Final Technical Memorandum

To: Samantha Owen, McMillen Jacobs

From: Kathy Dubé

Date: November 28, 2022

Re: Eklutna River Geomorphology/Sediment Transport Considerations for Flow Augmentation

1. Introduction and Purpose

This Technical Memorandum is intended to provide initial results of the 2022 components of the Eklutna River geomorphology and sediment transport study with respect to data collection, analysis, and modeling. This information is intended to be used as part of the evaluation of effects of potential flow releases into the Eklutna River. The information contained in the 2021 geomorphology and sediment transport report is not repeated here but provides important field data and analyses which, combined with 2022 data and analysis, were used as a basis for this technical memorandum. Tasks completed in 2022 included additional field work and data analysis to analyze sediment source areas, grade controls, and substrate, comparison of 2020 and 2022 LiDAR topographic surfaces, and development of a one-dimensional (1D) HEC-RAS sediment transport model. A more detailed report including methods and detailed results will be provided as part of 2022 study reporting.

One of the goals of the Eklutna River geomorphology and sediment transport analysis 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. There are four different levels of higher flows of interest that will move accumulated sediment and provide geomorphic channel change and maintenance in the Eklutna River that were investigated to help inform future flow releases:

1) flow that moves the surficial veneer of fine sediment;
2) flow that moves substantial amounts of the sediment wedge from behind the old lower dam site;
3) flow that disrupts the armor layer, transports gravel/cobble material, and moves interstitial fine sediment; and
4) flows that result in channel migration and floodplain inundation.

The geomorphic sediment transport analysis will help determine these different levels of flow and how they interact with the base fish/aquatic habitat flow releases. The 2021 flow release demonstrated that releases of 150 cfs for 11 days moved at least some of the surficial veneer of fine sediment and moved a substantial amount of the sediment wedge from the old dam site (flow levels 1 and 2 above). A 1-D HEC-RAS model was developed to help estimate flows that disrupt the armor layer and move interstitial fine sediment (flow level 3). Channel migration will be analyzed based on historic aerial photograph analysis and floodplain inundation will be analyzed using a 2-D HEC-RAS model being developed by Kleinschmidt (flow level 4); these will be reported in the Year 2 study report. Of particular concern in the Eklutna River is balancing sediment input and sediment transport in the river. If peak flows levels and durations are too high/long compared to input of sediment (particularly spawning-sized sediment), some components of aquatic habitat may decrease in value in some reaches of the river. Conversely, if peak flows are too low or short compared to sediment inputs (as under current conditions), deposition of excessive amounts of fines could occur.

2. Geomorphic Setting and Sediment Source Areas

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.

2.1 Geomorphic Setting

The Eklutna River downstream of Eklutna Lake includes a long, unconfined reach between the dam and the canyon (approx. River Mile (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 2-1). 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.

Between the Old Dam 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.

[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.

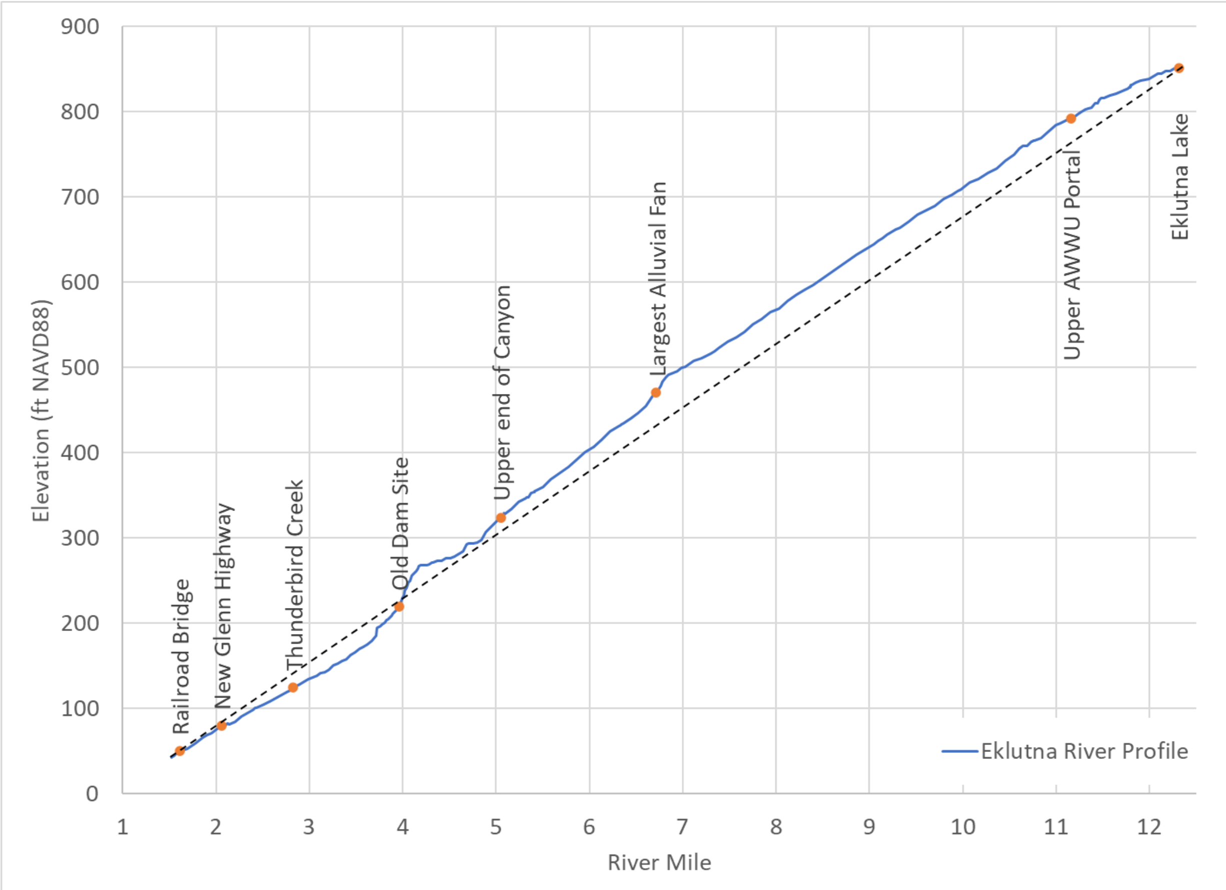

Figure 2-1. Longitudinal Profile of the Eklutna River (2020 LiDAR).

2.2 Sediment Source Areas

The current major sediment sources to the Eklutna River are shown in Figure 2-2 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 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 2-2 and 2-3). 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 2-year interval between the 2022-2020 LiDAR flights does not provide a long-term estimate of sediment input. However, comparison with previous LiDAR data sets (e.g., the 2015 Municipality of Anchorage LiDAR flight) was problematic due to the differences in resolution

(0.5 meter cell size in 2020/2022 vs. 3 meter cell size in 2015 – see Figure 2-4). The 2020-2015 LiDAR comparison volumes, while problematic, were lower than the 2022-2020 volumes, suggesting the 2022-2020 results may overestimate long-term sediment input rates.

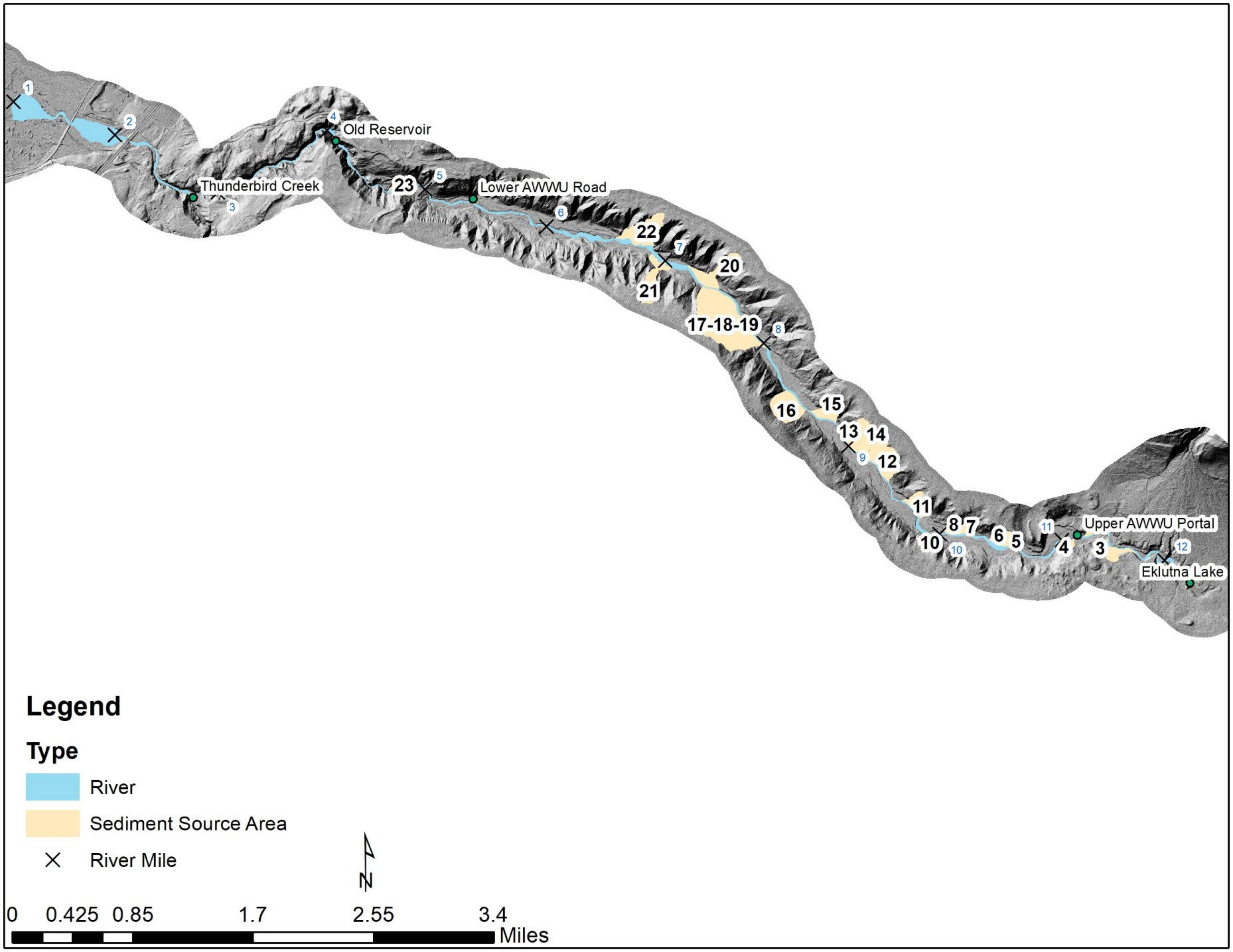

Figure 2-2. Eklutna River and Primary Sediment Source Areas.

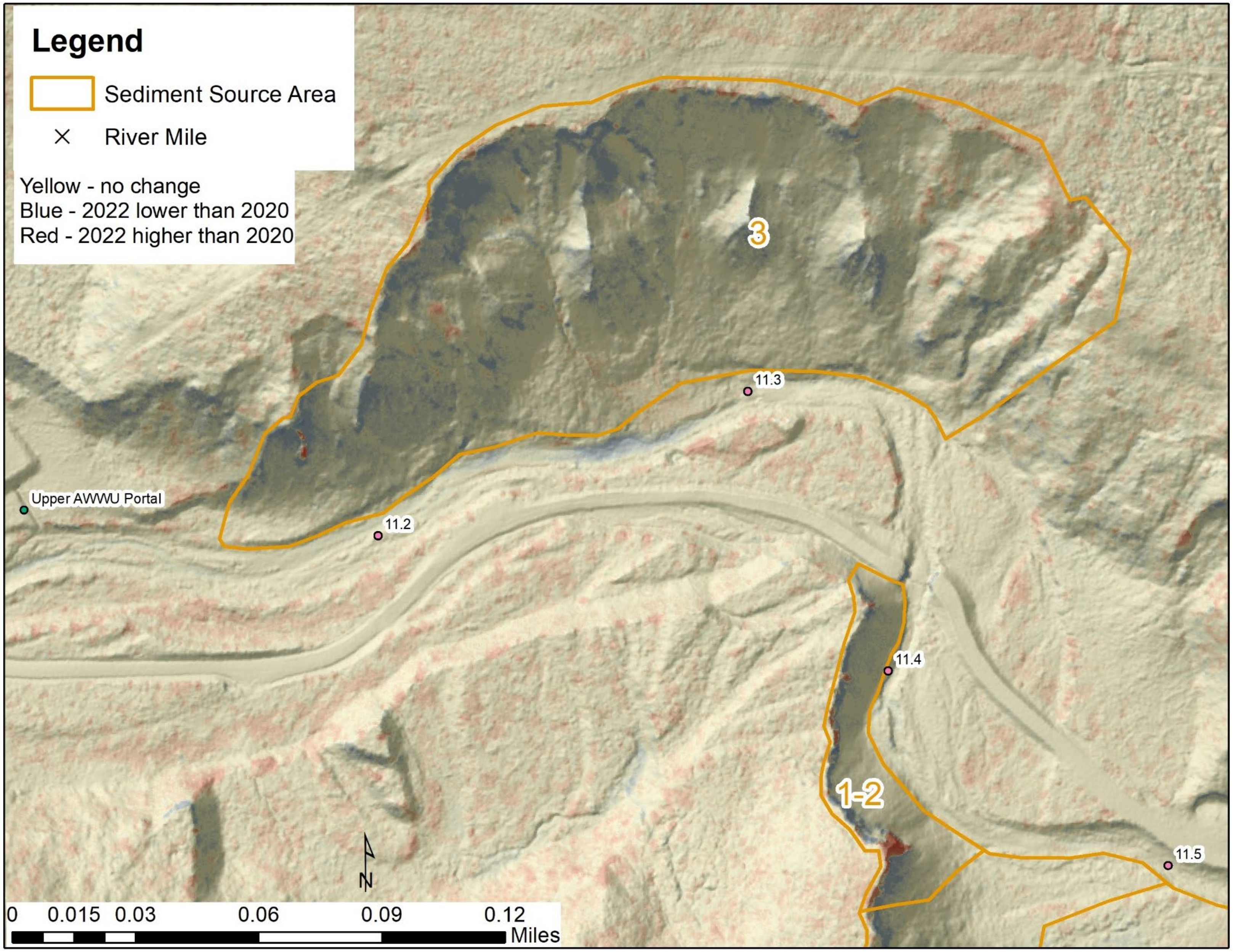

Figure 2-3. Comparison of 2022 minus 2020 LiDAR Elevation for Source Area 3.

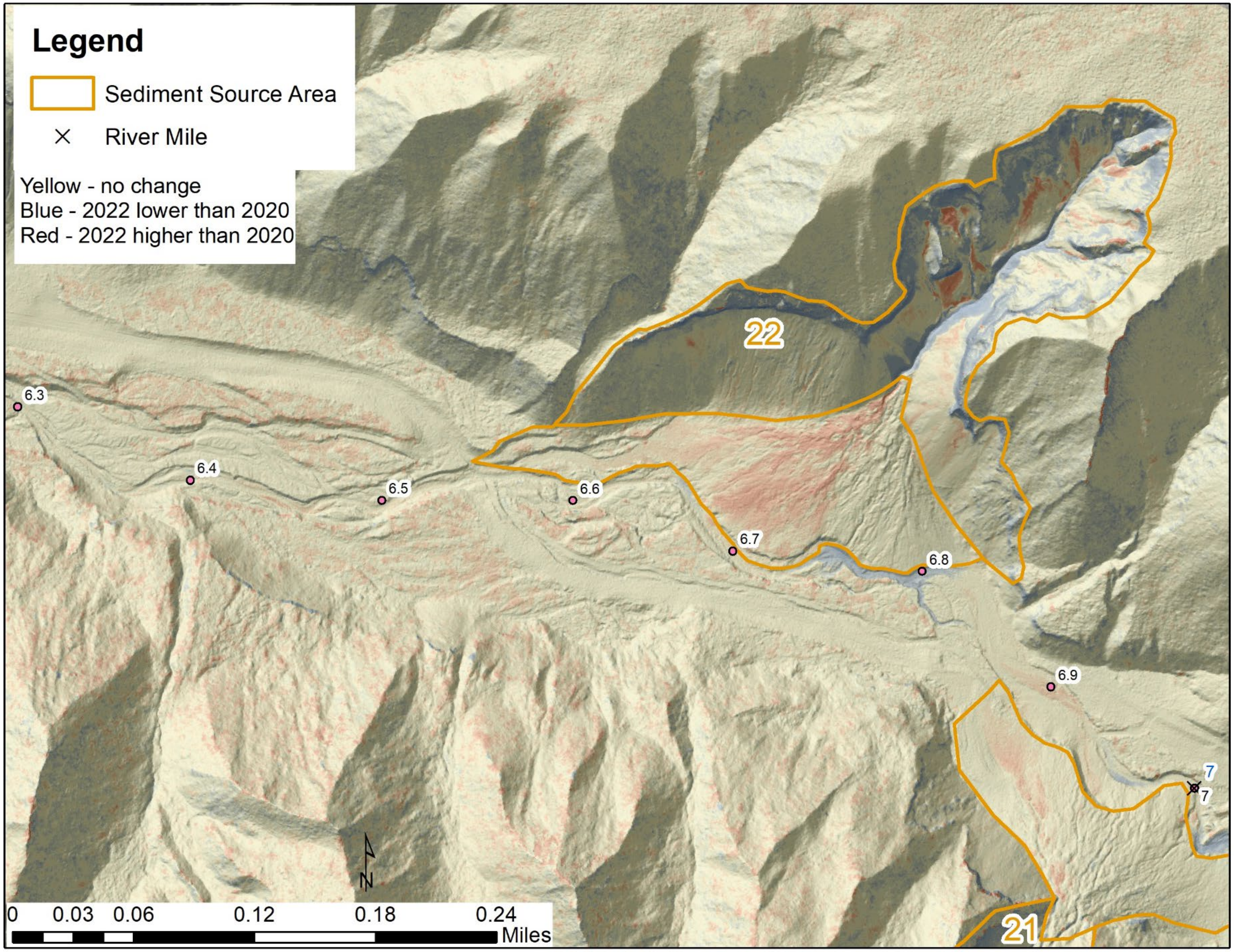

Figure 2-4. Comparison of 2022 minus 2020 LiDAR Elevation for Source Area 22.

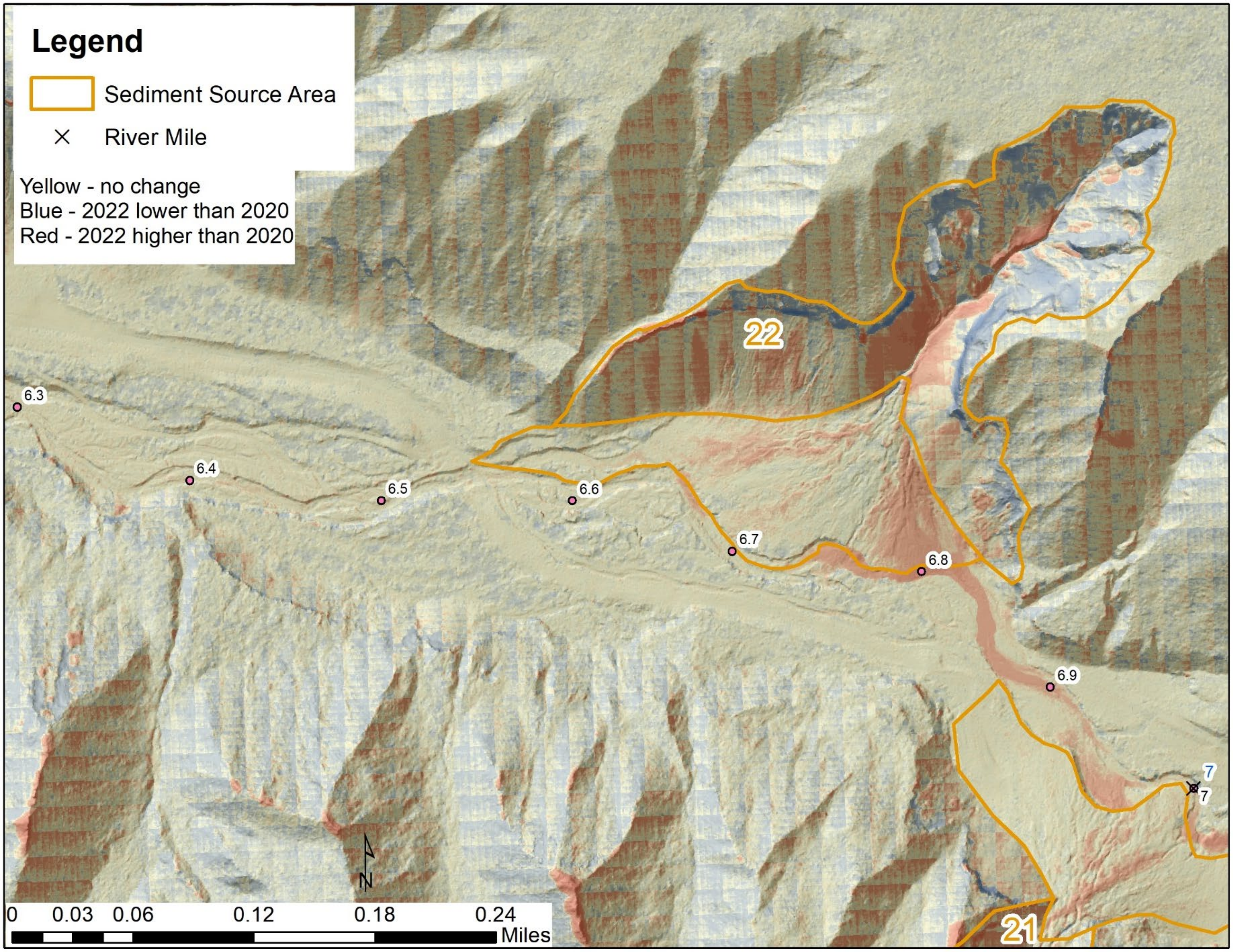

Figure 2-5. Comparison of 2020 minus 2015 LiDAR Elevation for Source Area 22 Showing Issues with Grid Size.

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 2-1. These volumes were used to estimate sediment inputs to the Eklutna River in the HEC-RAS sediment transport model.

Table 2-1. 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	50	50
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.

2.3 Substrate

Substrate is an important component of fish habitat. 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 2-2).

Table 2-2. 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.

The Native Village of Eklutna (NVE) collected information on substrate in 2019, prior to the 2021 study flow releases (Figure 2-6). 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 flow release, some of the silt and clay has been transported out of the upper valley and old reservoir area which can improve aquatic habitat conditions (see 2021 Geomorphology and Sediment Transport Report for grain size comparison pre- and post-study flow release). Future changes in substrate in the Eklutna River will occur as the river adjusts 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.

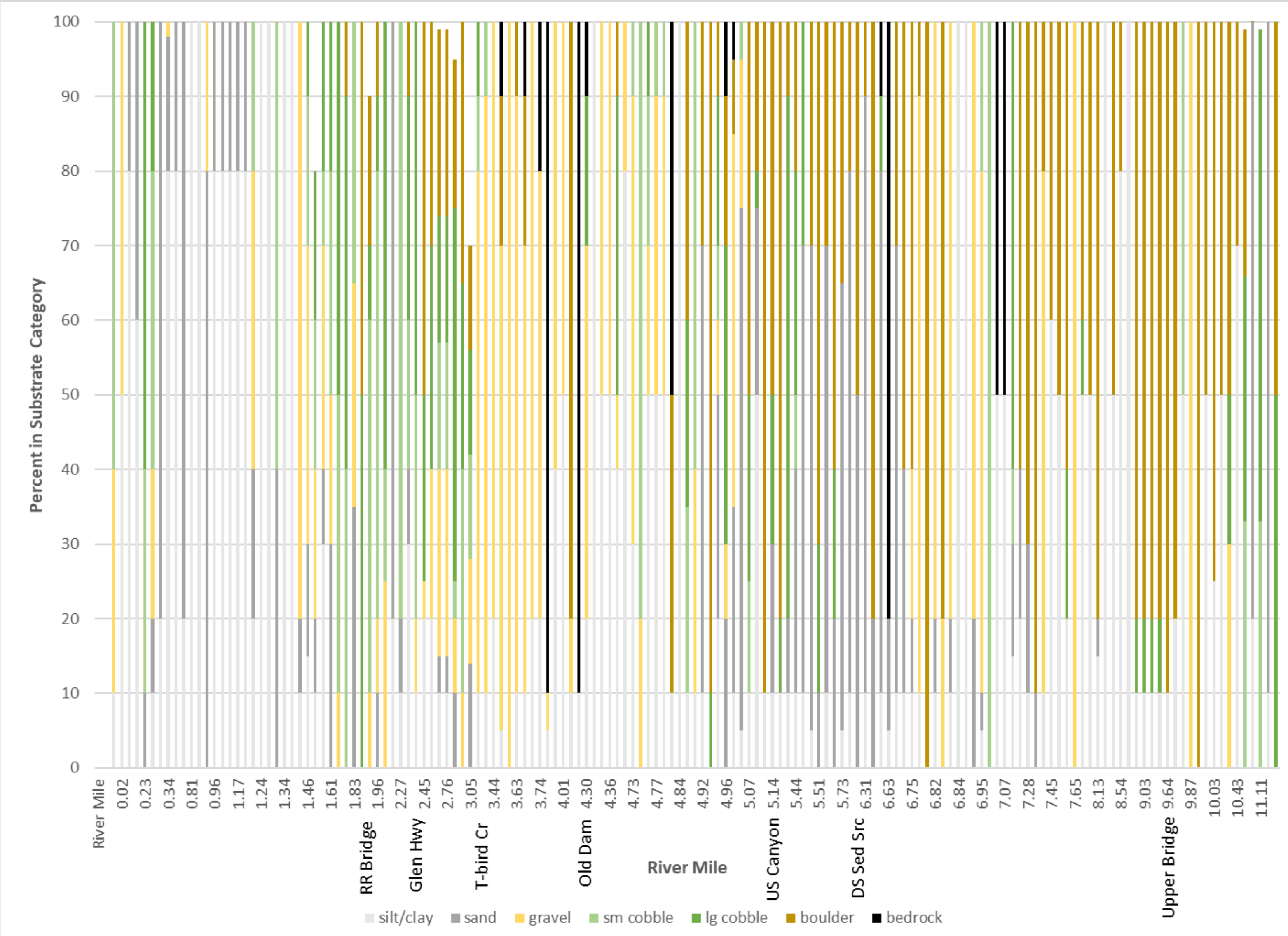

Figure 2-6. Eklutna River substrate 2019 (Source: NVE 2020)

Note that River Miles at upper end of the graph are not the same as GIS-based River Miles due to accumulated differences in walking (string box) distance vs. GIS map distance.

2.4 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. The creek could be re-directed into the Eklutna River downstream from Eklutna Dam and would provide a source of water and sediment to the river. Substrate in the streambed near the historic confluence with the Eklutna River shows the stream would provide primarily gravel-sized material with a median diameter of 35 mm.

3. 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.

3.1 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 2-3 shows the toe of the source area 3 fan eroded between RM 11.2-11.3 and Figure 2-4 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 as described in the 2021 report (transects B and E).

3.2 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 3-1) and during the 2021 study flow release (Figure 3-2). 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 3-1). An estimated 51,000 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 3-2). An estimated 30,000 cubic yards of material was transported out of the old reservoir area between 2020-2022. 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 3-3). 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.

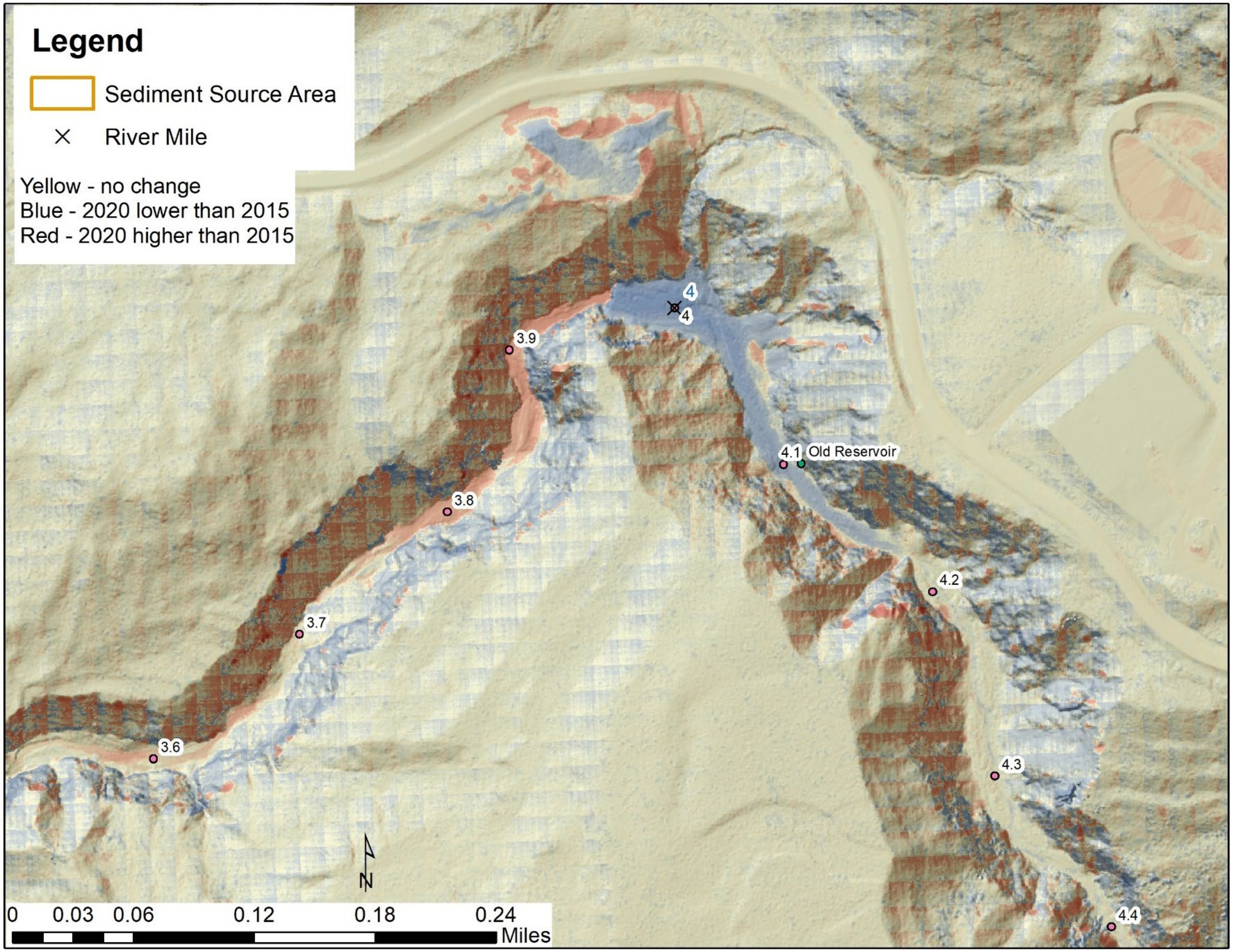

Figure 3-1. Comparison of 2020 minus 2015 LiDAR surfaces near Old RM 4 Dam.

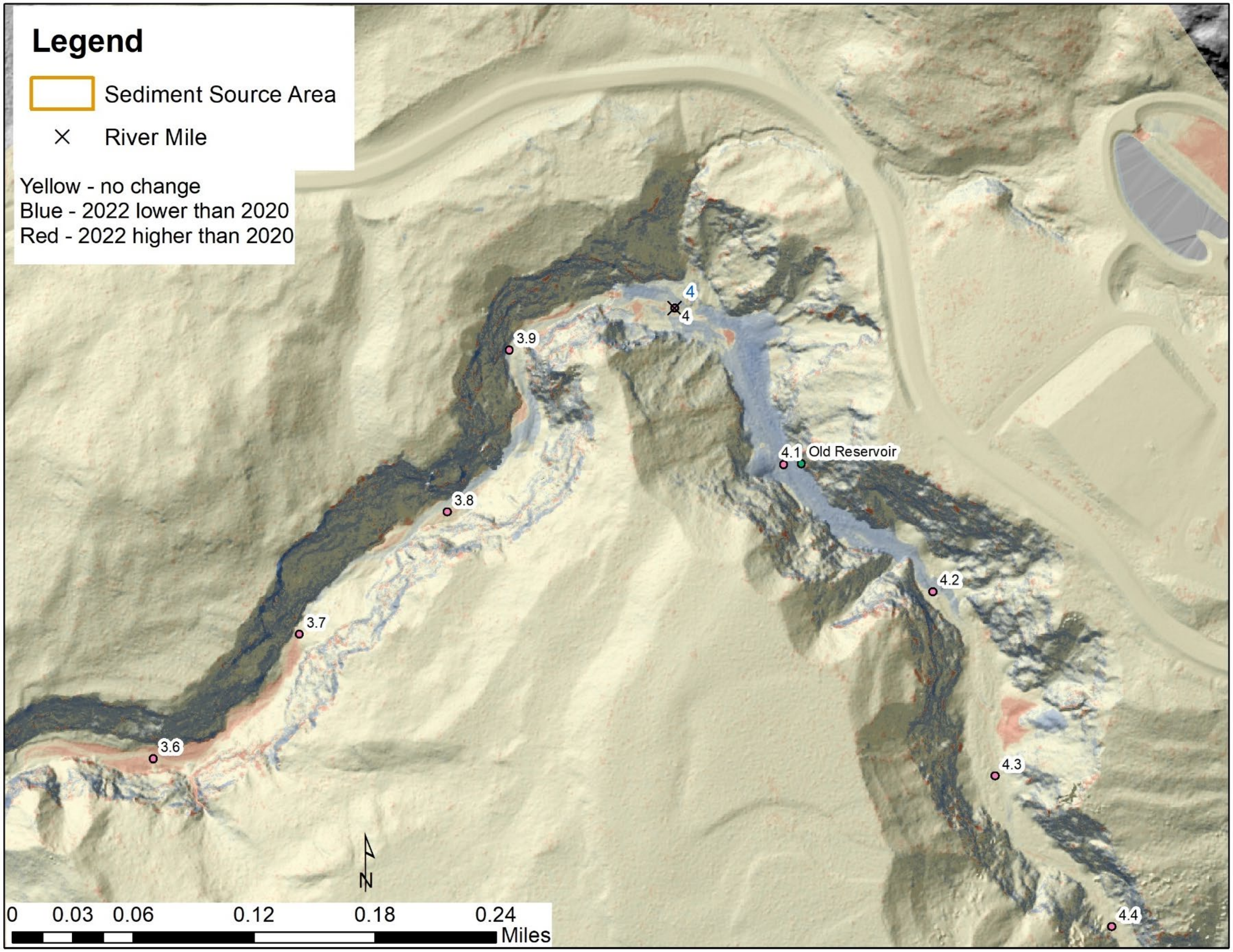

Figure 3-2. Comparison of 2022 minus 2020 LiDAR surfaces near Old RM 4 Dam.

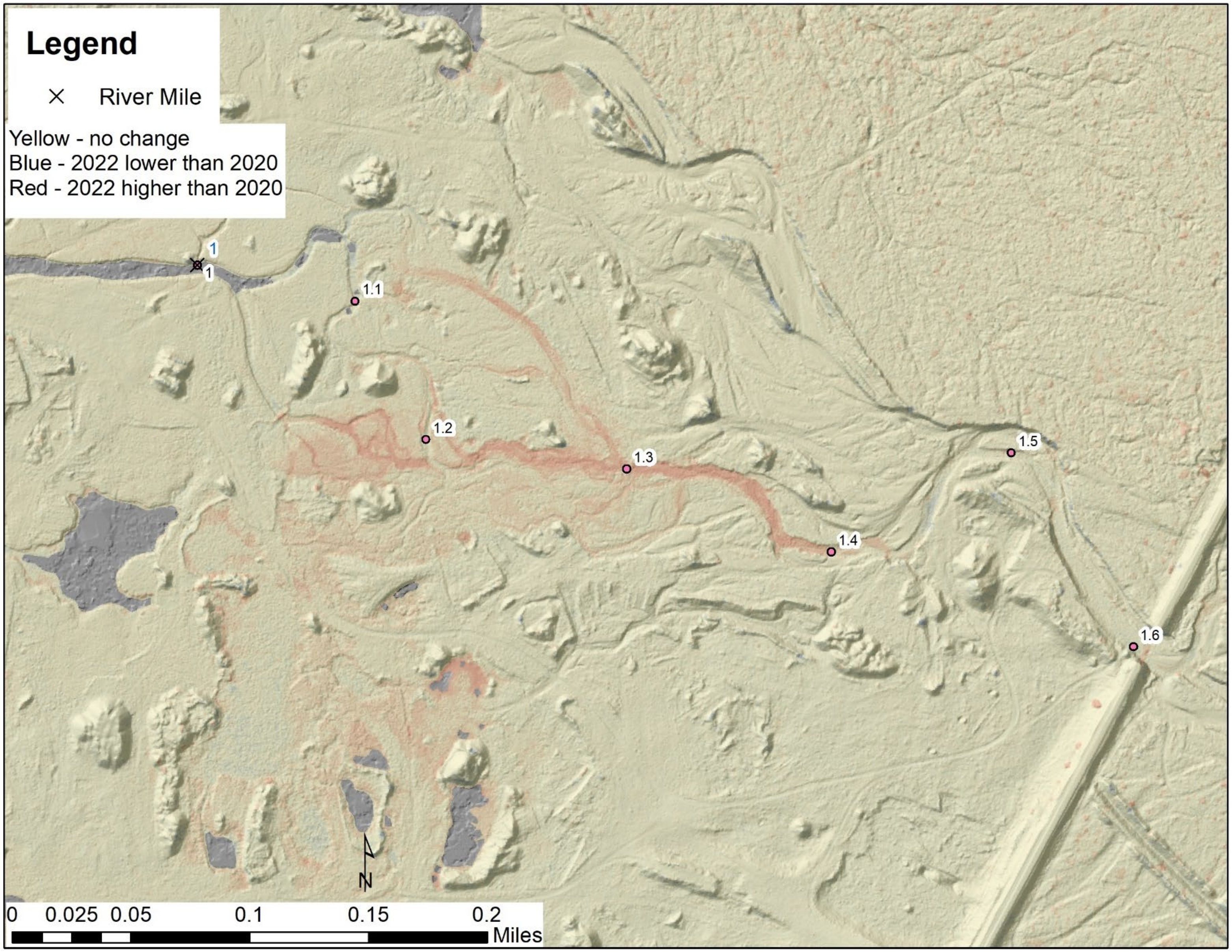

Figure 3-3. Comparison of 2022 minus 2020 LiDAR surfaces at mouth of Eklutna River (tidally influenced area).

4. Modeling of Flow Augmentation Scenarios

4.1 HEC-RAS 1-D Model

A HEC-RAS 1-D hydraulic model developed by Kleinschmidt 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.

4.1.1 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 (River Mile 12.3) to River Mile 1.5 (downstream from railroad bridge). Within this model reach, there is one major tributary (Thunderbird Creek) that joins the Eklutna River at River Mile 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

4.1.2 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.

4.1.3 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).

4.1.4 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.

4.1.5 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.

4.1.6 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 4-1. 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
	A	11.8	215735	Minor changes	Less than 0.1 foot change

4.2 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 model 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 4-2).

Peak flow releases of 72 hours (3 days) were modeled for demonstration purposes. 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 4-1). 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.

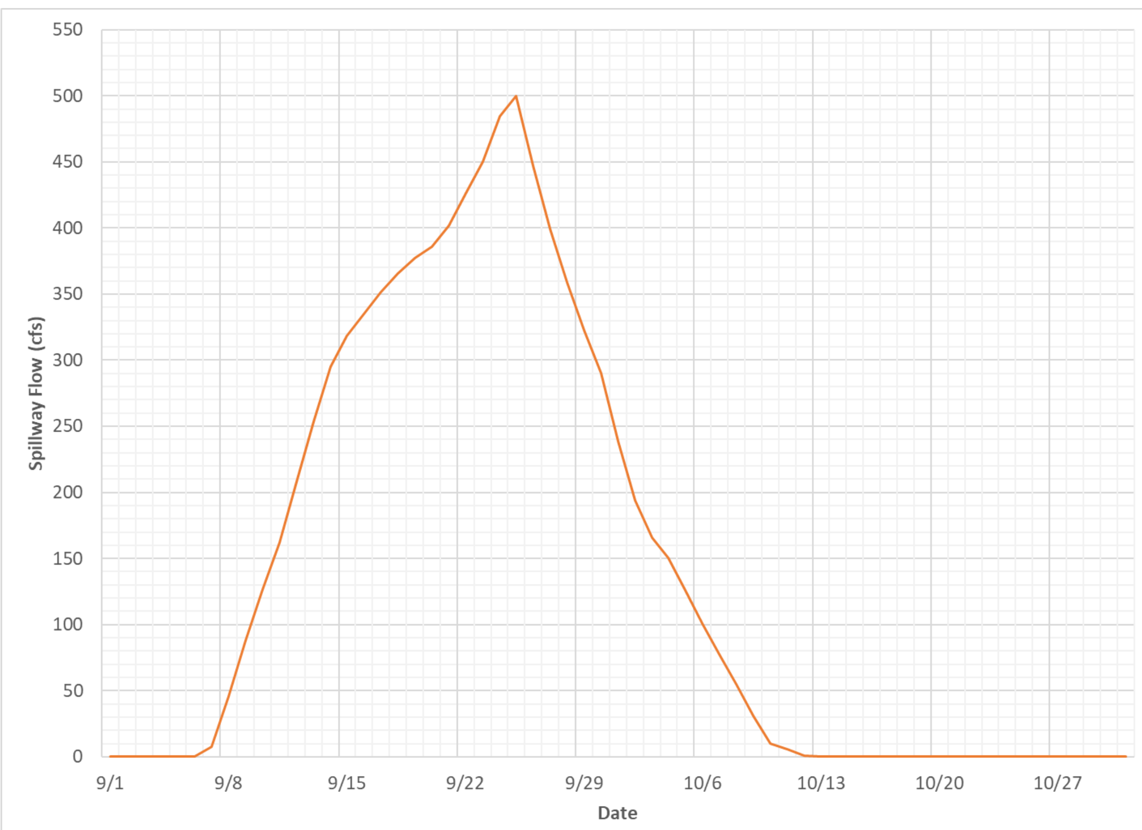

Figure 4-1. Calculated 500 cfs Uncontrolled (spillway) Flow Release Pattern Based on Average Daily Flow in September.

Table 4-2. 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, Flow Level 2 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.

Predicted grain size mobility based on computed shear stress under different base and peak flows are shown in Figure 4-2 and 4-3, 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 4-3). Again, the most stable spawning-sized substrate is between the New Glenn Highway Bridge and Thunderbird Creek as well as in the canyon area.

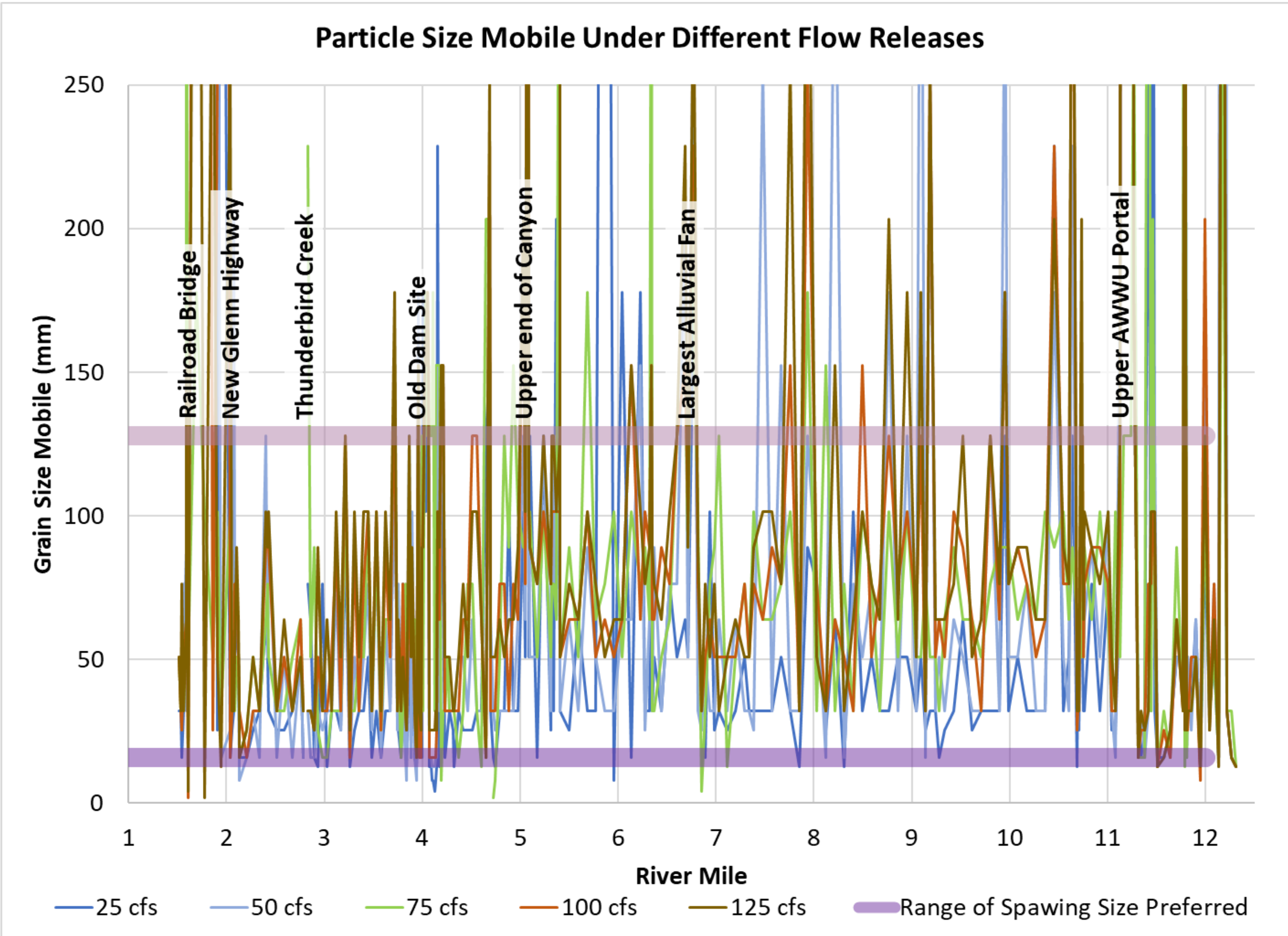

Figure 4-2. Eklutna River Grain Size Mobility under Base Flow Release Scenarios and Preferred Salmonid Spawning Range

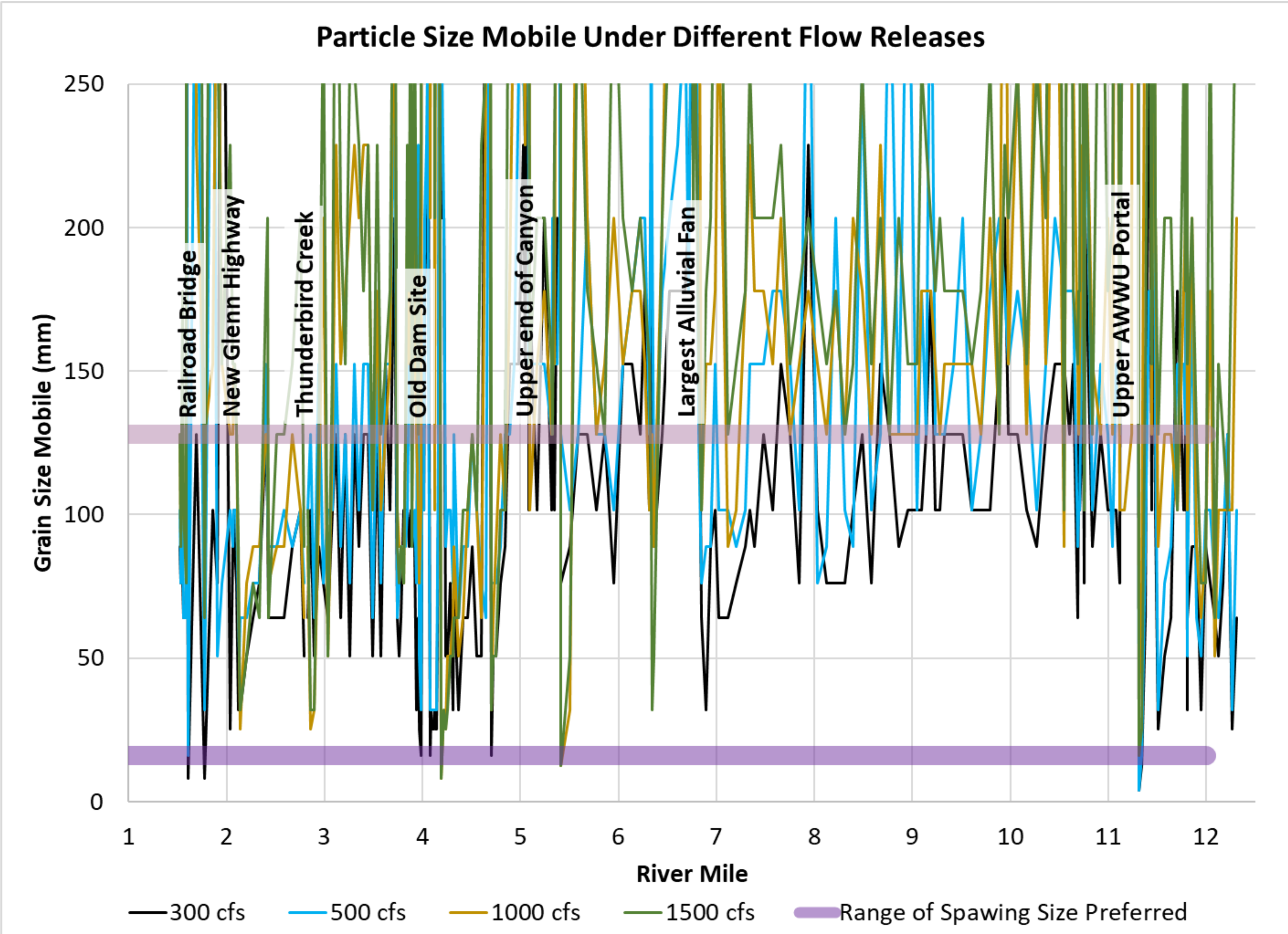

Figure 4-3. Eklutna River Grain Size Mobility under Peak Flow Release Scenarios and Preferred Salmonid Spawning Range

Figures 4-2 and 4-3 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 4-4 shows the predicted median (D_{50}) 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 4-1 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 4-5).

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 4-6).

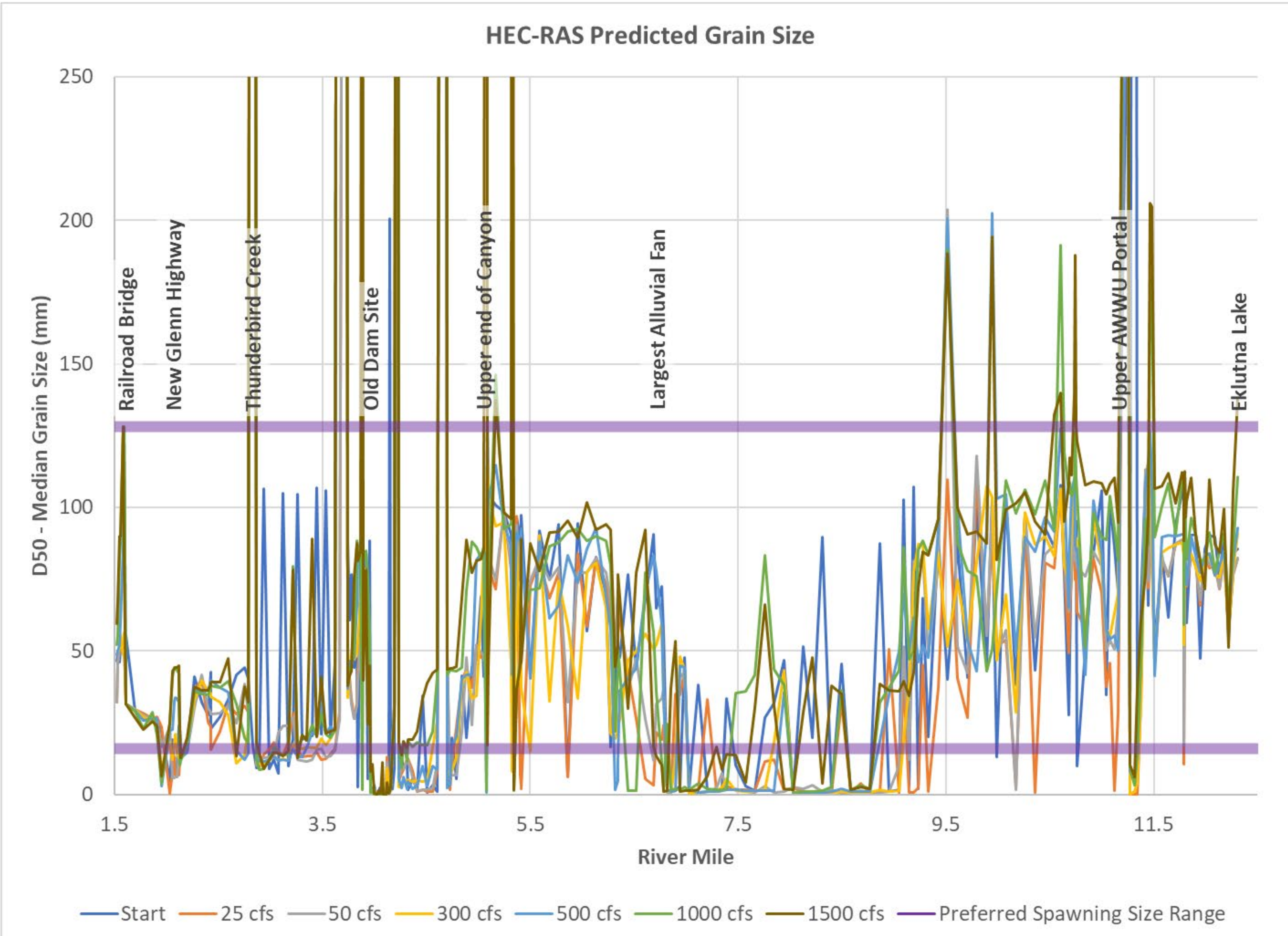

Figure 4-4. Eklutna River HEC-RAS Predicted Grain Size Following Different Release Scenarios (72 hour duration) and Preferred Salmonid Spawning Range

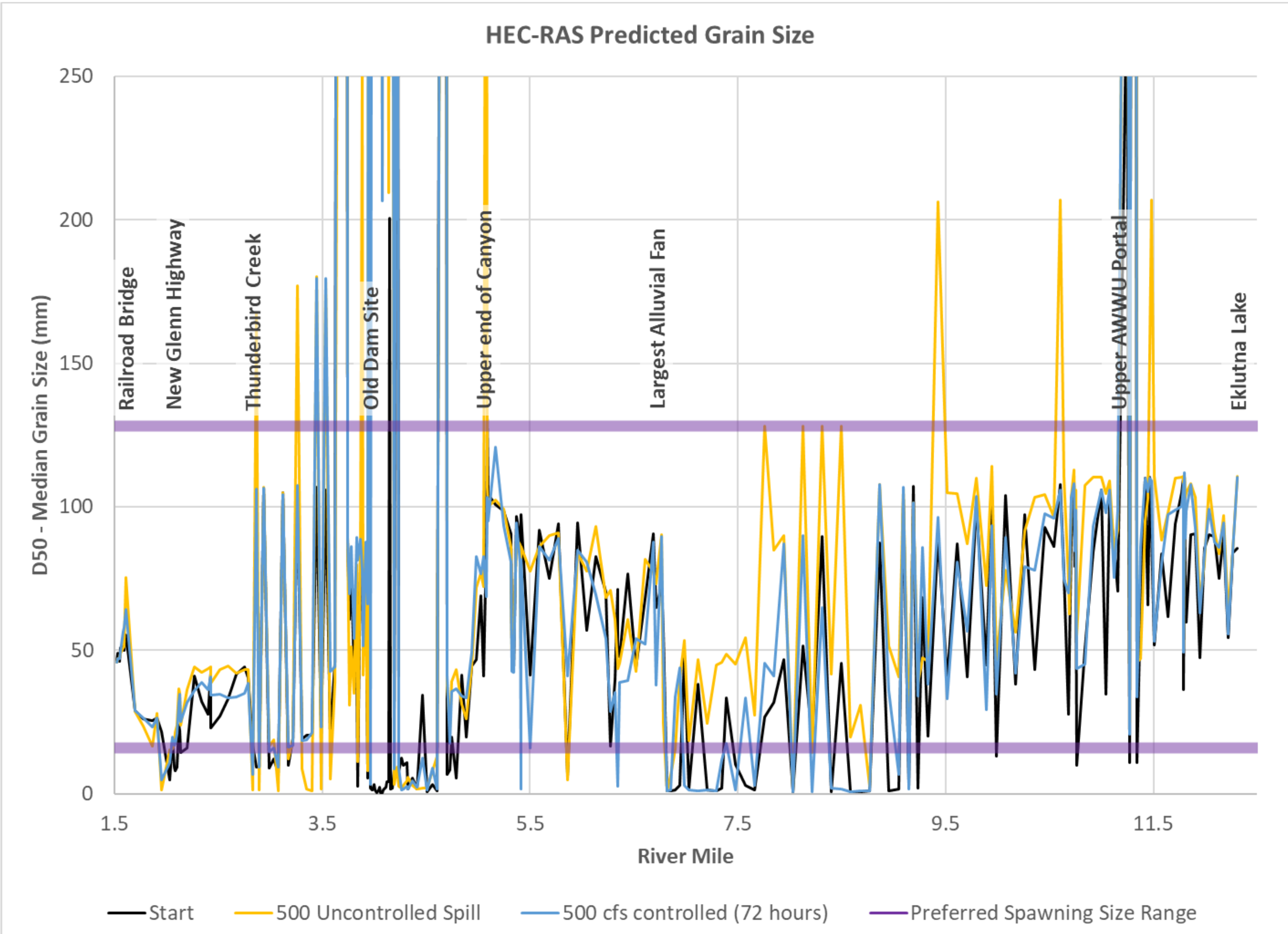

Figure 4-5. Eklutna River HEC-RAS Predicted Grain Size Following Controlled and Uncontrolled 500 cfs Flow and Preferred Salmonid Spawning Range

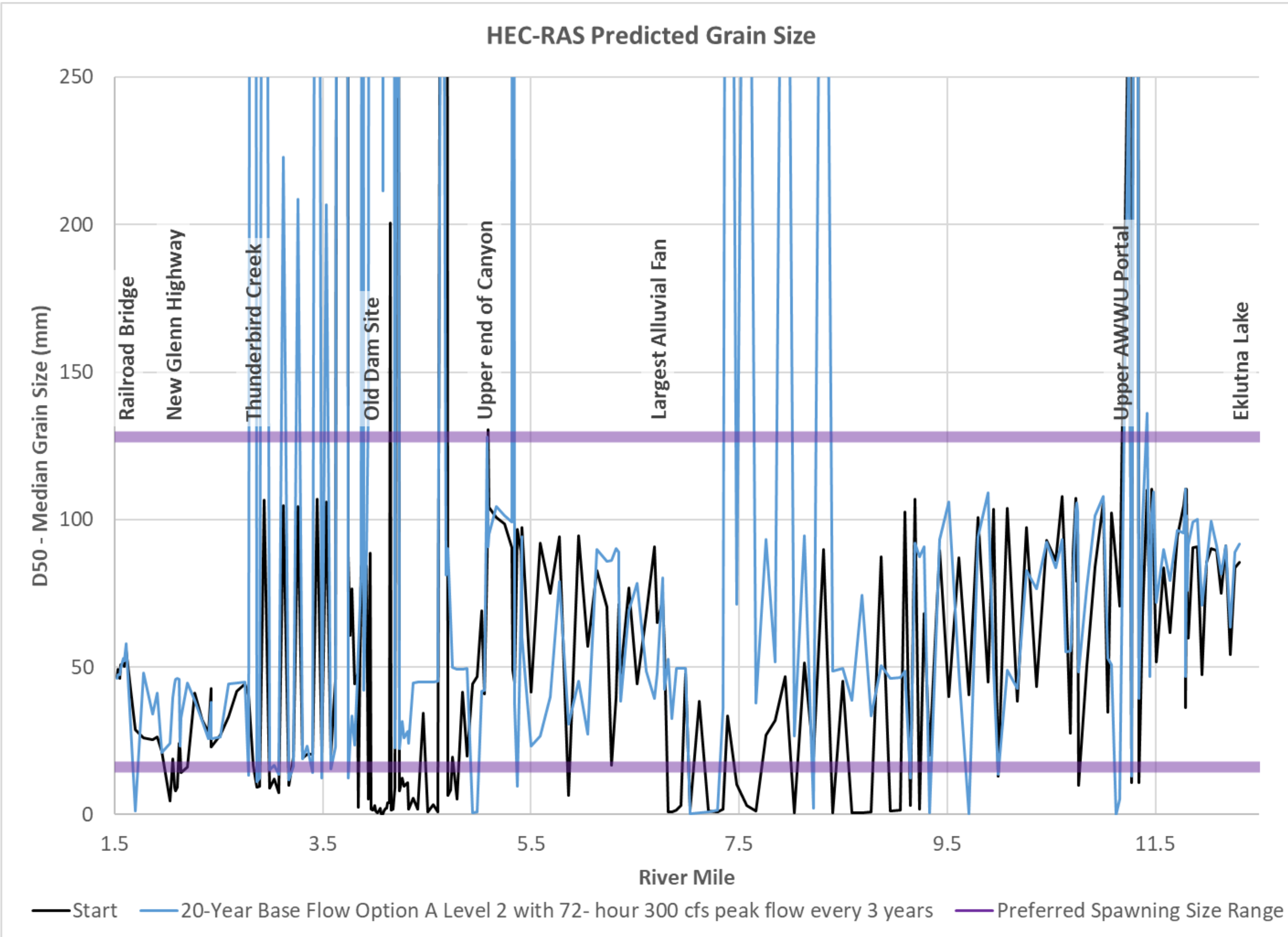

Figure 4-6. Eklutna River Predicted Grain Size Following 20-year Base Flow Option A, Level 2 with 72-hour 300 cfs peak every 3 Years.

4.3 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 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. Adjustments to flow releases should be anticipated as the channel develops under a new flow regime.

5. References

NVE (Native Village of Eklutna), 2020. Eklutna River Salmon Habitat Assessment and Collaboration to Recommend Restoration Flows. Report prepared by Carrie Ann Brophil and Marc Lamoreaux.

Technical Memo Comment-Response Table

Comment #	Agency/Interested Party	Draft Eklutna River Geomorphology/Sediment Transport Considerations for Flow Augmentation Technical Memo Section (Page) *"Text"*	Comment	Response
Section 1. Introduction and Purpose				
1	USFWS	Section 1. Introduction and Purpose (Page 1). *"There are four different levels of higher flows of interest that will move accumulated sediment and provide geomorphic channel change and maintenance in the Eklutna River: 1) flow that moves the surficial veneer of fine sediment; 2) flow that moves substantial amounts of the sediment wedge from behind the old lower dam site; 3) flow that disrupts the armor layer, transports gravel/cobble material, and moves interstitial fine sediment; and 4) flows that result in channel migration and floodplain inundation."* and "*The 2021 flow release demonstrated that releases of 150 cfs for 11 days moved at least some of the surficial veneer of fine sediment and moved a substantial amount of the sediment wedge from the old dam site (flow levels 1 and 2 above).*"	The TM describes flow levels of interest, one of which would move substantial amounts of sediment from behind the old lower dam site. The TM states the 2021 release of 150 cubic feet per second (cfs) moved a "substantial" amount of the sediment wedge from the old dam. This was shown in the comparative cross sections and photo points presented during the TWG meeting. We recommend comparing pre and post flow release cross sections to understand the design channel cross sectional area suitable for routing flows of this 150 cfs magnitude. This could also be used to validate models that estimate cross sectional area based on assumed flow and channel roughness.	Thank you for the suggestion; this will be included in the Year 2 Study Report.
	USFWS	Section 1. Introduction and Purpose (Page 1). *"There are four different levels of higher flows of interest that will move accumulated sediment and provide geomorphic channel change and maintenance in the Eklutna River: 1) flow that moves the surficial veneer of fine sediment; 2) flow that moves substantial amounts of the sediment wedge from behind the old lower dam site; 3) flow that disrupts the armor layer, transports gravel/cobble material, and moves interstitial fine sediment; and 4) flows that result in channel migration and floodplain inundation."*	At the incipient point of flooding, when the river accesses the bankfull flood stage, energy is dispersed across a depositional feature (floodplain) consistent with the size, pattern, and profile of the river. This results in reduced risk and maintains channel stability. Flow level 4 as described in the TM, are "flows that result in channel migration and floodplain inundation." However, that description links flood flows to channel migration. We recommend clarifying whether this is a reference to historical flood flows or project flood flows under a new regulated hydrologic regime.	This is a reference to potential future peak flows; however, analysis of past channel positions and past peak flows will be used to help guide the analysis. The TM has been updated.
2	USFWS	Section 1. Introduction and Purpose (Page 2). *"If peak flow levels and durations are too high/long compared to input of sediment (particularly spawning-sized sediment), some components of aquatic habitat may decrease in value in some reaches of the river."*	The TM states, "if peak flow levels and durations are too high/long compared to input of sediment (particularly spawning-sized sediment), some components of aquatic habitat may decrease in value in some reaches of the river." We recommend acknowledging the other extreme as well— if flows are too low or too short in duration, excessive deposition of fines may occur along with insufficient influx of spawning-sized gravels.	The TM has been updated to reflect this comment.

Technical Memo Comment-Response Table

Comment #	Agency/Interested Party	Draft Eklutna River Geomorphology/Sediment Transport Considerations for Flow Augmentation Technical Memo Section (Page) *"Text"*	Comment	Response
Section 2. Geomorphic Setting and Sediment Source Areas				
3	USFWS	Section 2.1 Geomorphic Setting (Page 2). *"The currently active alluvial fans have been providing more sediment to the valley than the river can transport and have resulted in long-term aggradation upstream of RM 7."*	Section 2.1, states, "the currently active alluvial fans have been providing more sediment to the valley than the [post dam] river can transport…" Please add the term 'post dam' to emphasize diminished sediment transport competency and capacity is a result of dam operations.	The TM has been updated to reflect this comment.
4	ADFG	Section 2.2 Sediment Source Areas (Pages 3-8). *"The current major sediment sources to the Eklutna River are shown in Figure 2-2 and include the alluvial fans in the upper valley and one smaller eroding bluff in the canyon just downstream from RM 5."*	The report states that the current major sediment sources to the Eklutna River include the upper valley alluvial fans and an eroding bluff in the canyon. Were other sources (such as the streambanks along the length of the channel) considered and if so, what is the relatively input of other sources? Or, what relative percentage of the overall sediment input is provided by the major sources listed compared to other sources? Would it be expected that these streambank or minor sources increase with flows that facilitate channel migration and floodplain inundation? This will likely be better understood after the 2-D HEC-RAS model is fully developed. We would expect more of this general input as the channel migrates. Either way, we think it would be informative to address other sources (describe relative input or possibly make statement about how minor other sources are) since the report only mentions the major sediment sources in the Sediment Source Areas section. Maybe these are the source of 95% of the substrate and the minor sources aren't a factor, but we feel it would be helpful to discuss the major sources in context with other sources, especially as the channel migrates and adjusts to various flows.	The TM has been updated to include a discussion of other smaller sediment sources.
Section 4. Modeling of Flow Augmentation Scenarios				
5	USFWS	Section 4.1 HEC-RAS 1-D Model (Page 15).	Section 4.1, describes the development of the HEC-RAS 1-D model, which considered just two reaches on the Eklutna River, from the dam to the confluence of Thunderbird Creek, and from Thunderbird Creek downstream. We would like to know if there would be added benefits to looking at sediment transport reaches broken down by factors other than perennial flow (i.e., deposition versus transport reaches, slope, lateral stability, stream type, etc.). Example reach breaks could include the Eklutna tailwater (above upper Anchorage Water and Wastewater Utility portal), depositional zone (River Mile [RM] 5 to 11), Canyon (RM 3 to 5), below Thunderbird Creek (RM 2 to 3), and the delta. What would be gained through added resolution and a functional approach to reach identification?	The HEC-RAS model reach designations are related to internal model designations; model output is at the resolution of each of the 241 cross sections included in the model, so much more detail is provided in the model output and analysis of output is not constrained to the two Eklutna River reaches. The detailed output was used for analysis.

Technical Memo Comment-Response Table

Comment #	Agency/Interested Party	Draft Eklutna River Geomorphology/Sediment Transport Considerations for Flow Augmentation Technical Memo Section (Page) *"Text"*	Comment	Response
General Comments				
12	USFWS	General Discussion	The LiDAR does a good job of showing the process by which sediment moves from head of gully features, down the fall line, to the alluvial fans, and potentially into the river below. Model outputs attempt to quantify sediment inputs to the river. We suspect the inputs are underestimated. Acknowledging that accuracy is an impossible goal given model limitations and the stochastic nature of mass wasting, model outputs provide a good representation of relative sediment contributions of the various active alluvial fans across the Eklutna River floodplain. This information is important for understanding stream channel restoration opportunities and design constraints. There will be portions of river (referred to as "unconfined") that are naturally laterally active and depositional. These dynamic areas are prone to channel migration and pose appreciable engineering challenges. We look forward to more discussion of channel restoration alternatives that support desired river function (water depths, scour, graded substrate) as well as the natural tendency of the river in the context of its watershed and sediment supply (laterally active, depositional) once a range of the base and peak flow regimes are determined. Channel form, base flow, and channel forming flows are inextricably linked. Given the considerable design challenges at this site, it is best for these integrative discussions to occur as soon as possible.	Continued analysis and discusion of channel restoration alternatives will be included as part of the future Project analyses, discussions, and alternative development process.

Technical Memo Comment-Response Table

Comment #	Agency/Interested Party	Draft Eklutna River Geomorphology/Sediment Transport Considerations for Flow Augmentation Technical Memo Section (Page) *"Text"*	Comment	Response
13	USFWS	General Discussion	Like the LiDAR analysis, the HEC-RAS modeling does a good job of showing the distinctions between functional reaches. The tool excels at modeling in-channel transport across baseline conditions for the range of flows at which it was calibrated, in this case, up to 150 cfs. Sediment transport functions are a combination of theoretical and empirical science. Due to the empirical nature of the transport function, empirical data is needed to calibrate a HEC-RAS sediment transport model. This point was reinforced by Gibson et. al (2017), who demonstrated the importance of multiple calibration metrics when evaluating sediment transport models in HEC-RAS. We recommend acknowledging the empirical data, collected to date, represents only one data point and the model will likely require additional calibration flows and refinement to increase its reliability for use in this system under the selected flow regime. Additionally, the model must be considered within the context of the current channel. The existing channel, formed by historical bankfull flows of 1,500 cfs, received test flows that were an order of magnitude lower. This means the test flows only spilled onto the inner berm of the original channel. In many cases this inner berm is sparsely vegetated, has a different sediment profile and lateral extent than the original floodplain. Like the physical habitat simulation model, the results are extremely limited as new channel geometry will influence model outputs. We recommend clarifying the term "floodplain" to indicate whether it is referring to the historical floodplain extent, or to the lateral extent of inundation under test flow scenarios (i.e., historical inner berm).	Text has been added to the calibration section (4.1.6). The HEC-RAS model is useful as a "snapshot in time" model of the current condition of the channel to help inform analysis of potential new flow regimes. We have discussed throughout the study process that the channel will change in the future as it adjusts to any new flow regime. It is likely that any future flow/measures will include a monitoring component to inform our understanding of these future channel changes and an adaptive management component. The term "floodplain" refers to the extent of innundation under peak flows in general, not the extent of test flows.
14	USFWS	General Discussion	There are river reaches that are, or have the potential to be, stable, single thread channels. There are other reaches, however, that are naturally laterally active, and potentially anastomosing, causing new channels to form. Physical surveys and modeling efforts help to identify these reach breaks and distinguish appropriate restoration tools. One common thread throughout the river corridor, however, is the importance of vertical stability. We recommend locations of known and suspected grade controls be identified throughout the system, including the elevation of the pool tail crest below the dam in relation to the proposed spillway gate, and in relation to the longitudinal profile. In addition, please provide a discussion of potential future river adjustments under various flow regimes, also include a figure, or overlay of the post-test flow release longitudinal profile in the TM to complement Figure 2-1.	A profile comparing the 2022 (Figure 2-1 in TM) and 2022 LiDAR will be included in the Year 2 Report. Apparent grade controls were mapped during the field inventories in 2020-2021 and will be shown on this figure as well. The grade controls were incorporated into the HEC-RAS model.