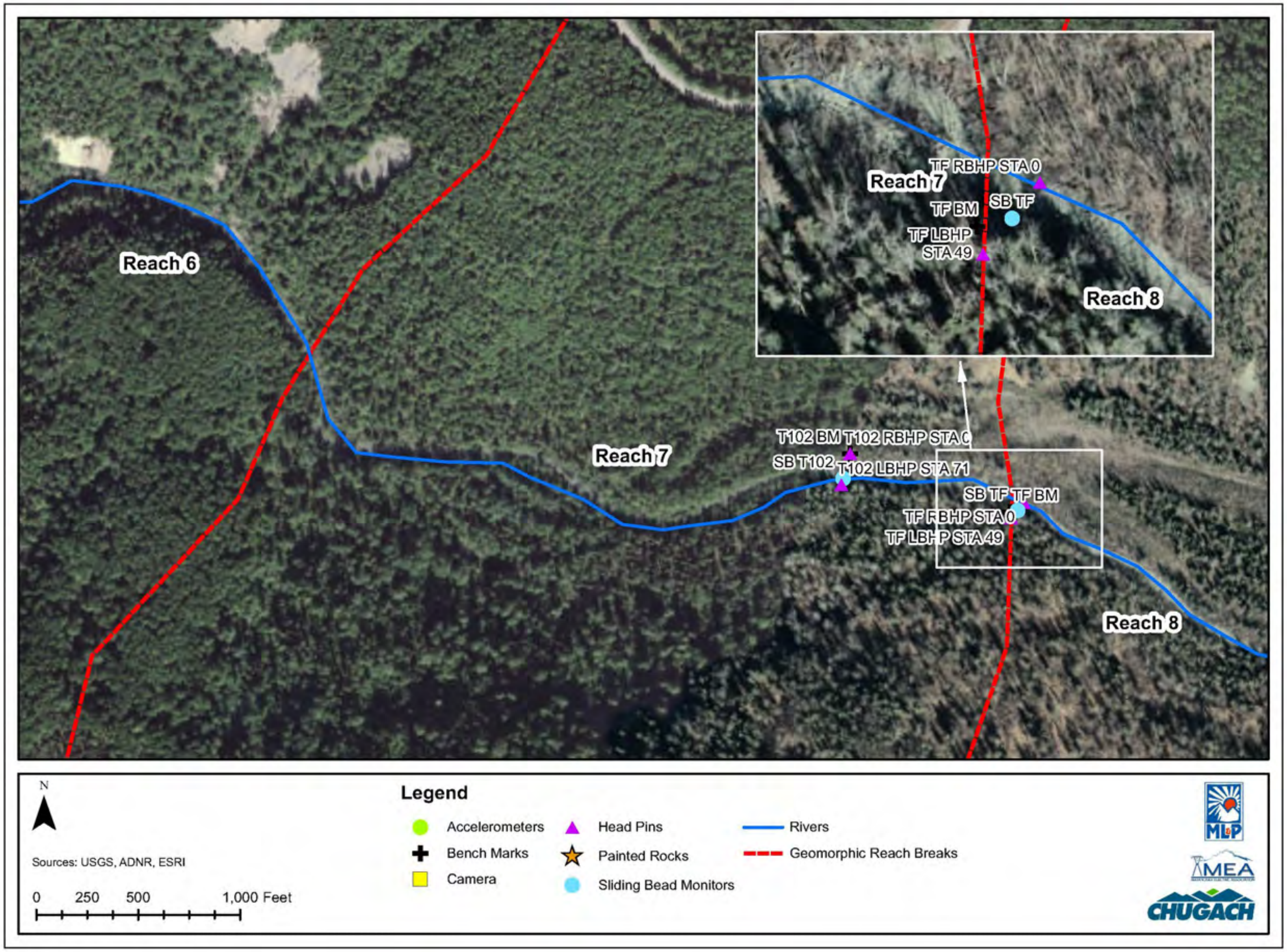


Figure 4.2-6. Sediment monitoring transect locations Map 6 of 10.

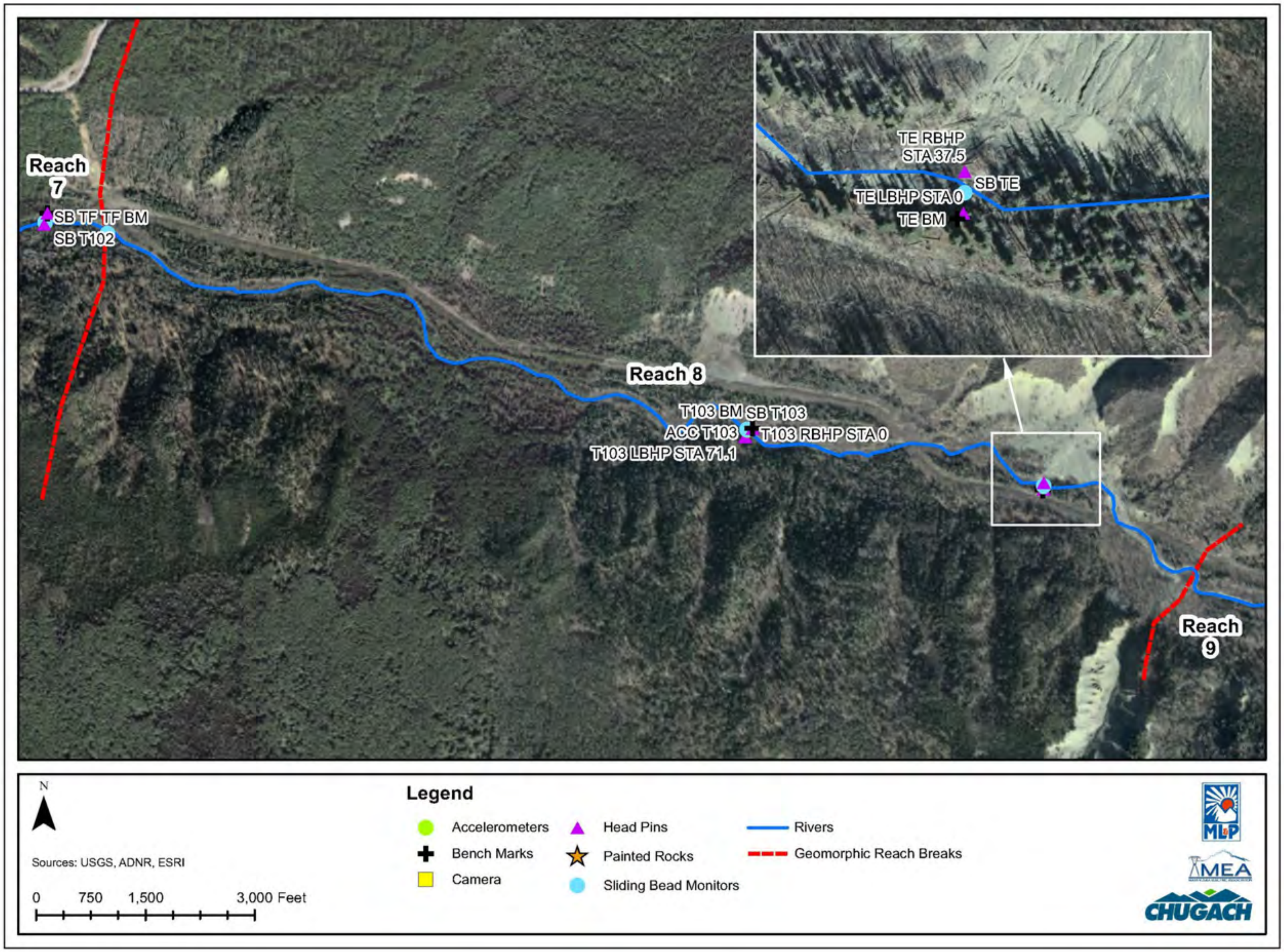


Figure 4.2-7. Sediment monitoring transect locations Map 7 of 10.

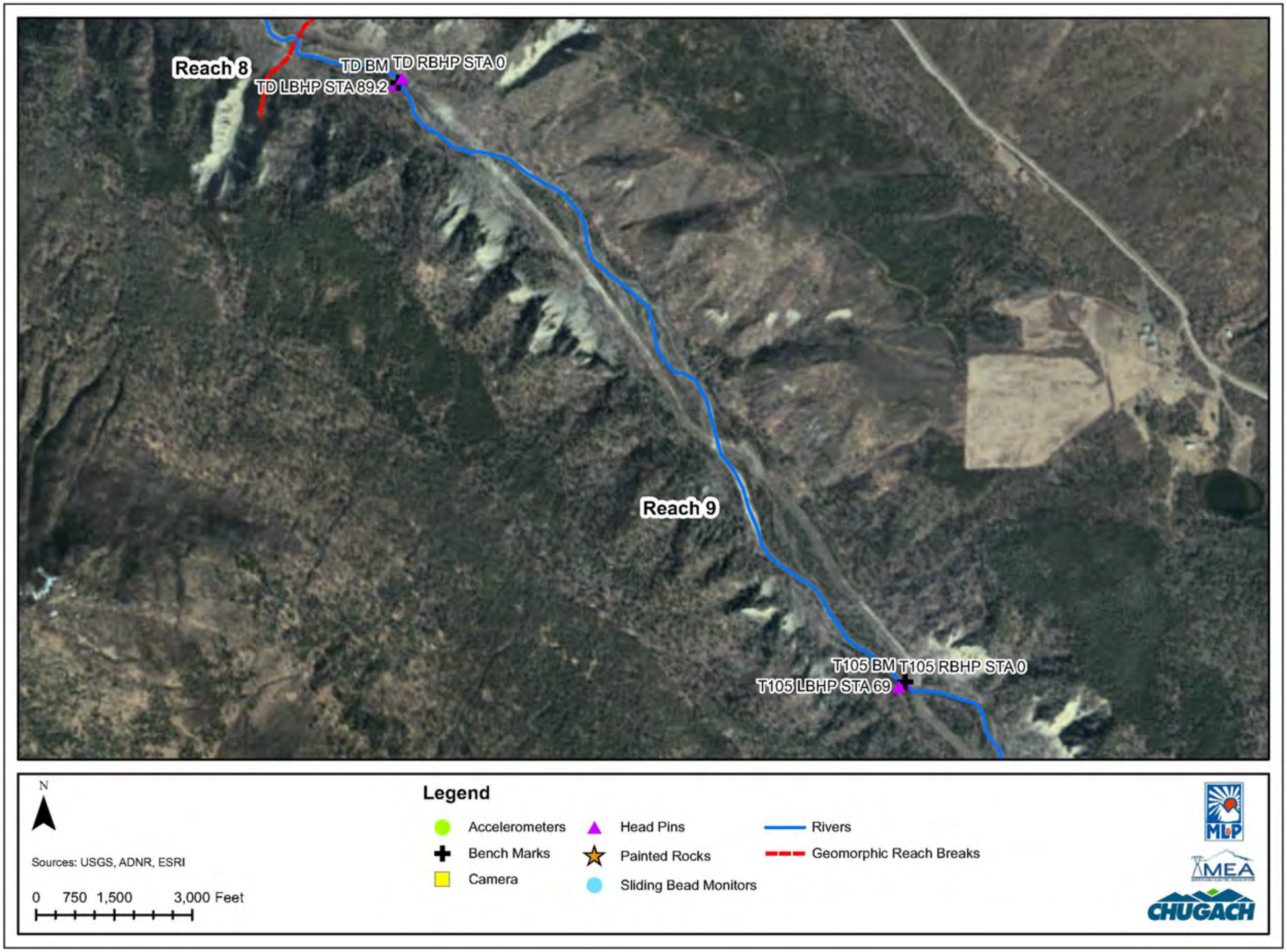


Figure 4.2-8. Sediment monitoring transect locations Map 8 of 10.

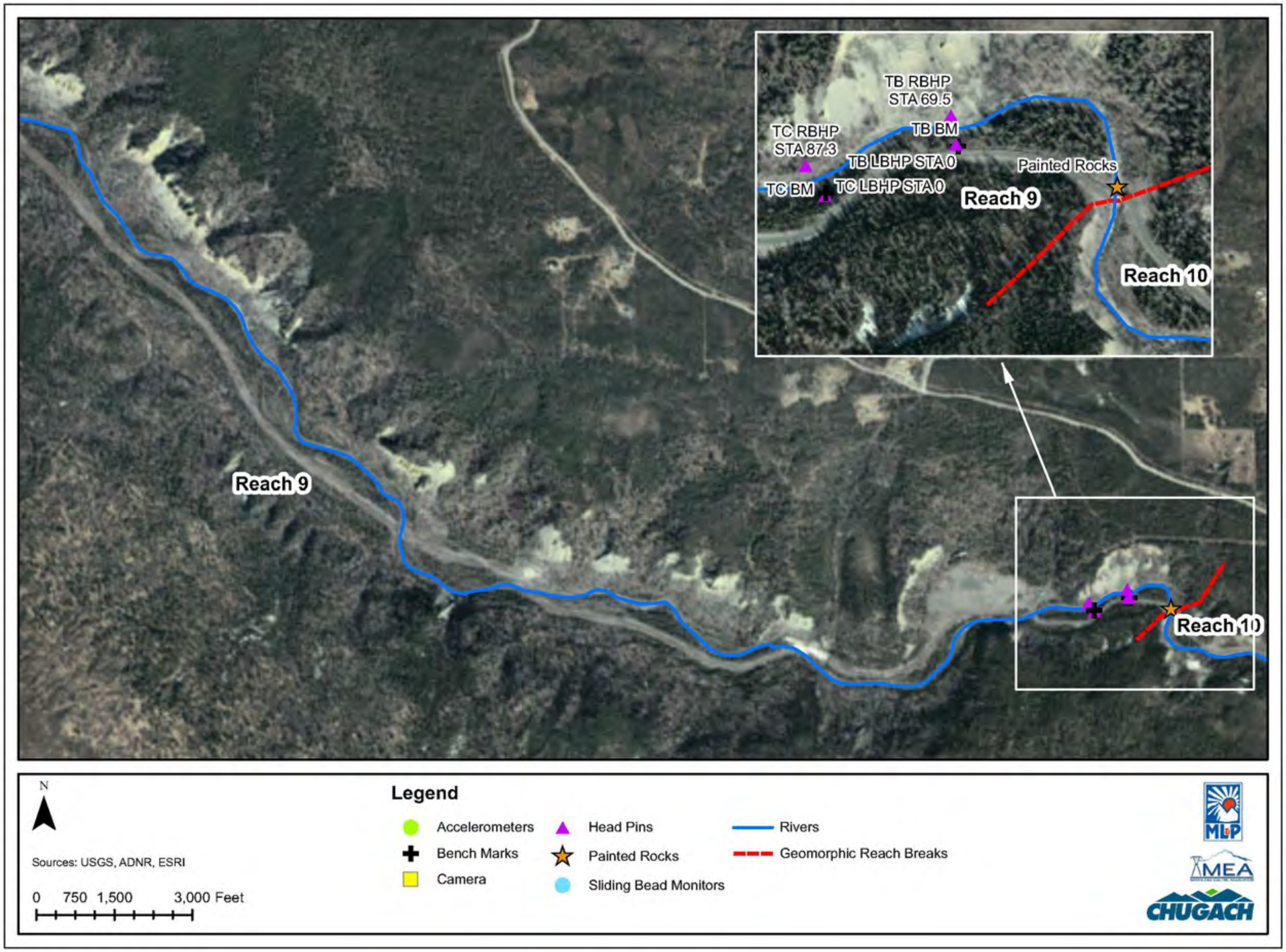


Figure 4.2-9. Sediment monitoring transect locations Map 9 of 10.

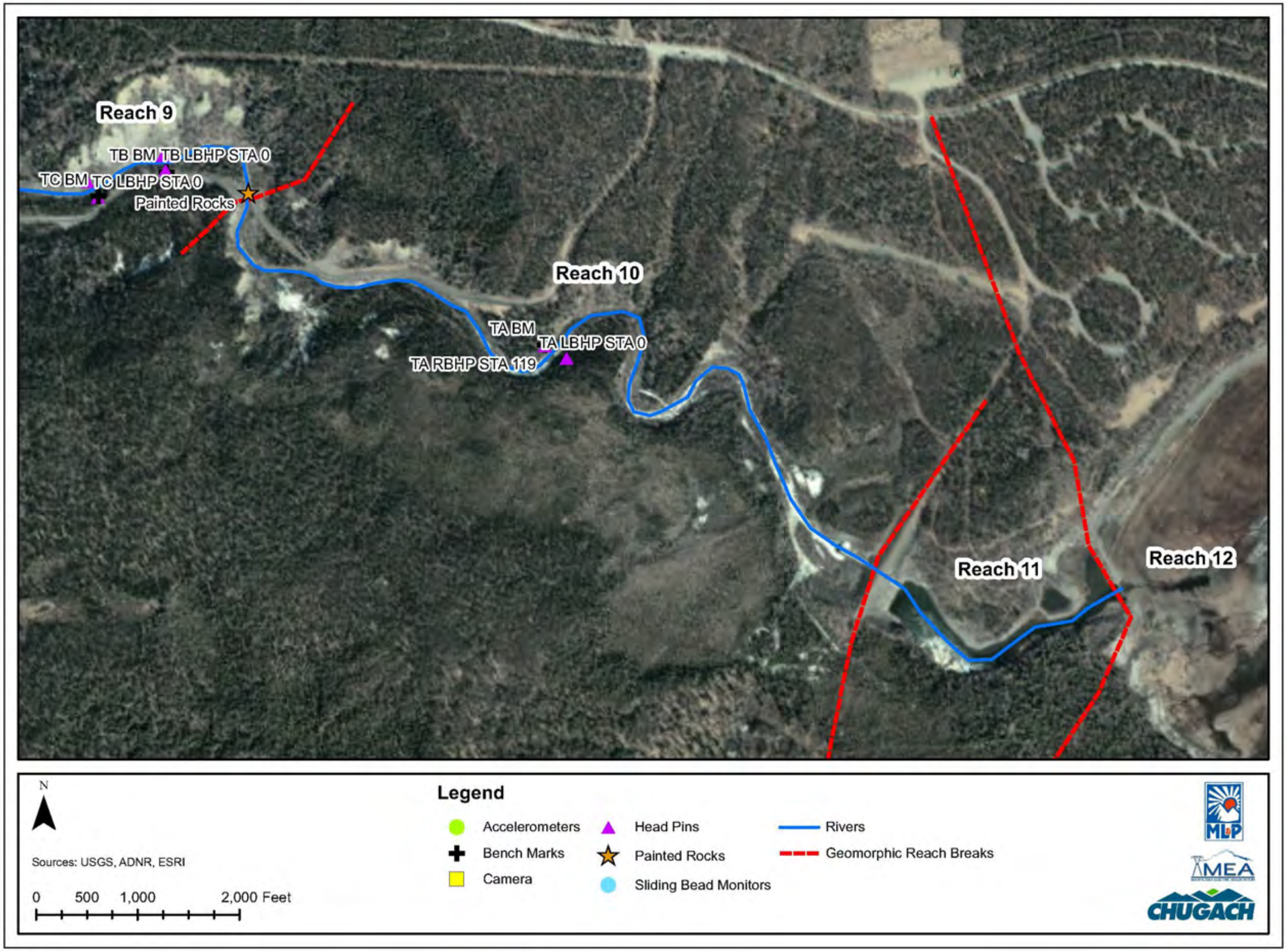


Figure 4.2-10. Sediment monitoring transect locations Map 10 of 10.

4.2.2. Cross Section and Substrate Data Collection

At each sediment monitoring transect, a benchmark and two transect headpins were installed, typically nails or plastic stakes with rock bolts used in bedrock areas. Cross sections were surveyed between headpins using a fiberglass tape, laser level, and survey rod. Stations along the tape/transect were located to define slope breaks above the bankfull channel and stations every foot within the bankfull channel. Grain size of substrate was recorded (using a gravelometer with phi scale e.g., <2mm, 2-2.8 mm, 2.8-4mm, 4-5.6 mm, 5.6-8mm, etc.) at each station within the bankfull channel for a minimum of 100 points within the bankfull channel. If the bankfull width of a cross section was less than 100 feet long (e.g., less than 100 pebble count points), additional passes across the channel were made so that at least 100 clasts are recorded at each site. Photos were taken of each transect.

Sub-surface sediment samples were taken in the vicinity of select transects by scraping away the surface armor layer and taking a bulk sample of sub-armor material. Sub-surface samples were taken at three locations in August 2021 where gravel/cobble material was available to sample. Substrate at the majority of transect locations consisted of fines covering cobble/boulder material and was not suitable for sub-surface sampling. Bulk samples were field sieved to remove particles larger than 32 mm, which were weighed in the field. A sub-sample of the remaining sediment (finer than 32 mm) was taken for laboratory sieving and weighing.

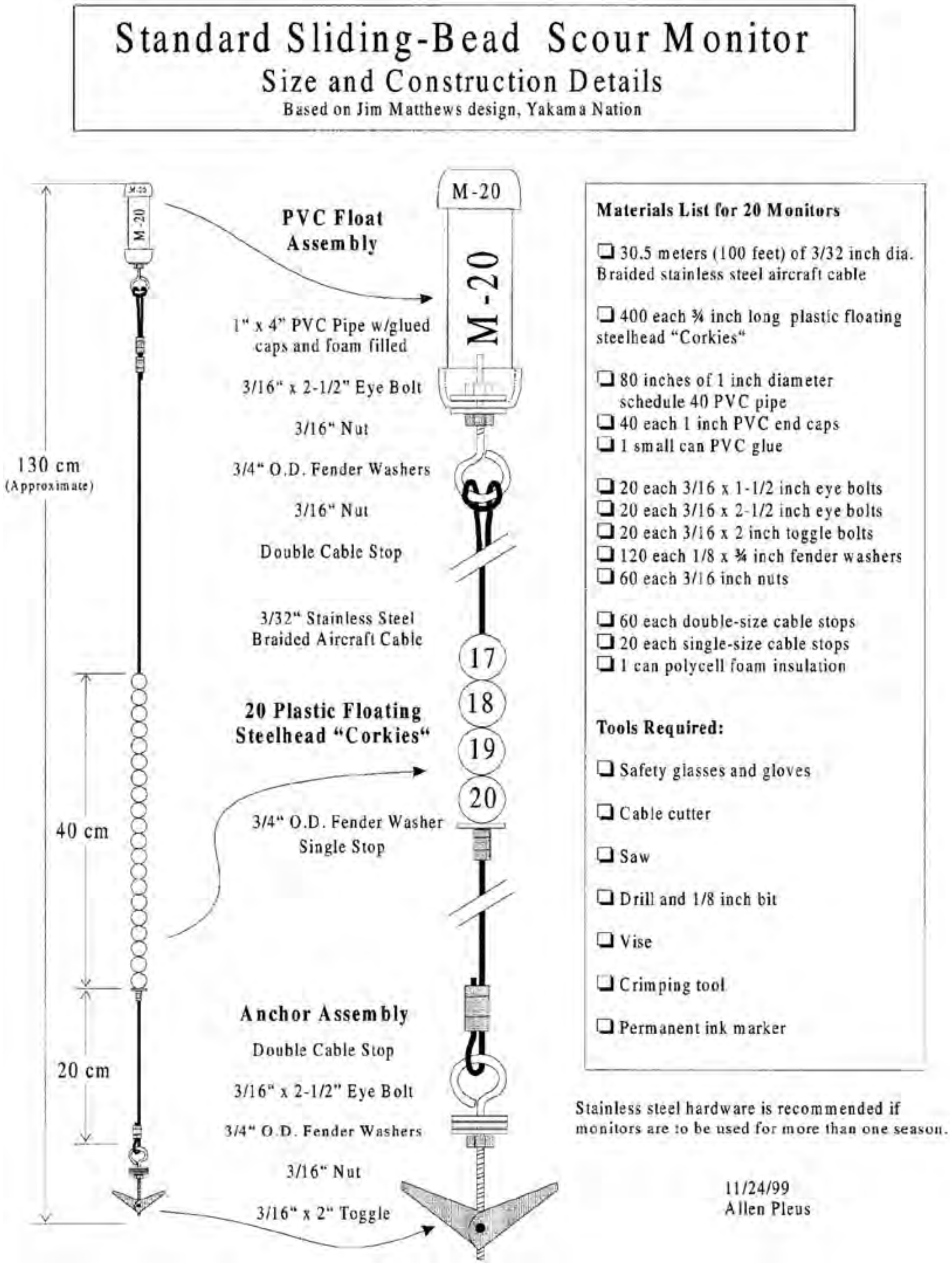
Three grab samples of fine-grained (silt/clay), compressed material from the exposed old dam deposits were taken in 2022 and sent for laboratory analysis of bulk density. They were processed using ASTM D7263 Method A, Standard Test Methods for Laboratory Determination of Density and Unit Weigh of Soil Specimens.

4.2.3. Scour Monitors and Accelerometers

Sliding bead scour monitors, slightly modified from Figure 4.2-11 (Schuett-Hames et al. 1999) were installed at 10 transects. The modification included using a 1.5-inch diameter plastic ball with a Passive Integrated Transponder (PIT) tag epoxied inside the ball instead of the PVC float since the smaller balls are less visible and easier to re-locate with a PIT tag reader. The sliding bead scour monitors record both scour and fill that takes place. The top bead on each monitor was set approximately level with the bottom of the riverbed. If the bed scours, beads are exposed and float to the top of the cable. Depth of scour is determined by number of beads exposed. If fill occurs, beads were buried, and depth of fill was determined by burial depth.

Accelerometers with a Hobo Pendant G accelerometer enclosed in a 2.5-inch black PVC holder attached to a cable and anchor as shown in Figure 4.2-12 were installed at 5 transects. The accelerometer recorded x-y-z position every 30 minutes. This allows the timing of any bed movement to be recorded, which can be correlated to flow when bed movement occurs.

The scour monitors installed in August 2020 were read in August 2021 by noting the number of beads that had floated to the top and/or any burial. All scour monitors were read in October/November 2021 following the September/October study flow releases. The accelerometers were removed in October/November 2021 or spring/summer of 2022.



Standard Sliding-Bead Scour Monitor
Size and Construction Details
Based on Jim Matthews design, Yakama Nation

Materials List for 20 Monitors

☐ 30.5 meters (100 feet) of 3/32 inch dia. Braided stainless steel aircraft cable

☐ 400 each ¾ inch long plastic floating steelhead "Corkies"

☐ 80 inches of 1 inch diameter schedule 40 PVC pipe
☐ 40 each 1 inch PVC end caps
☐ 1 small can PVC glue

☐ 20 each 3/16 x 1-1/2 inch eye bolts
☐ 20 each 3/16 x 2-1/2 inch eye bolts
☐ 20 each 3/16 x 2 inch toggle bolts
☐ 120 each 1/8 x ¾ inch fender washers
☐ 60 each 3/16 inch nuts

☐ 60 each double-size cable stops
☐ 20 each single-size cable stops
☐ 1 can polycell foam insulation

Tools Required:

☐ Safety glasses and gloves

☐ Cable cutter

☐ Saw

☐ Drill and 1/8 inch bit

☐ Vise

☐ Crimping tool

☐ Permanent ink marker

Stainless steel hardware is recommended if monitors are to be used for more than one season.

11/24/99
Allen Pleus

Figure 4.2-11. Sliding bead scour monitor (from Schuett-Hames et al. 1999).

Note: a 1.5-inch diameter plastic ball with a PIT tag was used in place of the PVC float since these have been found to be less visible and more stable during high flows.

Figure 4.2-12. Accelerometer before deployment.

4.2.4. Timelapse Cameras

Three timelapse cameras were installed in the old lower reservoir area (the area upstream from the lower dam site where sediment accumulated prior to removal of the dam) to record changes that took place during the study flow releases (see locations on Figure 4.2-5). Cameras were mounted on fence posts located on the top of the reservoir deposits and set to record every 10 minutes during daylight hours (Figure 4.2-13). Cameras were retrieved following the study flow releases.

Figure 4.2-13. Timelapse camera installation prior to study flow releases.

4.3. Sediment Sources and Input Rates

Sediment sources in the study area were assessed through a combination of aerial photograph/LiDAR analysis and field inventories.

Major sediment source areas were mapped using the 2021 aerial photographs and 2021/2022 LiDAR topographic data. The eroding area for each sediment source was delineated based on unvegetated areas within the study area and included gullies, streambanks, and eroding valley walls. The average volume of sediment from each source was estimated based on comparison of 2015, 2021, and 2022 LiDAR surfaces divided by time between LiDAR flights. Headscarp retreat for one of the larger sources (Source area 22) was visible and mapped from Google Maps aerial photographs from 1952-2022 to provide a longer-term estimate of sediment input rates from this source area.

Each of the major sediment sources was also observed in the field on July 6-8, 2022. At each of the source areas, grain size distribution was estimated (cobble, gravel, sand, fines) based on visual assessment of eroding banks or cliff faces. The percent of total sediment eroded from each source area that was delivered to the Eklutna River was noted based on observed grain size of sediment that reached the Eklutna River from each source. For example, if the sediment source area was directly adjacent to the river channel and all grain sizes from the source cliffs were observed to reach the river, delivery percent was noted as 100 percent. If the source cliffs were far from the Eklutna River channel and the majority of sediment from the eroding source cliffs was observed to be deposited within the valley bottom, it was noted that a small percentage of the sediment was delivered to the river. The delivery percentages are, as with the rest of the sediment observations in this report, a snapshot in time based on current river/source area locations. If the Eklutna River migrates substantially in the future, source area delivery percentages may change.

4.4. Channel Position Changes through Time

Historic aerial photographs and LiDAR hillshade were assessed to determine portions of the Eklutna River that showed evidence of current or historic channel migration. Based on this screening, the active Eklutna River channel in Geomorphic Reaches 1 and 2 between tidelands (approx. RM 0.7) and the old highway bridge (approx. RM 2.3) was selected for analysis. Geomorphic Reaches 3, 4, 5, and 6 are confined within a bedrock canyon that limit migration. In Geomorphic Reaches 7, 8, and 9 the river could migrate, but there was only one set of comprehensive aerial photographs available (1952) prior to the time when the majority of flow was diverted out of this reach of river; observations on subsequent photos showed little evidence of channel migration. Geomorphic Reach 10 is confined with limited opportunity for channel migration.

The active channel in Geomorphic Reaches 1 and 2 was mapped through time on historical aerial photographs using 1949, 1957, 1972, 1990, and 2020 photos. The active channel includes the wetted channel and unvegetated river bars. The historical aerial photographs were geo-rectified in ArcMap. Recent (2020) aerial photograph mosaics were available digitally and fully rectified. Note that particularly for the older photographs upstream of the canyon, limited positions were available for geo-rectifying because not much infrastructure existed to provide consistent reference locations. Areas downstream from the canyon had more infrastructure/development that provided better reference locations. Photographs were selected that had the river as close to the center of the image as possible to reduce errors associated with lens distortion around the edges of the photos. Note that there is error in exact channel position associated with geo-rectification errors, but for the purposes of this study, where general channel migration/lack of migration was of interest, the error was acceptable.

4.5. Sediment Transport Model Development

4.5.1. HEC-RAS 1-D Model

A HEC-RAS one-dimensional (1-D) hydraulic model developed by Kleinschmidt (Reiser et al. 2023) was augmented to use the Quasi Unsteady (Sediment) routine within HEC-RAS Version 6.2 to help assess the effects of flow augmentation in the Eklutna River. The model is one tool that is available to help assess how a new flow regime will affect sediment transport and geomorphology in the Eklutna River.

4.5.1.1. Hydraulic Model Development

A one-dimensional riverine hydraulic model (HEC-RAS 1D, Version 6.2) was developed and included a 10.8-mile long reach of the Eklutna River from Eklutna Dam (RM 12.3) to RM 1.5 (downstream from railroad bridge). Within this model reach, there is one major tributary (Thunderbird Creek) that joins the Eklutna River at RM 2.8. The HEC-RAS 1D model included the following three reaches:

1) Upper Eklutna – from Eklutna Dam to the confluence with Thunderbird Creek (9.5 miles)
2) Lower Eklutna – from the confluence with Thunderbird Creek to just downstream from the railroad bridge (1.3 miles)
3) Thunderbird Creek – from the confluence with the Eklutna River to Thunderbird Falls

Ground-based data collection was performed in 2021 for the three different study flow releases from Eklutna Dam. The morphology of the HEC-RAS 1D model relied on the following three sources of data:

1) LiDAR data acquired on May 15, 2020
    a) Projection: UTM Zone 6 North
    b) Horizontal Datum: NAD 83 (2011)
    c) Vertical Datum: NAVD88 (GEOID12B)
    d) Units: meters
2) Geomorphology study cross sections surveyed in 2021. The bottom profile of each instream flow transect was surveyed using a tape measure and an automatic level. The cross sections were surveyed prior to any study flow releases from Eklutna Dam and were then surveyed following each study flow release from Eklutna Dam (low, medium, and high).
3) Instream flow study cross sections surveyed in 2021. Horizontal and vertical control was established for each instream flow cross section using RTK GPS. The bottom profile of

each instream flow transect was surveyed using a tape measure and an automatic level. Water surface elevations were surveyed, and discharges were measured for three different study flow levels (low, medium, and high). These data were used to calibrate hydraulic roughness in the HEC-RAS 1D model.

A total of 241 cross sections were incorporated into the HEC-RAS 1D model. Data collected from the instream flow study were used to calibrate hydraulic roughness in the HEC-RAS 1D model at three different measured study flow levels (25 to 122 cfs as measured at the instream flow monitoring transects) and were used to extrapolate hydraulic conditions for 1,500 cfs (peak flow for the geomorphology study). The effective roughness option was used to calibrate the hydraulic model to the measured flows and also used to extrapolate Manning's n for 1,500 cfs.

At the 1,500 cfs flow level, Manning's n in the channel ranged from 0.027 to 0.074 with a median value of 0.040. Manning's n in the overbank areas ranged from 0.029 to 2.41 with a median value of 0.053. Manning's n values in the overbank areas were greater than Manning's n values in the channel as would be expected. Simulated hydraulic conditions at the 1,500 cfs level are expected to be reasonably accurate for the current channel configuration. HEC-RAS 1D models are routinely used to extrapolate up to large flood levels that might result from extreme storm events such as a 100-year storm or a Probable Maximum Precipitation (PMP) event, as well as a dam break flood, so extrapolation of the Eklutna River model to 1,500 cfs is within the range of normal model use.

Additions to the 1D HEC-RAS hydraulic model needed to run the sediment transport calculations include providing information on substrate, sediment inputs, and sediment transport functions as described below

4.5.1.2. Bed Gradations

Bed gradation provides information on the grain size composition of the riverbed. For initial calibration runs, the 2020 (pre-study flow release) measured substrate gradations were used. However, the pre-study flow release substrate measurements between Thunderbird Creek and the upper-most large sediment source (approximately RM 11.4) include a large proportion of fine-grained sediment that does not reflect the underlying substrate that will be present after a few years of a new flow regime. To best estimate the effects of future flow releases, the river substrate used for future flow scenarios was based on best judgment of underlying sediment from substrate sampling upstream of RM 11.4 and observations of substrate on historic (higher elevation) river bars and within the channel following the 2021 study flow releases.

4.5.1.3. Moveable Bed Limits and Maximum Scour Depth

Moveable bed limits were set to a reasonable channel width based on potential high flow channel widths that could develop under future flow scenarios. Maximum scour depth was set to 5 feet for the majority of transects with the exception of mapped bedrock or grade controls (1-2 feet) and the old reservoir deposits (up to 20 feet based on estimated sediment depths).

4.5.1.4. Boundary Conditions (Sediment Input)

Boundary conditions set the amount of incoming sediment in the model. The upper boundary condition was set to 0 sediment input since all upstream sediment is deposited in Eklutna Lake. A rating curve for Thunderbird Creek input was estimated based on substrate size in the creek. Sediment time series were set for the alluvial fan sediment sources with average annual inputs as shown in Table 2-1 above.

4.5.1.5. Sediment Transport Function

The Meyer-Peter Muller transport function was chosen based on the dominant substrate size in the river (gravel-cobble) and stream gradient. Erosion of fine-grained sediment from within the old reservoir are not expected to be modeled accurately with this transport function because erosion rates of consolidated fine-grained sediment vary widely and are site-specific based on relative grain size and consolidation of the fine sediment. In addition, time-lapse photography of the reservoir during the flow release showed that mass wasting via undercut banks, toppling, and slumping occurred within the reservoir deposits. These processes are not modeled in HEC-RAS. Because we have accurate information on the actual amount of erosion in the old reservoir deposits from the LiDAR comparison, and the majority of the fine-grained silt/clay will be transported downstream as washload, this is not considered a limitation of the overall model. Modeled erosion processes between RM 4-4.2 will not accurately reflect measured erosion within the old reservoir deposits, but the remainder of the river will not be subject to these limitations.

4.5.1.6. Calibration and Confidence

The HEC-RAS sediment transport model was run to test how well the model predicted changes that took place at the 20 geomorphic monitoring transects during the 2021 test flows. Measured Eklutna River and Thunderbird Creek flows were run and the measured and modeled net channel change (depth of erosion or deposition) were compared (Table 4-1). The modeled and measured channel changes were closely comparable at transects upstream of the old reservoir deposits. Within the old reservoir, as described above, the model predicted up to 20 feet of channel erosion through the sediments but the erosion was confined to a narrow channel since mass wasting and bank toppling are not modeled. Downstream from the old dam, model results were not as closely aligned with measured erosion/deposition depths, but the model did correctly predict erosion and deposition trends. Some of the model difficulty in these downstream areas was likely due to field evidence that suggests at least one wave of eroded reservoir deposits moved downstream as a debris torrent (likely following some of the larger mass wasting events observed on the time lapse cameras) rather than as river-borne sediment transport. HEC-RAS does not model debris torrent transport with highly viscous flow. Sediment transport scenarios under future conditions through and downstream from the old reservoir will not be subject to debris torrents and should provide more reliable results. The sediment transport calibration data provide excellent confidence in model results at flows up to the 2021 flow release levels (150 cfs). The sediment transport function chosen (Meyer-Peter Muller) has been widely-used to compute sediment transport in gravel-bed rivers for decades and used to extrapolate to high flow conditions. However, model results are less certain at very high flow levels (e.g., 1,500 cfs) where field data are not available to compare to model results.

Table 4.5-1. Comparison of Measured and Modeled Channel Change during 2021 Flow Release at Geomorphic Monitoring Transects.

Area	Transect ID	River Mile (RM)	HEC-RAS Transect	2020-2021 Measured Transect Changes	HEC-RAS Modeled Change
Downstream from Old (Lower) Dam	101	1.6	39080	Up to 1 foot deposition on edge of bar and 1 foot erosion in channel	5 feet of erosion (note that this transect is just upstream of a bridge; the sediment transport model has difficulty with bridges. The transect just downstream from bridge has 1.7 feet of erosion which is more representative of non-bridge transect changes)
	G	2.15	48205	Up to 1 foot of deposition (gravel) in channel	2.5 feet of deposition
	ADFG 8 Down	2.9	61320	Up to 0.5 foot of erosion during flow release	1.7 feet of erosion
	ADFG 6 Down	3.3	68505	Up to 2 feet of deposition during flow release	0.3 feet of deposition
	ADFG 2 Down	3.8	77134	Up to 1 foot of deposition followed by 1-2 feet of erosion during flow release	0.6 feet of deposition
Old Reservoir Deposits	204	4.0	79786	2-3 feet of deposition then 4 feet of erosion during flow release	4 feet of erosion
	203	4.05	81177	Up to 30 feet of erosion of stored sediment; thalweg erosion 3 feet	20 feet of erosion (in narrow channel)
	202	4.1	81448	Up to 14 feet of erosion of stored sediment; thalweg erosion 2 feet	20 feet of erosion (in narrow channel)
	201	4.15	82249	Up to 14 feet of erosion of stored sediment; thalweg erosion 9 feet	20 feet of erosion (in narrow channel)
Upstream from Old Reservoir	ADFG 4 Up	4.4	87709	Up to 1 foot of erosion in channel	Less than 0.1 foot of change
	102	5.3	103502	Little change	Less than 0.1 foot of change
	F	5.4	104923	Cut and then deposition of up to 1 foot during flow release	0.7 feet of deposition
	103	6.3	121186	Up to 1 foot of erosion in channel during flow release	0.9 feet of erosion
	E	6.6	128374	Up to 1 foot deposition in left bank channel; new right bank channel with 2 feet of erosion	3.2 feet of erosion (model does not simulate cutting of new channel)
	D	7.1	135979	Up to 1 foot of deposition	1.1 feet of deposition
	105	10.5	161517	Overbank deposition and up to 1.5 feet of erosion in channel	1.2 feet of erosion
	C	11.15	205961	Up to 0.5 feet of erosion	1.1 feet of erosion
	B	11.2	207178	Up to 3 feet of erosion	0.7 feet erosion
	Painted Rocks	11.3	209017	n/a	0.9 feet erosion

Area	Transect ID	River Mile (RM)	HEC-RAS Transect	2020-2021 Measured Transect Changes	HEC-RAS Modeled Change
	A	11.8	215735	Minor changes	Less than 0.1 foot change

4.5.1.7. 1-D HEC-RAS Model Limitations

The HEC-RAS model has been developed based on current hydraulic and sediment conditions. It should be noted that the existing surficial substrate in the Eklutna River upstream from Thunderbird Creek is the result of many decades of sediment input from alluvial fans and accumulations in the old reservoir area with minimal flow in the river and, as shown in Figure 2-6, includes a large proportion of fine-grained sediment. The 2021 study flow release demonstrated that substrate conditions will change substantially in the future as finer-grained sediment is winnowed out of the existing substrate. To best estimate the effects of potential future flow releases, the river substrate used for model runs was based on best judgment of underlying sediment from substrate sampling upstream of the current sediment sources and observations of substrate on historic (higher elevation) river bars. This is one area of uncertainty in model results. In addition to an adjustment in substrate conditions, vegetation (e.g., alders, willows) have encroached upon the former river channel and are altering hydraulic conditions in the channel, particularly upstream from Thunderbird Creek. As the river adjusts to a new long-term flow regime, this vegetation will die, and river hydraulics will change, another source of uncertainty in future channel conditions.

4.5.2. Two-Dimensional HEC-RAS Model

A HEC-RAS two-dimensional (2-D) hydraulic model was developed by Kleinschmidt Associates for four reaches of the Eklutna River with complex hydraulics (Figure 4.5-1; Reiser et al. 2023). Details of the 2-D hydraulic model development are included in Reiser et al. (2023). Depth and velocity output rasters from the 2-D hydraulic model were used to calculate sediment transport potential based on critical shear stress of particles that could be entrained under a given flow.

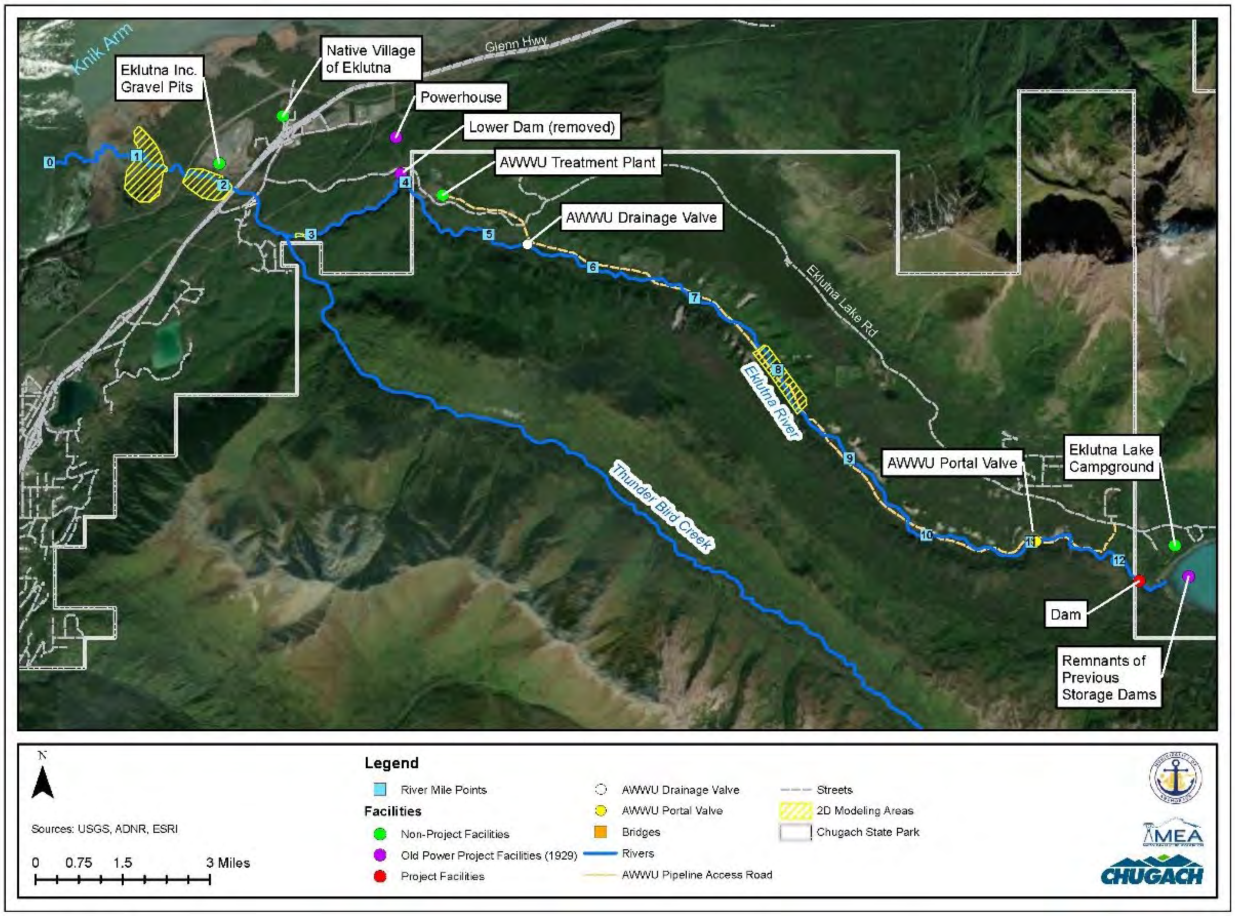


Figure 4.5-1. Location of 2-D Hydraulic Model Areas.

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

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

where:
D_{crit} = critical diameter (mm)
V = Velocity (ft/s)
d = Depth (ft)

4.6. Need for a High Calibration Flow

Per proactive discussions with the Aquatics TWG, the Geomorphology and Sediment Transport Study Plan included a provision for a high calibration flow in the fall of 2022, if needed and if liability and permitting issues could be resolved. From a sediment transport perspective, a high calibration flow would be warranted if data collected before and after the 2021 study flow releases was not sufficient to provide calibration data for the planned 1-D HEC-RAS sediment transport model.

One of the goals of the sediment transport model is to estimate flows that do geomorphic work in the river, sometimes referred to as “flushing flows” or channel maintenance flows. These flows are higher than normal base or moderate flows in a river system. We hypothesize that there are three different levels of higher flows of interest that will move accumulated sediment in the Eklutna River: 1) a flow that moves the surficial veneer of fine sediment; 2) a range of flows that moves substantial amounts of the sediment wedge from behind the old lower dam site; and 3) a flow that disrupts the armor layer and moves interstitial fine sediment. A goal of the sediment transport analysis is to help determine these different levels of flow.

Monitoring during and after the 2021 study flow release of approximately 150 cfs showed that this flow was sufficient to accomplish three levels of flushing flows in the existing channel configuration. The surface veneer of fine sediment was moved, a substantial amount of the sediment wedge at the lower dam site was moved, and the armor layer was disrupted at locations with gravel substrate. Fine sediment, sand, gravel, and cobble particles up to 128 mm in size were transported at some of the transects. Substrate in the heavily armored, pre-project channel (e.g., underlying channel) in geomorphic reach 10 was not disrupted, but data on substrate movement that did occur was sufficient to extrapolate and calibrate the sediment transport computations. The 2021 data provide sufficient information to calibrate and run the 1-D HEC-RAS sediment transport model to estimate potential channel changes from a variety of high flow conditions. The data and modeling will allow further evaluation of these three flushing flow goals as well as evaluate erosion at the toe of the alluvial fan sediment sources.

In addition to the three levels of high flows discussed above, there is another level of high flows that result in channel migration. Flows that cause channel migration are generally much higher than the other three levels of flushing flows/channel maintenance flows discussed above. Channel migration cannot be directly modeled using HEC-RAS or other widely accepted models due to the often stochastic nature of channel migration (accumulations of large woody debris can play a role in channel migration) and limitations of models to accurately calculate erosion of cohesive materials (e.g., riverbanks with tree and riparian vegetation roots). Because flow levels that result in channel migration are high and occur infrequently, they were assessed, as normal for most channel migration studies, using a combination of aerial photographic and LiDAR data and a record of peak flows. Release of a flow high enough to directly assess channel migration was not recommended due to the very large magnitude of flow required.

Based on the results of the 2021 study flow releases and monitoring data, a high calibration flow was not needed to calibrate the 1-D HEC-RAS sediment transport model.

5 RESULTS

5.1. Existing Substrate and Sediment Monitoring Data

The following is a brief summary of some of the available existing substrate and sediment monitoring data that for the Eklutna River collected by other researchers.

5.1.1. Substrate Data 2019 (Native Village of Eklutna)

NVE completed a stream habitat assessment of the Eklutna River from Cook Inlet to Eklutna Lake in 2019 (NVE 2020). Substrate composition in each habitat unit (e.g., pool, riffle, glide) was recorded as percent in each substrate class: silt/clay; sand; gravel; small cobble; large cobble; boulder; and bedrock. The data collected by NVE show that there were several distinct differences in substrate composition along the Eklutna River (Figure 5.1-1). Figure 5.1-1 shows a single bar for each habitat unit, with the percentage of substrate in that habitat unit represented by the percentage of each bar, color coded by silt/clay (light gray), sand (dark gray), gravel (yellow), small cobble (light green), large cobble (dark green), boulder (brown), and bedrock (black). For example, substrate in the first (most-downstream) habitat unit is 10 percent silt/clay (light gray), 30 percent gravel (yellow), and 60 percent small cobble (light green).

Substrate downstream of approximately RM 1.4 is primarily fine-grained silt/clay and sand deposited in the tidal flats. Substrate is coarse between RM 1.4 (just downstream from the railroad bridge) to the confluence with Thunderbird Creek and composed of cobble and gravel with boulders closer to Thunderbird Creek. Between Thunderbird Creek and the lower dam site, substrate is primarily gravel with some bedrock and silt/clay. The river through the old lower dam deposits was characterized as silt/clay with some sand and gravel. Between RM 5 to 6.6, the substrate was primarily sand with boulders; this is a zone that is heavily influenced by local sediment sources from eroding valley walls. Upstream of RM 7, substrate was composed of silt/clay and boulders, with decreasing amounts of fine-grained sediment upstream of RM 9. Close to Eklutna Lake, substrate was primarily cobble and boulder reflecting the lack of fine-grained sediment from upstream sources or valley wall erosion.

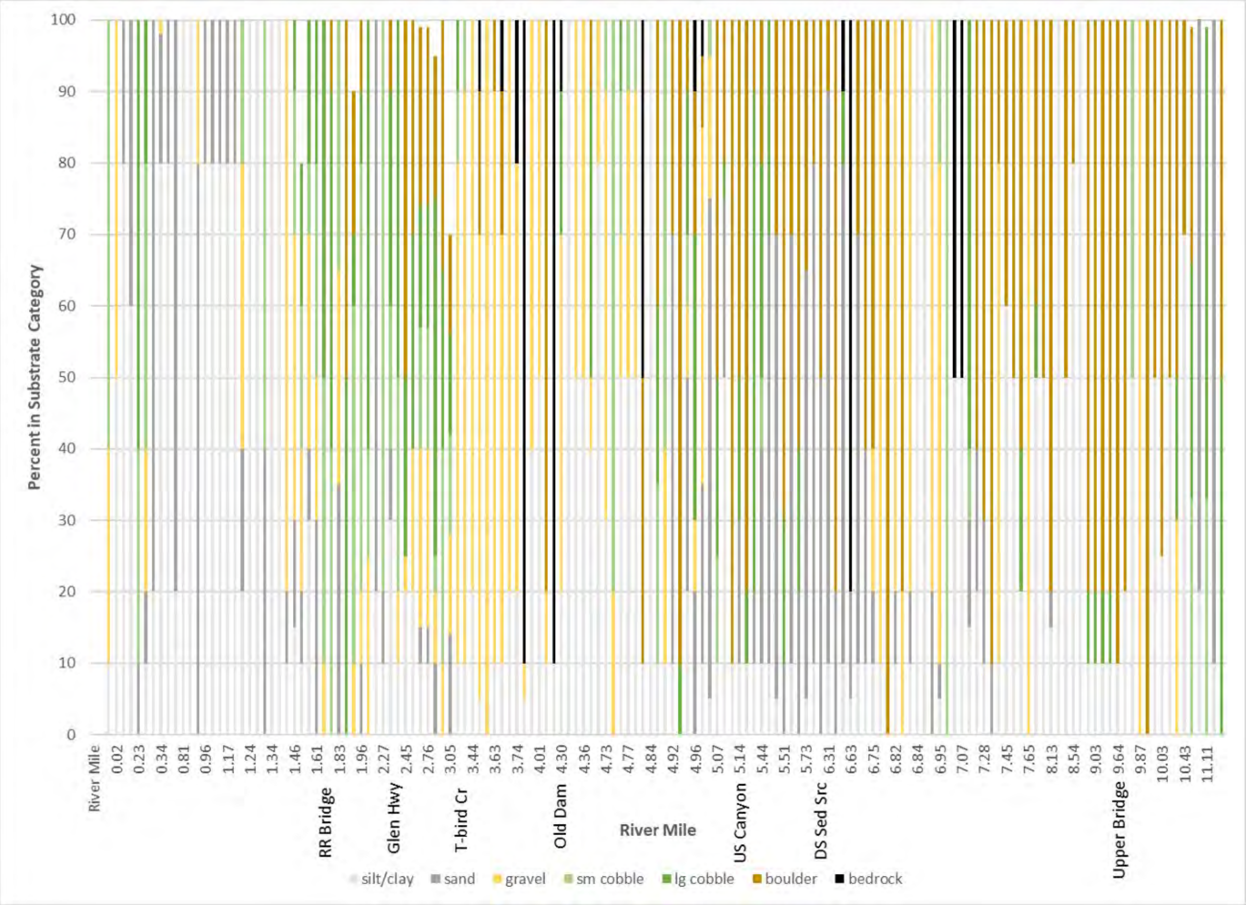


Figure 5.1-1. Eklutna River substrate 2019 (Source: NVE 2020).

5.1.2. ADFG Monitoring Transects (ongoing)

Eklutna Inc. and ADFG have established monitoring transects to evaluate sediment mobilization following removal of the lower dam. Pre-removal transects were established in 2017 to collect baseline data on channel geometry and substrate conditions at seven locations, two upstream and five downstream of the lower dam site. Post-removal monitoring was collected at three of these locations in 2019 and 2020 (Kirsch and Benkert 2020). These data are included in Section 5.3 for sites where scour monitors were deployed as part of the present study.

5.1.3. Eklutna Inc. Bridge Monitoring Transects (ongoing)

Eklutna Inc. is monitoring cross sections upstream and downstream from the three bridges below the lower dam site as part of the analysis of effects of dam removal (Figure 5.1-2). Surveys were conducted in 2017, 2018, and 2019 and showed minor changes in channel configuration. The largest change was up to 1.5 feet of aggradation in one of the channels upstream of the railroad bridge (cross section 2 left bank channel on Figure 5.1-2).

CONTROL POINT TABLE				
POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION
1	2723180.03	1749724.90	90.82	REBAR
4	2722364.06	1750635.49	95.60	REBAR
5	2722396.46	1750751.68	96.66	REBAR
6	2722622.32	1749824.42	85.69	REBAR
7	2722654.48	1749872.86	88.23	REBAR
8	2722805.36	1749698.09	81.81	REBAR
9	2722726.84	1749533.14	80.81	REBAR
10	2723210.74	1749744.78	87.39	REBAR
11	2723449.64	1747800.53	56.79	REBAR
12	2723307.77	1747778.37	53.38	REBAR
13	2723223.79	1747755.60	54.89	REBAR
14	2723308.30	1747526.84	52.82	REBAR
15	2723362.02	1747482.55	53.11	REBAR

CROSS SECTION ENDPOINT TABLE				
POINT	NORTHING	EASTING	ELEVATION	DESCRIPTION
500	2723397.33	1747572.14	51.87	X-SECTION 1 – NORTH
501	2723300.20	1747521.53	57.94	X-SECTION 1 – SOUTH
502	2723480.78	1747859.94	57.74	X-SECTION 2 – NORTH
503	2723114.95	1747673.61	54.96	X-SECTION 2 – SOUTH
504	2722831.90	1749719.32	81.86	X-SECTION 3 – NORTH
505	2722683.86	1749586.52	80.27	X-SECTION 3 – SOUTH
506	2722654.25	1749982.03	84.07	X-SECTION 4 – NORTH
507	2722530.30	1749865.67	83.82	X-SECTION 4 – SOUTH
508	2722437.58	1750716.74	93.22	X-SECTION 5 – NORTH
509	2722364.79	1750642.31	95.74	X-SECTION 5 – SOUTH

SURVEY NOTES

1. FIRST FIELD SURVEY WAS PERFORMED BY F. ROBERT BELL & ASSOCIATES ON JUNE 23 AND 26, 2017.
2. FIRST FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2017–02, PAGES 17–22.
3. SECOND FIELD SURVEY WAS CONDUCTED BY F. ROBERT BELL & ASSOCIATES ON DECEMBER 27, 2017. THE SECOND SURVEY MEASURED TOP OF ICE AS THE RIVER WAS FROZEN.
4. SECOND FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2017–04, PAGES 17–19.
5. THIRD FIELD SURVEY WAS CONDUCTED BY F. ROBERT BELL & ASSOCIATES ON MAY 15, 2018.
6. THIRD FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2018–01, PAGES 35–40.
7. FOURTH FIELD SURVEY WAS CONDUCTED BY F. ROBERT BELL & ASSOCIATES ON OCTOBER 12, 2018.
8. FOURTH FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2018–03, PAGES 26–29.
9. FIFTH FIELD SURVEY WAS CONDUCTED BY F. ROBERT BELL & ASSOCIATES ON JUNE 4, 2019.
10. FIFTH FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2019–01, PAGES 58–60.
11. SIXTH FIELD SURVEY WAS CONDUCTED BY F. ROBERT BELL & ASSOCIATES ON SEPTEMBER 30, 2019.
12. SIXTH FIELD SURVEY INFORMATION FOR THIS PROJECT IS LOCATED IN FIELD BOOK NO. 2019–03, PAGES 15–17.

LEGEND

○	SET REBAR
XXX	POINT NUMBER

DATE: __/__/__

REVISION:

BELL & ASSOCIATES
ENGINEERING | SURVEYING | 3D SCANNING
801 WEST FIREWEED LANE, SUITE 201
ANCHORAGE, AK 99503
(907)274–5257
www.bellalaska.com

EKLUTNA RIVER DAM REMOVAL
Lower River
Cross Section Location Map

CLIENT:
EKLUTNA SERVICES, INC.

ADDRESS:
10950 Mausel Street, Unit B-1a
Eagle River, AK 99577

JOB NUMBER: 2017–2414.04
FIELD BOOK: FRBA17–02, FRBA17–04, FRBA18–01, FRBA18–03, FRBA19–01, FRBA19–03.

DRAWN BY: WEM
CHECKED BY: VFS
SCALE: 1:150

DATE:
10/14/19

SHEET:
C1.0

Figure 5.1-2. Eklutna Inc. bridge monitoring cross sections Map 1 of 2.

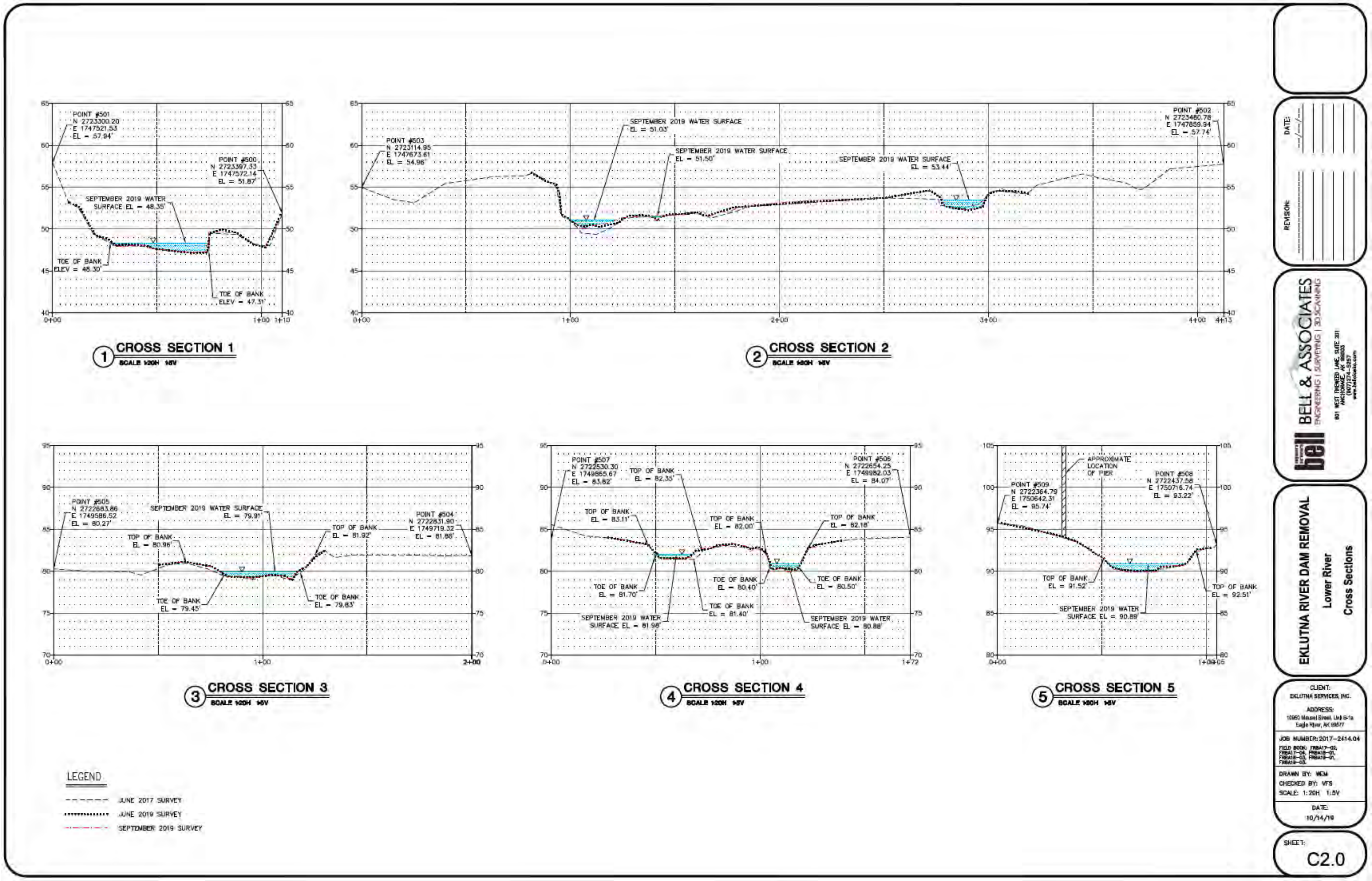


Figure 5.1-2. Eklutna Inc. bridge monitoring cross sections Map 2 of 2.

5.2. Geomorphic Reaches

Geomorphic reaches have been developed based on key geomorphic characteristics such as flow/tributary input, confinement, and sediment sources. Geomorphic reaches are shown on Figures 3.0-1, 4.2-1 (above) and summarized in Table 5.2-1.

Table 5.2-1. Geomorphic reaches.

Geomorphic Reach	River Mile Range	Confinement	Average Gradient	Comments
1	0-1.6	Unconfined	0.6%	Tidal influence at downstream end of this reach.
2	1.6-2.3	Unconfined	1.2%	Railroad bridge confines flow at downstream end of this reach. Includes flooded forest; past gravel removal in this reach.
3	2.3-2.85	Confined	1.1%	Downstream from Thunderbird Creek.
4	2.85-3.95	Confined	1.7%	Between Thunderbird Creek and old lower dam site
5	3.95-4.45	Confined	2.0%	Old lower reservoir deposits
6	4.45-5.05	Confined	1.5%	Canyon upstream from old reservoir deposits
7	5.05-5.4	Moderately confined	1.8%	Wider bedrock canyon downstream from lower AWWU access road
8	5.4-7	Unconfined	1.7%	Wide valley; contains major sediment sources
9	7-11.38	Unconfined	1.3%	Wide valley; upstream of major sediment sources (includes smaller sediment sources)
10	11.38-12.3	Moderately confined by erodible valley walls	0.8%	Upstream of sediment sources; upstream of upper AWWU bridge

5.3. Substrate and Channel Field Data

The following sections describe the data collected at the sediment monitoring transects. Field data collection occurred prior to and after the 2021 study flow releases. The flow release schedule is described in Section 4.2 above. Flow at a given point in the river during the releases depended on the amount of water being released, infiltration, tributary inflow, and travel time of released water as described in the Instream Flow Study Year 2 Report (Reiser et al. 2023).

5.3.1. Monitoring Transects, Pebble Counts, and Scour Monitor Data

5.3.1.1. Transect 101 RM 1.6

Transect 101, at RM 1.6, is located just upstream from the railroad bridge crossing (**Figure 5.3-1**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement showing up to 1 foot of deposition at the edge of the bar and up to 1 foot of channel deepening following the flow releases (**Figure 5.3-2**). Grain size measurements were taken pre- and post-flow release across the transect as well as one pre-flow release pebble count at the top of the right bank point bar (**Figure 5.3-3**). Substrate is predominantly gravel (median grain diameter 21-29 mm) and showed an increase in fine sediment following the study flow releases. A sub-surface sample was taken at this site; median grain diameter (D50) was 14 mm (**Figure 5.3-4**). An accelerometer and a sliding bead scour monitor were installed in August 2021 but were not recovered post flow release. Based on profile changes measured in the field, it is suspected that scour was deep enough to dislodge the monitors.

Figure 5.3-1. Transect 101, October 8, 2021.

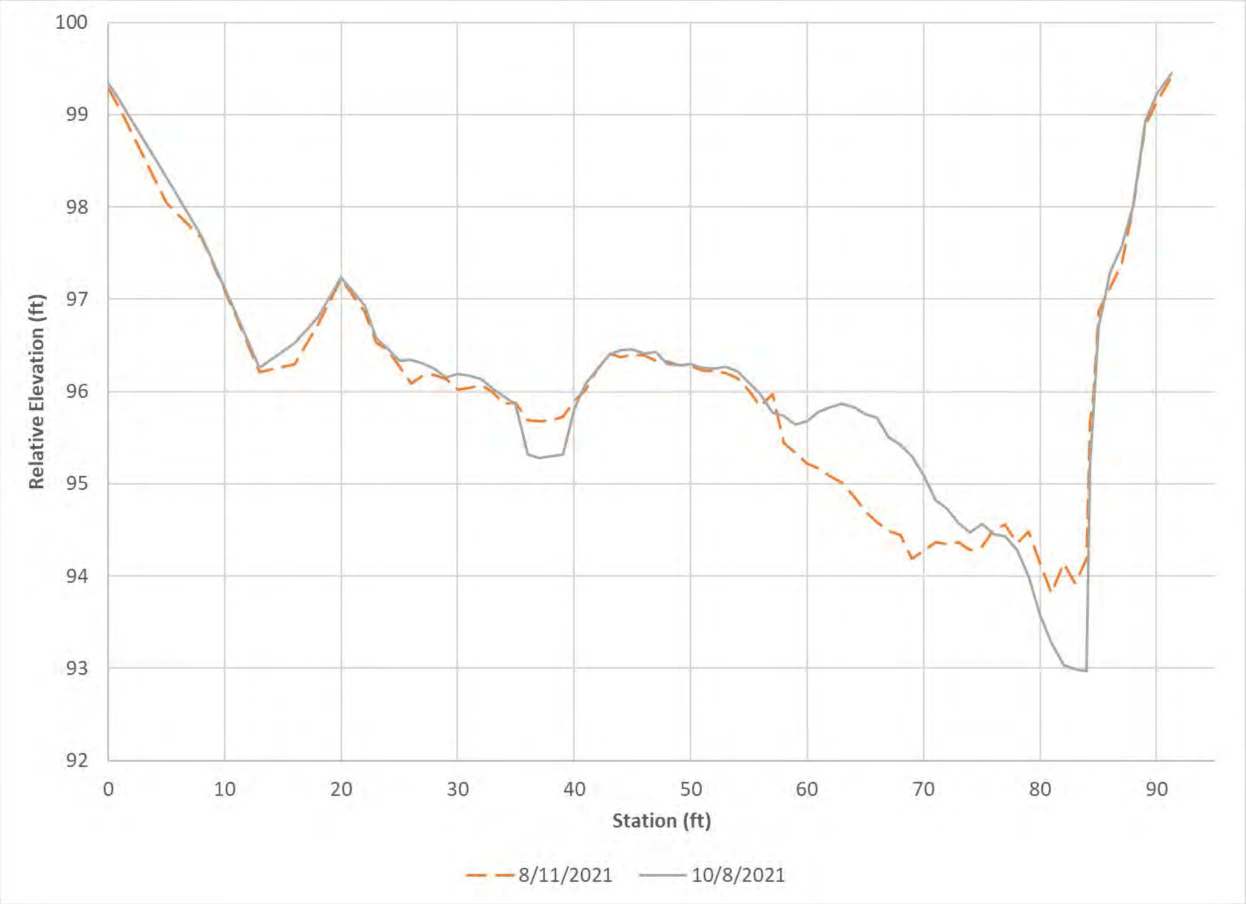


Figure 5.3-2. Transect 101 cross-sectional changes.

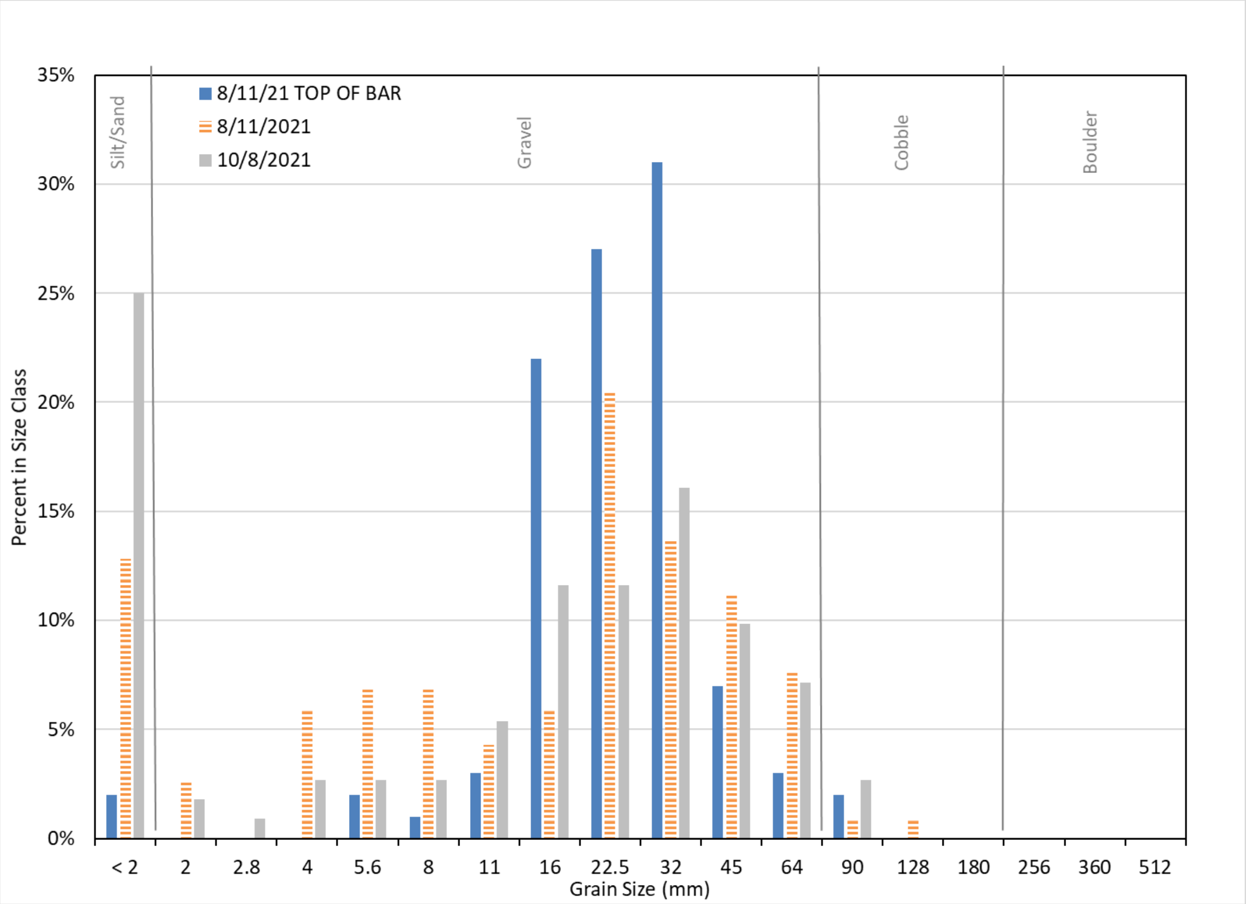


Figure 5.3-3. Transect 101 substrate grain size distribution changes.

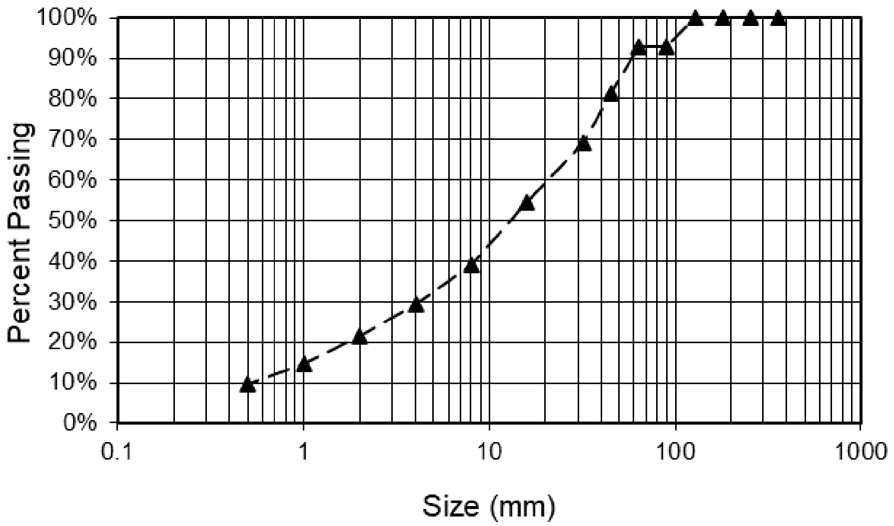


Figure 5.3-4. Transect 101 sub-surface grain size distribution.

5.3.1.2. Transect G RM 2.15

Transect G, at RM 2.15, is located just upstream of the New Glenn Highway bridges (**Figure 5.3-5**). This transect was established in September 2020 and included two pre-flow release measurements and one post-flow release measurement. The post-flow measurement showed deposition of 0.5 to 1 foot within the channel following the study flow releases (**Figure 5.3-6**). Grain size measurements were taken pre- and post-flow release across the transect (**Figure 5.3-7**). Substrate is predominantly gravel and showed an increase in median grain diameter from 13 to 23 mm following the study flow releases. An accelerometer and a sliding bead scour monitor were installed in August 2020. The sliding bead monitor was read in August and October 2021 and showed 3 inches of bed lowering between August 2020 and August 2021 followed by burial with 0.84 feet of gravel (up to 45 mm) in October 2021 following the study flow releases. The accelerometer was located, but not yet recovered post flow release due to deep, cold-water conditions in both 2021 and 2022. It is buried by 0.6 feet of gravel.

Figure 5.3-5. Transect G, October 12, 2021.

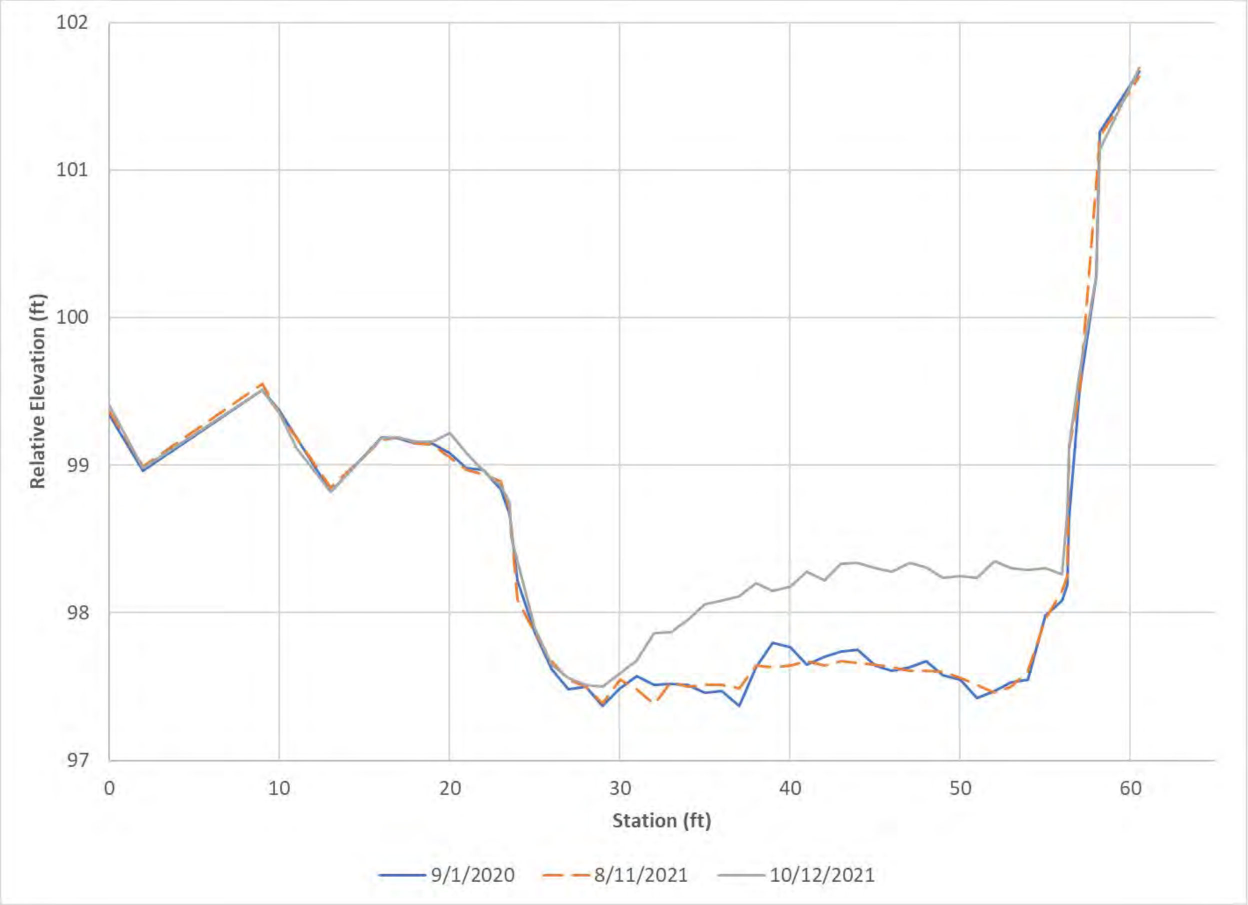


Figure 5.3-6. Transect G cross-sectional changes.

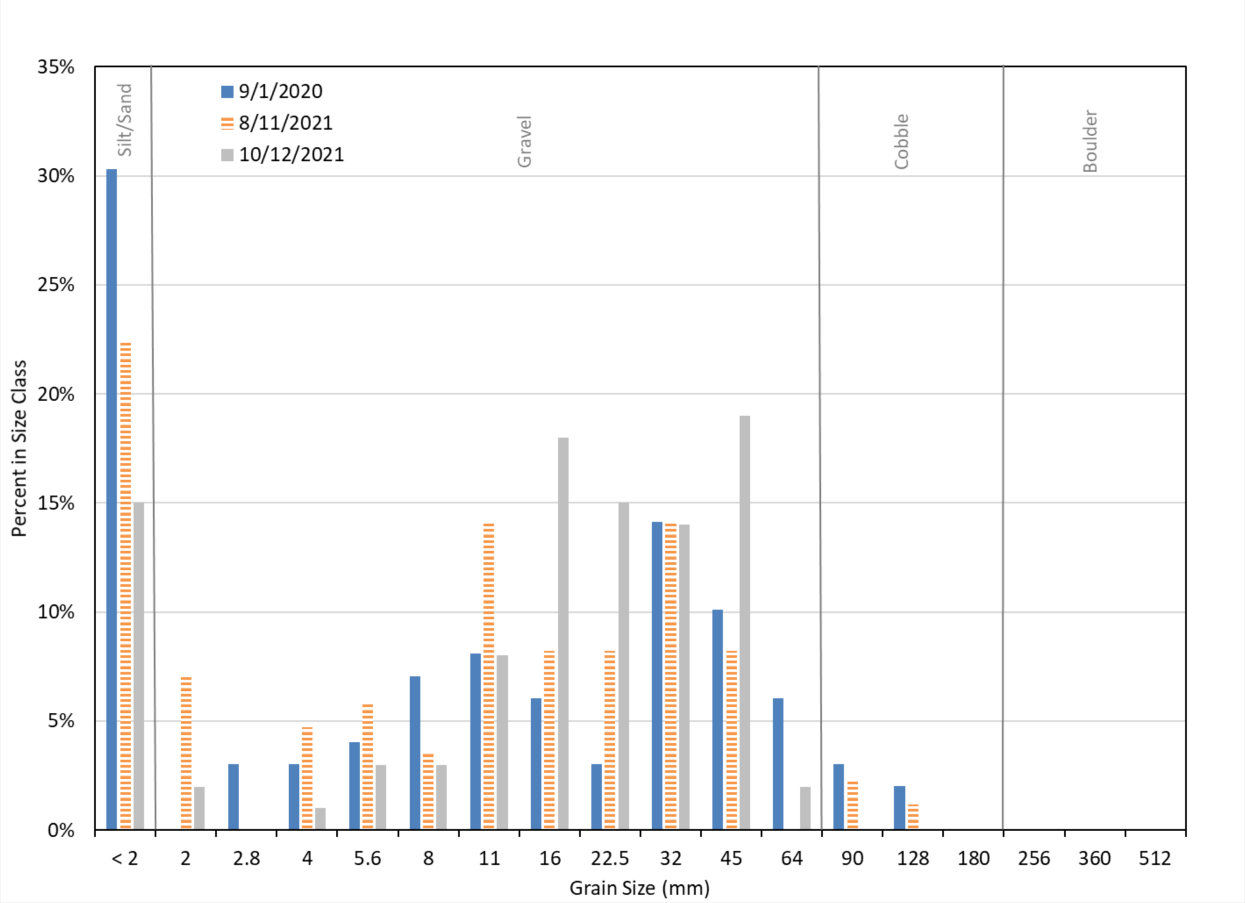


Figure 5.3-7. Transect G substrate grain size distribution changes.

5.3.1.3. Transect ADFG8 Down RM 2.9

Transect ADFG8 Down at RM 2.9 was established in 2017 as part of the aquatic habitat monitoring effort post dam removal and is located just upstream of the confluence with Thunderbird Creek (**Figure 5.3-8**). This transect included two pre-flow release measurements made by ADFG staff and one post-flow release measurement made as part of the current study. The channel at this transect has had up to 1 foot of aggradation following dam removal followed by about 0.5 foot of erosion following the study flow releases (**Figure 5.3-9**). A sliding bead scour monitor was installed at this location in August 2020. The sliding bead monitor was read in August and October 2021 and showed 0.5 foot of bed lowering between August 2020 and August 2021 followed by 4 inches of scour and then 3-4 inches of fill following the study flow releases (October 2021 reading).

Figure 5.3-8. Transect ADFG8 Down pre-flow (top) and post-flow (bottom).

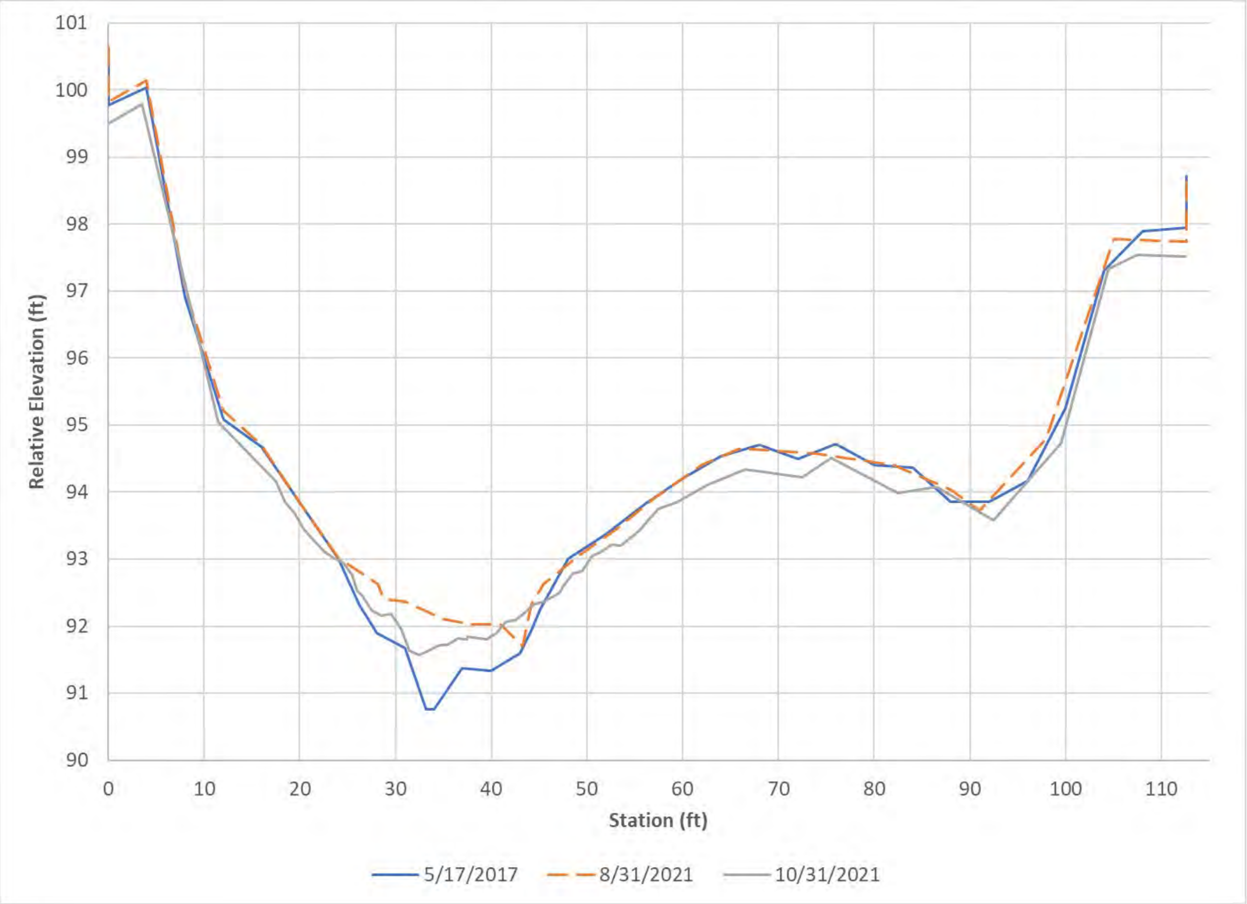


Figure 5.3-9. Transect ADFG8 Down cross-sectional changes.

5.3.1.4. Transect ADFG6 Down RM 3.3

Transect ADFG6 Down at RM 3.3 was established in 2017 as part of the aquatic habitat monitoring effort post dam removal (**Figure 5.3-10**). This transect included two pre-flow release measurements made by ADFG staff and one post-flow release measurement made as part of the current study. Up to 0.5 feet of deposition was recorded between 2017 (pre dam removal) and 2020. The post-flow measurement showed deposition of up to 2 feet within the channel following the study flow releases (**Figure 5.3-11**). A sliding bead scour monitor was installed at this location in August 2021 but was not located in October 2021 following the study flow release due to deep, cold water conditions. In July, 2022 the sliding bead monitor was recovered and showed 6 inches of scour following by 1 foot of deposition at this location with deposition including particles of 64-90 mm size class.

Figure 5.3-10. Transect ADFG6 Down pre-flow (top) and post-flow (bottom).

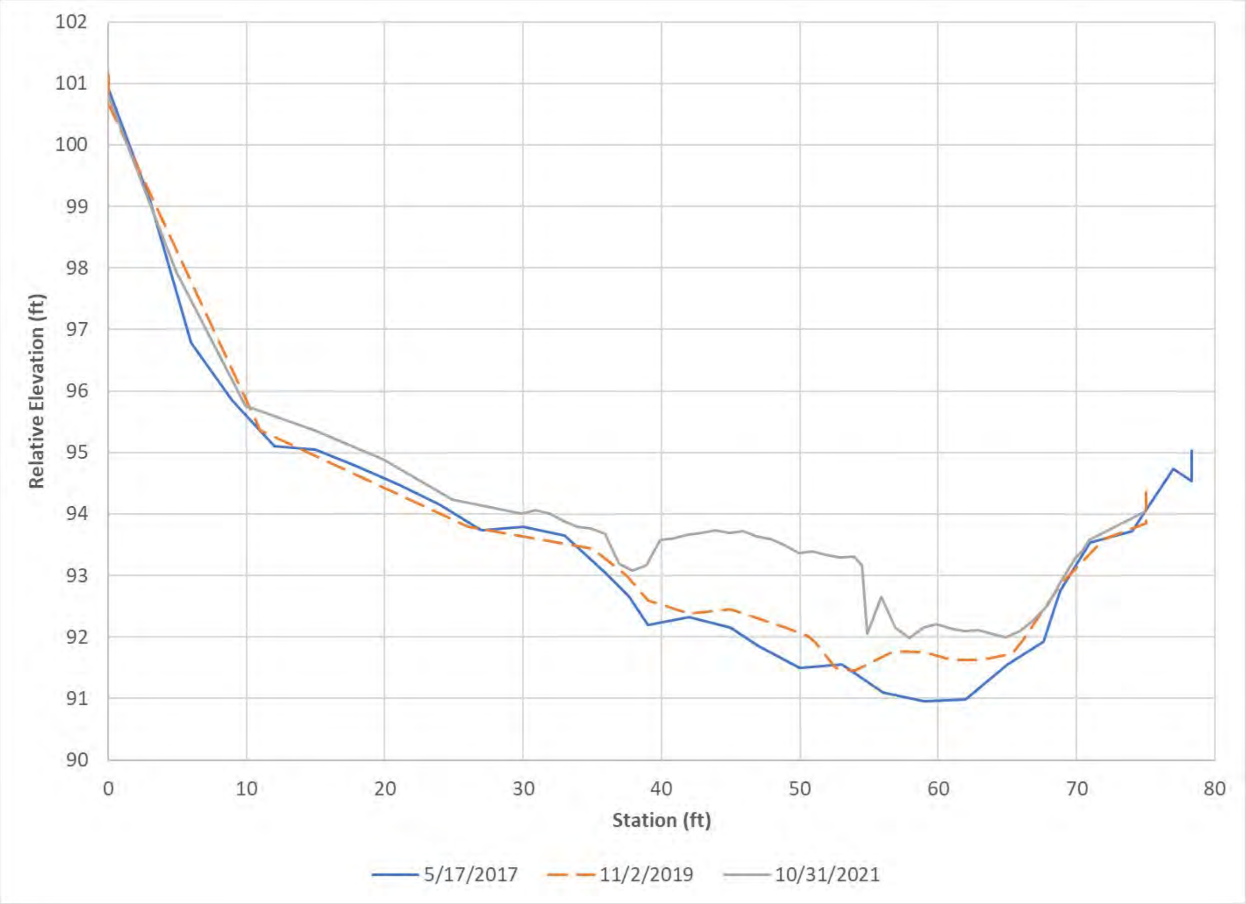


Figure 5.3-11. Transect ADFG6 Down cross-sectional changes.

5.3.1.5. Transect ADFG2 Down RM 3.8

Transect ADFG2 Down at RM 3.8 is located just below the old lower dam site and was established in 2017 as part of the aquatic habitat monitoring effort post dam removal (**Figure 5.3-12**). This transect included three pre-flow release measurements made by ADFG staff and one post-flow release measurement made as part of the current study.

This transect is very dynamic, with up to 4 feet of deposition recorded between the pre-dam removal measurement in 2017 and the first post-dam measurement in 2019 (**Figure 5.3-13**). An additional foot of deposition occurred between 2019 and 2020. During the study flow releases, up to 1 foot of additional deposition occurred, likely including a debris flow down the channel based on the debris flow levees on both sides of the channel (debris flow levees were also observed at other locations downstream from this transect). The debris flow could have been triggered by the slide that occurred in the lower dam deposits as recorded on the timelapse cameras and/or the surge of water from the breaching of the upstream beaver dam (the lowest in the series of 3 dams near RM 7) that was recorded at the downstream stream gage. By the end of the study flow releases, the channel had eroded several feet to the 2019 level.

Grain size measurements were taken pre- and post-flow release across the transect (**Figure 5.3-14**). Substrate is predominantly gravel (median grain diameter 14-26 mm) and showed an increase in fine sediment as well as an increase in coarse sediment following the study flow releases (bimodal size distribution).

An accelerometer and sliding bead scour monitor were installed at this location in August 2021. The sliding bead monitor was not recovered following the flow release; the channel survey suggests this location was scoured out. The accelerometer was recovered in October 2021, exposed at the edge of the channel. Accelerometers record their position in space (x,y,z) through time and when installed in the substrate, they record periods of movement which correlate to erosion of the bed to the point where the accelerometer is exposed. Plots of the x,y,z position show abrupt changes when the accelerometer is exposed and starts to move. The accelerometer at ADFG2 Down recorded movement on September 14, 2021 (0830) followed by a fairly stable period until September 20 at 1630 when it was in motion until September 29 (**Figure 5.3-15**). Material up to 90 mm in diameter was mobilized at this location during the flow releases.

Figure 5.3-12. Transect ADFG2 Down pre-flow (top) and post-flow (bottom).

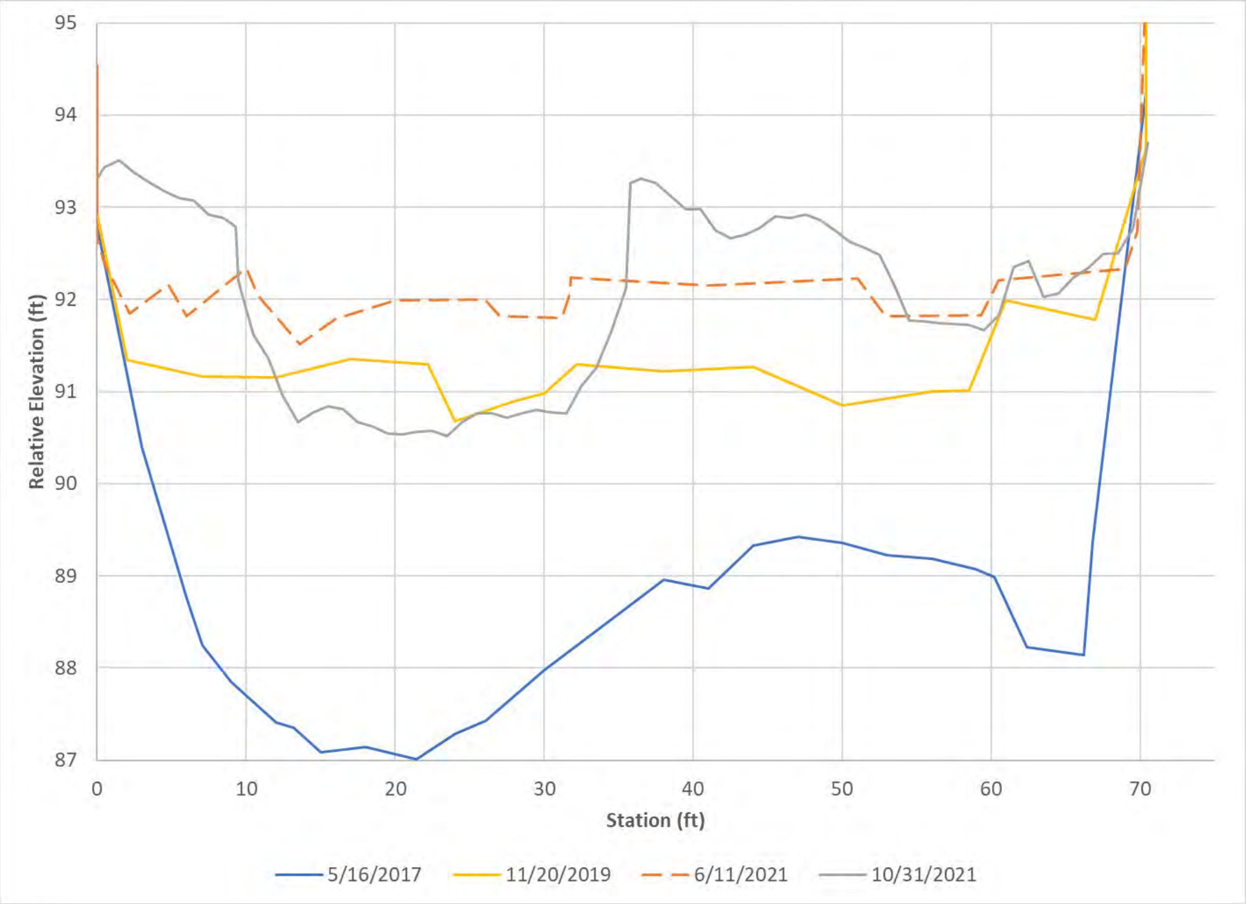


Figure 5.3-13. Transect ADFG2 Down cross-sectional changes.

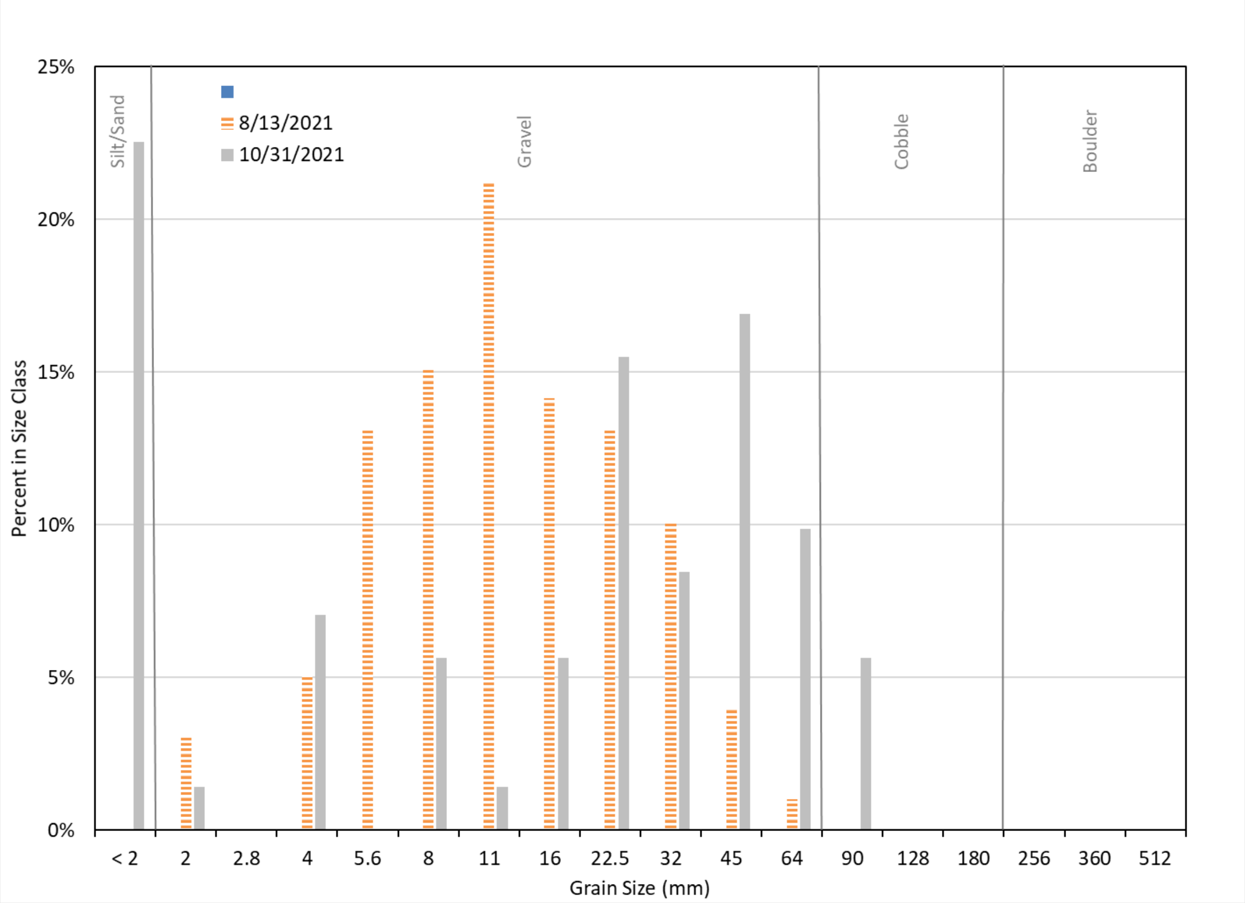
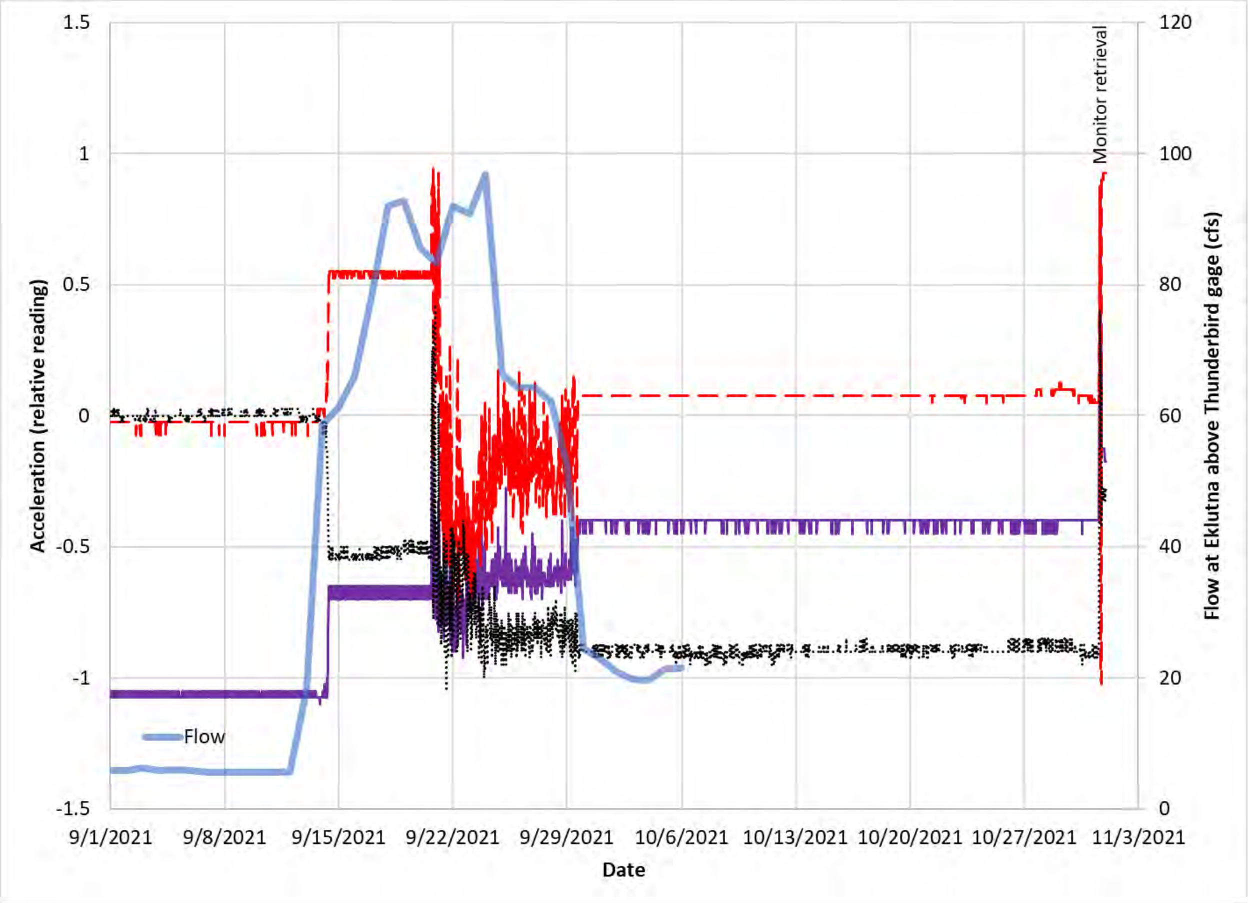


Figure 5.3-14. Transect ADFG2 Down substrate grain size distribution changes.



Flow data provisional, from Stream Gaging Year 2 Report

Figure 5.3-15. Transect ADFG2 Down accelerometer data.

5.3.1.6. Transect 204 RM 3.95

Transect 204, at RM 3.95, is located at the old lower dam abutments (**Figure 5.3-16**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. The post-flow measurement showed deposition of up to 3 feet of sediment within the channel following the flow releases, and then subsequent erosion of the deposited sediment back to nearly pre-flow release elevations (**Figure 5.3-17**).

Figure 5.3-16. Transect 204 pre-flow (top) and post-flow (bottom).

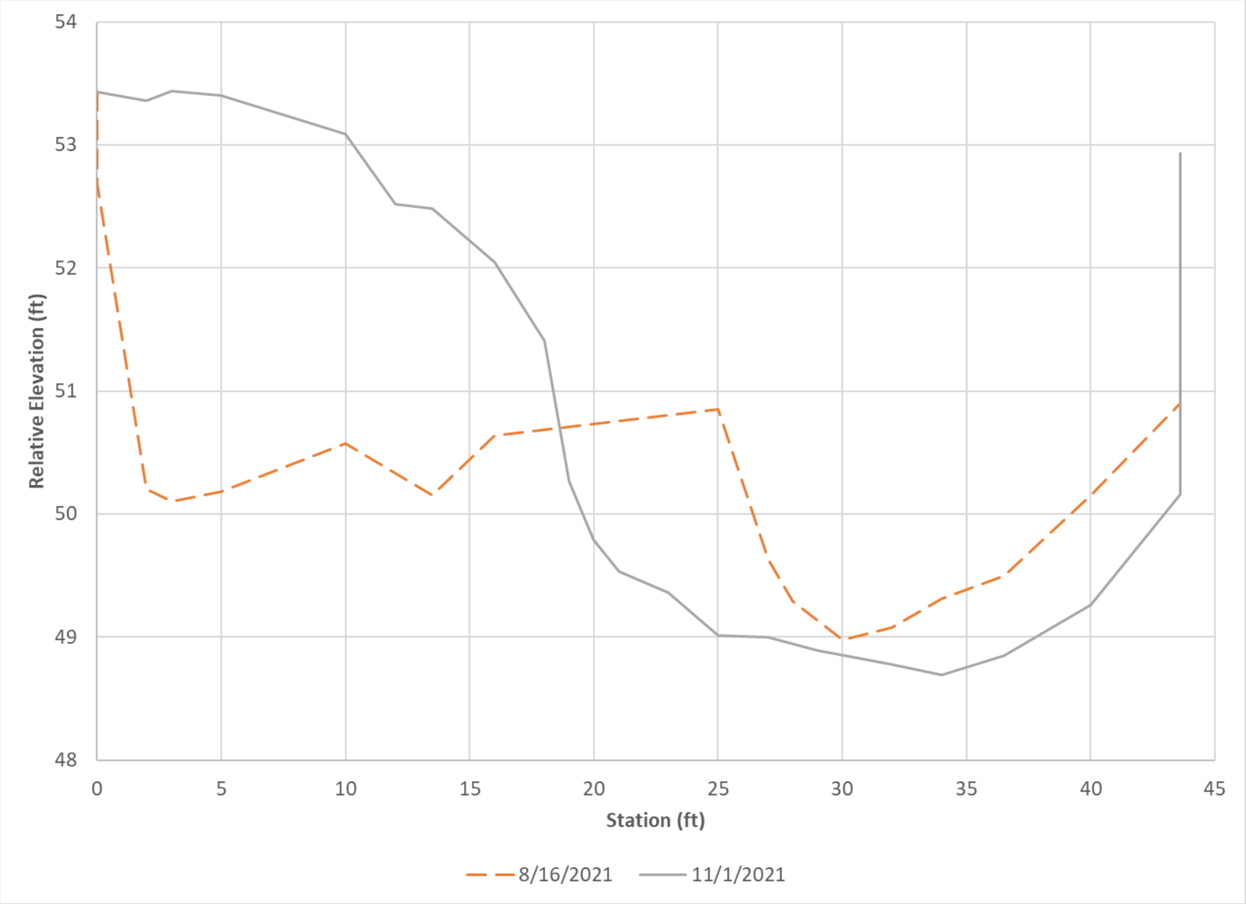


Figure 5.3-17. Transcript 204 cross-sectional changes.

5.3.1.7. *Transect 203 RM 4.05*

Transect 20, at RM 4.05, is located in the old reservoir deposits (**Figure 5.3-18**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. This transect showed major erosion of the old reservoir deposits, with up to 30 vertical feet of erosion of the accumulated reservoir sediments and up to 3 feet of thalweg lowering (**Figure 5.3-19**). Two mechanisms for this erosion were captured on timelapse videos (cameras G1 and G2): undercutting and toppling of the consolidated silt/clay banks; and a large slump that occurred and quickly removed a large portion of the deposits. A remnant of that slump block can be seen in the center of the post-flow photo in **Figure 5.3-18**.

Figure 5.3-18. Transect 203 pre-flow (top) and post-flow (bottom).

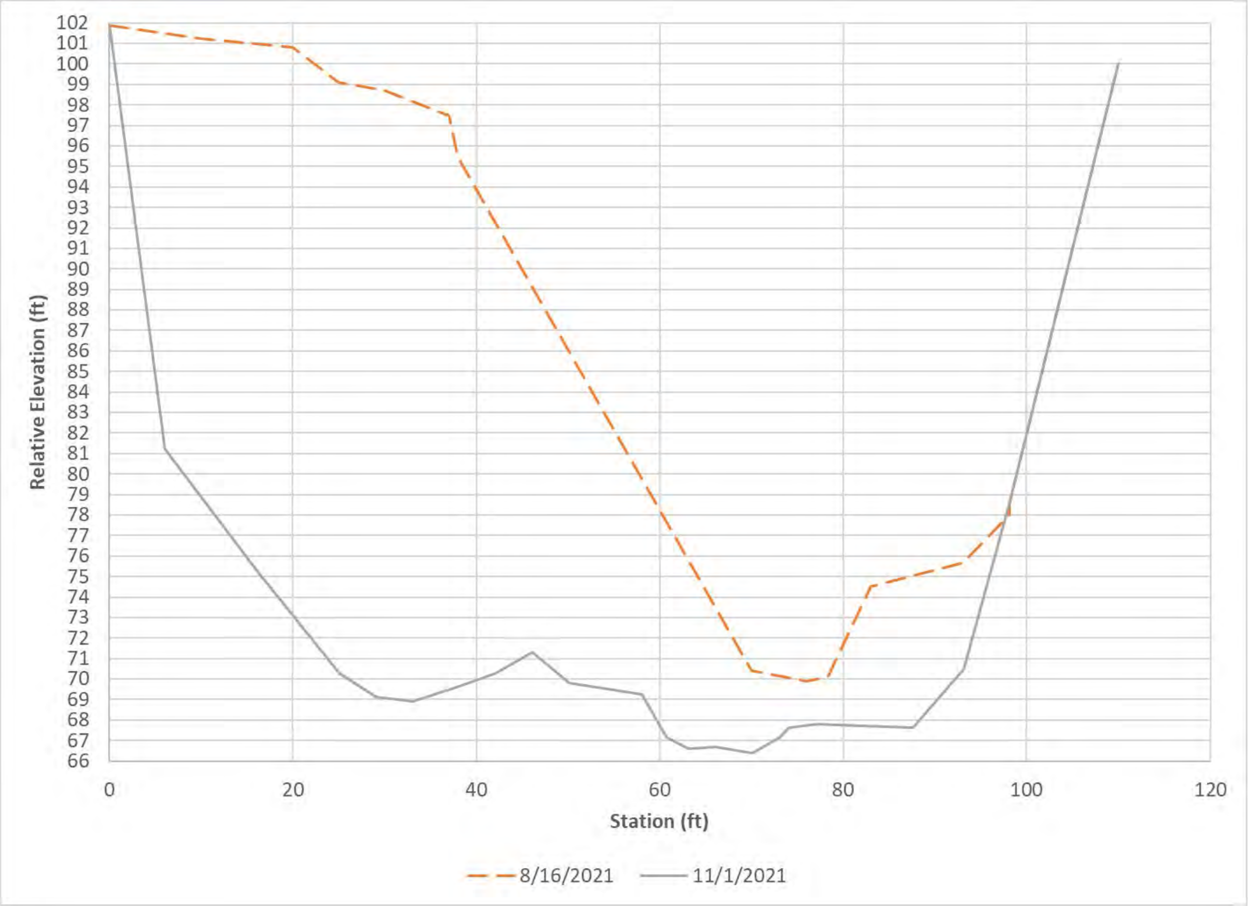


Figure 5.3-19. Transect 203 cross-sectional changes.

5.3.1.8. Transect 202 RM 4.06

Transect 204, at RM 4.06, is located in the old reservoir deposits (**Figure 5.3-20**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. The post-flow measurement showed erosion of a large amount of reservoir sediment, particularly on the right bank where up to 14 feet of erosion occurred (station 0 is right bank; **Figure 5.3-21**). The thalweg lowered approximately 2 feet.

Figure 5.3-20. Transect 202 pre-flow (top) and post-flow (bottom).

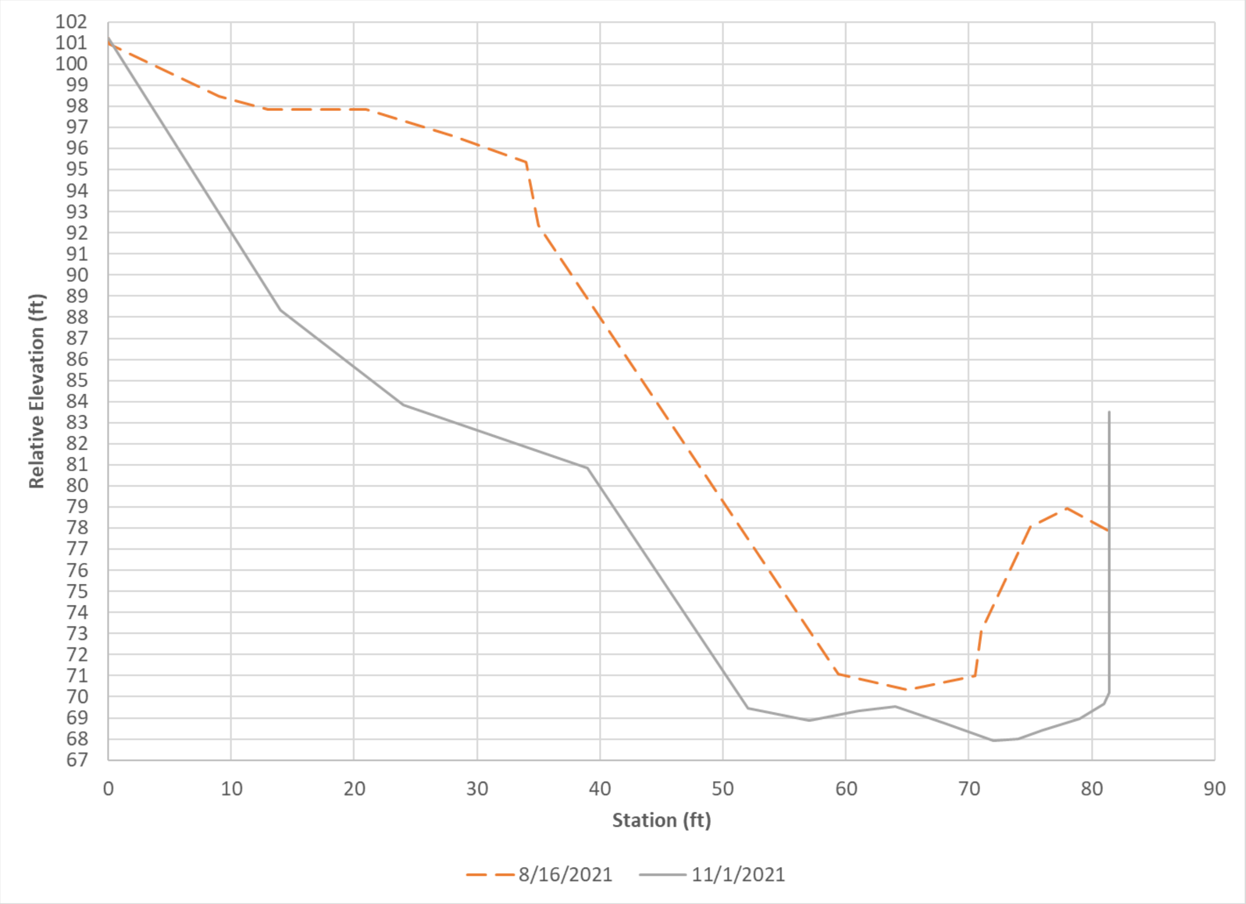


Figure 5.3-21. Transect 202 cross-sectional changes.

5.3.1.9. Transect 201 RM 4.1

Transect 201, at RM 4.1, is located at the upstream end of the old reservoir (**Figure 5.3-22**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. The post-flow measurement showed erosion of up to 14 feet of the stored reservoir sediment and 9 feet of channel lowering following the study flow releases (**Figure 5.3-23**). A time-lapse video (camera G3) was located pointing upstream from this site and recorded erosion and headcutting during the study flow release. A sub-surface sample was taken at this site and is shown in **Figure 5.3-24**.

Figure 5.3-22. Transect 201 pre-flow (top) and post-flow (bottom).

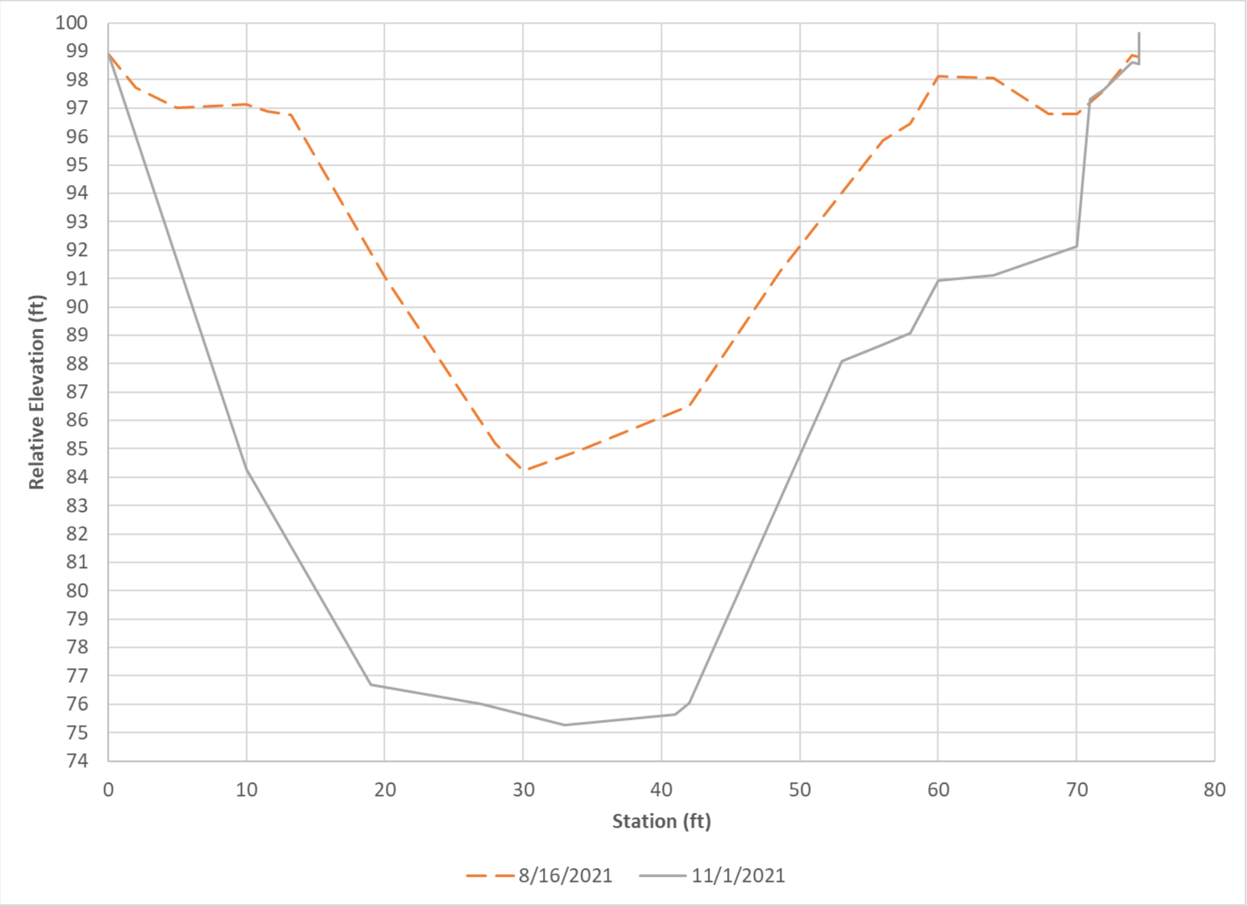


Figure 5.3-23. Transect 201 cross-sectional changes.

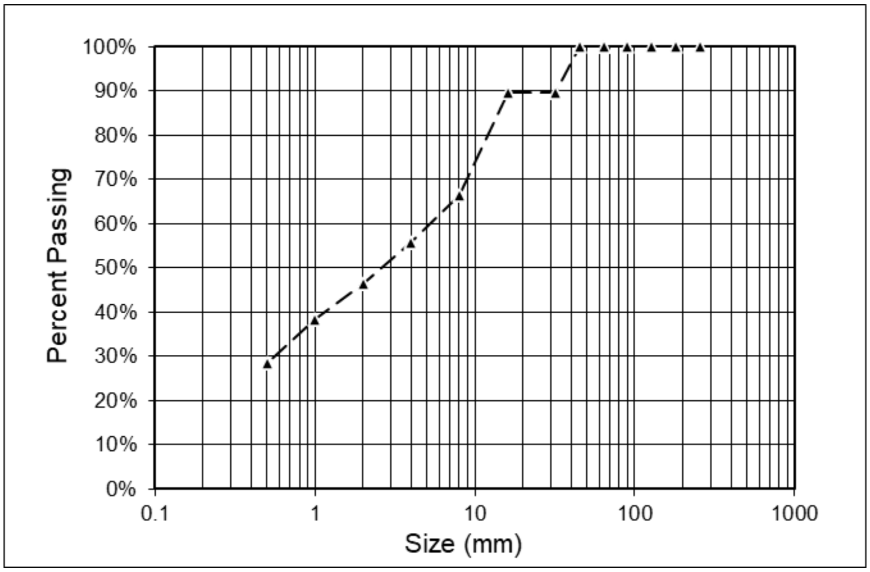


Figure 5.3-24. Transect 201 sub-surface grain size distribution.

5.3.1.10. Transect ADFG4 Up RM 4.4

Transect ADFG4 Up at RM 4.4 was established in 2017 as part of the aquatic habitat monitoring effort post dam removal and is located upstream of the old dam deposits (**Figure 5.3-25**). This transect included two pre-flow release measurements made by ADFG staff and one post-flow release measurement made as part of the current study. The post-flow measurement showed deposition of less than 0.5 feet on the left bank bar and erosion of nearly 1 foot within the channel following the study flow releases (**Figure 5.3-26**). Grain size measurements were taken pre-flow release across the transect and showed substrate was dominated by gravel with a median grain diameter of 13 mm (**Figure 5.3-27**). An accelerometer and sliding bead scour monitor were installed at this location in August 2021. The accelerometer was found in October 2021 following the flow releases. The accelerometer at ADFG4 Up recorded movement on September 14, 2021 starting at 0230 and major movement from 1730 through September 25 (**Figure 5.3-28**). The sliding bead monitor was recovered in July 2022 and showed 5.5 inches of erosion followed by 2 inches of deposition of fine-grained material.

Figure 5.3-25. Transect ADFG4 Up, November 1, 2021.

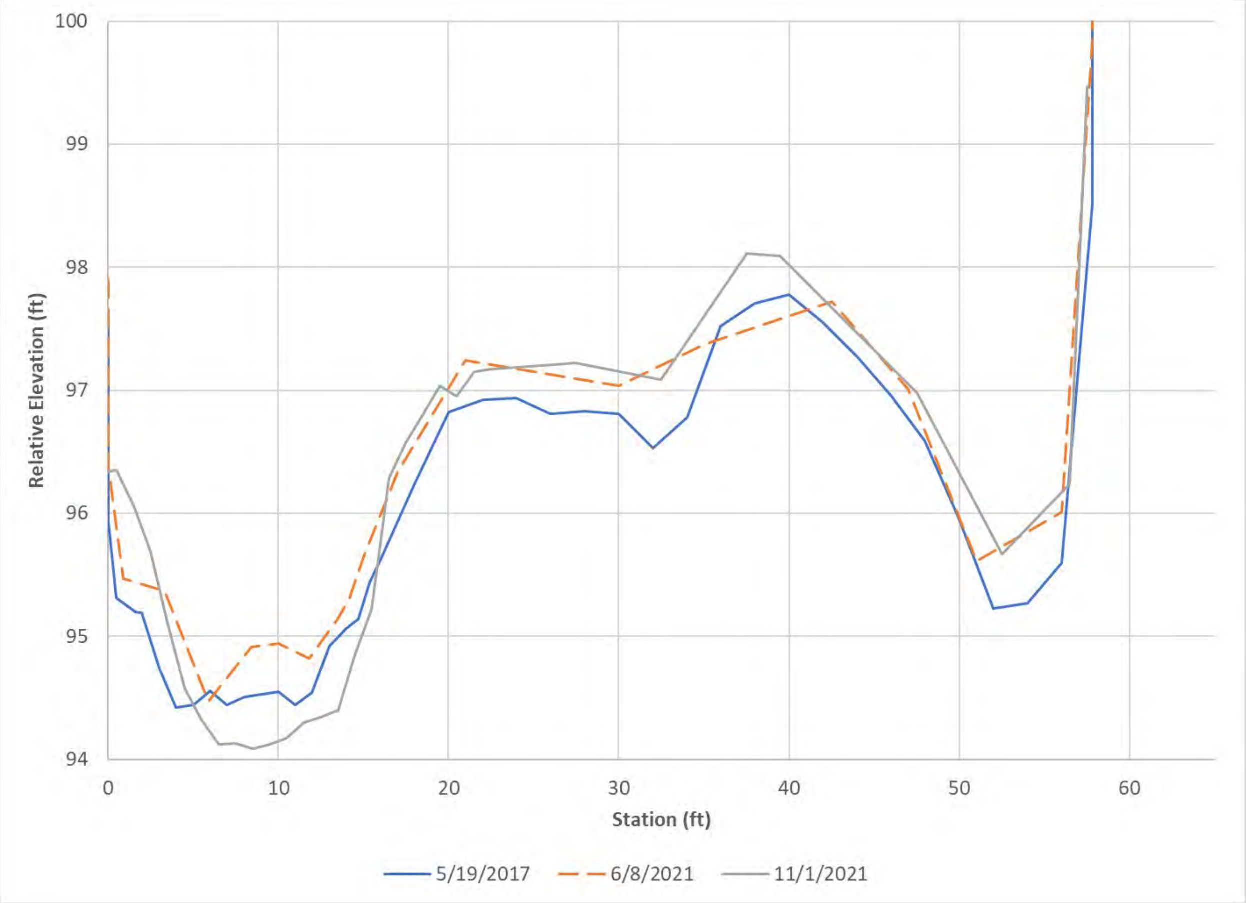


Figure 5.3-26. Transect ADFG4 Up cross-sectional changes.

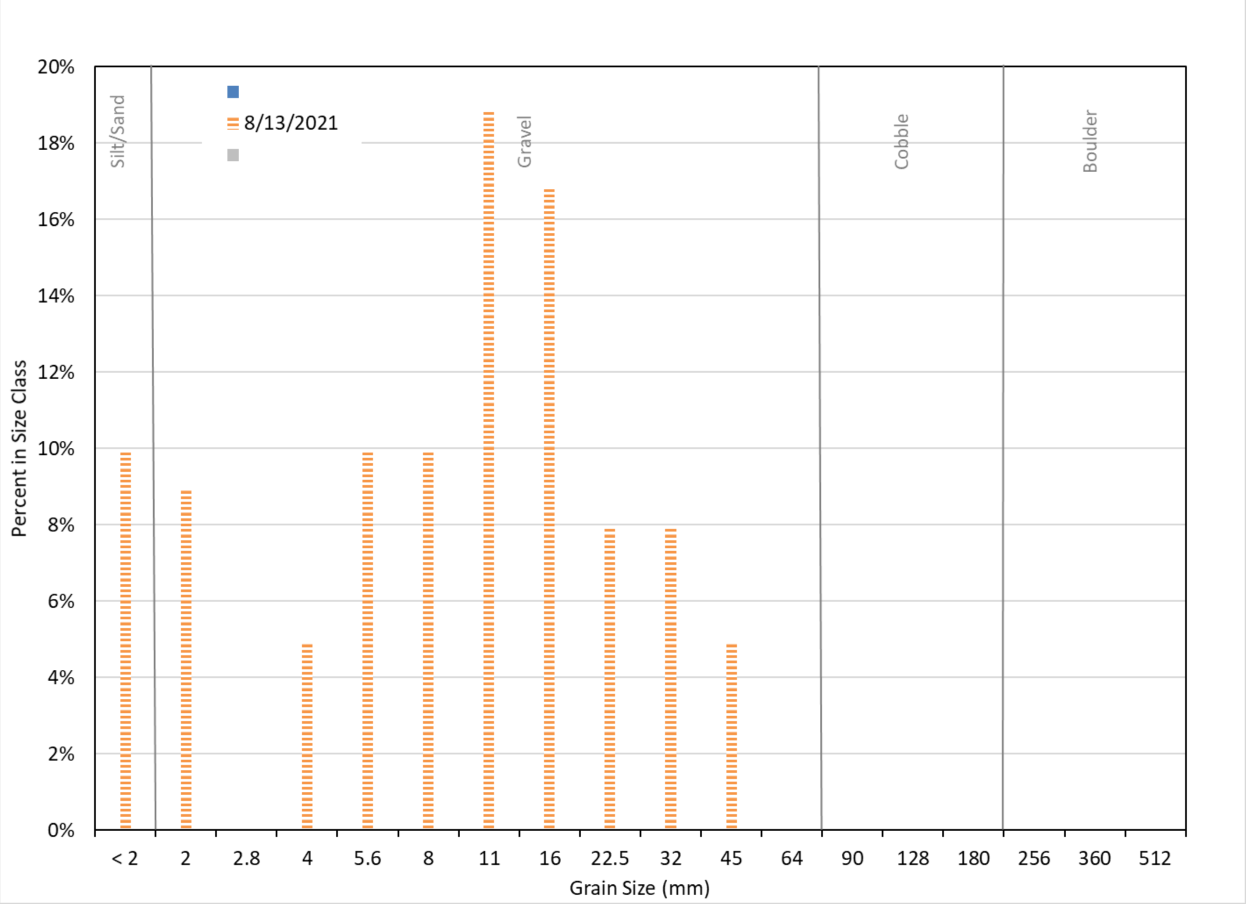
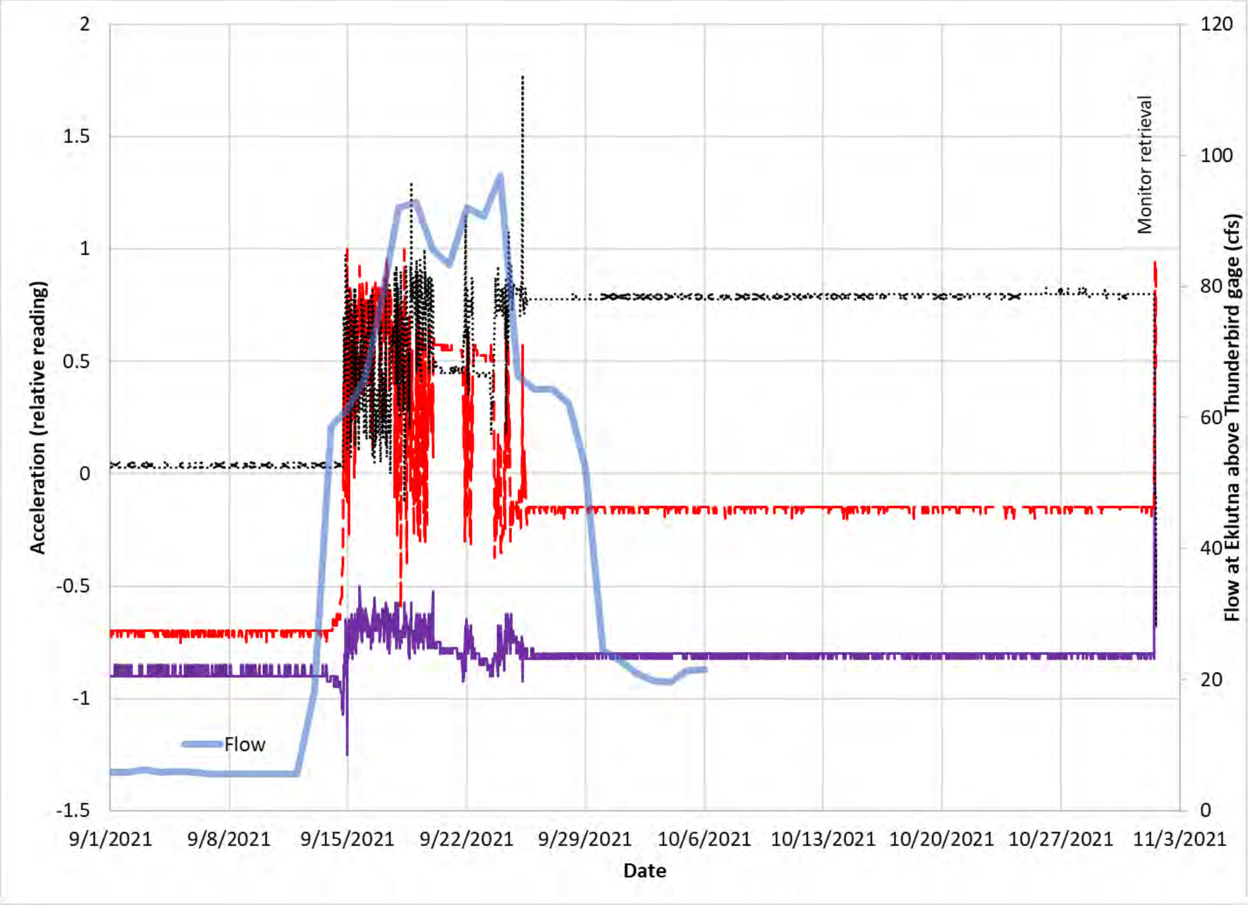


Figure 5.3-27. Transect ADFG4 Up substrate grain size distribution.



Flow data provisional, from Eklutna Stream Gaging Year 2 Report

Figure 5.3-28. Transect ADFG4 Up accelerometer data.

5.3.1.11. Transect 102 RM 5.3

Transect 102, at RM 5.3, is located at an instream flow transect (**Figure 5.3-29**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. There was little change in the cross section from pre- to post-release (**Figure 5.3-30**). Grain size measurements were taken pre- and post-flow release across the transect and showed a mix of gravel and sand particles with little change following the study flow releases (**Figure 5.3-31**). A sliding bead scour monitor was installed in August 2020. The sliding bead monitor showed no change in October 2021 following the study flow releases.

Figure 5.3-29. Transect 102.

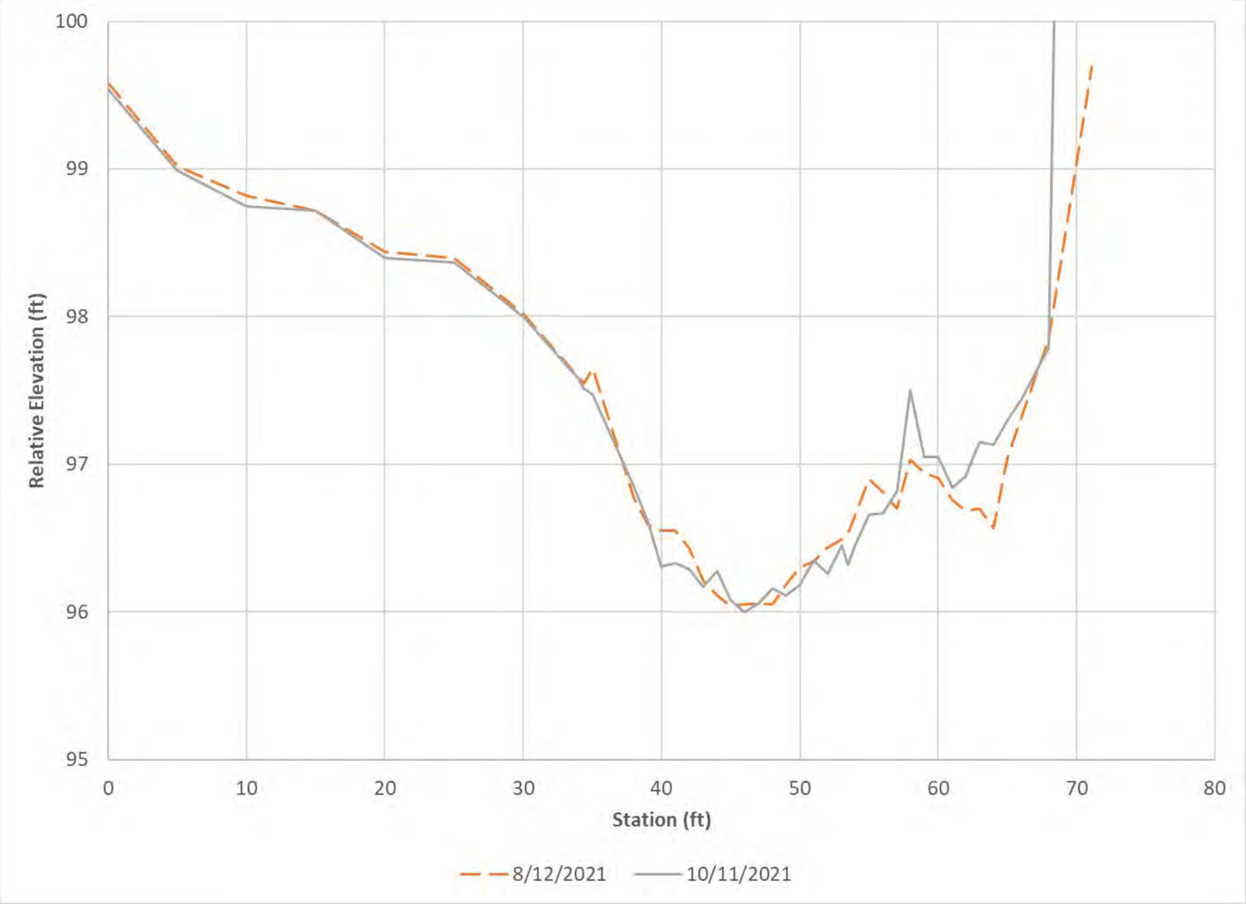


Figure 5.3-30. Transect 102 cross-sectional changes.

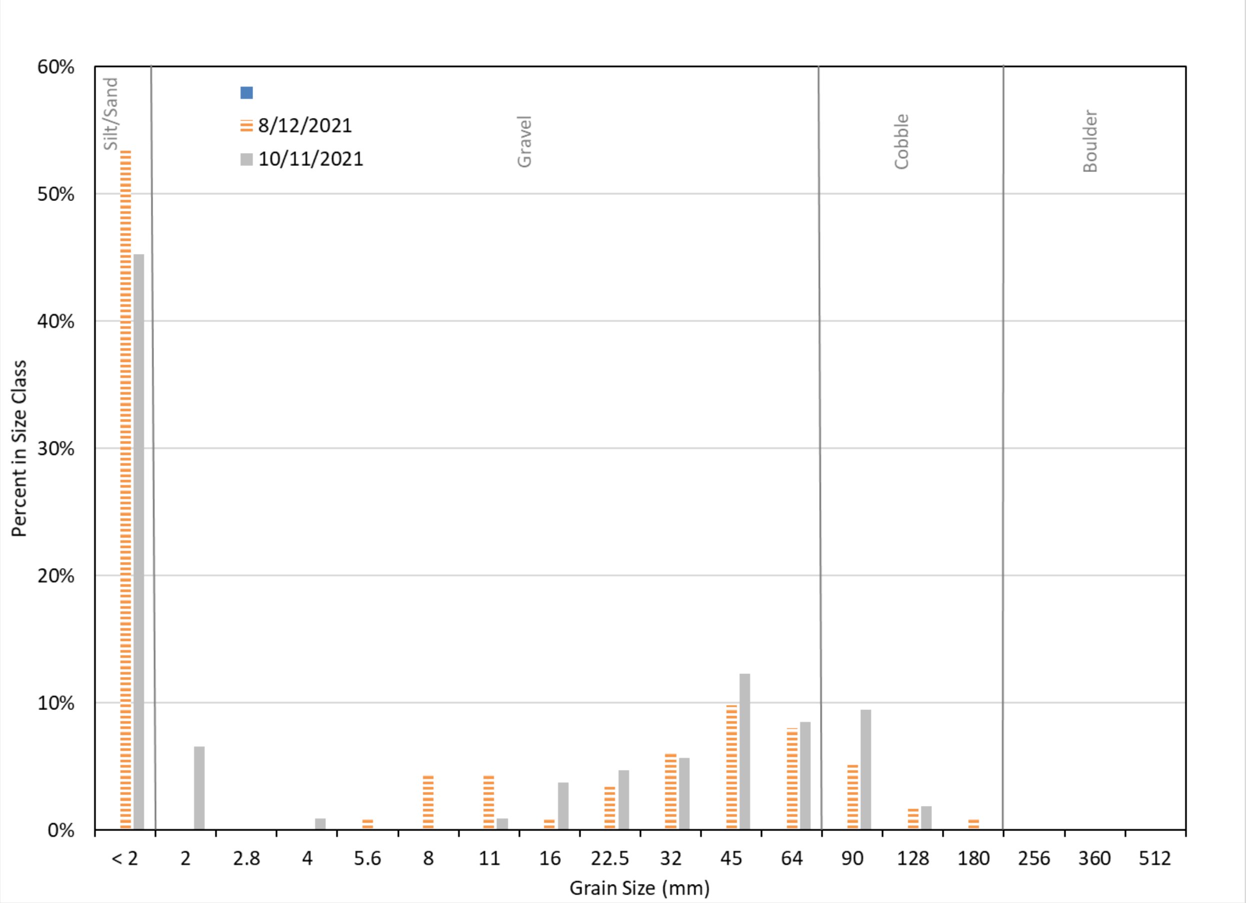


Figure 5.3-31. Transect 102 substrate grain size distribution changes.

5.3.1.12. Transect F RM 5.4

Transect F, at RM 5.4, is located in a pool at the downstream end of the AWWU access road (**Figure 5.3-32**). This transect was established in August 2020 and included two pre-flow release measurements and one post-flow release measurement. The fine sediment in this pool showed erosion of up to 0.5 feet between August 2020 and August 2021, with additional cut and fill following the study flow releases (**Figure 5.3-33**). Grain size measurements were taken pre- and post-flow release across the transect and showed little change to the fine-grained substrate during any of the measurements (**Figure 5.3-34**). A sliding bead scour monitor was installed in August 2020. The sliding bead monitor was read in August and October 2021 and showed 9 inches of bed lowering between August 2020 and August 2021 and little change in October 2021 following the study flow releases.

Figure 5.3-32. Transect F, October 10, 2021.

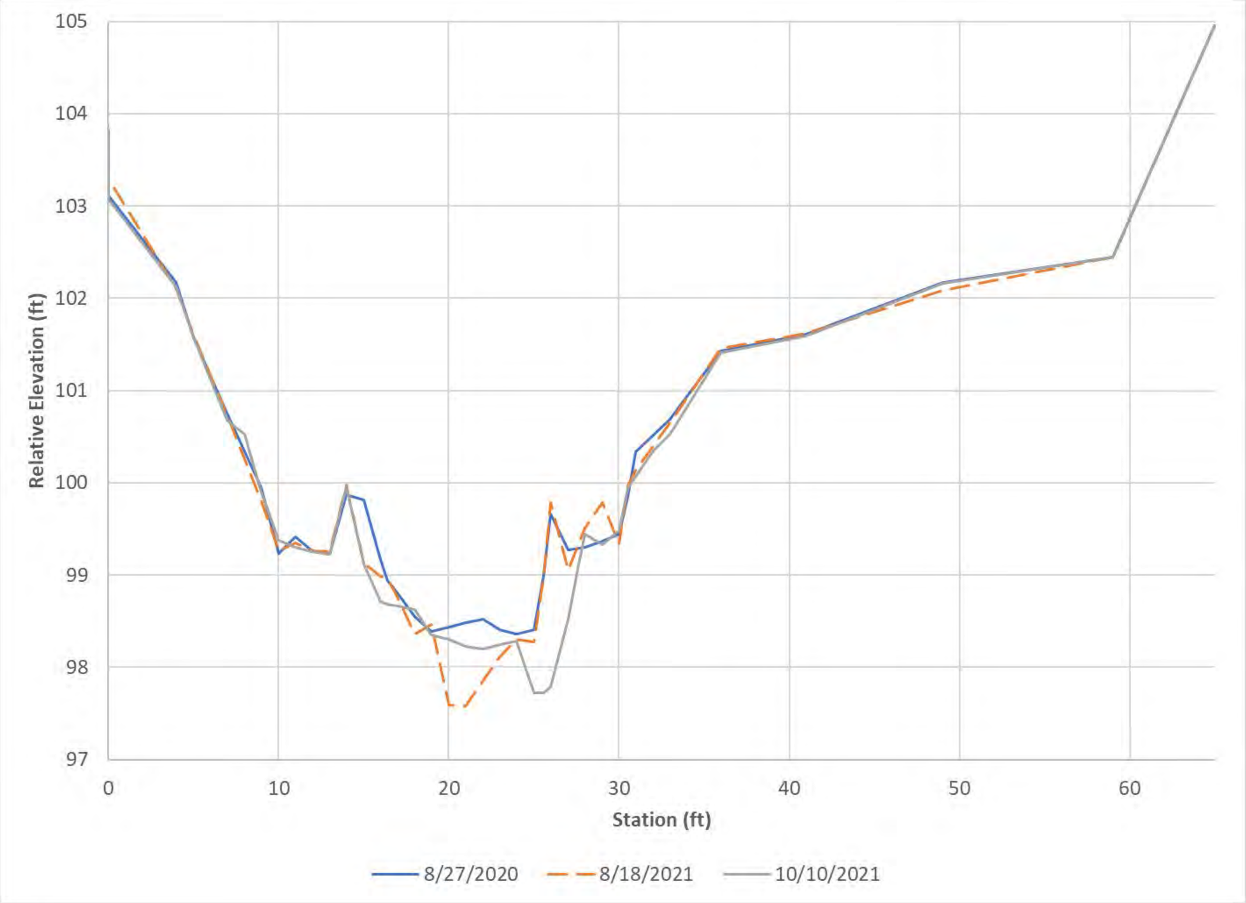


Figure 5.3-33. Transect F cross-sectional changes.

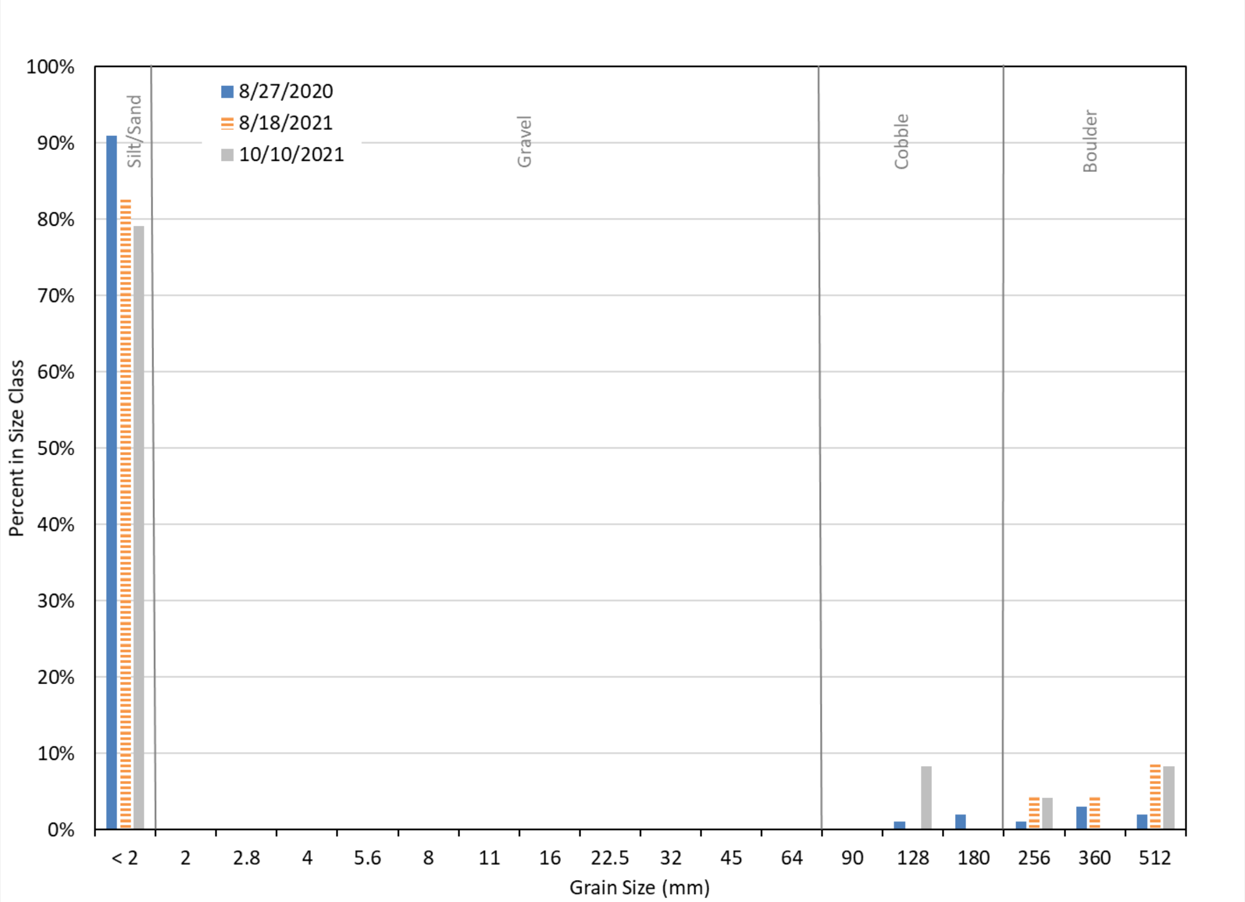


Figure 5.3-34. Transect F substrate grain size distribution changes.

5.3.1.13. Transect 103 RM 6.3

Transect 103, at RM 6.3, is located near instream flow transects (**Figure 5.3-35**). This transect was established in August 2021 and included one pre-flow release measurement and one post-flow release measurement. The post-flow measurement showed up to 1 foot of scour within the channel following the flow releases (**Figure 5.3-36**). Grain size measurements were taken pre- and post-flow release across the transect (**Figure 5.3-37**). Substrate is predominantly fine sediment and showed a slight decrease in fine sediment following the study flow releases. A sub-surface sample was taken at this site with a median (D_{50}) diameter of 1 mm (**Figure 5.3-38**). An accelerometer and a sliding bead scour monitor were installed in August 2021 about 10 feet downstream from the transect. The sliding bead monitor was not recovered, likely due to the estimated 2 feet of scour with subsequent fill at this location. The accelerometer was located and was buried under 1 foot of gravel/cobble material and recorded movement starting on September 13, 2021 at 1630 followed by battery failure which resulted in no additional data collection (**Figure 5.3-39**).

Figure 5.3-35. Transect 103, October 9, 2021.

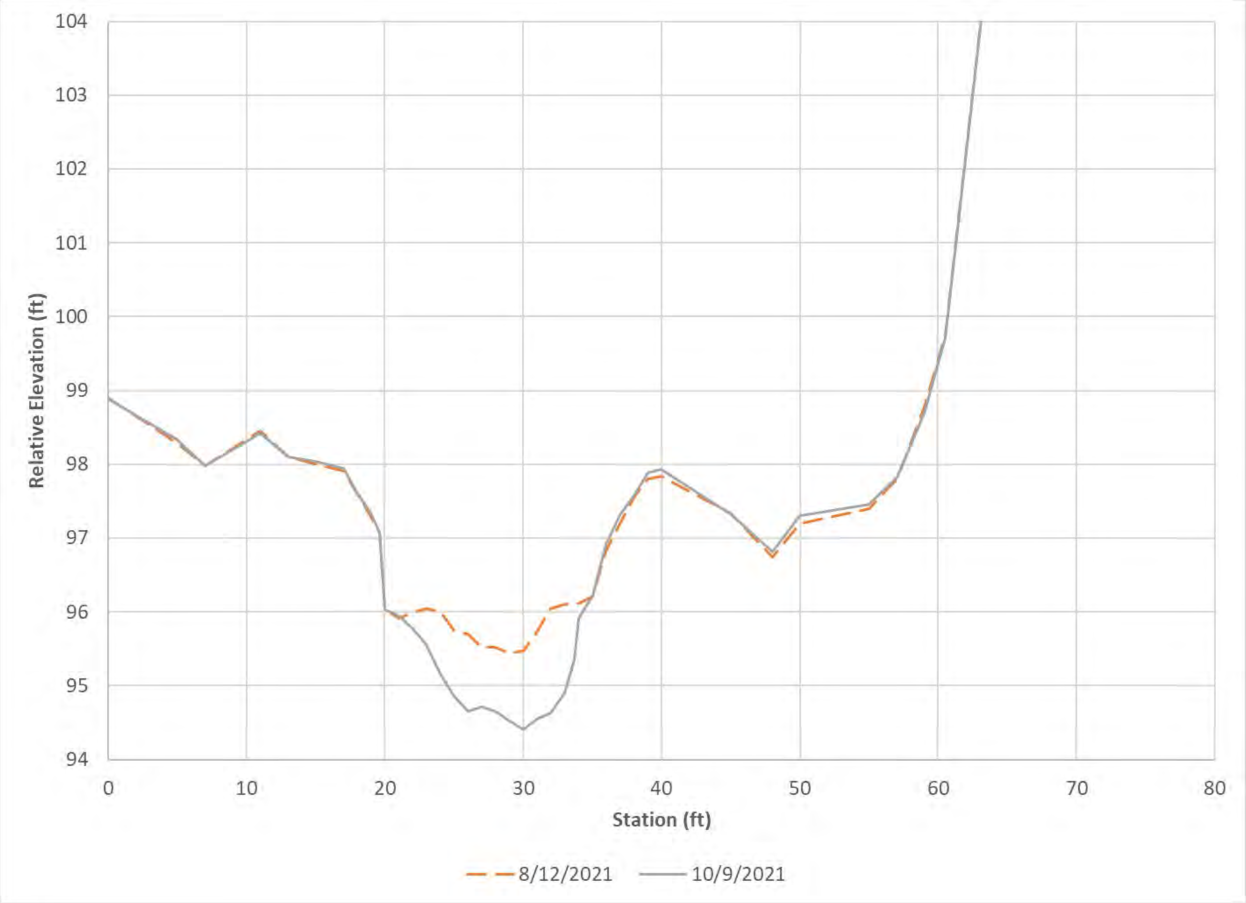


Figure 5.3-36. Transect 103 cross-sectional changes.

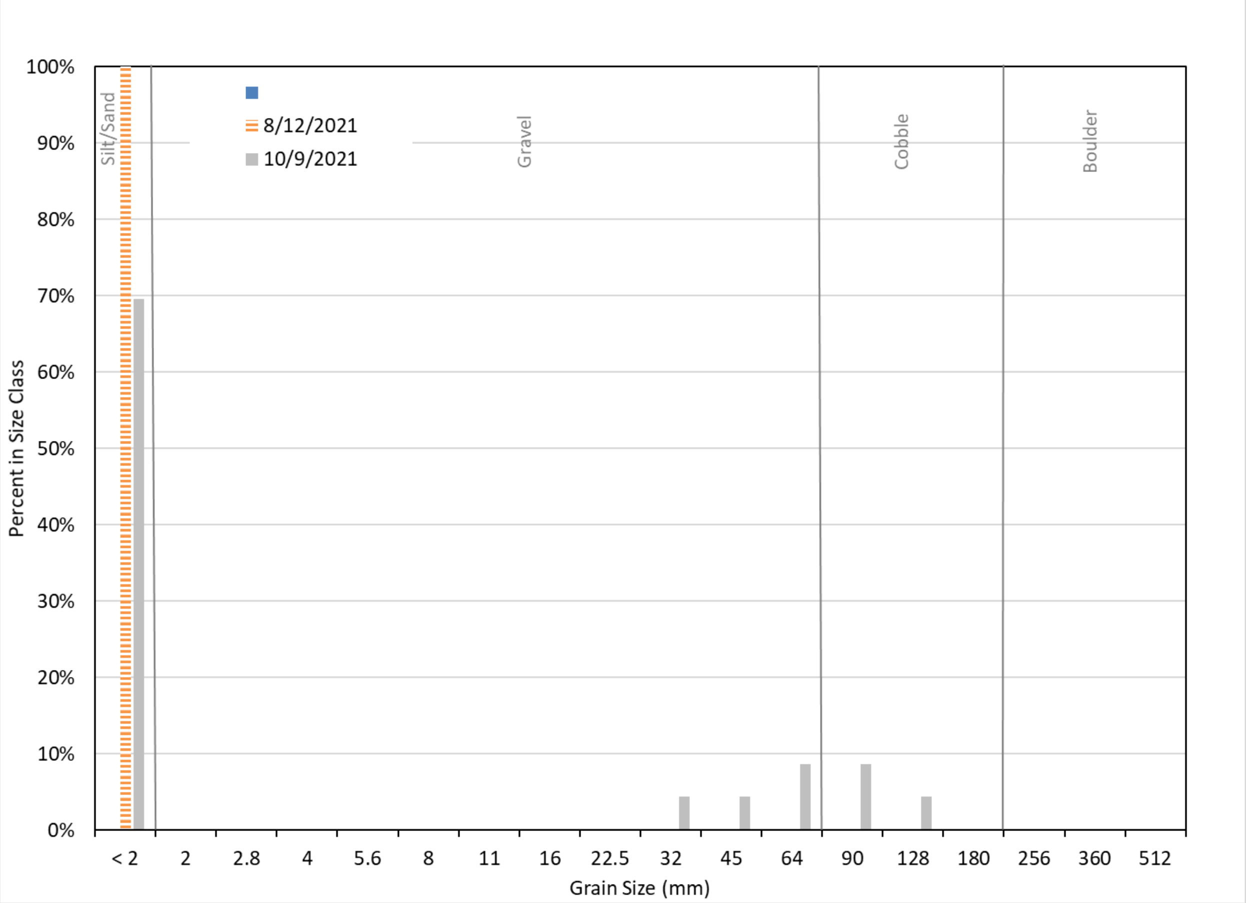


Figure 5.3-37. Transect 103 substrate grain size distribution changes.

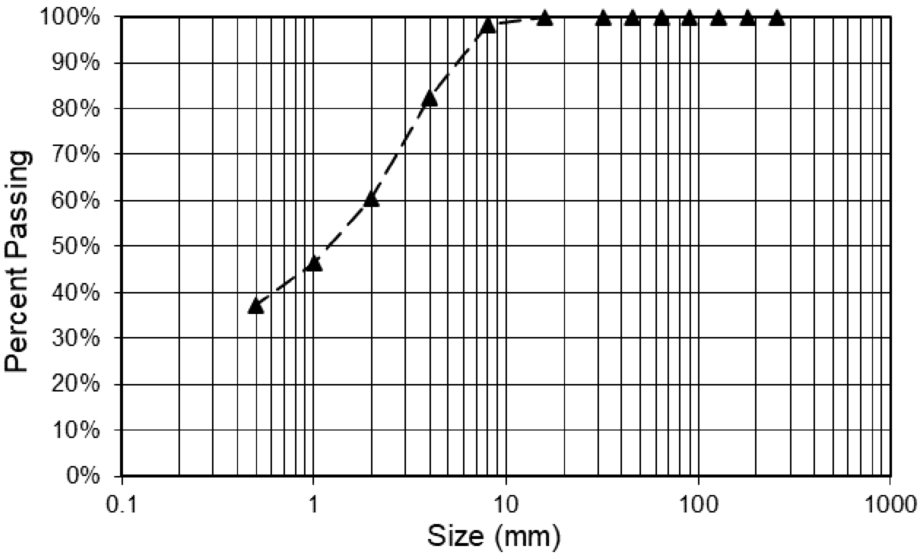
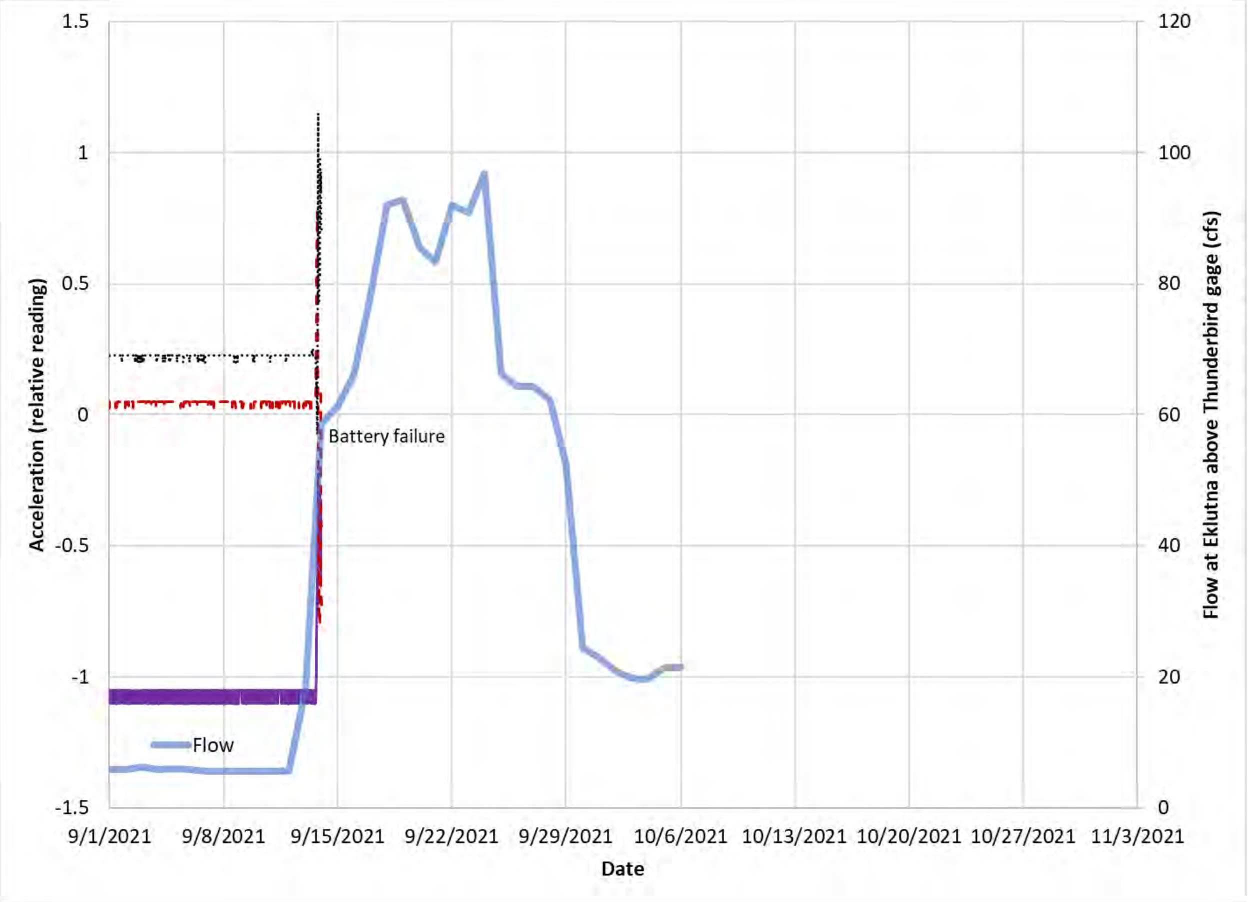


Figure 5.3-38. Transect 103 sub-surface grain size distribution.



Flow data provisional, from Eklutna Stream Gaging Year 2 Report

Figure 5.3-39. Transect 103 accelerometer data.

5.3.1.14. Transect E RM 6.75

Transect E, at RM 6.75, is located at a large alluvial fan sediment source (**Figure 5.3-40**). This transect was established in 2020 and included two pre-flow release measurements and one post-flow release measurement. This transect experienced major changes during the study flow releases as the river cut a new channel on the right bank by eroding the toe of the alluvial fan and abandoning the former channel/transect location. Based on terrace deposits, it appears that this phenomenon has occurred previously when the toe of the alluvial fan was eroded, presumably during a spill event, and the alluvial fan later filled the right bank channel resulting in the move to the left bank channel. Post-flow measurement showed deposition of up to 1 foot within the channel following the study flow releases and an estimated 2 feet of erosion in the right bank channel (**Figure 5.3-41**). Grain size measurements were taken pre- and post-flow release across the transect and showed the channel was dominated by gravel during all three measurements, with a progressive decrease in fine-grained sediment through time (**Figure 5.3-42**). A sliding bead scour monitor was installed in August 2020. The sliding bead monitor was read in August and October 2021 and showed 1.5 inches of bed lowering between August 2020 and August 2021 followed by burial with 0.5-1 foot of gravel and cobble (up to 128 mm) in October 2021 following the study flow releases.

Figure 5.3-40. Transect E left bank channel (top) and new right bank channel (bottom), October 8, 2021.

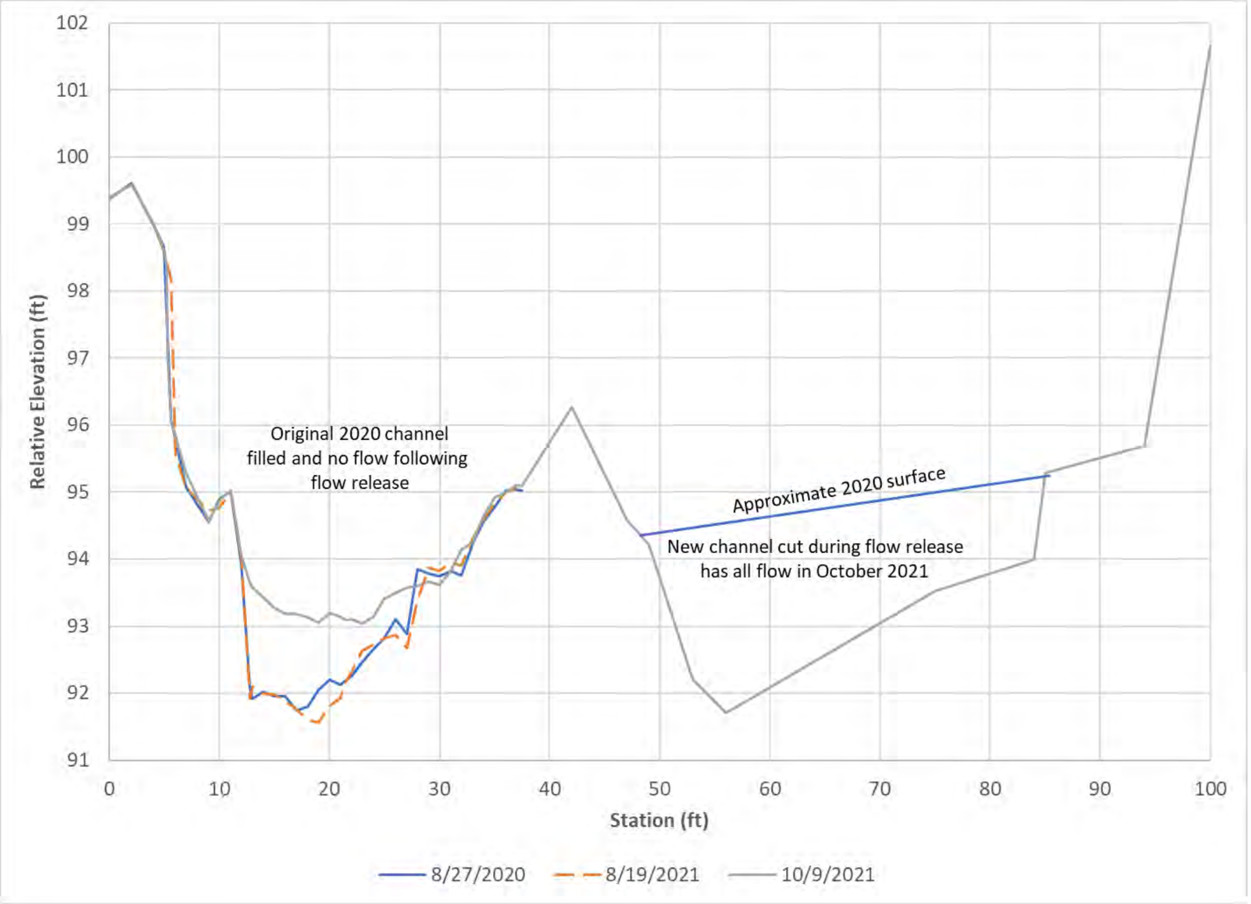


Figure 5.3-41. Transect E cross-sectional changes.

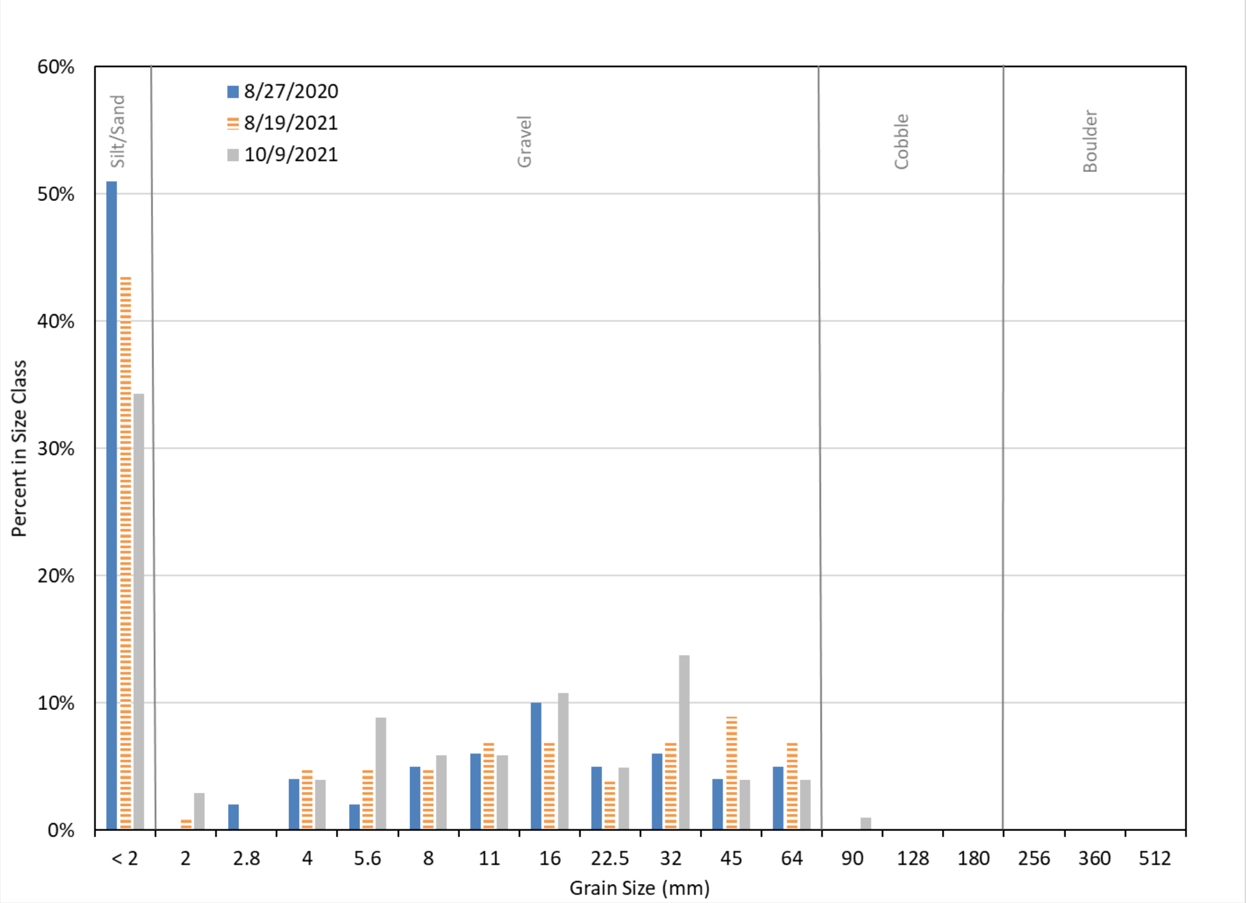


Figure 5.3-42. Transect E substrate grain size distribution changes.

5.3.1.15. Transect D RM 7.2

Transect D, at RM 7.2, is located upstream from two major sediment sources. This transect was established in August 2020 and included two pre-flow release measurements and one post-flow release measurement. Between August 2020 and August 2021, a series of beaver dams was established in the vicinity of this transect and resulted in the inundation of the transect during the 2021 measurements (**Figure 5.3-43**). Deposition of 0.5 to 1 foot within the channel following beaver dam construction was measured (**Figure 5.3-44**). Grain size measurements were taken pre- and post-flow release across the transect and showed that deposition of fine-grained sediment covered the original gravel/cobble bed (**Figure 5.3-45**).

Figure 5.3-43. Transect D before (top) and after (bottom) inundation by beaver dam.

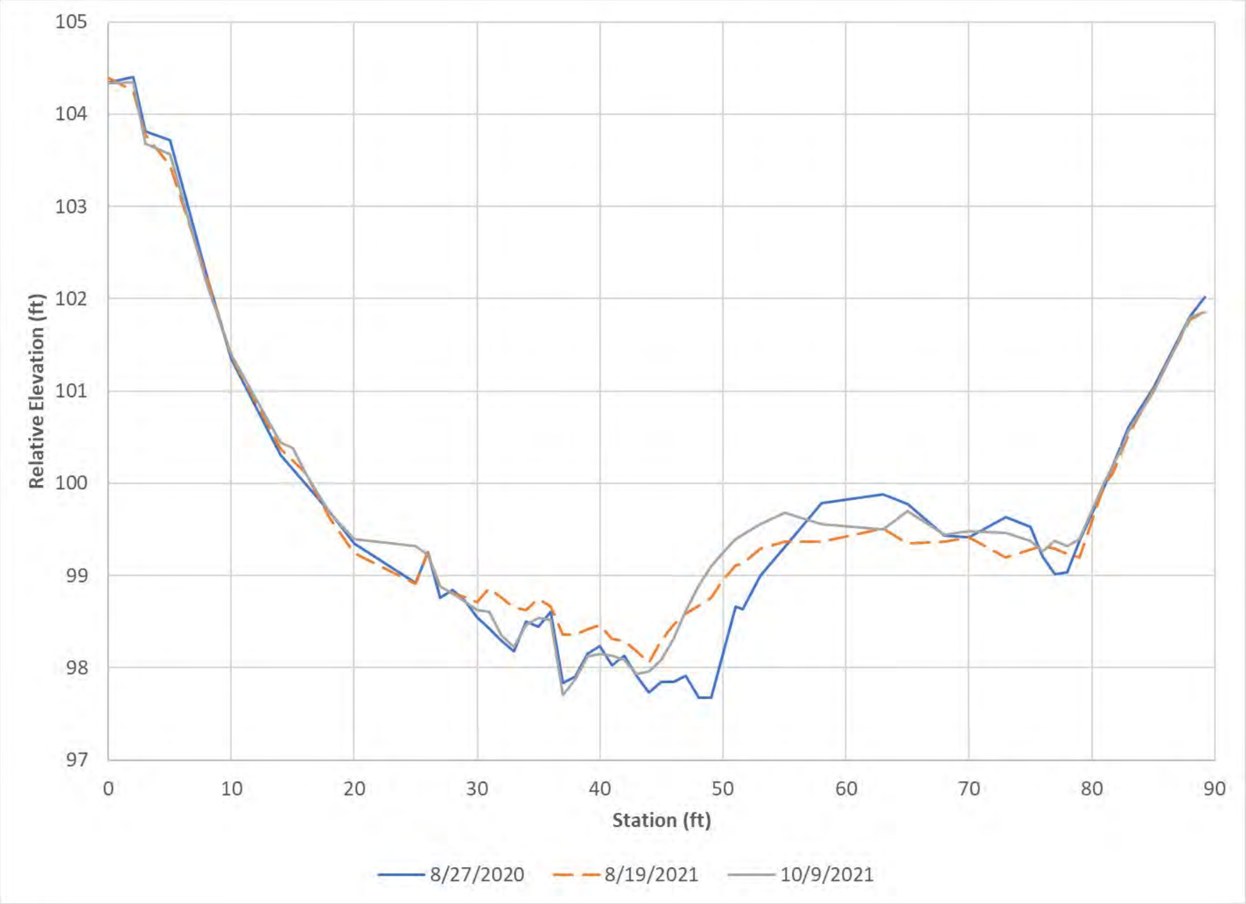


Figure 5.3-44. Transect D cross-sectional changes.

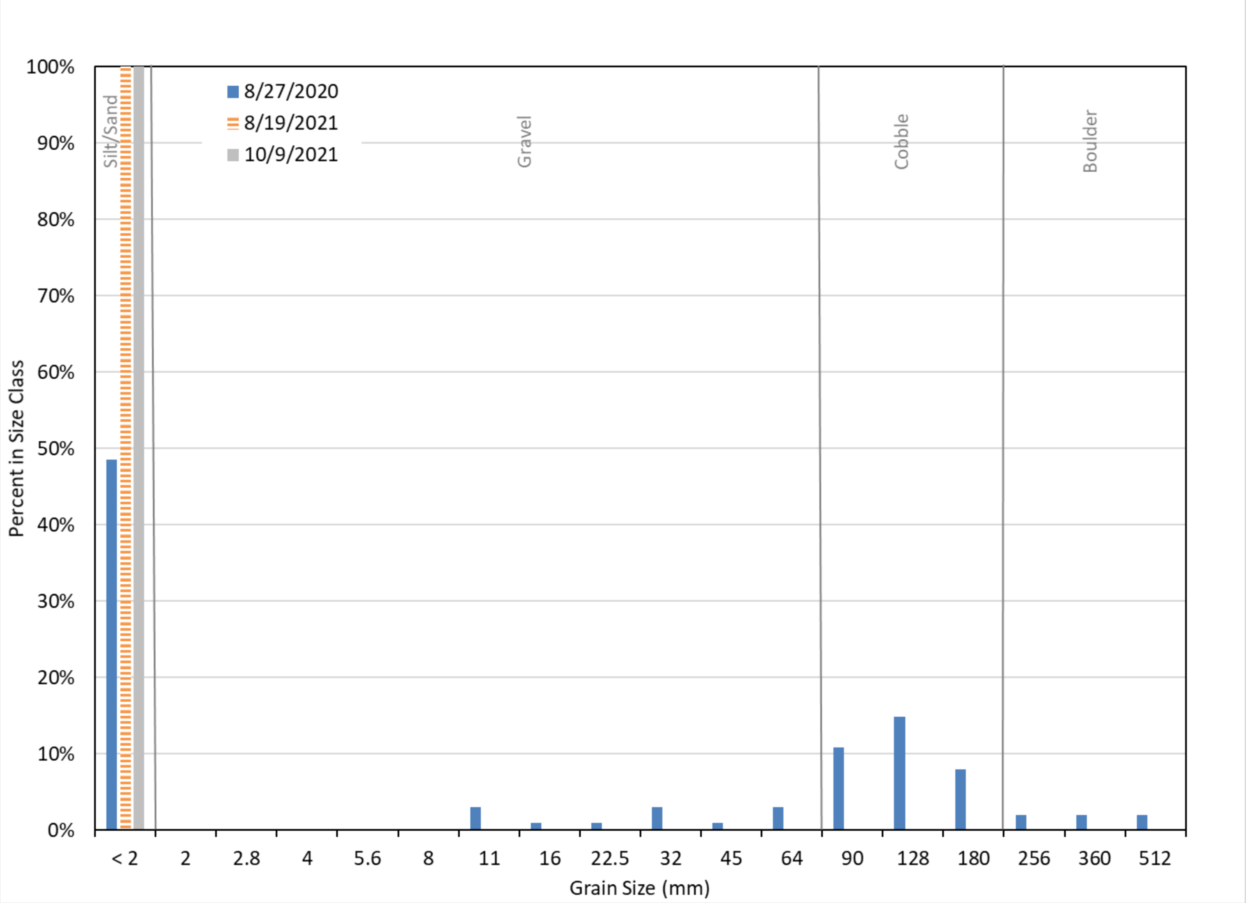


Figure 5.3-45. Transect D substrate grain size distribution changes.

5.3.1.16. Transect 105 RM 8.7

Transect 105, at RM 8.7, is located several hundred feet downstream of the sixth AWWU access road crossing below Eklutna Lake Dam (**Figure 5.3-46**). This transect was established in August 2021 and included one pre-flow release measurements and one post-flow release measurement. The post-flow measurement showed up to 1.5 feet of erosion within the channel as well as overbank deposition of fine sediment on the left bank (in the lee of a log) following the study flow releases (**Figure 5.3-47**). Grain size measurements were taken pre- and post-flow release across the transect. Substrate is predominantly fine-grained and showed a slight decrease in fine sediment following the study flow releases (**Figure 5.3-48**).

Figure 5.3-46. Transect 105, October 8, 2021.

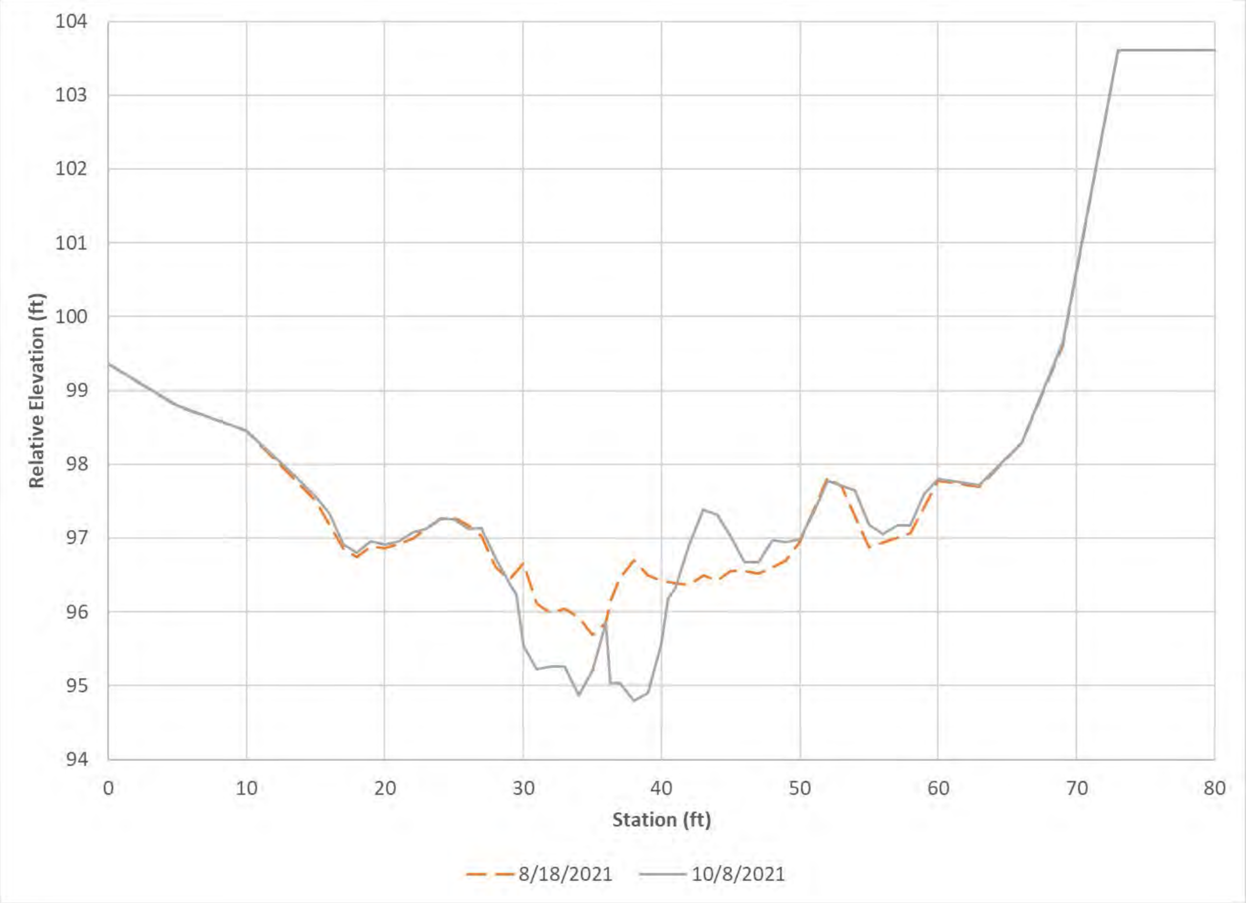


Figure 5.3-47. Transect 105 cross-sectional changes.

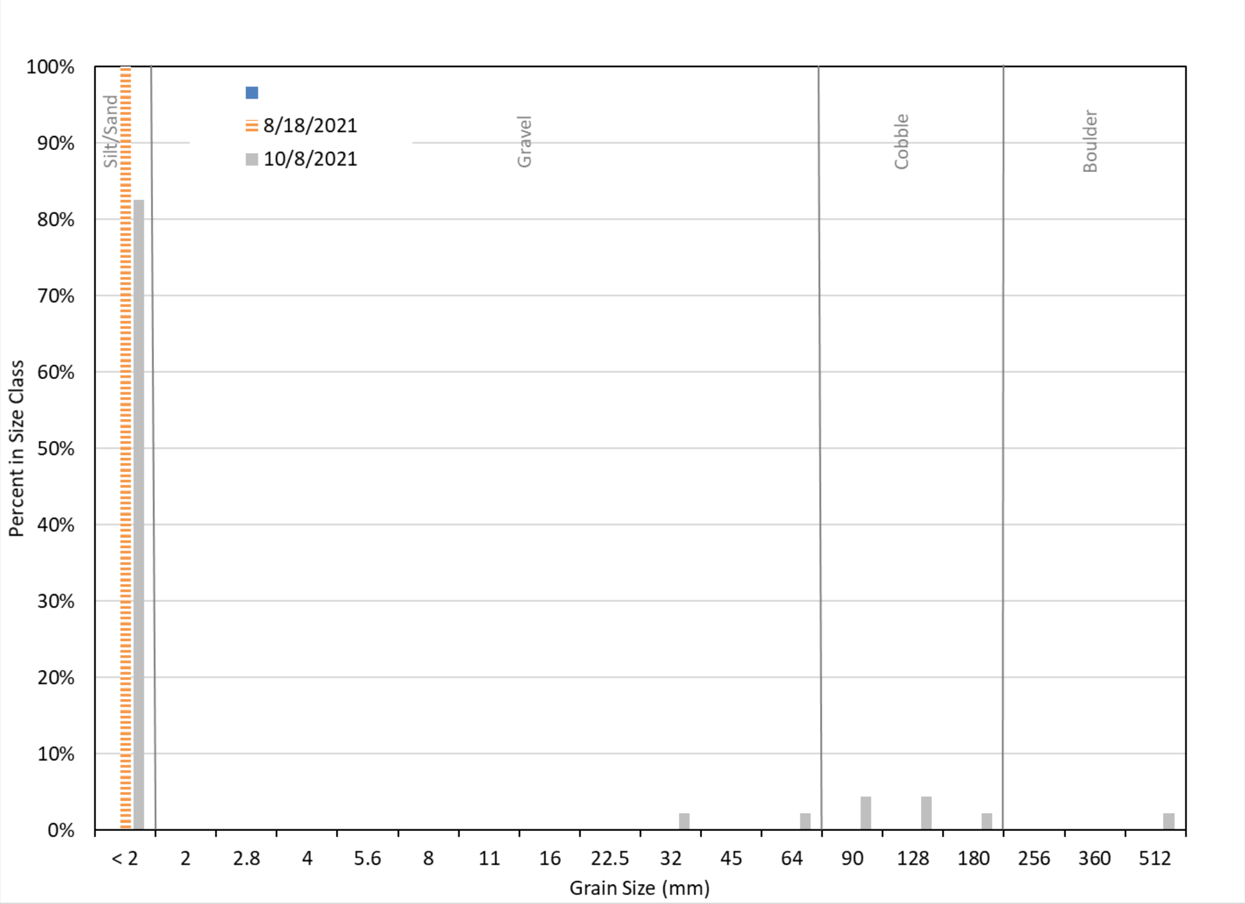


Figure 5.3-48. Transect 105 substrate grain size distribution changes.

5.3.1.17. Transect C RM 11.2

Transect C, at RM 11.2, is located just downstream from the alluvial fan source at Transect B (**Figure 5.3-49**). This transect was established in August 2020 and included two pre-flow release measurements and one post-flow release measurement. The post-flow measurement showed erosion of up to 0.5 foot within the channel following the study flow releases (**Figure 5.3-50**). Grain size measurements were taken pre- and post-flow release across the transect (**Figure 5.3-51**). Substrate following the study flow releases was predominantly gravel (median grain diameter 2-3 mm prior to the flow release and 18 mm following the flow release) and showed a marked decrease in fine sediment as the original channel bed was uncovered.

Figure 5.3-49. Transect C before (top) and after (bottom) flow release showing erosion of fine sediment and re-establishment of river channel.

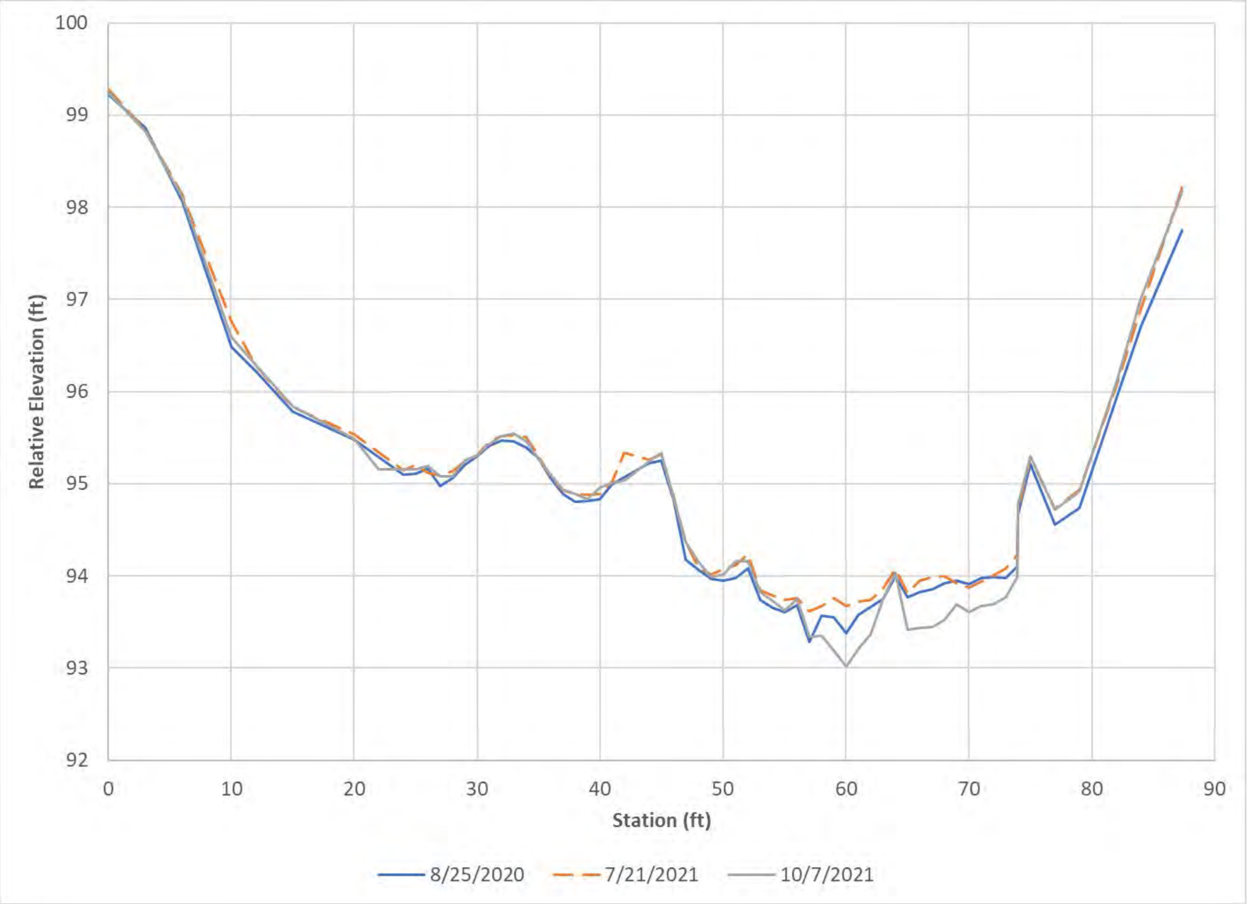


Figure 5.3-50. Transect C cross-sectional changes.

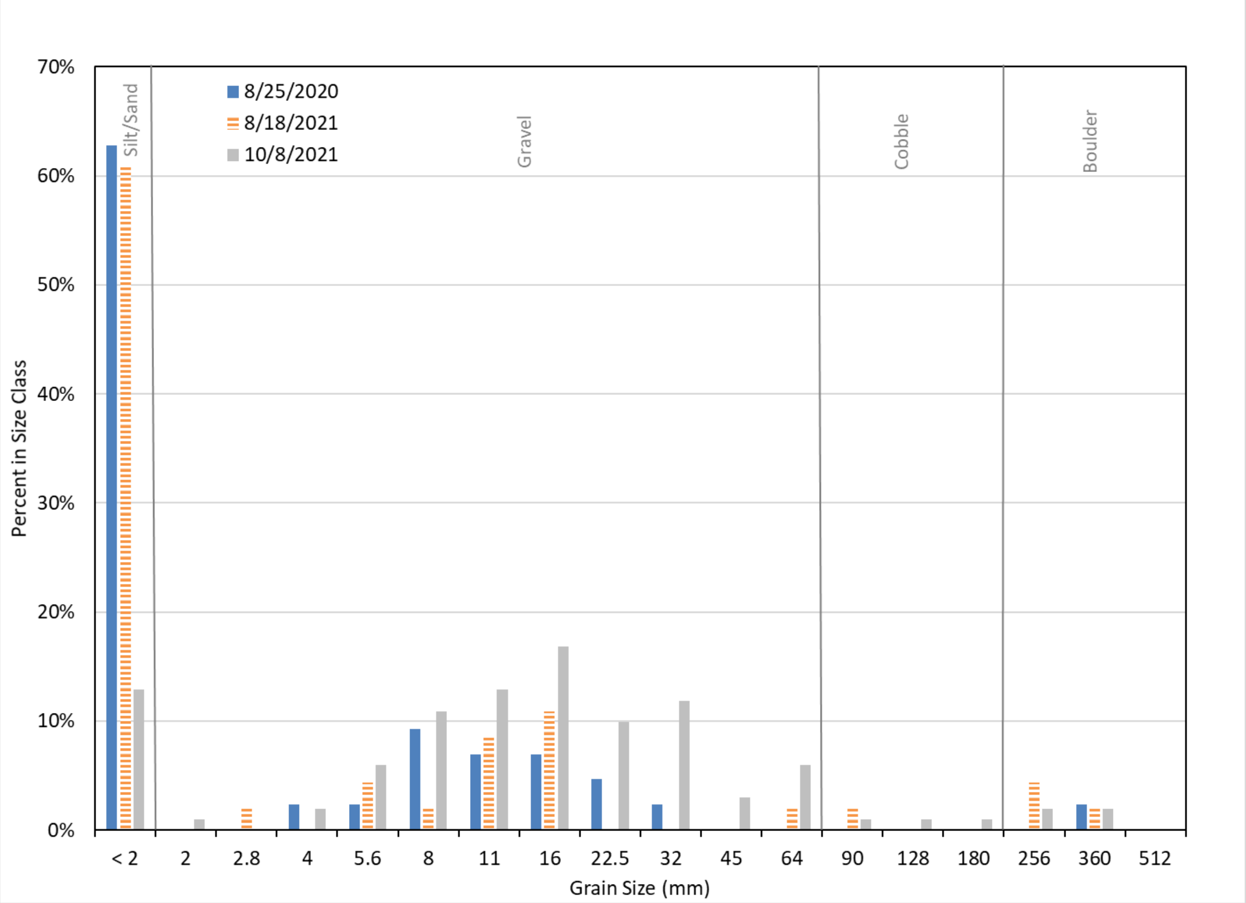


Figure 5.3-51. Transect C substrate grain size distribution changes.

5.3.1.18. Transect B RM 11.25

Transect B, at RM 11.25, is located between the two AWWU bridges at the toe of the first major sediment source downstream from Eklutna Lake Dam (**Figure 5.3-52**). This transect was established in September 2020 and included two pre-flow release measurements and one post-flow release measurement. The transect includes the toe of the alluvial fan sediment source. The post-flow measurement showed erosion of over 3 feet as the river re-established a channel by eroding the toe of the alluvial fan deposits (**Figure 5.3-53**). Grain size measurements were taken pre- and post-flow release across the transect and showed a change from nearly 100 percent fine sediment prior to the study flow releases to a median grain diameter of 51 mm (gravel) following the study flow releases as the underlying gravel, cobble, and boulder substrate was exposed (**Figure 5.3-54**).

A line of painted rocks was deployed on the alluvial fan deposits at this location to track erosion of the fan through time. The rocks were visually assessed at several times during the start of the high flow release to document how fast the fan eroded.

Figure 5.3-52. Transect B before (top) and after (bottom) flow release showing erosion of toe of alluvial fan deposits and re-establishment of river channel.

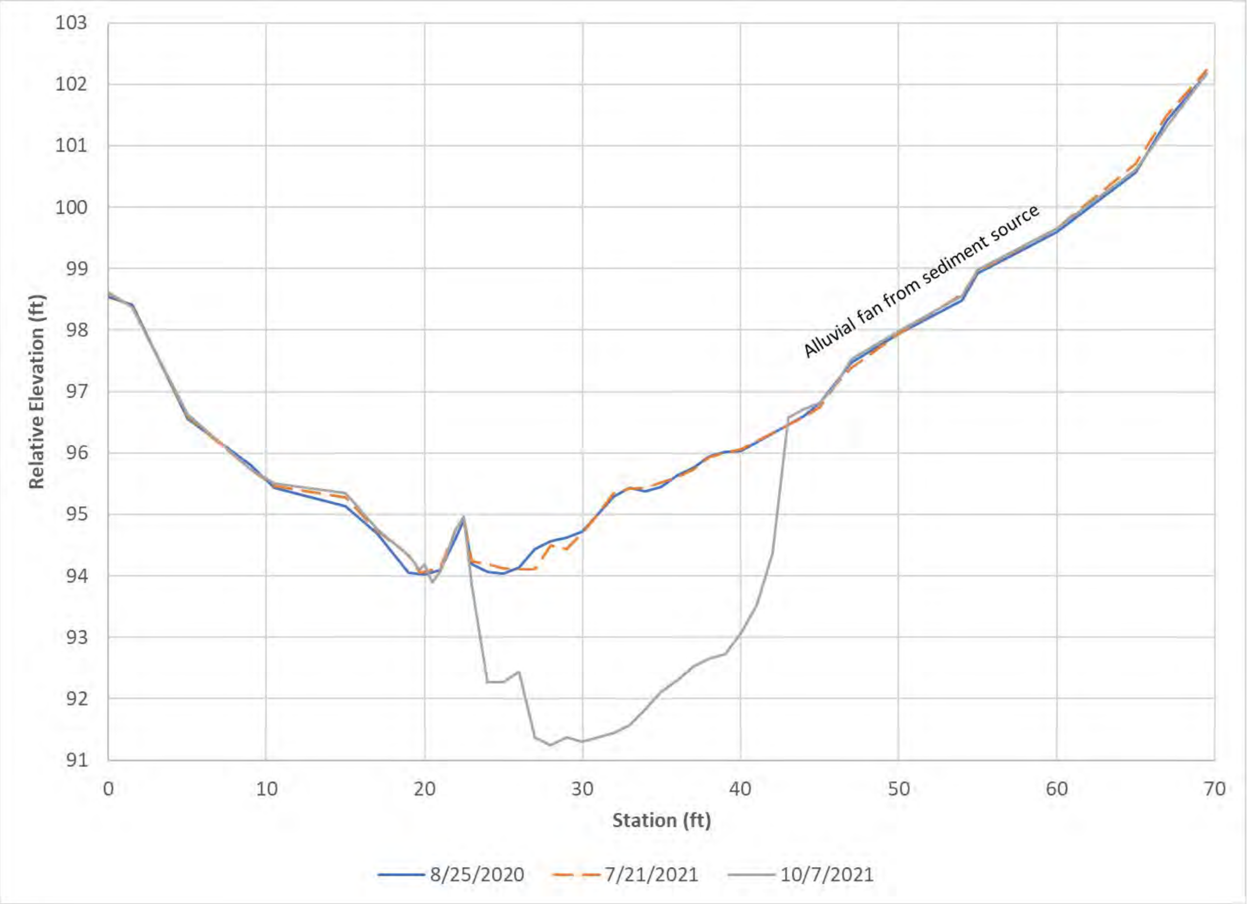


Figure 5.3-53. Transect B cross-sectional changes.

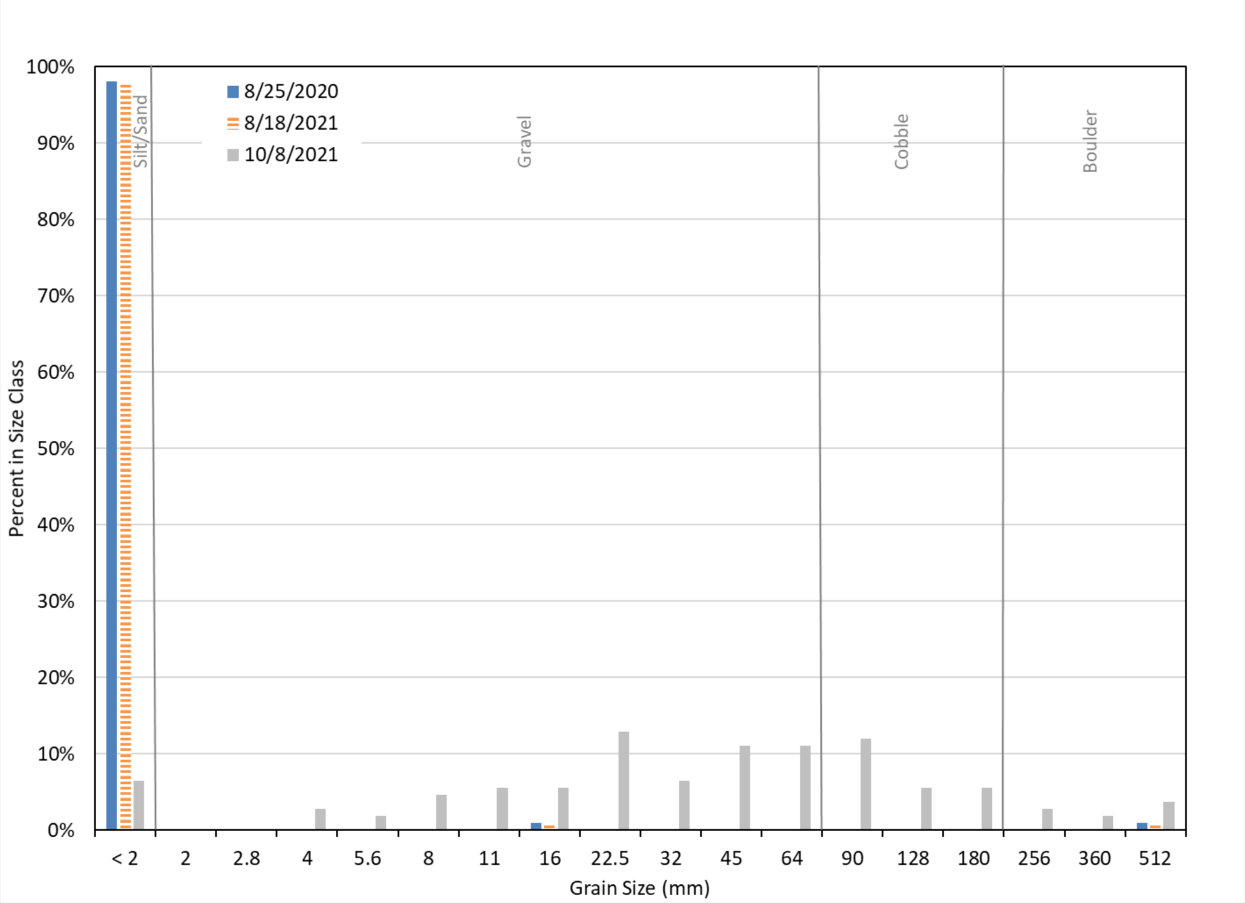


Figure 5.3-54. Transect B substrate grain size distribution changes.

5.3.1.19. Painted Rocks at Upper AWWU Bridge RM 11.3

Painted rocks were deployed just downstream from the upper AWWU bridge (RM 11.3) just prior to the study flow releases. Three rows with 13 painted rocks each were deployed across the streambed, one row of 32 mm particles, one row of 64 mm, and one row of 128 mm particles (**Figure 5.3-55**). Following the flow releases, 2 of the 32 mm particles remained on the streambed, 8 of the 64 mm particles (several of the central 64 mm particles were buried by gravel) and all of the 128 mm particles remained with one covered by gravel. A transect was surveyed following the study flow releases (**Figure 5.3-56**).

Figure 5.3-55. Painted Rocks Transect before (top) and after (bottom) flow release.

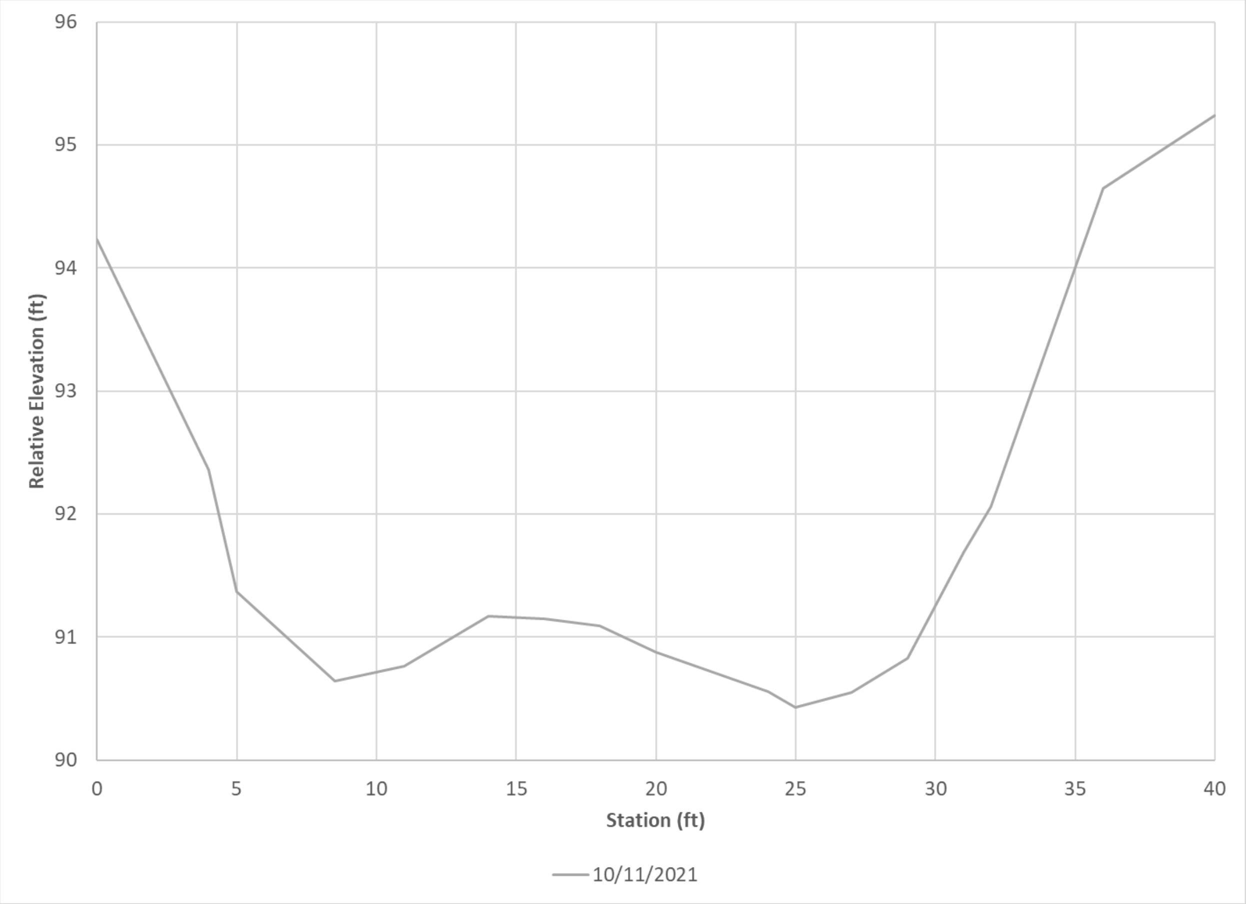


Figure 5.3-56. Painted rocks transect cross-section.

5.3.1.20. Transect A RM 11.75

Transect A, at RM 11.75, is located downstream from the Eklutna Lake Dam near the site of the USFWS 2019 study transects and near the upper instream flow study transects (**Figure 5.3-57**). This transect was established in August 2020 and included two pre-flow release measurements and one post-release measurement. The post-flow measurement showed little change in channel cross section (**Figure 5.3-58**). Grain size measurements were taken pre- and post-flow release across the transect and showed little change (**Figure 5.3-59**). Substrate is predominantly gravel and cobble (median grain diameter 67-78 mm).

Figure 5.3-57. Transect A, October 7, 2021.

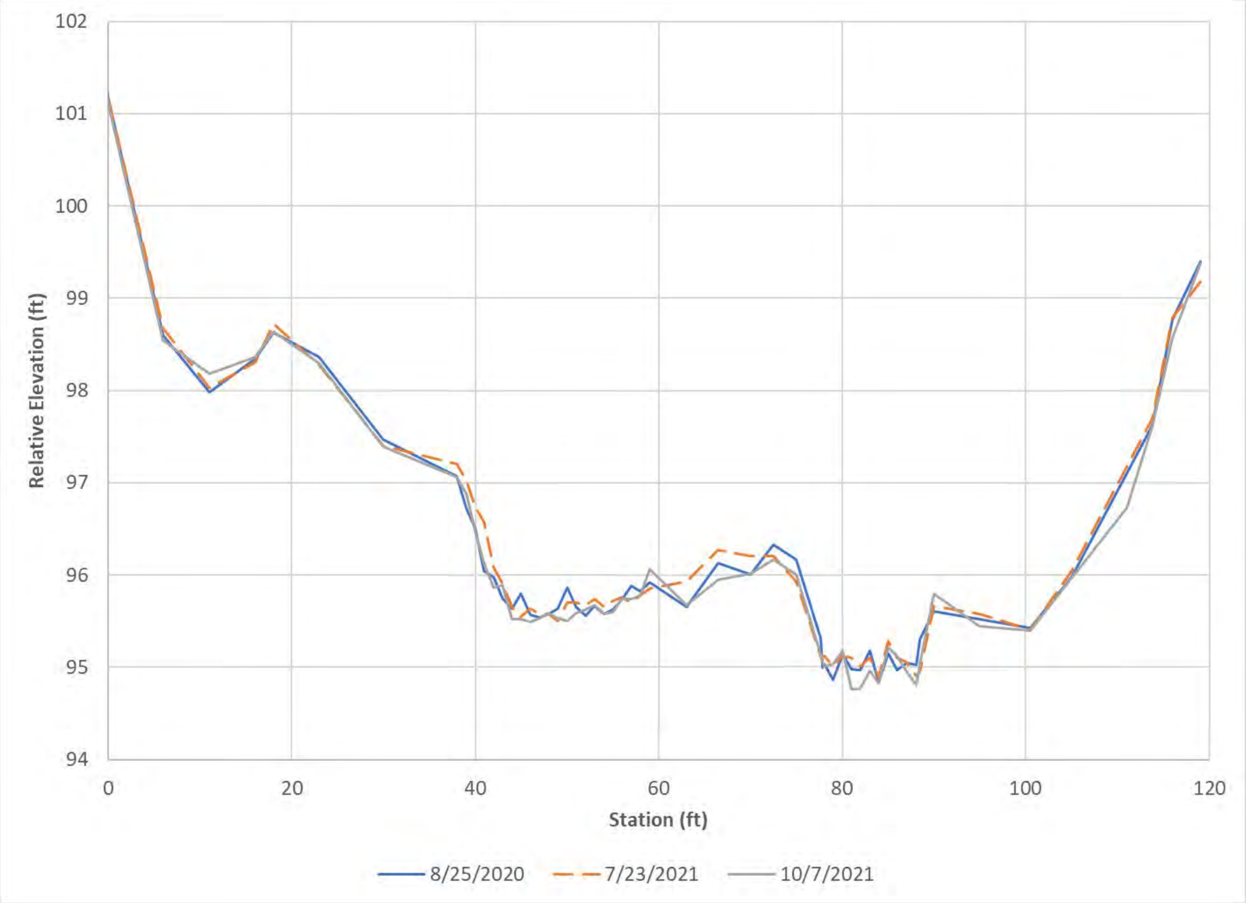


Figure 5.3-58. Transect A cross-sectional changes.

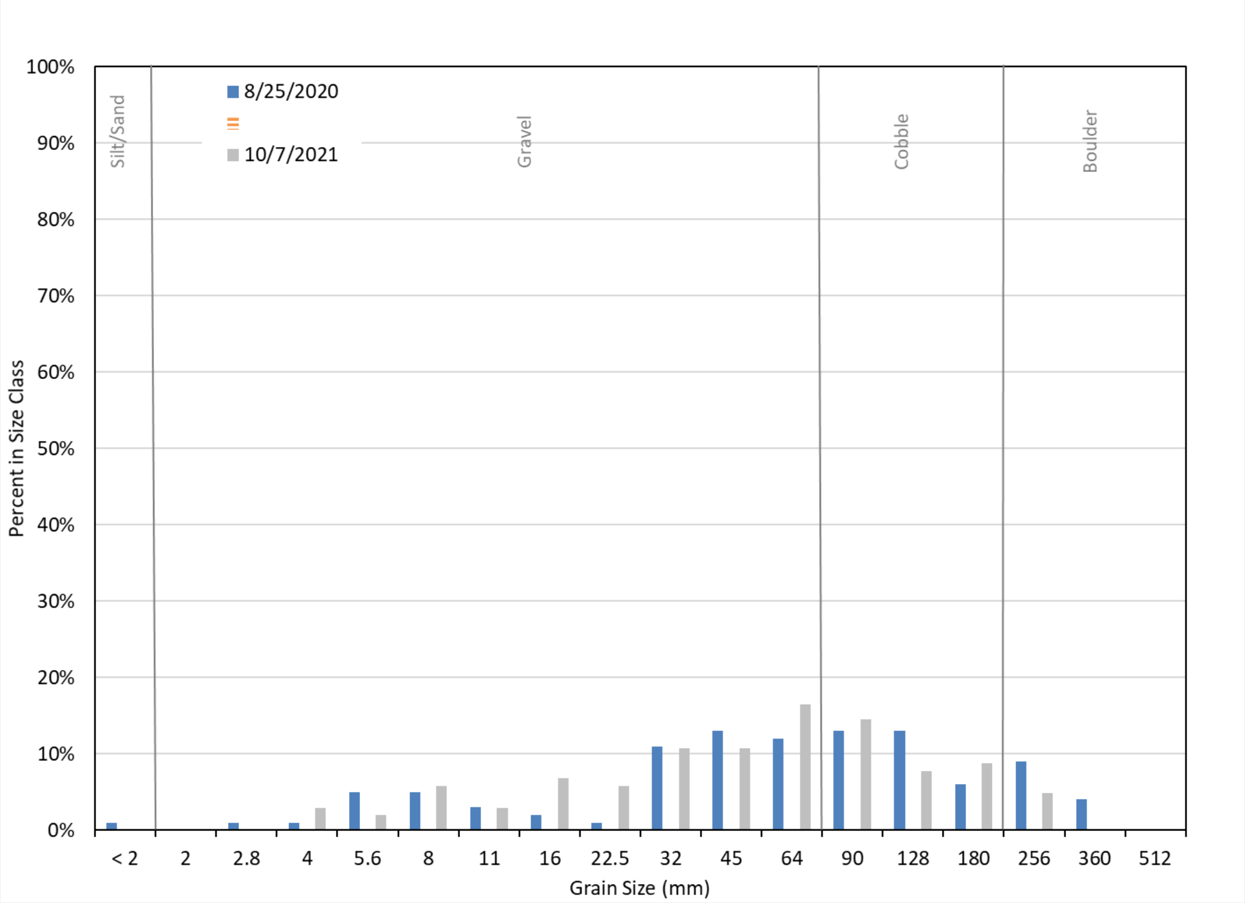


Figure 5.3-59. Transect A substrate grain size distribution changes.

5.3.1.1. Summary of Cross Section Areas at Highest Flow Release

The estimated wetted area for channel cross sections surveyed in Geomorphic Reaches 8, 9, and 10 during the highest (150 cfs) flow release was calculated based on field evidence of high-water marks (Table 5.3-1). Cross sectional areas ranged from 28 to 72 square feet, with an average of 45 square feet (Transect B was not included in average as noted in Table).

Table 5.3-1. Estimated Wetted Cross Section Area during Highest Flow Release.

Transect	Cross Section Area (sq ft)	Notes
A	68	
B	72	High water mark too high – channel was actively cutting during high flow release.
C	46	
105	46	
D	n/a	Beaver Pond, no water mark.
E	97/2 = 48 per channel	Flow eroded a new channel, only 1 active at a time.
103	38	
F	39	
102	28	

5.3.2. Bulk Density Samples

Three bulk density measurements of the fine-grained, compressed material in the old reservoir deposits resulted in dry bulk densities of 99.1, 99.4, and 106.2 lb-f/ft^3. These data were used in the HEC-RAS model to specify bulk density of the fine-grained material.

5.3.3. Timelapse Cameras

The three timelapse cameras recorded changes in the old lower dam deposits during the flow release. Erosion of the deposits via stream undercutting and one large mass wasting event were recorded, as well as headcutting at the upper end of the deposits. The majority of change occurred during the higher flow portion of the study flow releases; once flow levels dropped the rate of change/erosion also dropped. Timelapse videos are available online at the Project website: https://eklutnahydro.com/september-2021-flow-releases/ .

5.3.4. Grade Control Mapping

Grade controls were mapped in the field by visual observations of locations where large, channel-spanning boulders, bedrock, or similar permanent channel controls were located. All mapped grade controls were located within the bedrock canyon (geomorphic reaches 4 and 5) and are shown in Section 6.1 on the profile in Figure 6.1-1. The majority of features formed as a result of rockfalls from canyon walls that left large, immobile boulders blocking the canyon. Not all rockfalls are large enough to span the channel, and some do not include boulders large enough to be immobile under potential/historic peak flow conditions. These temporary grade controls were not included in this analysis. The grade control features were used in the 1-D HEC-RAS sediment transport model to control depth of future potential channel erosion at these locations. One of the features, located at RM 4.2 at the upstream end of the old reservoir deposits, persisted through the 2020-2022 study period and may or may not be a permanent feature depending upon how the boulders at this location adjust to the headcutting that is occurring in the old reservoir deposits. This location was modeled as a grade control in the current sediment transport model.

5.4. Sediment Source Areas and Sediment Input Rates

The current major sediment sources to the Eklutna River are shown in **Figure 5.4-1** and include the alluvial fans in the upper valley and one smaller eroding bluff in the canyon just downstream from RM 5. These sediment sources provide fine-grained sediment (sand, silt, clay), coarser-grained gravel and cobble that are preferred by salmonids for spawning, and boulders that are not mobile under most flow conditions but provide local hydraulic variability which is an important aspect of aquatic habitat. Other, smaller sediment sources exist along the river, such as eroding banks downstream from Thunderbird Creek, but these contribute minor amounts of sediment compared to the mapped major sediment sources. There are few eroding banks in the wide alluvial valley upstream from RM 5 and the bedrock canyon between RM 5 and Thunderbird Creek provides relatively minimal amounts of material from bank erosion (with the exception of the large eroding bank mapped as Sediment Source 23 and occasional rockfalls).

Comparison of the 2022-2020-2015 LiDAR topographic surfaces was used to estimate an average annual contribution of sediment to the Eklutna River from each of the mapped sources (see examples in **Figure 5.4-2**, **Figure 5.4-3** and **Figure 5.4-4** for examples). The net elevation change at each LiDAR grid cell was summed over each sediment source area to provide a volume of sediment exported from each source area. The 7-year interval between the 2022-2015 LiDAR flights does not provide a long-term estimate of sediment input. Historical aerial photographs from 1952 to present were reviewed to determine if changes in sediment source areas were visible. Only one source area (Source 22) had enough change to be measurable on the aerial photographs. The area of this source area was digitized on the 1952, 1957, 1963, 1972, 1990, and 2020 aerial photographs to measure the change in area between photo periods (**Figure 5.4-5**). The source area (not the fan) was multiplied by bank height (100 feet) to estimate volume of material eroded during each period for comparison with the 2020-2022 input rate (**Figure 5.4-6**). This particular sediment source area provided a very large volume of sediment in the 1957-1963 period; there appeared to be ground disturbance upslope from this source area that may have contributed to the instability and anomalously large contributions. The sediment formed a fan that crossed and blocked the Eklutna River valley and forced the river to the opposite side of the valley during this same 6-year period, a feature that persists in the landscape today. Input rates since 1963 have been consistent and align closely with the 2020-2022 LiDAR input estimate.

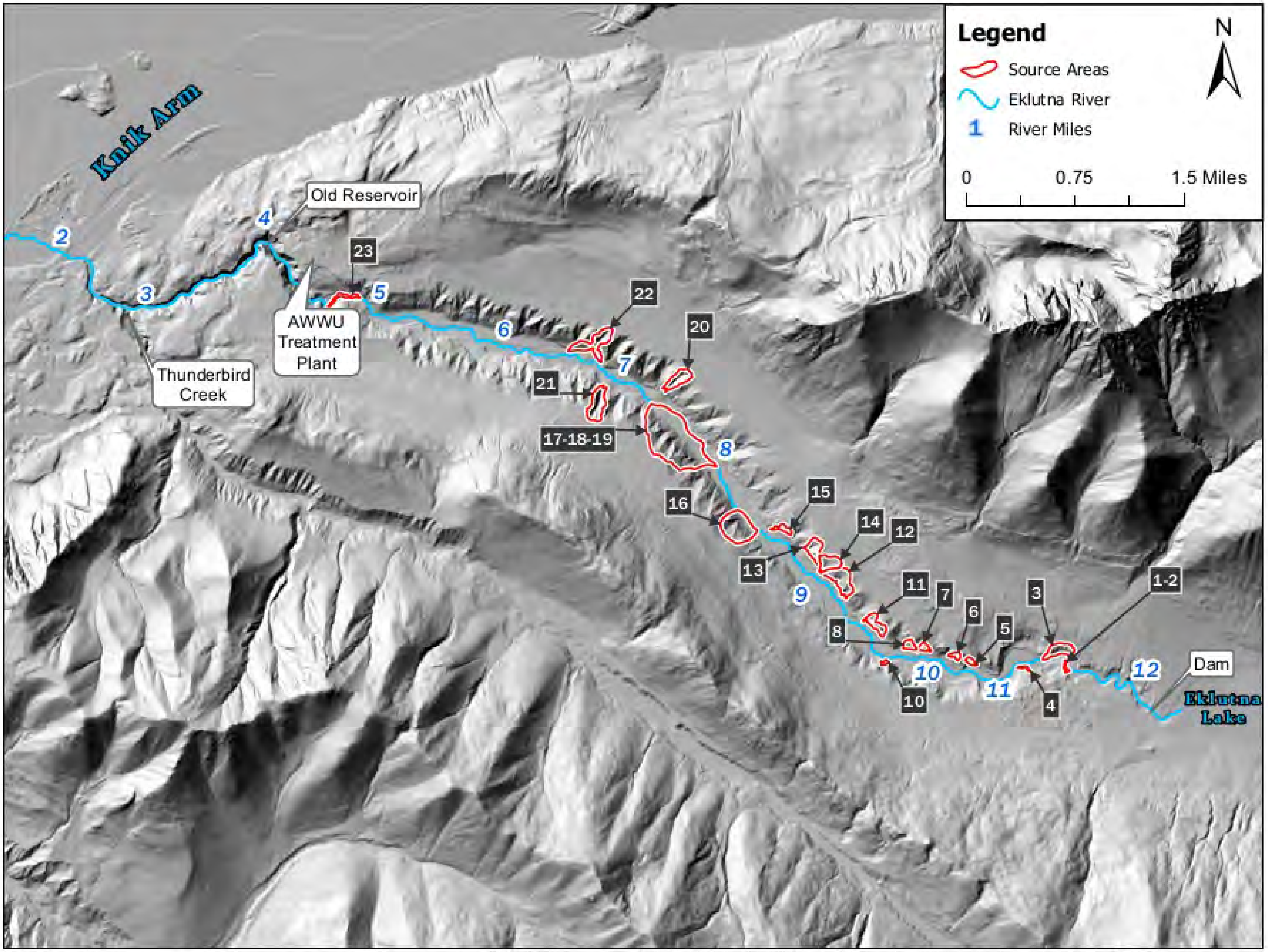


Figure 5.4-1. Eklutna River and Primary Sediment Source Areas.

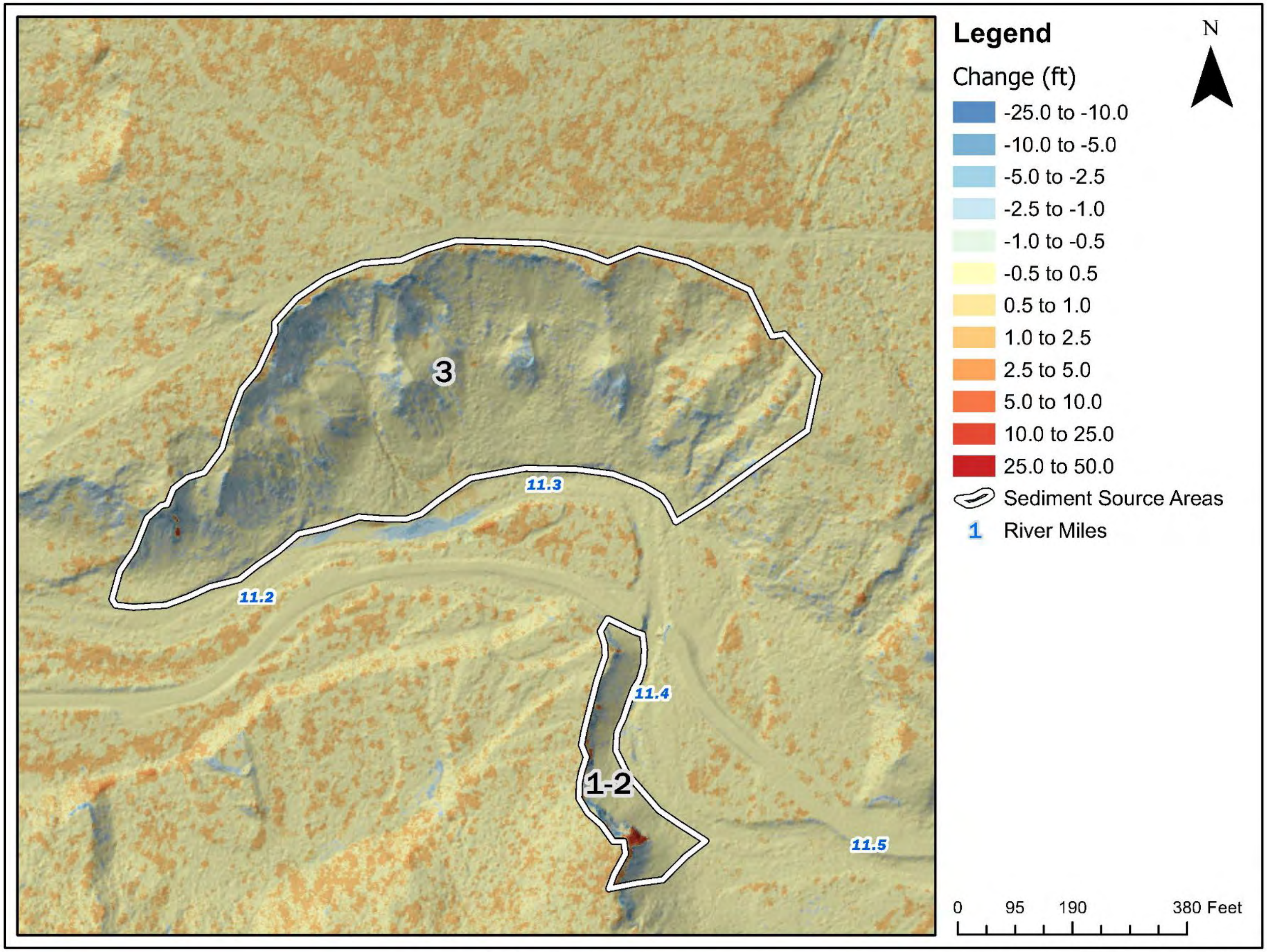


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Figure 5.4-2. Comparison of 2022 minus 2020 LiDAR Elevation for Source Area 3.

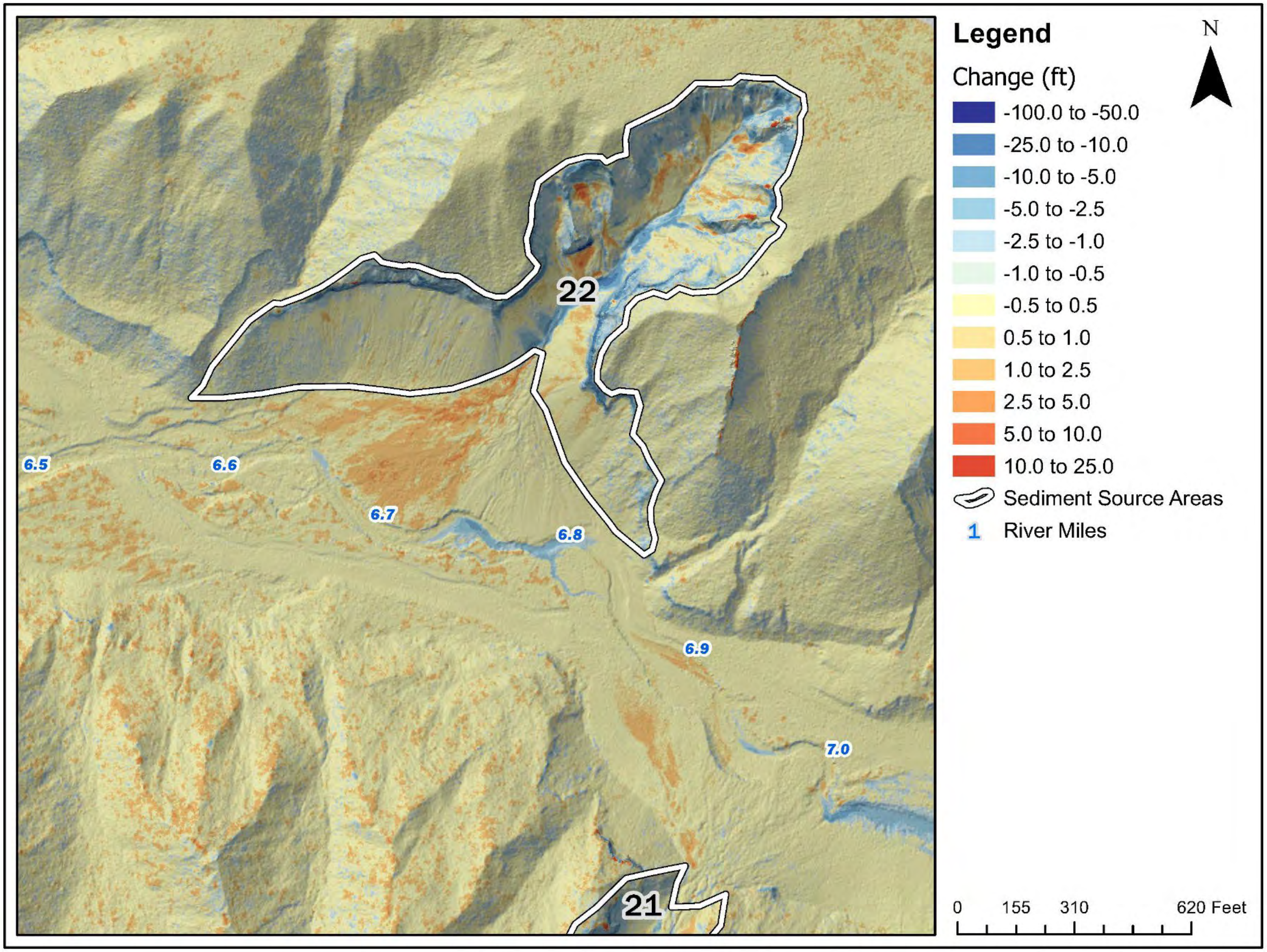

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Figure 5.4-3. Comparison of 2022 minus 2020 LiDAR Elevation for Source Area 22.

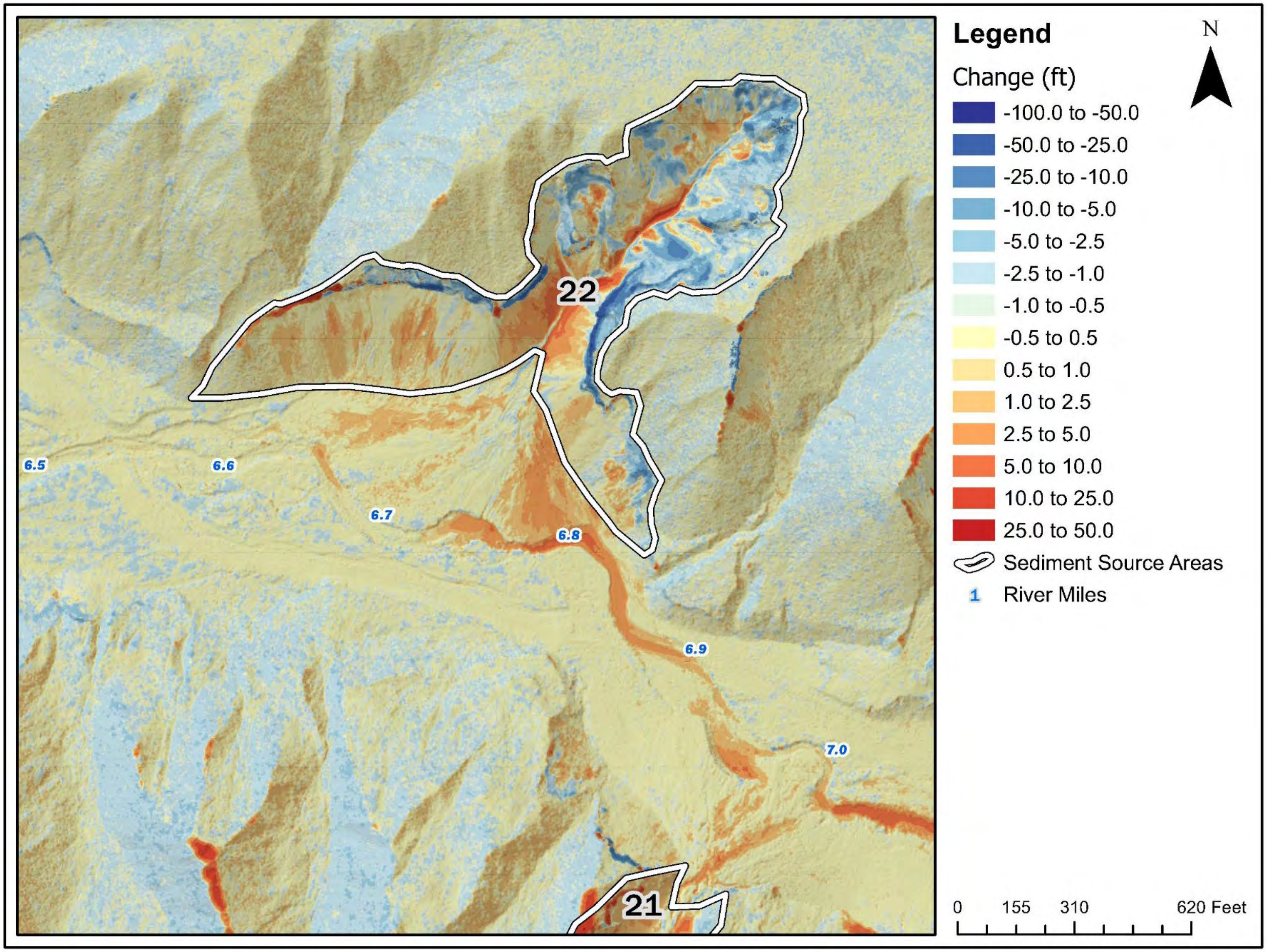

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Figure 5.4-4. Comparison of 2020 minus 2015 LiDAR Elevation for Source Area 22.

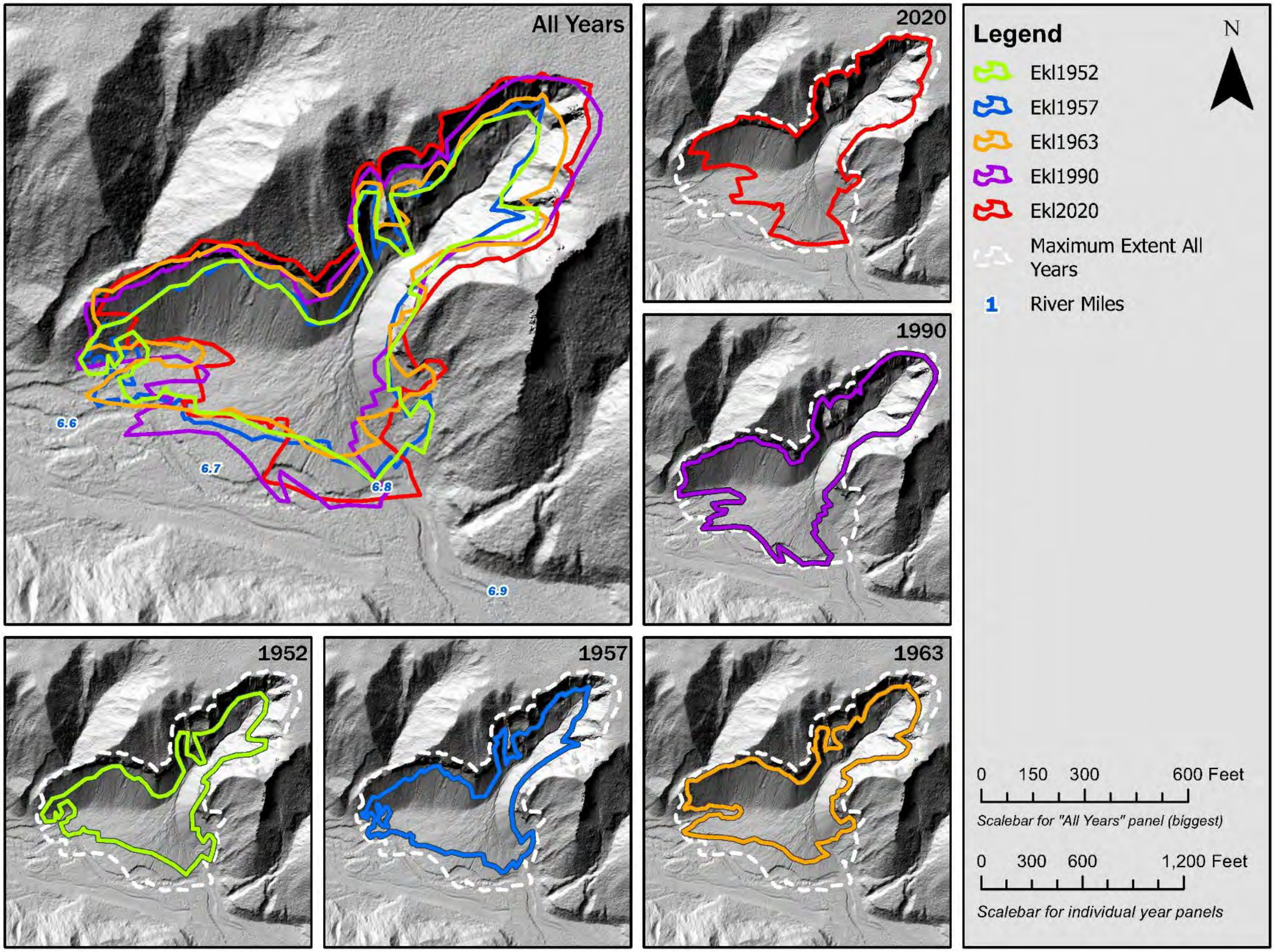

Figure 5.4-5. Growth of Source Area 22 through time.

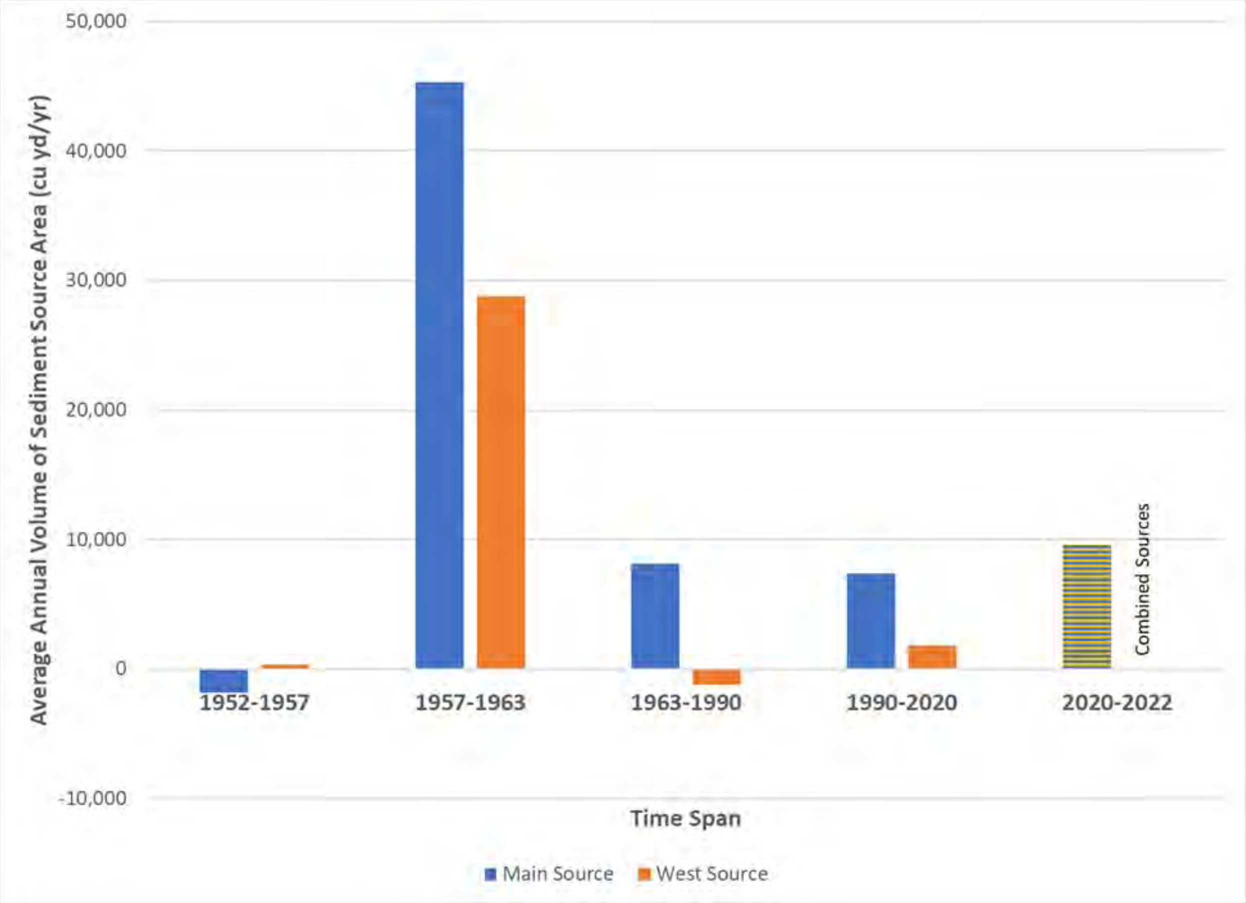

Figure 5.4-6. Average annual volume of sediment by aerial photo period for Source Area 22.

The average annual 2022-2020 volume contributed to the Eklutna River channel as well as the grain size distribution of each of the mapped sediment sources based on field observations and sediment sampling is shown in Table 5.4-1. Note that percent delivery was based on proximity of the sediment source to the Eklutna River channel. These volumes were used to estimate sediment inputs to the Eklutna River in the HEC-RAS sediment transport model.

Table 5.4-1. Estimated Average Annual Sediment Supplied to the Eklutna River Channel from Primary Sediment Source Areas[1].

Sediment Source Area	Estimated Delivery (%)	Estimated Average Annual Volume of Sediment Supplied to Eklutna River Channel (tons/yr)	Percent Cobble/Gravel	Percent Fine-grained Sediment (sand, silt, clay)[2]
1 and 2	100	25	80	20
3	100	2,600	55	45
4	100	700	80	20
5	0	0		
6	40	2,700	50	50
7	10	230	25	75
8	25	840	70	30
9	0	0		
10	100	140	80	20
11	25	1,500	70	30
12	50	3,400	55	45
13	5	450	55	45
14	50	650	55	45
15	25	630	50	50
16	25	860	50	50
17	0	0		
18	0	0		
19	0	0		
20	0	0		
21	50	4,300	50	50
22	50	6,700	50	50
23	100	4,700	50	50
Total	**--**	**30,425 tons/yr**	**16,425 tons/yr**	**14,000 tons/yr**

[1] These estimates are based on a short-term record (2022-2022) may not be completely representative of long-term sediment input.

[2] Much of the silt and clay would move as suspended or wash load through the river if baseflows are provided.

5.5. Channel Migration

Channel migration downstream from the canyon (Geomorphic Reaches 1 and 2) was evaluated using historic aerial photographs from 1949 through 2020 (**Figure 5.5-1**). In 1949 and 1952, prior to water being withdrawn from Eklutna Lake and taken out of the basin, the channel carried fine sediment and had a wide, braided character with little vegetation on mid-channel bars downstream from RM 2. These characteristics were also evident in the 1957 aerial photographs. In the 1972 photos, the river was less braided between RM 1.6 (railroad bridge) and RM 2 and was channelized downstream from RM 1.6 into a location north of the former riverbed to allow for gravel mining south of and in the former riverbed between RM 1.2-1.5. Channelization continued through the 1980’s. In the 1990 photo, the river was just starting to break through into the gravel pit (former riverbed) area and flood the former pits, but it appeared the main outlet continued through the channelized area. In 1996 (poor image quality hampered detailed analysis of 1996), the main channel was flowing into the gravel pits and out to Knik Arm through the pits. Since 1996, the river has continued to flow into the old gravel pit ponds and has abandoned the former channelized flow area. The gravel bars in the former braided section in Geomorphic Reach 2 (between RM 1.6-2) has become vegetated; the channel in this area (aka the “Flooded Forest”) was not visible on the aerial photograph after about 1996. Little migration was observed upstream from RM 1.5 after 1996, but some migration still occurs in the tidally-influenced reach downstream from RM 1.5 due to sediment deposition in this low-gradient area. This is apparent from field observations following the 2021 flow release that resulted in sediment deposition and channel changes in this area.

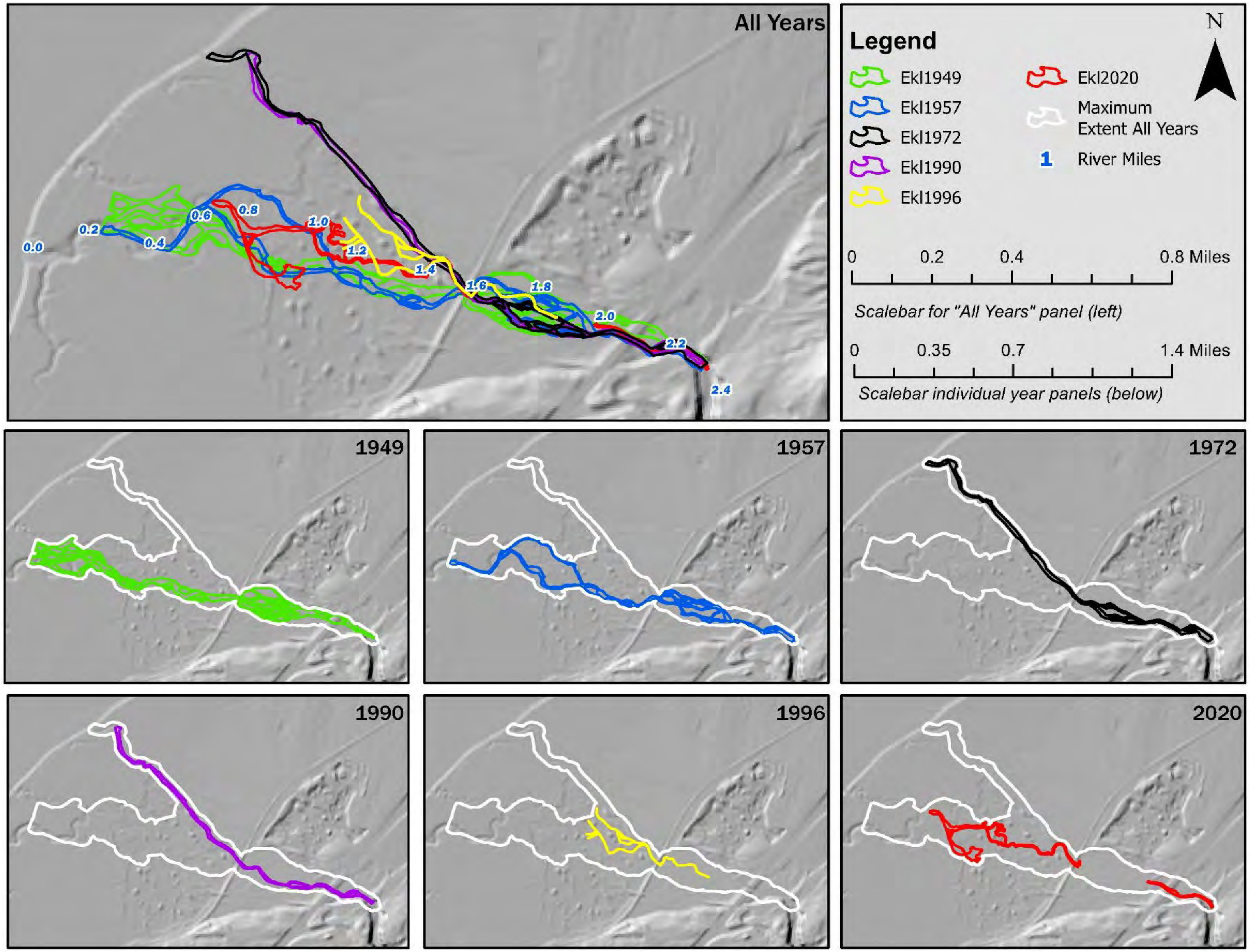

Figure 5.5-1. Eklutna River Channel Migration, Geomorphic Reaches 1 and 2.

There were limited aerial photographs of sufficient coverage and photo quality to delineate channel changes in the other unconfined sections of the Eklutna River (Geomorphic Reaches 7, 8 and 9 between RM 5 and 11.3). The channel position was mapped on the 1952 aerials and compared to the 1957 and 1963 aerials and showed evidence of braiding and recent movement between RM 5.3-6.7 (downstream from sediment source area 22) and RM 7.6 – RM 8 between 1952-1957 but little change in 1963 (except for a much smaller channel due to less water). Following 1963, vegetation growth obscured the channel position on the aerial photographs upstream from RM 5.

It is hypothesized that channel migration in the Eklutna River is triggered by high sediment loading rather than just being a response to high flows. The majority of current channel migration occurs in the tidally-influenced, low gradient areas downstream from RM 1.5 as sediment deposition causes changes in channel position. Little change has occurred upstream from RM 1.5 as vegetation has grown on gravel bars on the sides of the former larger river channel and stabilized the banks.

5.6. Lach Q'atnu Creek

Historically, Lach Q'atnu Creek flowed across an alluvial fan and into the Eklutna River near RM 12. Currently the creek is diverted into Eklutna Lake. Substrate in the streambed near the historic confluence with the Eklutna River shows the stream likely provided primarily gravel-sized material with a median diameter of 35 mm.

6 DISCUSSION

Understanding the geomorphic setting of the Eklutna River is important to understanding both the short- and long-term adjustments the river will make to a new flow regime. Results from this study will also be used during the alternatives analysis.

6.1. Geomorphic Setting

The Eklutna River downstream of Eklutna Lake includes a long, unconfined reach between the dam and the canyon (approx. RM 5-12.5), the confined bedrock canyon that includes the old dam site, the moderately confined reach downstream from the Old Glenn Highway Bridge where the river location is pinned by the New Glenn Highway Bridge and the Railroad Bridge, and an unconfined, tidally-influenced reach downstream from the Railroad Bridge[1]. The longitudinal profile of the river shows several additional features that exert large-scale grade controls and influence sediment transport in the river (Figure 6.1-1). Between the Railroad Bridge and the Old Dam Site (RM 1.5-4), the river has a concave profile, suggesting that it is in long-term equilibrium with the former sediment load downstream of the Old Dam prior to its removal. Removal of the Old Dam in 2018 has resulted in changes to the sediment load that will continue to work through the system for several decades.

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[1] Note that the HEC-RAS model, as described in the Study Plan, does not include the zone of tidal influence downstream from the Railroad Bridge due to complexities of tidal influence and saltwater interactions. This tidally-influenced zone is a low gradient deposition zone.

Between the old lower dam site and Eklutna Lake, the river has a convex upward profile, with a prominent sediment wedge in the old reservoir site (RM 4-4.5). In the upper Eklutna valley (between RM 5 and 12.5), there are several large alluvial fans that are currently providing sediment to the valley. LiDAR and aerial photograph evidence shows that the process of valley wall erosion and alluvial fan development has been occurring since the last glacial maximum (approximately 16,500 years ago) as the Eklutna River cut down through thick accumulations of outwash in the upper valley and the Elmendorf Moraine near the Thunderbird Creek confluence. The currently active alluvial fans have been providing more sediment to the valley than the current river flows (with the current Eklutna Hydroelectric Project dam in place near the outlet of Eklutna Lake) can transport and have resulted in long-term aggradation upstream of RM 7. Evidence of the recent (since 1960’s) aggradation upstream of the largest, valley-spanning alluvial fan (Source Area 22) can be seen at RM 6.7.

The stream profile based on the 2015, 2020, and 2022 LiDAR are shown on Figure 6.1-1 for comparison. The primary profile changes have occurred at the site of the Old Dam (RM 4) as material has been transported out of that area since dam removal in 2018, deposition in 2022 downstream from RM 1.5 as this material was deposited in the low-gradient, tidally-influenced zone, and changes associated with beaver dam construction upstream from Sediment Source Area 22 at RM 7. These changes are discussed in more detail in the next section.

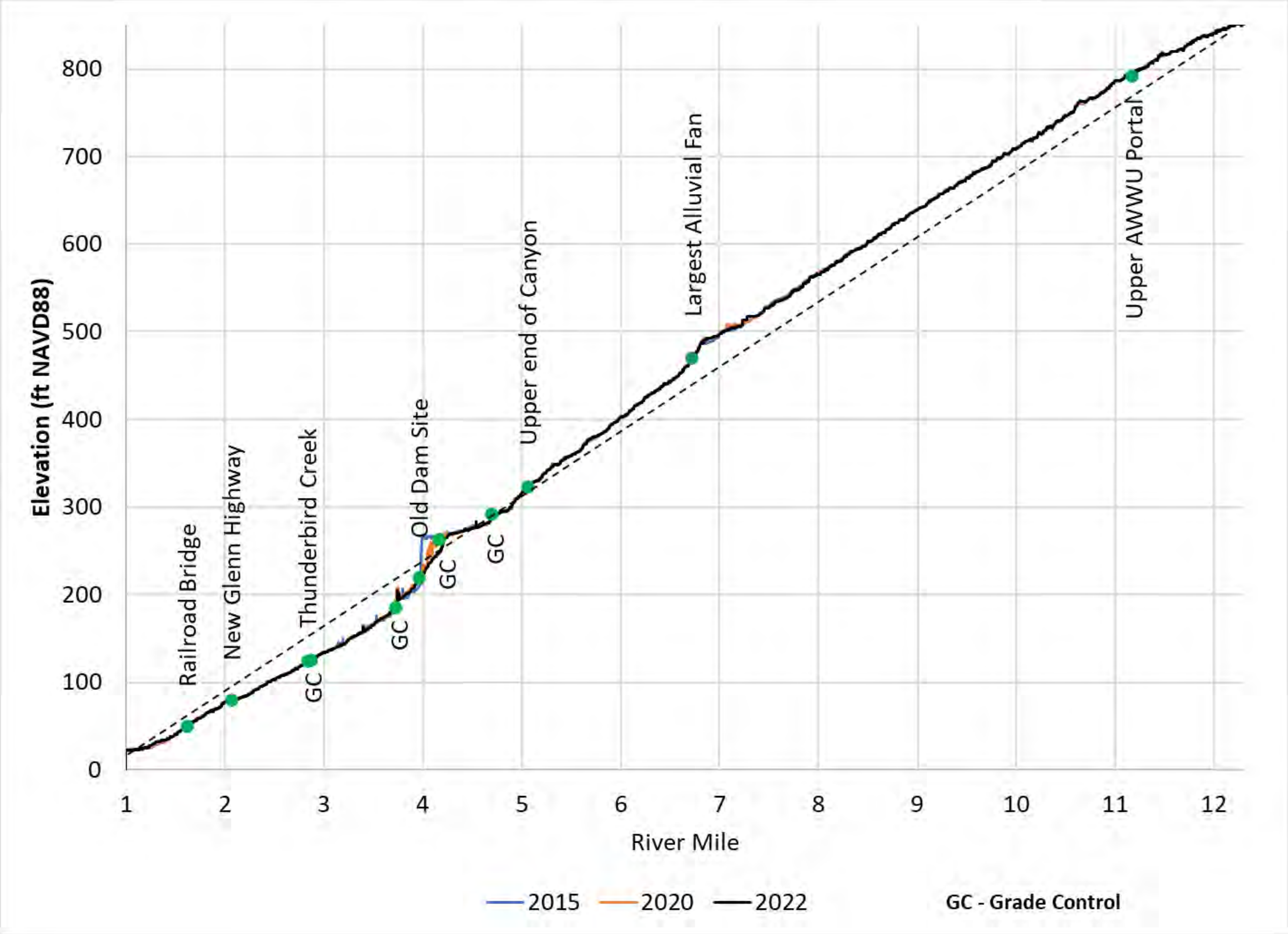

Figure 6.1-1. Longitudinal Profile of the Eklutna River (2020 LiDAR).

6.2. River Channel Changes from 2021 Flow Release

The 2021 study flow releases resulted in changes to the Eklutna River channel, including transport of fine-grained sediment out of the old reservoir at RM 4, mobilization of the fine-grained veneer upstream from Thunderbird Creek, and mobilization of the gravel substrate in many areas of the channel as described in the 2021 geomorphology and sediment transport report. Comparison of the 2015, 2020, and 2022 LiDAR showed several areas of channel change as the flows mobilized substrate.

6.2.1. Erosion of Alluvial Fan Deposits

A new stream channel was eroded through the toe of several of the alluvial fans that had been encroaching on the channel between RM 6-12. **Figure 5.4-2**, above, shows the toe of the source area 3 fan eroded between RM 11.2-11.3 and **Figure 5.4-3** shows erosion of a new channel between RM 6.7-6.8. These are the locations of two of the geomorphic monitoring transects that showed major changes (transects B and E, **Figure 5.3-53** and **Figure 5.3-41** above, respectively).

6.2.2. Old Reservoir Deposits (RM 4) and Downstream Channel

The fine-grained sediments that had accumulated in the old RM 4 reservoir were mobilized and a large volume was transported downstream prior to the 2021 study flow release (**Figure 6.2-1**) and during the 2021 study flow release (**Figure 6.2-2**). Comparison of the 2020 and 2015 LiDAR surfaces showed erosion of the reservoir deposits up to approximately RM 4.18 with deposition in the channel between the old dam site and RM 3.5 (**Figure 6.2-1**). An estimated 52,000 cubic yards of material was transported out of the old dam site between 2018 when the dam was removed and 2020.

Comparison of the 2022 and 2020 LiDAR in the old reservoir showed additional transport of material out of the old reservoir, with erosion proceeding up to RM 4.21 (**Figure 6.2-2**). An estimated 30,000 cubic yards of material was transported out of the old reservoir area between 2020-2022. Based on observations on the time lapse cameras, much of the material moved out during the first few days of the 2021 flow release as channel incision and mass wasting of the fine-grained material occurred. Surveys of cross sections prior to and following the release confirm these conclusions (**Figure 5.3-17**, **Figure 5.3-19**, **Figure 5.3-21**, and **Figure 5.3-23** above). Changes in the channel downstream from the dam showed erosion of a new channel into the previously deposited sediment between RM 3.8-3.9, little change between RM 3.7-3.8, and aggradation from RM 3-3.7. These changes are consistent with observations in the channel during field work. Sediment accumulated in the tidally-influenced mouth of the Eklutna River downstream from the Railroad Bridge between 2020 and 2022 (**Figure 6.2-3**). This is also consistent with field observations of channel changes in this area and is likely the result of deposition of the finer-grained material moved out of the old reservoir area.

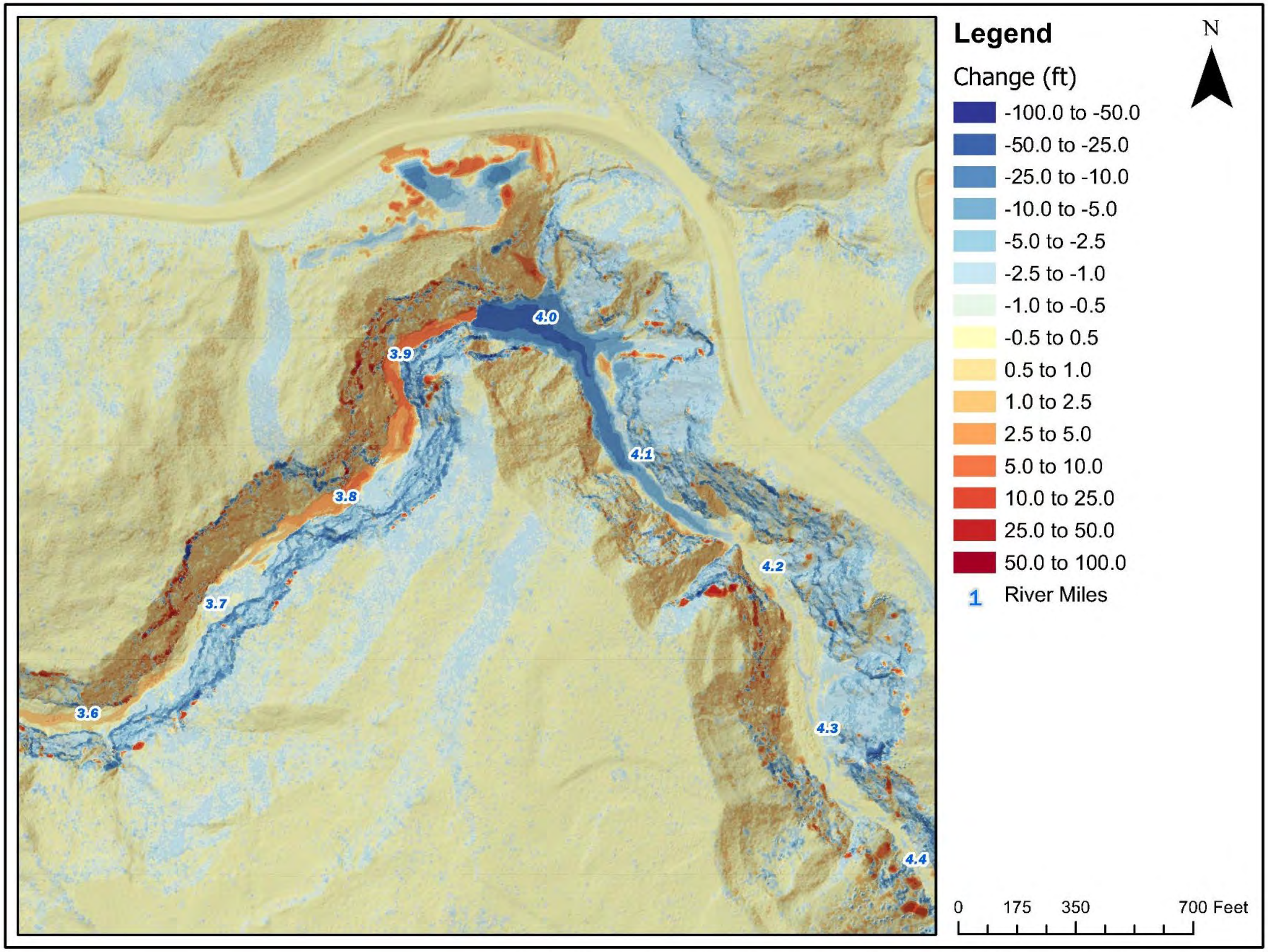

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Figure 6.2-1. Comparison of 2020 minus 2015 LiDAR surfaces near Old RM 4 Dam.

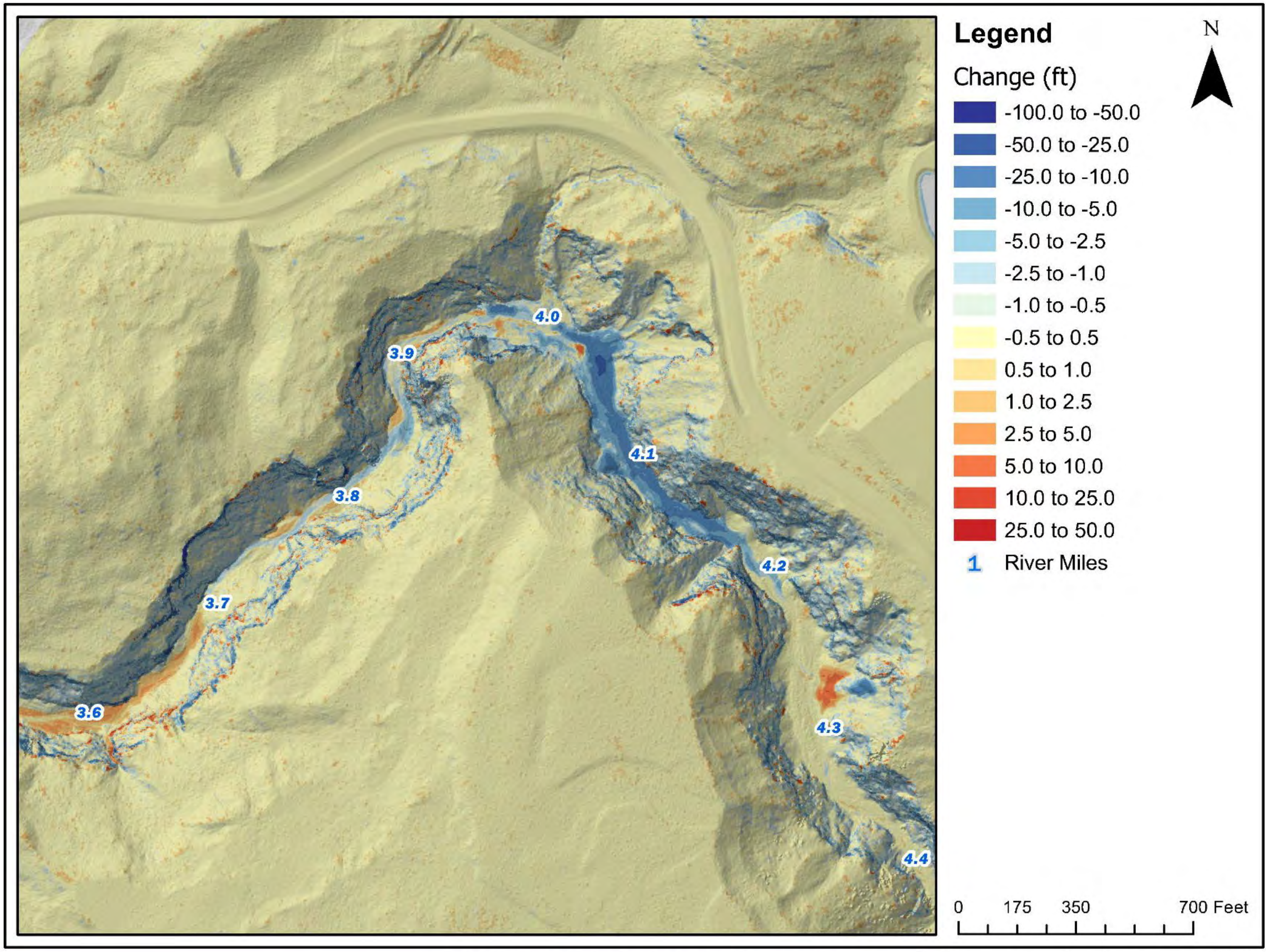

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Figure 6.2-2. Comparison of 2022 minus 2020 LiDAR surfaces near Old RM 4 Dam.

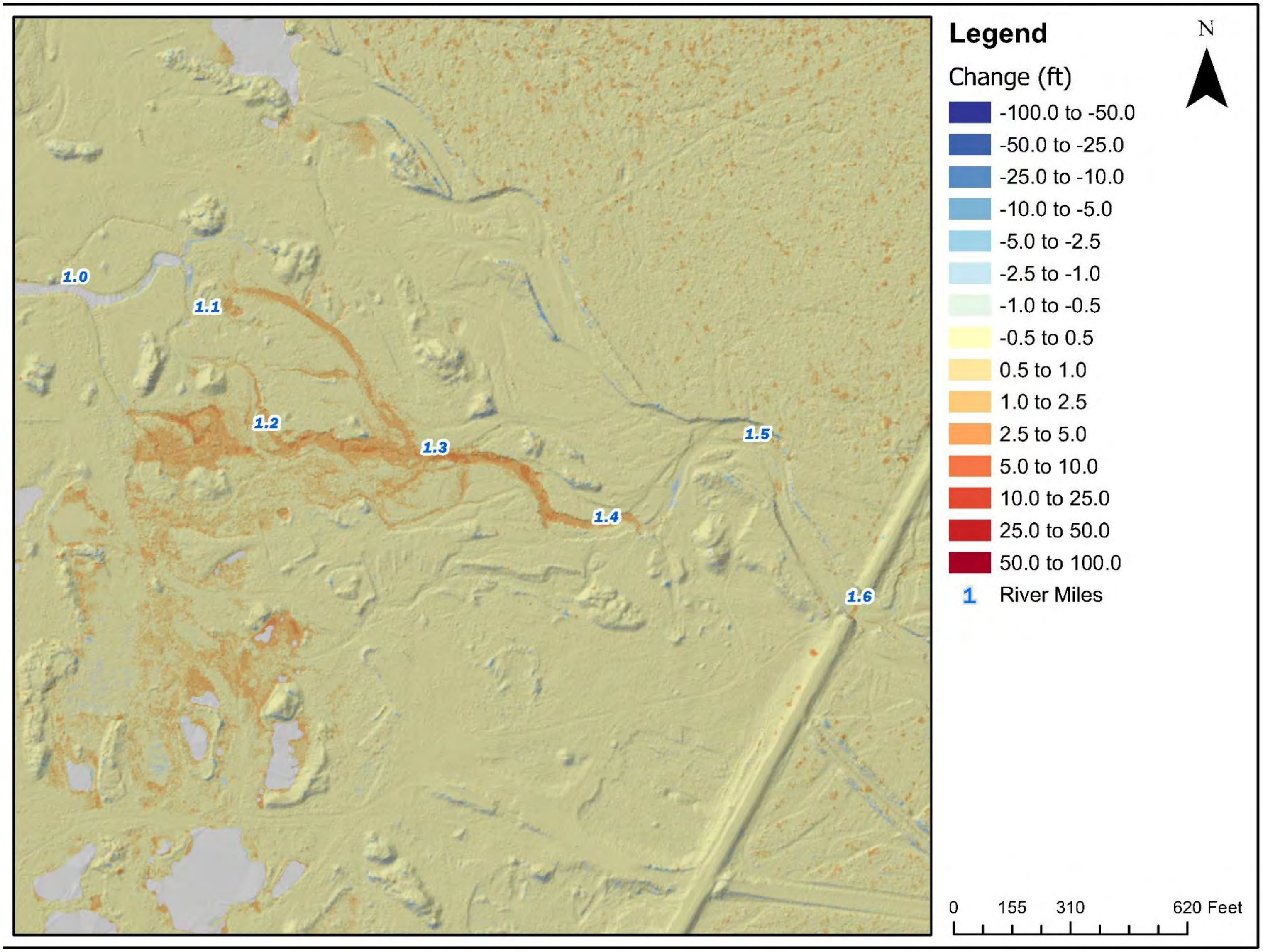

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Figure 6.2-3. Comparison of 2022 minus 2020 LiDAR surfaces at mouth of Eklutna River (tidally influenced area).

6.2.3. Summary of Changes at Sediment Monitoring Transects

There were many changes in the Eklutna River as a result of the 2021 study flow releases including erosion and deposition within the channel, transport of sediment up to 128 mm in size, and erosion of alluvial fans and sediment that was stored in the old lower reservoir (Table 6.2-1).

Table 6.2-1. Summary of 2020-2021 channel changes, accelerometer, and sliding bead scour monitor data.

Transect ID	River Mile (RM)	Geomorph Reach	Transect Changes	Sliding Beads	Accelero meter	Comments
101	1.6	2	Up to 1 foot deposition on edge of bar and 1 foot deeper channel	Not recovered, scoured out	Not recovered, scoured out	Gravel substrate
G	2.15	2	Up to 1 foot of deposition (gravel) in channel	2020 – 3 inches of erosion 10 inches of deposition during flow release	Not recovered, buried 0.6 feet in gravel	Gravel substrate; coarsening during flow release
ADFG 8 Down	2.9	4	Up to 1 foot of deposition following dam removal; up to 0.5 foot of erosion during flow release	2020 – 6 inches of erosion 4 inches of scour and fill during flow release	n/a	
ADFG 6 Down	3.3	4	Up to 0.5 foot of deposition following dam removal; up to 2 feet of deposition during flow release	6 inches of scour, 1 foot of subsequent deposition	n/a	
ADFG 2 Down	3.8	4	Up to 4 feet of deposition following dam removal; up to 1 foot of deposition in 2019 and up to 1 foot of deposition followed by 1-2 feet of erosion during flow release	Not recovered, scoured out	Exposed; movement recorded 9/14-9/29 2021	Gravel substrate
204	4.0	5	2-3 feet of deposition then 4 feet of erosion during flow release	n/a	n/a	Gravel substrate

Transect ID	River Mile (RM)	Geomorph Reach	Transect Changes	Sliding Beads	Accelero meter	Comments
203	4.05	5	Up to 30 feet of erosion of stored sediment; thalweg erosion 3 feet	n/a	n/a	Fines on banks, rubble in channel
202	4.1	5	Up to 14 feet of erosion of stored sediment; thalweg erosion 2 feet	n/a	n/a	Fines on banks, rubble in channel
201	4.15	5	Up to 14 feet of erosion of stored sediment; thalweg erosion 9 feet	n/a	n/a	Sand on banks, gravel and cobble in channel
ADFG 4 Up	4.4	5	Up to 1 foot of erosion in channel	5.5 inches of erosion followed by 2 inches of deposition	Exposed; movement recorded 9/14-9/25 2021	Gravel substrate
102	5.3	7	Little change	No change	n/a	Gravel substrate
F	5.4	7/8	Up to 0.5 foot of erosion in channel during 2020; cut and fill of up to 1 foot during flow release	9 inches of erosion in 2020	n/a	Fine sediment
103	6.3	8	Up to 1 foot of erosion in channel during flow release	Not recovered; scoured out	Buried 1 foot; movement started 9/13	Accelerometer indicates total channel scour may have been 2 feet followed by 1 foot of fill.
E	6.6	8	Up to 1 foot deposition in left bank channel; new right bank channel with 2 feet of erosion	Buried 1 foot	n/a	Toe of alluvial fan sediment source cut during flows – new right bank channel
D	7.1	9	Up to 1 foot of deposition	n/a	n/a	Beaver pond inundated transect in 2020 and 2021
105	10.5	9	Overbank deposition and up to 1.5 feet of erosion in channel	n/a	n/a	Fine sediment
C	11.15	9	Up to 05 feet of erosion	n/a	n/a	Fine sediment in channel removed exposing underlying cobble/gravel
B	11.2	9	Up to 3 feet of erosion	n/a	n/a	Toe of alluvial fan sediment source eroded during flow; fines in channel removed exposing underlying cobble/gravel

Transect ID	River Mile (RM)	Geomorph Reach	Transect Changes	Sliding Beads	Accelero meter	Comments
Painted Rocks	11.3	9/10	n/a	n/a	n/a	Painted rocks – 32 mm size moved; deposition of gravel in other areas
A	11.8	10	Minor changes	n/a	n/a	Cobble/boulder in main channel – few changes. Likely representative of old channel conditions.

6.3. Sediment Transport Modeling of Example Flow Scenarios

The following flow scenarios are just example flows so decision makers can see how the model can be used and the sensitivity of the model to different flow levels and are not intended to recommend any particular flow release scenario(s).

As an example of how the models developed for the Eklutna River can be used, several initial potential flow scenarios were run through the 1D HEC-RAS sediment transport model to help bracket the effects of potential baseflow and peak flow conditions on sediment transport in the Eklutna River (Table 6.3-1). Two types of results are discussed in the following sections:

- Grain size mobility calculated based on shear stress under a specific flow release. These results show the theoretical size of substrate that the flow release could mobilize at the different transect locations along the river. These results do not integrate sediment input, transport, and bed armoring that would take place over time under a flow scenario but do provide information on the size of particles that could be mobilized and removed from the riverbed. These results were prepared for the 1-D model output for the entire river (Section 6.3.1.1) and the 2-D model output for the four detailed analysis reaches (Section 6.3.2)
- Predicted substrate median (D_{50}) grain size on the bed of the river following a long-term flow release scenario (for example, following 20 years of flow releases) that integrates sediment input from source areas, sediment transport, and re-deposition on the riverbed. These results show the predicted substrate following a long-term flow release scenario and are available using the 1-D model (Section 6.2.1.2)

The 1-D sediment transport model can be run for short or long periods of time and can integrate long-term effects of various baseflow/peak flow combinations. Peak flows of 300 cfs and 1,000 cfs were also run using 2-D hydraulic model output at the four 2-D locations. 2-D output is a snapshot in time type of analysis showing the hydraulic conditions under a specific flow rather than a long-term model integrating various flow conditions.

Table 6.3-1. 1-D Sediment Transport Model Initial Flow Scenarios Analyzed

Condition	**Flow Release(cfs)**
Baseflows	25
	50
	75
	100
	125
Controlled Peak flow (72 hours)	300
	500
	1,000
	1,500
Uncontrolled September peak flow (500 cfs peak, approximately 30 days of spill)	500 (varies from 1 to 500 cfs over 30-day spill)
20-year baseflow/peak flow scenario as an example of a long-term scenario	Instream flow Release Option A (water release at dam), Flow Level 2 (48 cfs November through June, 30 cfs July through October)with a 500 cfs 72-hour peak flow release every 3 years

Note that additional flow scenarios can be run using other flows and various combinations of baseflows and peak flows as well as different flow release points; these results bracket the range of flows that can be reasonably modeled with existing calibration data.

Model results in the following sections are displayed to show how potential future peak flows can affect river substrate because substrate is an important component of fish habitat that can be affected by peak flows, and one of the primary habitat factors that can change in the future. Anadromous fish, depending on the species, prefer clean gravel and cobble-sized substrate for spawning and fry use interstitial spaces between cobbles for hiding. Substrate preferences for the Eklutna River used as part of the fisheries/instream flow modeling show particles between 2-128 mm are preferred by coho and sockeye; larger Chinook prefer 16- 256 mm particles (Table 6.3-2).

Table 6.3-2. Preferred Spawning-sized Substrate for Eklutna Anadromous Fish Used for Instream Flow Modeling.

Substrate Category	Grain Size (mm)	Coho and Sockeye Spawning Habitat Suitability Curve (HSC) Preference	Chinook Salmon Habitat Suitability Curve Preference
Fines	<2	0	0
Small Gravel	2-16	0.74	0
Large Gravel	16-64	1	0.41
Small Cobble	64-128	0.7	1
Large Cobble	128-256	0	0.5
Boulder	>256	0	0
Bedrock		0	0

Note: HSC preference is on a scale of 0 to 1 with 0 = not preferred; 1 = highly preferred.

As discussed in Section 5.1.1, the NVE collected information on substrate in 2019, prior to the 2021 study flow releases (Figure 5.1-1, above). These data show that spawning-sized substrate (large gravel, cobble) dominates the stream between RM 1.4 (just downstream from the Railroad Bridge) and Thunderbird Creek. This is the same area where the majority of salmonid spawning has been observed. Between Thunderbird Creek and the Old Dam Site, gravel dominates the substrate. Between the upstream end of the canyon and the largest alluvial fan, sand and boulders dominate the substrate, with a mix of boulders and accumulated silt and clay up to the AWWU portal. There are few areas dominated by gravel and cobble, which indicates that areas with preferred spawning substrate may be limited. Based on transect measurements of grain size following the 2021 study flow releases, some of the silt and clay has been transported out of the upper valley and old reservoir area, which can improve aquatic habitat conditions. If instream flows are part of the future Fish and Wildlife Program for the Project, then changes in substrate will occur as the river adjust to a new flow regime. Evaluating a flow regime that will move fines out of the river without flushing spawning-sized gravel is one goal of the sediment transport modeling.

6.3.1. 1-D Sediment Transport Model Example Scenarios

6.3.1.1. Peak Flow Release Scenarios

Peak flow releases of 72 hours (3 days) were modeled using the 1-D sediment transport model for demonstration purposes. Initially, a sample 500 cfs uncontrolled flow release (spill event) was modeled for comparison with the controlled 72-hour flow release. The 500 cfs uncontrolled release was based on releasing flow over the spillway and was computed based on average daily inflow during September with the aim of hitting 500 cfs with natural inflow and then reducing spill as fast as possible, resulting in some spill for 30 days (**Figure 6.3-1**). A realistic high flow release could mimic a natural high flow hydrograph which would include a sharp increase from base to peak flow and a gradual decrease back to base flow conditions. Various alternative release scenarios can be run as needed as well as different flow release locations.

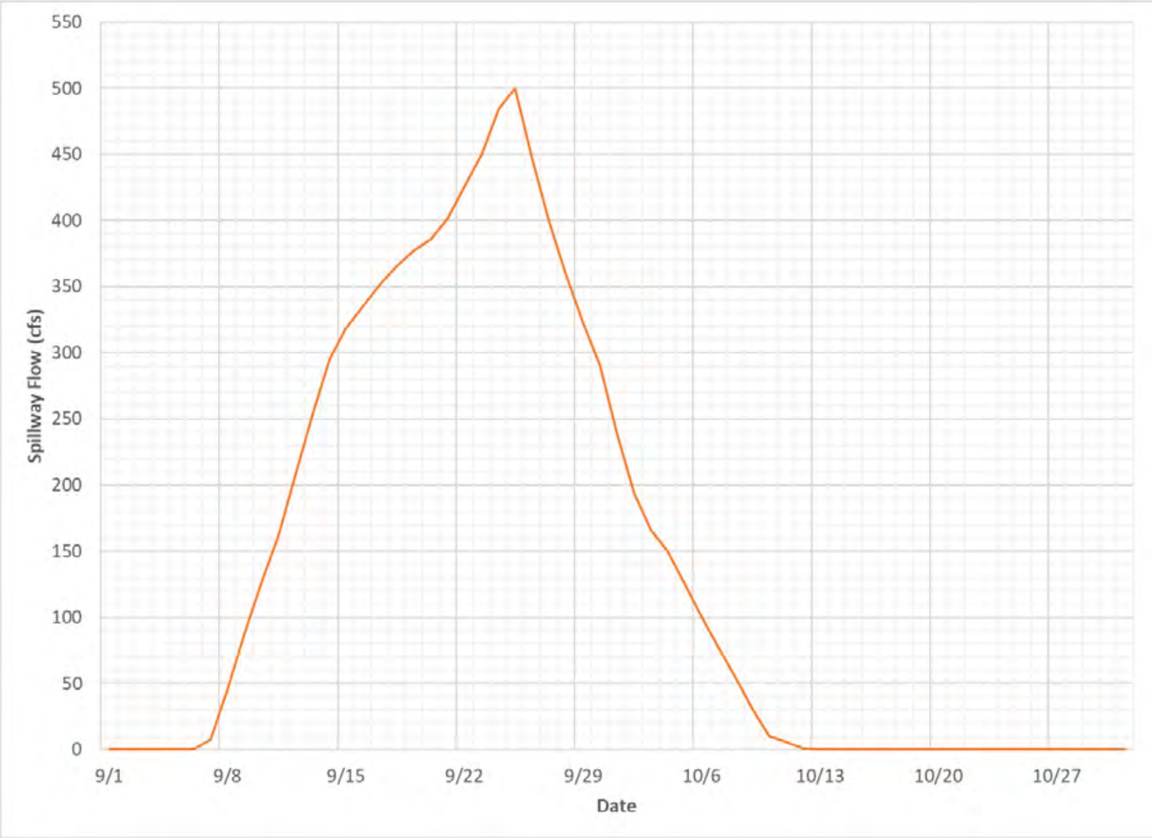

Figure 6.3-1. Calculated 500 cfs Uncontrolled (spillway) Flow Release Pattern Based on Average Daily Flow in September.

Predicted grain size mobility based on computed shear stress under different base and peak flows are shown in **Figure 6.3-2** and **Figure 6.3-3**, respectively. The range of base flows is predicted to be capable of mobilizing the smallest-sized preferred spawning substrate upstream from approximately RM 5, with larger base flows mobilizing larger particles. The 2021 study flow release of 150 cfs mobilized material up to 128 mm in diameter at most of the sediment monitoring transects, consistent with the HEC-RAS model results. Note that between the New Glenn Highway Bridge and Thunderbird Creek little cobble/gravel mobilization is predicted. This is consistent with the location where the majority of salmonid spawning occurs under current conditions and suggests that spawning-sized gravel in this area is relatively stable, allowing embryos to develop without being scoured.

Under the modeled peak flow scenarios, particularly the highest peak flow scenarios, much of the spawning-sized substrate upstream from approximately RM 5 is predicted to be capable of being mobilized and the finer-grained spawning substrate would be mobilized downstream from RM 5 (**Figure 6.3-3**). Again, the most stable spawning-sized substrate is between the New Glenn Highway Bridge and Thunderbird Creek as well as in the canyon area.

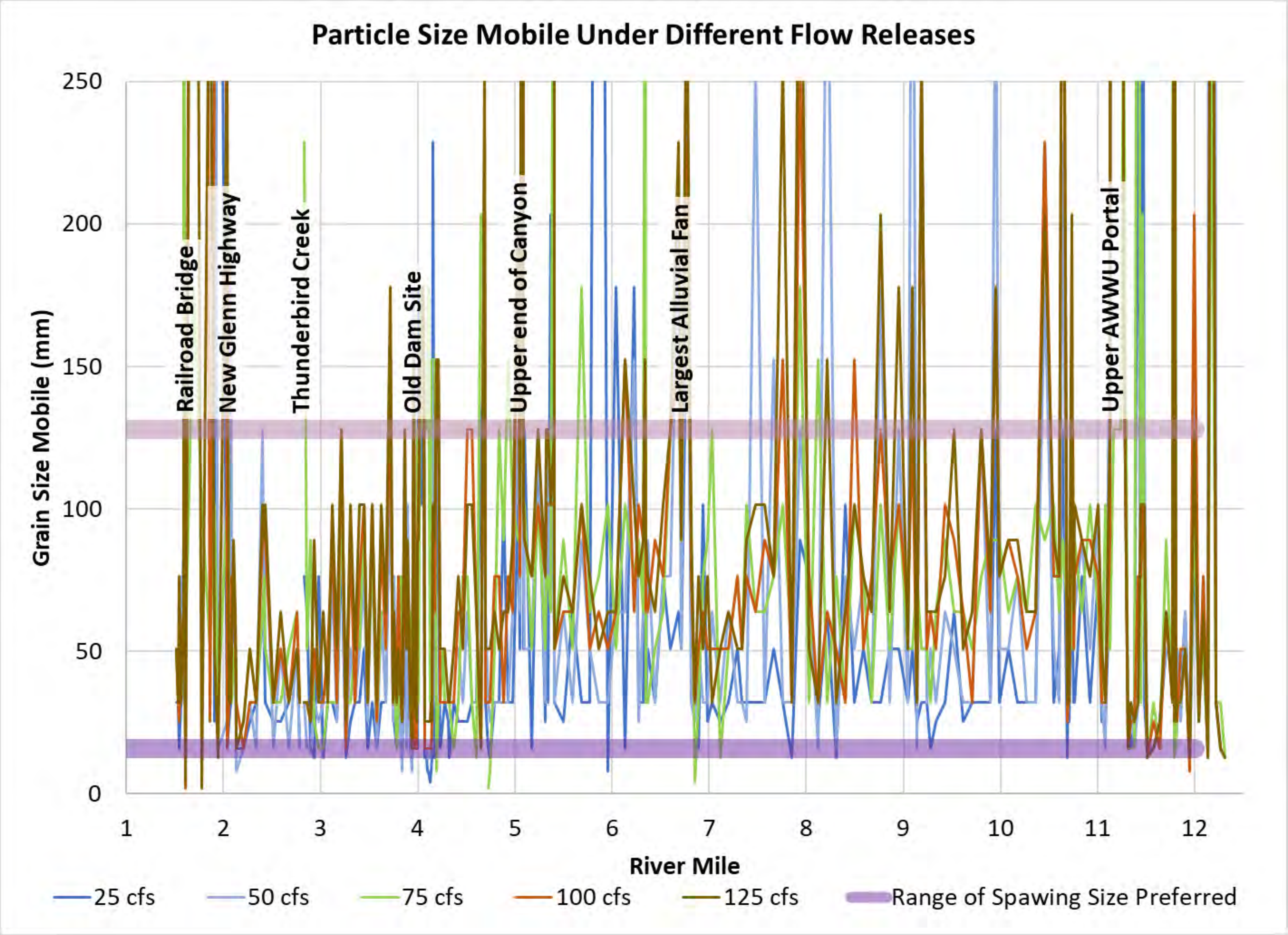

Figure 6.3-2. Eklutna River Grain Size Mobility under Base Flow Release Scenarios and Preferred Salmonid Spawning Range

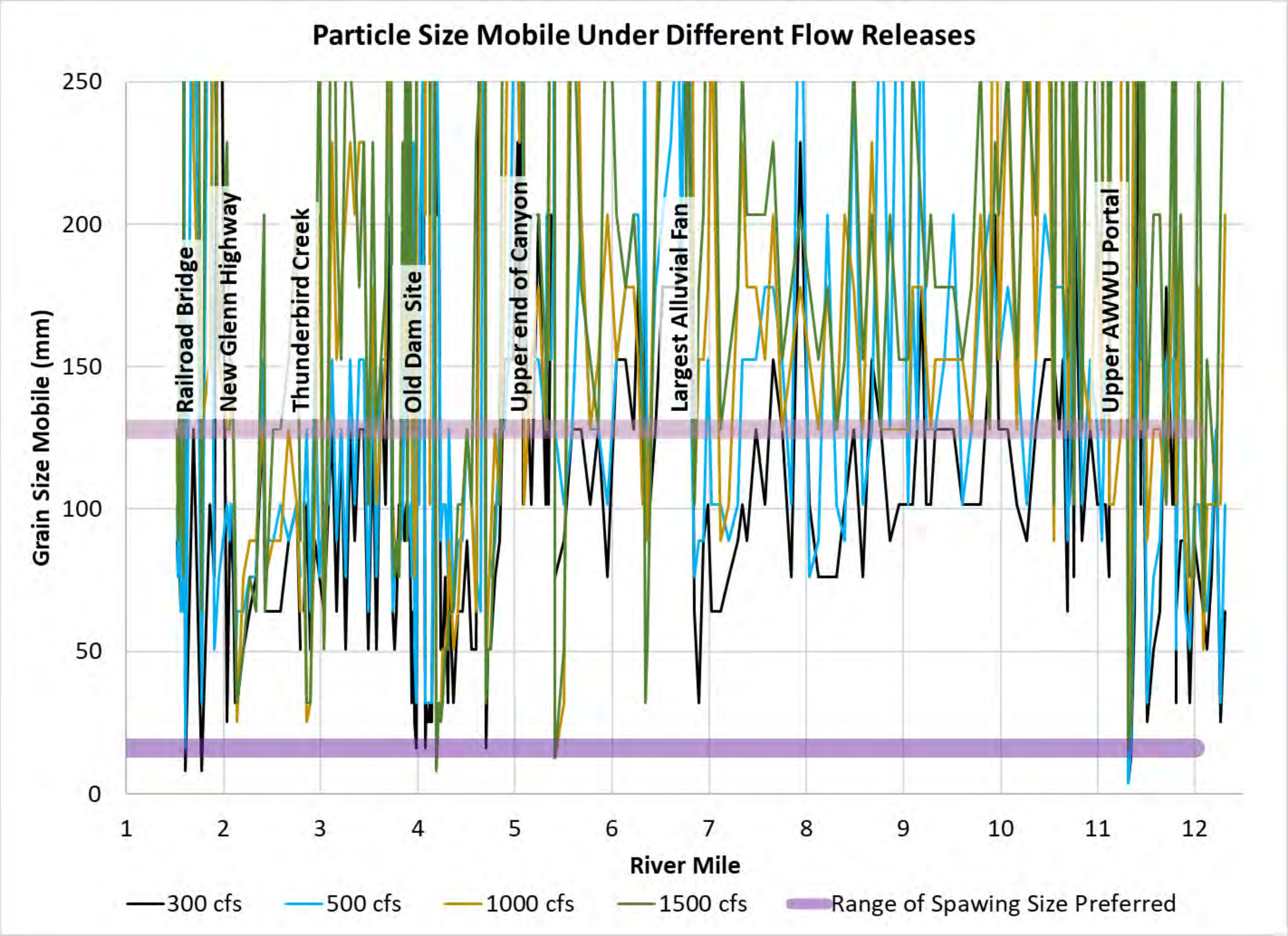

Figure 6.3-3. Eklutna River Grain Size Mobility under Peak Flow Release Scenarios and Preferred Salmonid Spawning Range

Figure 6.3-2 and **Figure 6.3-3** show the calculated grain size predicted to be capable of being mobilized under a given flow; actual transport rates depend on duration of flow as well as the mix of grain sizes on the riverbed at a particular location. To test how substrate would respond to short-duration peak flow events (72-hour release) in conjunction with the estimated sediment input from the mapped sediment sources, model runs with short-duration peak flows were run. The goal of these short-term flows would be to mobilize the substrate but not last long enough to flush it out of the river. **Figure 6.3-4** shows the predicted median (D50) grain size of the substrate following short-term peak flow releases of various magnitudes (as well as base flow scenarios for comparison). The model results suggest that peak flows of 300 to 500 cfs would achieve the objective of moving substrate but not flushing spawning-sized gravel from the system. However, larger peak flows, such as 1,000 cfs, appear to move more of the preferred spawning-sized substrate between Thunderbird Creek and the Old Dam site and upstream of approximately RM 9 suggesting that long-term flows of higher duration may flush spawning-sized sediment out of the river.

A comparison of a 500 cfs controlled 72-hour release with a 500 cfs uncontrolled flow release (see **Figure 6.3-1** for uncontrolled release flow levels) shows that more substrate is mobilized during the longer duration uncontrolled flow release, and ending grain size is large in some locations, but not all spawning-sized substrate is flushed from the river (**Figure 6.3-5**).

6.3.1.2. Long-term (20-Year) Release Scenario

One long-term (20-year) model run was made using Instream Flow Release Option A (release at the dam) with Flow Level 2 (30-48 cfs release providing 70% habitat maxima) with a 72-hour 300 cfs peak flow every 3 years as an example of how the HEC-RAS model can be used to evaluate long-term flow conditions. At the end of the 20-year run, substrate in several reaches of the river had coarsened substantially (**Figure 6.3-6**).

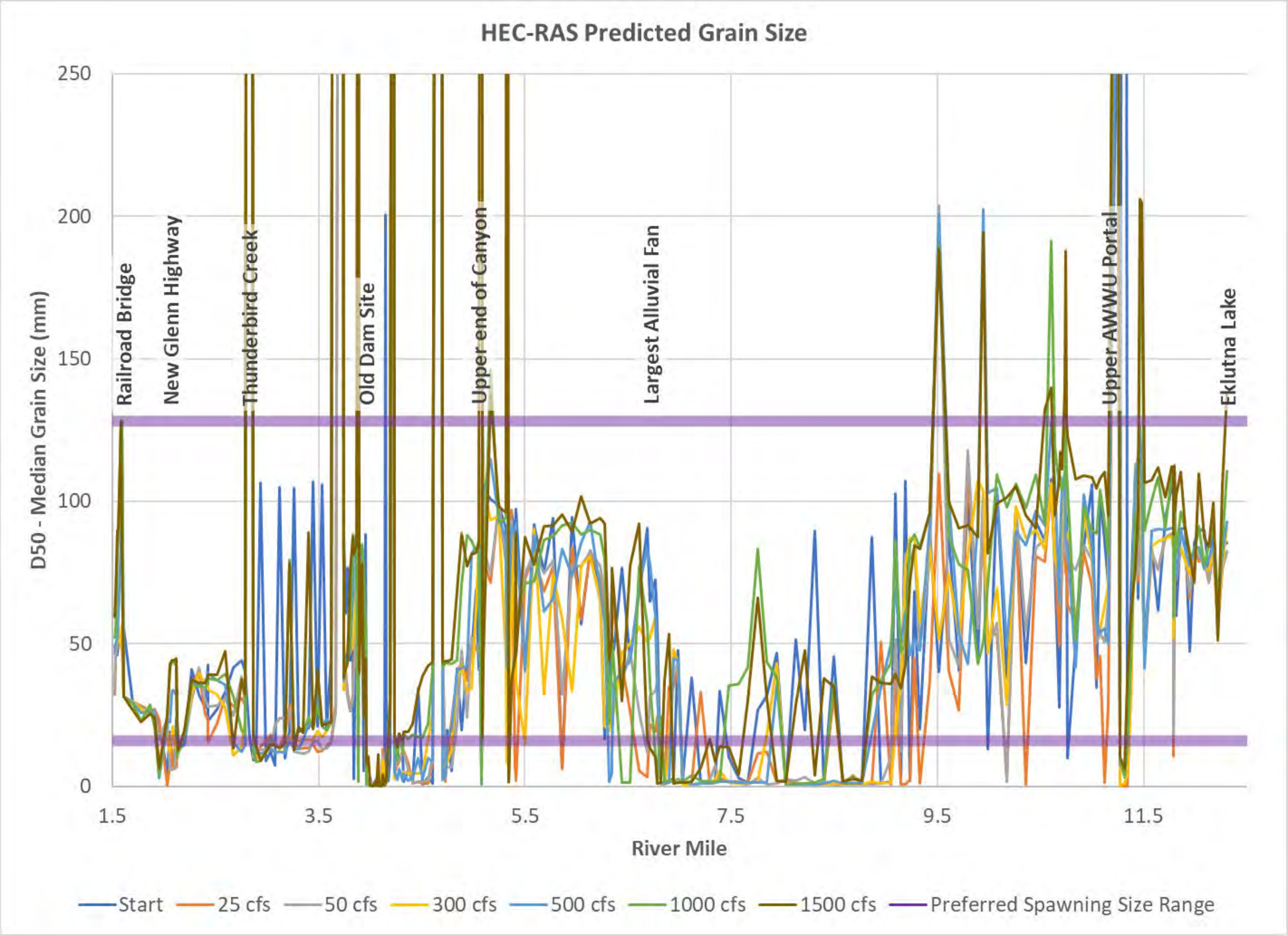

Figure 6.3-4. Eklutna River HEC-RAS Predicted Grain Size Following Different Release Scenarios (72-hour duration) and Preferred Salmonid Spawning Range

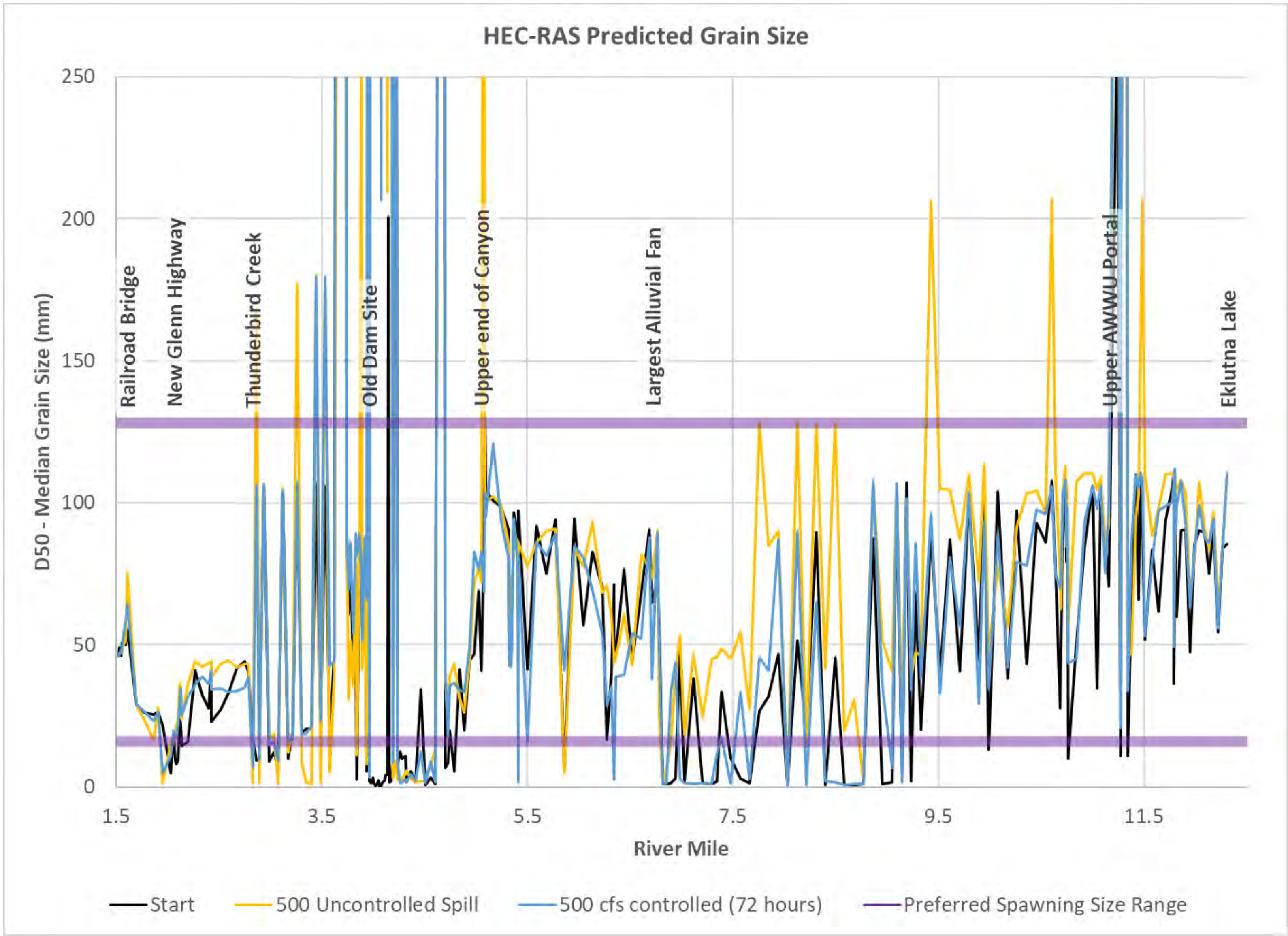

Figure 6.3-5. Eklutna River HEC-RAS Predicted Grain Size Following Controlled and Uncontrolled 500 cfs Flow and Preferred Salmonid Spawning Range

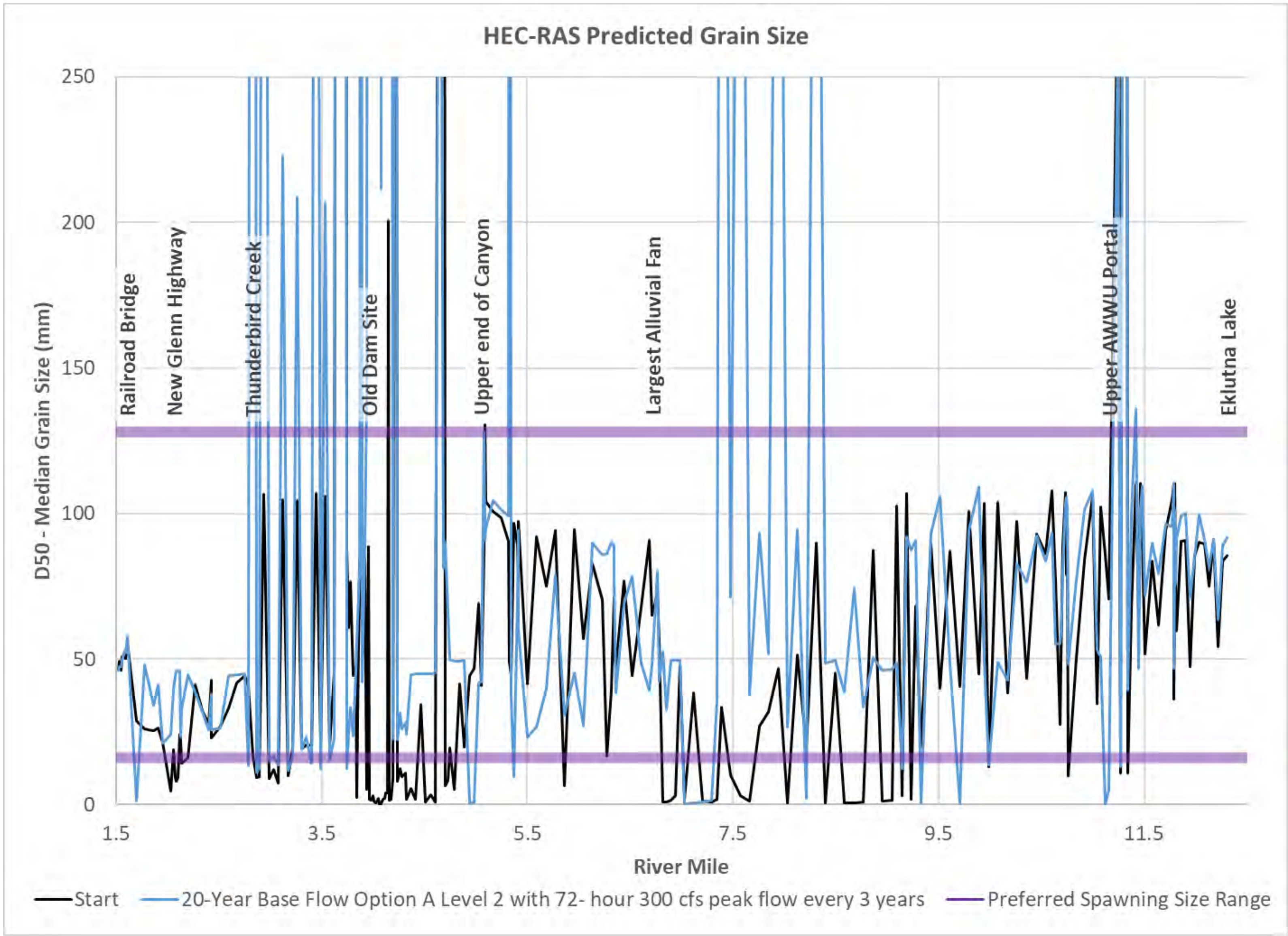

Figure 6.3-6. Eklutna River Predicted Grain Size Following 20-year Base Flow Option A, Level 2 with 72-hour 300 cfs peak every 3 Years.

6.3.2. 2-D Hydraulic Model

The 2-D hydraulic model output was used to compute grain size mobility for the four different detailed analysis areas for bounding high flow values of 300 and 1,000 cfs.

Analysis area 3 is in the tidally-influenced, low-gradient area downstream from RM 1.5. This area is primarily a deposition zone as shown in the modeling, with only the finest grain size classes predicted to be mobilized in all but the upstream-most part of the main channel even under the 1,000 cfs flow conditions (**Figure 6.3-7**).

Analysis area 4 is between the Railroad Bridge and the New Glenn Highway Bridge, often referred to as the “flooded forest.” Flow in this area follows multiple flow paths, with a primary channel down the center of the area and a secondary channel to the south (**Figure 6.3-8**). In the main channel, material in the gravel-cobble size is predicted to be mobilized under a 300 cfs flow and gravel-boulder (in some spots) under a 1,000 cfs flow. Gravel is predicted to be mobilized in the secondary channel under both flow scenarios and fine material in most overbank areas.

Analysis area 6 is at RM 3, in the confined canyon just upstream from the Thunderbird Creek confluence. In this area, flow of 300 cfs is predicted to mobilize 64-512 mm material in the center of the channel and flow of 1,000 cfs is predicted to mobilize 256-512+ mm material (**Figure 6.3-9**).

Analysis area 10 is located near RM 8 in the upper, less-confined Geomorphic Reach 9. This area showed evidence of braiding/multiple channels in the 1952 aerial photographs and shows a multiple channel pattern in the 2-D model results for 300 cfs and 1,000 cfs flows (**Figure 6.3-10**). In the main part of the channel, the model predicts that grain sizes of 16-128 mm would be mobilized under 300 cfs flow release, and 64-512 mm would be mobilized under a 1,000 cfs release.

Based on hydraulic modeling, higher peak flows are predicted to mobilize cobble and larger material in the main channel areas; this is consistent with the observed underlying substrate in main channel areas, representative of substrate in the former riverbed prior to out of basin water withdrawal from Eklutna Lake. Any future flow release scenarios should consider the low-flow channel location and preferred substrate size in relation to peak flow release levels.

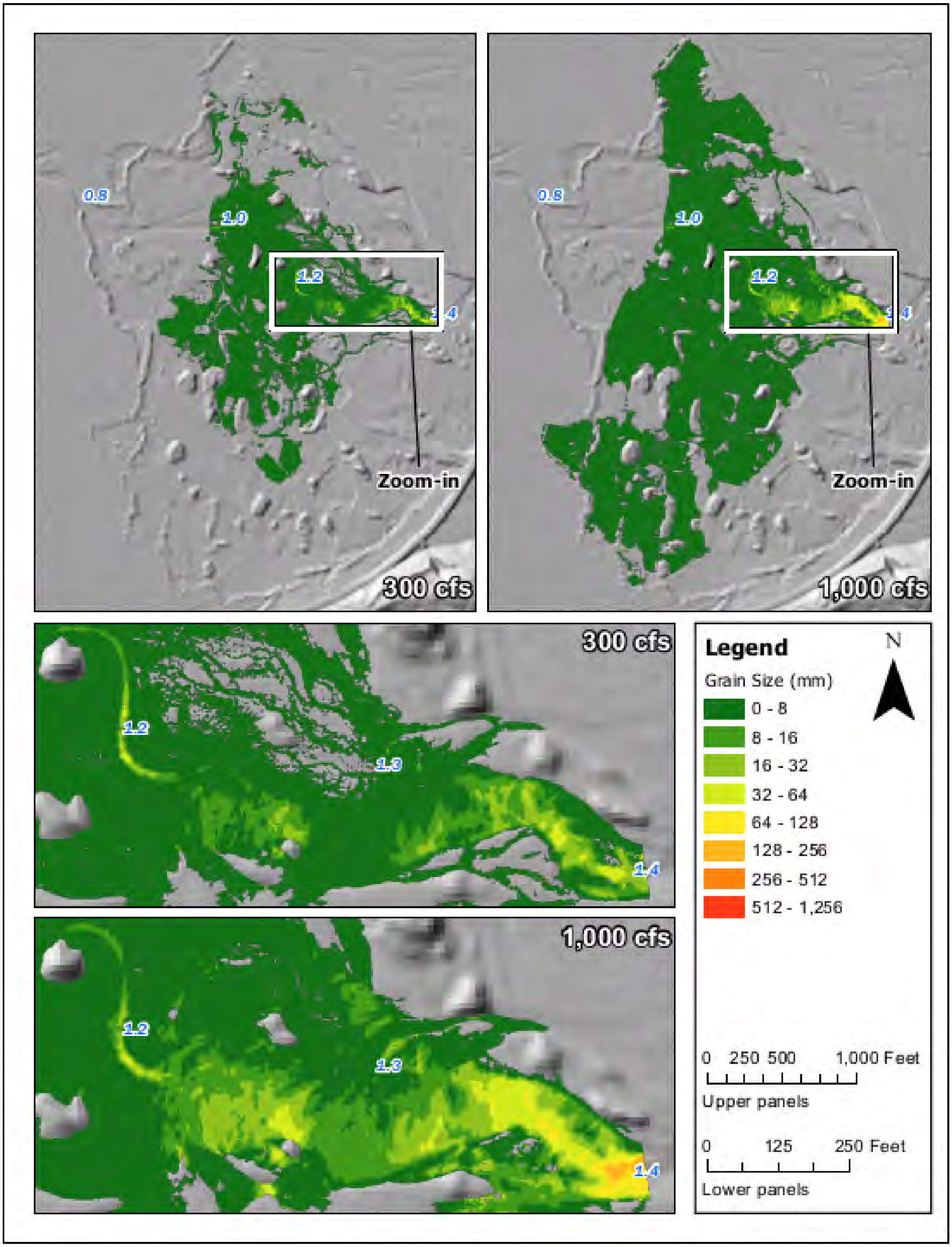

Figure 6.3-7. Eklutna River Grain Size Mobility Results from the 2-D Hydraulic Model, Analysis Areas 3 for flow of 300 cfs and 1,000 cfs.

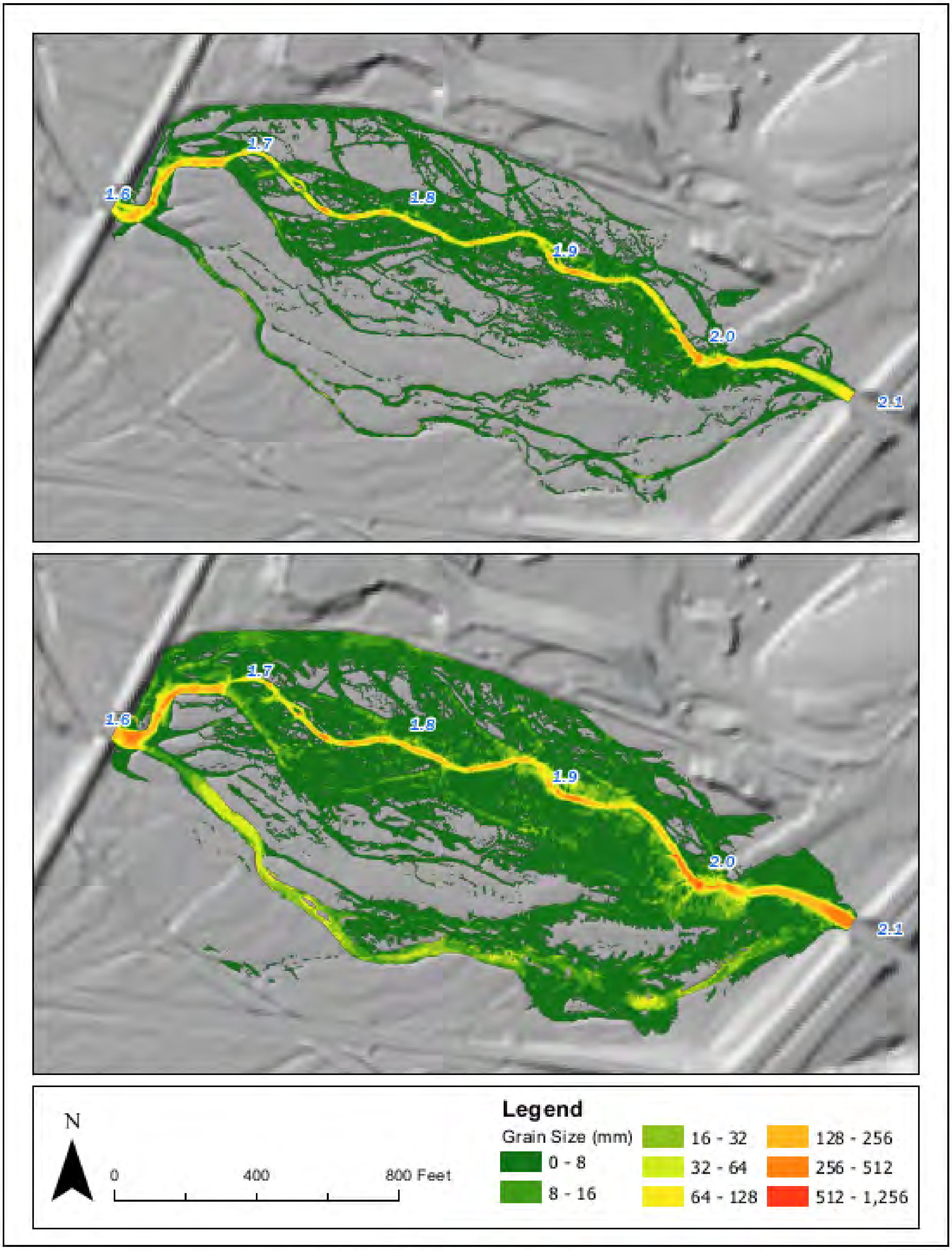

Figure 6.3-8. Eklutna River Grain Size Mobility Results from the 2-D Hydraulic Model, Analysis Areas 4 for flow of 300 cfs (top) and 1,000 cfs (bottom).

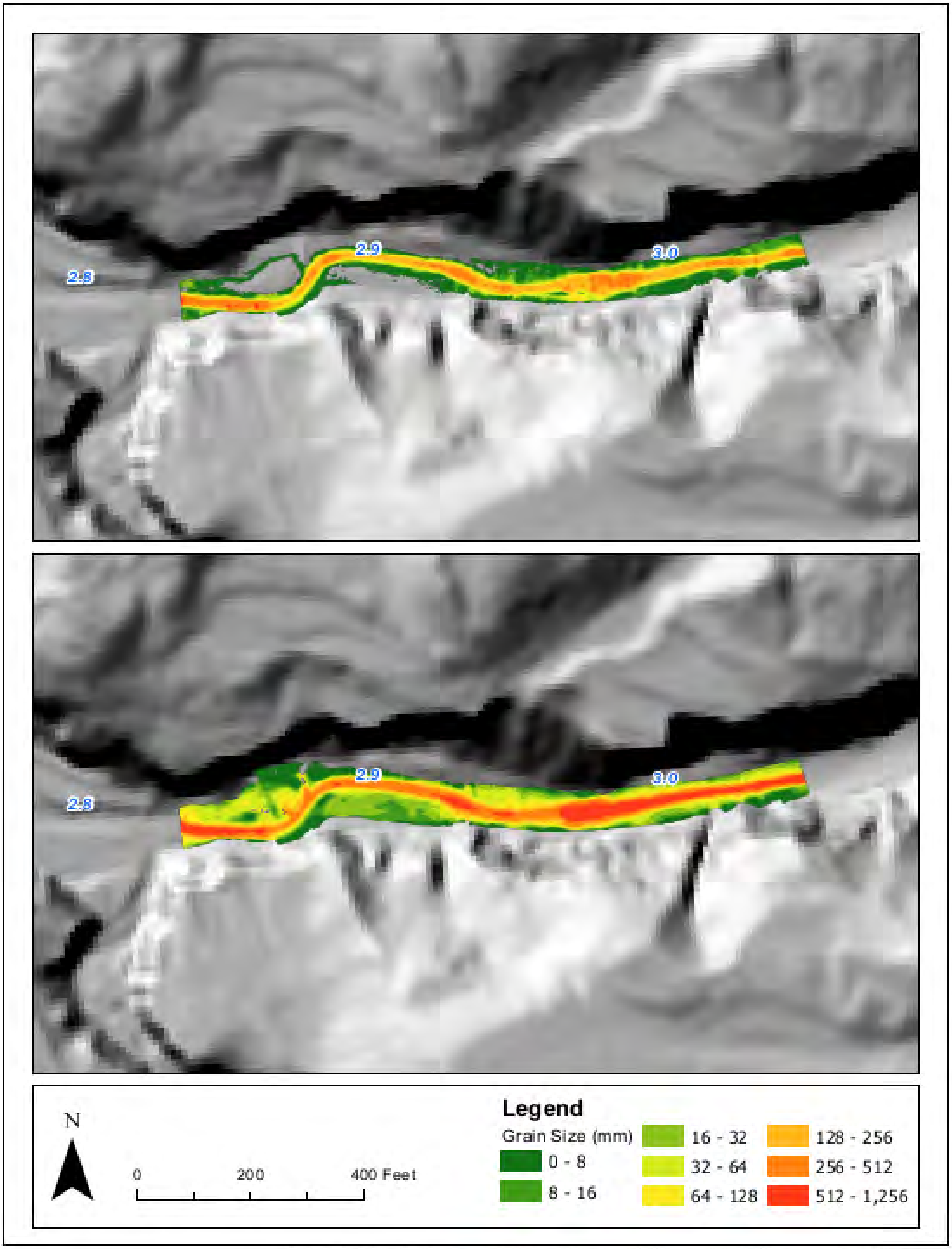

Figure 6.3-9. Eklutna River Grain Size Mobility Results from the 2-D Hydraulic Model, Analysis Area 6 for flow of 300 cfs (top) and 1,000 cfs (bottom).

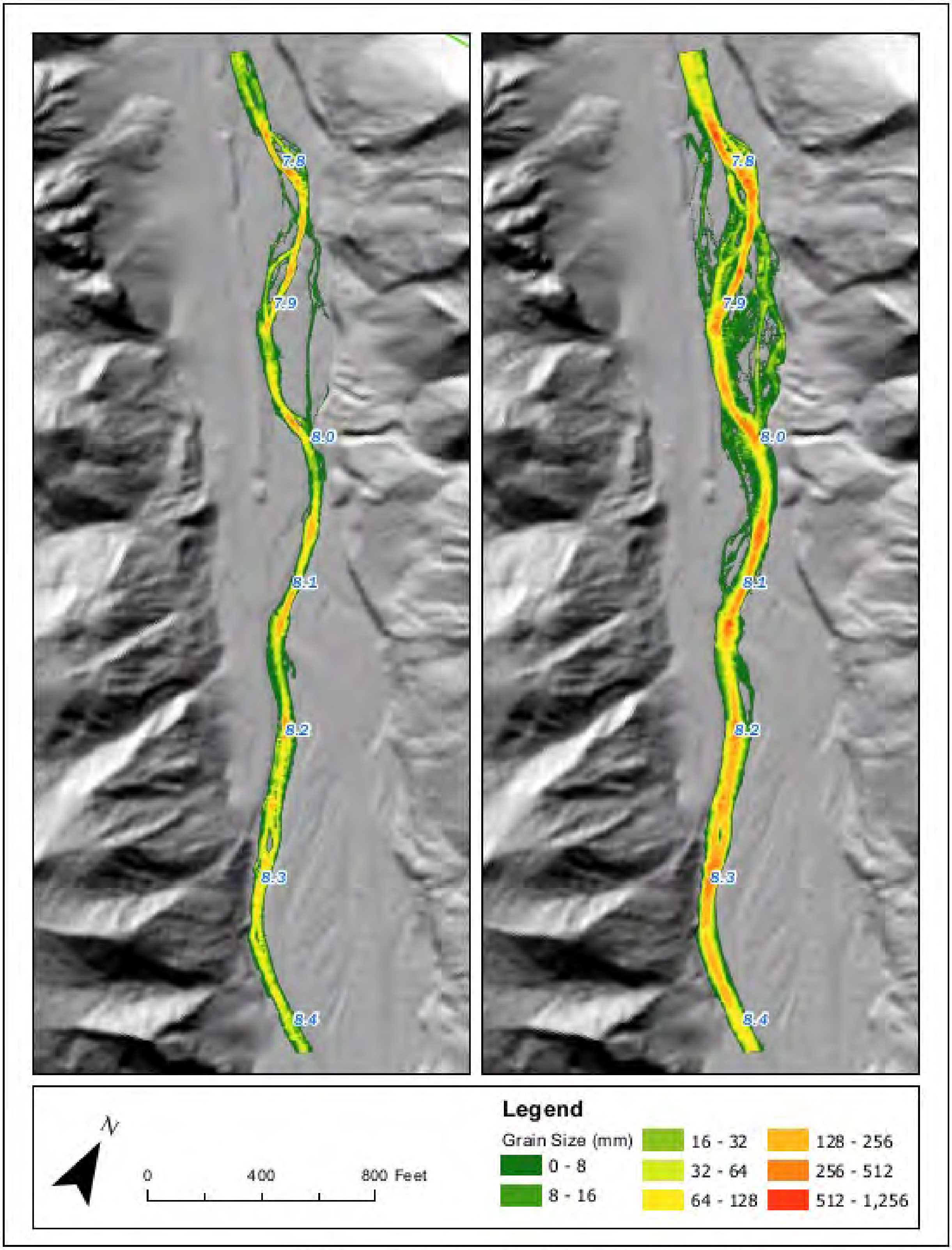

Figure 6.3-10. Eklutna River Grain Size Mobility Results from the 2-D Hydraulic Model, Analysis Area10 for flow of 300 cfs (left) and 1,000 cfs (right).

7 VARIANCES FROM FINAL STUDY PLAN

One variance from the methodology outlined in the study plan took place in the geomorphology/sediment transport study:

1) Three timelapse cameras were installed in the old lower reservoir area to gather data on changes to stored sediments during the study flow releases (Section 4.2.4).

In accordance with the provisions of the Geomorphology and Sediment Transport Study Plan, a high calibration flow was not implemented because data collected during the 2021 study flow releases was sufficient to calibrate the HEC-RAS sediment transport model and evaluate sediment transport effects of potential higher flows (Section 4.6).

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