AMENDMENT TO BRADLEY LAKE HYDROELECTRIC PROJECT (FERC No. 8221), DIXON DIVERSION PROJECT

Geomorphology and Sediment Transport Study Report

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WATERSHED GEODYNAMICS

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Appendix A Representative Timelapse Camera Images of August 7, 2024 Peak Flow

ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
A	
AEA	Alaska Energy Authority
C	
cfs	Cubic foot per second
D	
DLA	Draft License Application
E	
EFMR	East Fork Martin River
F	
FERC	Federal Energy Regulatory Commission
ft	Foot
ft/s	foot per second
G	
GIS	Geographic Information Systems
L	
LiDAR	Light detecting and ranging
M	
mm	Millimeters
O	
OCH	off-channel habitat
R	
RM	River Mile
W	
WFMR	West Fork Martin River

1.0 INTRODUCTION

1.1 Background

The Alaska Energy Authority (AEA), Licensee and owner of the 120-megawatt Bradley Lake Hydroelectric Project (Bradley Lake Project; Federal Energy Regulatory Commission [FERC] No. P-8221), is pursuing a FERC license amendment. The purpose of the proposed amendment is to gain authorization to divert seasonal meltwater coming from Dixon Glacier at the headwaters of the Martin River to the Bradley Lake to increase power production. The Bradley Lake Project is located on the Bradley River in the Kenai Peninsula Borough northeast of the town of Homer in Southcentral Alaska (Figure 1-1).

AEA filed an Initial Consultation Document (ICD) (AEA 2022a) with FERC on April 27, 2022. The ICD describes existing facilities and current Bradley Lake Project operations; characterizes the affected environment; and describes two proposed project alternatives for producing energy from Dixon Glacier meltwater. Following the ICD filing, AEA hosted Joint Agency and Public Meetings in Homer, Alaska on June 14, 2022 to discuss the ICD and receive stakeholder input. In November 2022, AEA filed a Draft Study Plan (DSP) (AEA 2022b) with FERC, based on the two alternatives, outlining ten studies, including the *Hydraulic Modeling, Geomorphology, and Aquatic Habitat Connectivity Evaluation*. Stakeholders filed comments to the DSP in December 2022. AEA briefly paused the FERC amendment process while it conducted additional feasibility studies and narrowed down the proposed project alternatives.

Based on further investigations, AEA decided to move forward with the proposed alternative diverting Dixon Glacier meltwater to Bradley Lake (Dixon Diversion Project or Project). The proposed Project would include construction of: a diversion dam near the toe of the Dixon Glacier; an approximately 4.9-mile-long diversion tunnel bored through the mountain extending from Dixon Glacier to Bradley Lake, diverting water from the Martin River basin to Bradley Lake; approximately 1 mile of new, 16-foot-wide, gravel-surfaced access road from the existing Upper Battle Creek diversion access road to the outlet of the proposed diversion tunnel; and modification of the existing Bradley Lake Dam to raise the maximum normal pool elevation currently at 1,180 feet by as much as 7, 14, or 28 feet (1,208 feet elevation). The entire proposed Project is located on State-owned land.

AEA re-initiated the amendment process in 2024 by hosting public meetings in March and April 2024 to review the selected Project alternative, stakeholder comments to the DSP and AEA's proposed modifications to the DSP. Meeting summaries are posted to AEA's Dixon Diversion Project website at Dixon Diversion Project.

AEA implemented geomorphology investigations in 2023 and 2024. An initial report on the 2023 geomorphology observations was developed in early 2024 (Watershed GeoDynamics 2024). This report describes the results of the Geomorphology and Sediment Transport Analysis component of the *Hydraulic Modeling, Geomorphology, and Aquatic Habitat Connectivity Evaluation* completed by Watershed Geodynamics during 2024. Analysis of potential effects of future changes to flow regimes and river conditions as a result of the proposed Project to divert water from the Dixon Glacier outflow to generate additional power will be completed in 2025 and provided in the Draft Amendment Application.

1.2 Modifications from the Draft Study Plan

One modification was made to the DSP (AEA 2022b) for the geomorphology and sediment transport evaluation. The following task was added:

- Install timelapse cameras that show changes in braided channel reaches and correlate the timing of channel changes observed with the flow at that time to help determine flow levels that initiate channel change/bedload transport.

Figure 1-1 Location of the proposed Dixon Diversion Project at the Bradley Lake Hydroelectric Project (FERC No. P-8221) near Kachemak Bay, Alaska.

2.0 GEOMORPHOLOGY STUDY GOALS AND OBJECTIVES

The East Fork Martin River (EFMR) flows from the Dixon Glacier through a high-gradient canyon to the confluence with the West Fork Martin River (WFMR), where it forms the Martin River which flows through a lower-gradient, very dynamic glacial outwash plain to Kachemak Bay. The Dixon Glacier supplies a large amount of sediment to the river and includes material from boulder to clay size. This material is transported through the EFMR canyon reach and then deposited in the Martin River outwash plain as the valley widens and water velocity drops, forming a braided river pattern. Braided rivers are indicative of watersheds that produce more sediment than the available river flow can carry. AEA proposes to divert water from the terminus of the Dixon Glacier into Bradley Lake and allow gravel and larger particles to continue into the Martin River. In order to understand the potential effects of the proposed Dixon Diversion on the Martin River, it is important to understand the geomorphic history of the Martin River valley and how past changes in sediment/water loading have affected the valley. This report relies on historic aerial photographs (1950-2024), field observations and substrate sampling, timelapse camera footage of river changes in response to flows (2023 and 2024), and hydraulic model analysis to provide an understanding of past river valley changes and tools to analyze potential future changes. This information, combined with the fisheries, hydraulic, hydrologic, and riparian study results, will allow AEA to evaluate potential effects on aquatic and riparian ecosystems in the Martin River valley.

The geomorphology and sediment transport analysis outlined in DSP Section 4.5 (AEA 2022b) analyzed available historic aerial photograph and LiDAR data as well as collected information on substrate size and analyzed potential future sediment transport and accumulation trends based on output from the two-dimensional (2D) hydraulic. The geomorphology and sediment transport analysis includes eight tasks:

- Segment the Martin River into geomorphic analysis reaches based on confinement, degree of braiding, and gradient.
- Delineate past changes to Martin River, adjacent forest community growth/destruction patterns (resulting from channel migration), and stream/pond connectivity through time using historic aerial photographs (1984 through present are available, possibly older series as well).
- Map the degree of channel braiding in each reach of the Martin River through time to determine past changes to braiding patterns in each geomorphic reach. This step will help to determine expected future variability in braiding patterns.

- Compare LiDAR and any other topographic datasets to estimate average annual volume of coarse-grained sediment provided to the river (combined Martin River and EFMR) from the Dixon Glacier based on aggradation volumes.
- Collect pebble count data and sub-surface samples during low flow conditions in each geomorphic reach.
- Install timelapse cameras showing changes in braided channel reaches and correlate the timing of channel changes observed with the flow on that day to help determine flow levels that initiate channel change/bedload transport.
- Analyze sediment transport and deposition potential along the Martin River based on the 2D hydraulic model output under current/proposed flow regime(s).
- Compare sediment input and sediment transport potential to estimate future deposition rates and locations.
- Coordinate with team members assessing riparian and aquatic habitat conditions and connectivity to help develop a multi-disciplinary analysis of the effects of changes in flow regimes.

3.0 STUDY AREA

The study area consists of the Martin River watershed from its mouth to the EFMR and WFMR confluence and extends up the WFMR to the Red Lake outlet and extends up the EFMR to the toe of Dixon Glacier (Figure 3-1).

Figure 3-1 Martin River geomorphology and sediment transport study area.

4.0 METHODS

The methods used to meet the study objectives and complete the eight tasks of the geomorphic and sediment transport analysis are described below.

4.1 Geomorphic Reach Mapping and Channel Change Mapping from Historic Aerial Photographs

Geomorphic reach mapping of the Martin River current/recent conditions and analysis of the Martin River changes through time were made based on available LiDAR and aerial photography datasets (Table 4-1). Aerial photographs that did not have positioning data were geo-rectified within ArcGIS Pro using landmarks. Note that there are errors inherent in georectification of older aerial photographs due to lens distortion around the edges of the photographs; positioning on these older images is not precise but is sufficient for the purposes of the analysis of overall channel changes through time.

Table 4-1 Available LiDAR and aerial photography.

Product	Acquisition Date
NIR-LiDAR and digital imagery[1]	5/2024
NIR-LiDAR[2]	10/13/2022
4 band digital imagery[2]	7/28/2022
Sentinel 2 satellite imagery (various dates) [3]	2017-2023
Aerial imagery (05915 series)[4]	9/3/1996
Aerial imagery (58200 series) [4]	8/2/1982
Aerial imagery (63640 series) [4]	7/16/1977
Aerial imagery (4KACH series) [4]	9/6/1964
Aerial imagery (BM064 series) [4]	5/25/1951 and 8/15/1952
Aerial imagery (BM 0375 series) [4]	8/6/1950

1 NV5 2024
2 NV5 2023
3 Satellite Imagery obtained from Copernicus Brower https://dataspace.copernicus.eu/
4 Imagery obtained from USG Earth Explorer website https://earthexplorer.usgs.gov/

4.1.1 Recent/Current Geomorphic Reach Delineation and Valley Mapping

The Martin River valley was delineated into geomorphic reaches and map units based on confinement, channel/off-channel connectivity, and vegetation characteristics visible using the 2022 LiDAR and aerial photography (Table 4-1; NV5 2023) and updated in 2024 using the 2024 LiDAR and aerial photography. The valley was defined as the relatively flat valley bottom areas within the steeper side slopes. Mapping extended from the mouth of the Martin River to approximately 0.5 miles upstream of the EFMR canyon (approximately EFMR River Mile (RM) 0.5) and from the mouth of the WFMR upstream of Red Lake. The initial 2023 mapping was field checked during the May 2023 field visits (see Section 4.2) and adjusted as needed based on field observations. The 2024 updates were checked during 2024 field visits.

4.1.2 Mapping Past Changes to Martin River Valley and Degree of Braiding

Mapping of Martin River channel conditions was completed in ArcMap Pro by digitizing active channel area within the Martin River valley using the 1950 through 2024 historic aerial and satellite imagery (Table 4-1) and noting changes to channel conditions and active channel extent through time. Note that the 1964 aerial image coverage was not complete – no aerial photographs were found for the river upstream from PRM 3.6.

Wetted channel lines were digitized using the 2022 aerial images. While the number of wetted channels depends on the flow in the river, the digitized channel lines provide an indication of the relative amount of braiding. The braiding index (total channel length/main channel length) was calculated using the 2022 digitized channels for each geomorphic reach.

The position of the terminus of the Dixon Glacier was also digitized on each set of aerial photographs. A GIS coverage of glacial extent in 2007 mapped by Giffen et al. was obtained to supplement terminus position mapping. The relative position of the main (northern) terminus (e.g., distance from 1950s terminus) was measured for each image.

4.1.3 LiDAR Aggradation/Degradation Analysis

The 2022 and 2024 LiDAR data were used in ArcMap Pro to determine topographic changes in the Martin River valley by subtracting the 2022 LiDAR elevation from the 2024 LiDAR elevation at each grid cell. The resulting grid was summed for the different geomorphic units in the river valley to determine net aggradation or degradation from 2022-2024. Because the 2024 LiDAR included bathymetric data (e.g., the surface of the ground beneath the water in rivers and ponds), a correction was applied to the 2024-2022 net volume difference to account for the volume of water in the Martin River based on the volume of water per linear foot of channel in the upper, confined reaches of the river where there was little net change between 2022-2024. This volume/linear foot was assumed to be consistent along the valley, a realistic assumption based on the minor amount of tributary inflow along the valley.

A rough estimate of long-term riverbed aggradation in the delta was made comparing the as-built drawings of the right bank levee and the three borrow pit/mitigation ponds located near the mouth of the Martin River with the 2022 and 2024 LiDAR. The drawings showed up to 5 feet of freeboard (top of levee vs. riverbed) at levee construction, and water depths of up to 20 feet in the mitigation ponds.

No other/historic LiDAR or detailed topographic data were found for the Martin River valley to calculate aggradation or degradation volumes; aerial photographs and field observations of aggradation and degradation patterns were used to assess general aggradation and degradation trends through time.

4.2 Field Visits

Field visits to the Martin River in 2023 were conducted on May 16, May 22-24, and November 2. Field visits were conducted in 2024 on April 18, April 27-29, May 7, August 21, and October 30.

The following tasks were completed during the visits:

MAY 16, 2023

- Installed three timelapse cameras set to photograph braided areas of the Martin River valley (see Section 4.4 for details).

MAY 22-24, 2023

- Video footage of Martin River and EFMR from tidewater to Dixon Glacier.
- Surficial Wolman pebble count data (100 clasts each) collected at 15 locations along Martin River from Geomorphic Reach 2 through 9.
- General geomorphic observations, field checking of mapped Geomorphic Unit breaks and off-channel connectivity corridors.

NOVEMBER 2, 2023

- Photographs of new delta forming in the mitigation ponds and the new Martin River mouth from helicopter.
- Surveyed elevations along new delta and took GPS points to outline extent of delta deposits in mitigation ponds.

- Took GPS points to preliminarily outline the lateral extent of the erosion/headcutting in the Martin River valley upstream from the levee breach point.
- Pebble count at representative bar in Martin River at levee breach location.
- Video of Martin River and EFMR from Martin River mouth to Dixon Glacier to compare with May 2023 video.

APRIL 18, 2024

- Installed eight timelapse cameras set to photograph braided and off-channel areas of the Martin River valley (see Section 4.4 for details).
- Video of Martin River from mouth to EFMR/WFMR confluence area.

APRIL 27-29, MAY 7, 2024

- A total of 21 surficial Wolman pebble count data (100+ clasts each) collected along Martin River, including 13 in-river pebble counts to assist with determining Manning's n value for hydraulic modeling.
- Sub-surface substrate samples at 8 locations along the Martin River.

AUGUST 21, 2024

- General observations of channel changes following the August 8, 2024 high flow event.
- Video of Martin River from mouth to EFMR/WFMR confluence area.
- Change batteries and micro SD cards in six timelapse cameras (camera GE05 was retrieved because the tree it was installed in had fallen and no other suitable mounting locations were available due to channel changes; camera GE01 was not accessible due to high flow conditions)

OCTOBER 30, 2024

- Retrieve seven remaining timelapse cameras.
- General observations of channel changes since the August 21, 2024 site visit.
- Video of Martin River from mouth to EFMR/WFMR confluence area.

4.3 Pebble Counts and Sub-surface Sampling

4.3.1 Pebble Counts

In 2023, Wolman pebble counts (100 clasts) were collected at 14 bar locations along the Martin River and one location in the WFMR to characterize substrate size in Geomorphic

Reaches along the river on May 22-24 and at one location on the new delta fan on November 2 (Figure 4-1). In 2024, a total of 21 Wolman pebble counts (100+ clasts each) were collected in the Martin River watershed (19 along the Martin River one along the EFMR and one along the WFMR) to characterize either substrate at river bars within the high flow channel in locations indicative of bedload transport, or substrate across the width of the low flow channel to aid in developing appropriate Manning's n values for the 2D hydraulic model. At eight of the river bar pebble count locations, concurrent sub-surface samples were taken in 2024 to aid in bedload transport analysis as described in Section 4.5 (green dots in Figure 4-1).

The Martin River is a braided river downstream from Geomorphic Reach 9; river bar pebble count locations were selected at the head of river bars in non-braided reaches and at the head of anabranch bars in braided reaches (after Guerit et al. 2014). A mid-channel bar just downstream of the levee breach was sampled during the November site visit. At each river bar location, 100 clasts were selected using a random-walk method in an area covering approximately 100 square feet (the random walk covered the representative geomorphic facies at each location). For instream sample locations, traverses across the estimated "bankfull" width were made, with one clast measured each step across the channel until at least 100 clasts were measured. If less than 100 clasts were measured on one pass across the river, a second entire pass was made to ensure the entire width of the channel was represented in each pass.

For all of the pebble counts, each clast was passed through a gravelometer and the size range was recorded (e.g., 2-4 millimeter (mm), 4-8 mm, 8-16 mm, etc.). Particles smaller than 2 mm were not counted in any of the locations due to the abundance of interstitial fine material, a lag deposit of fines in many locations, and the desire to capture variations in the coarser bedload-sized material along the river.

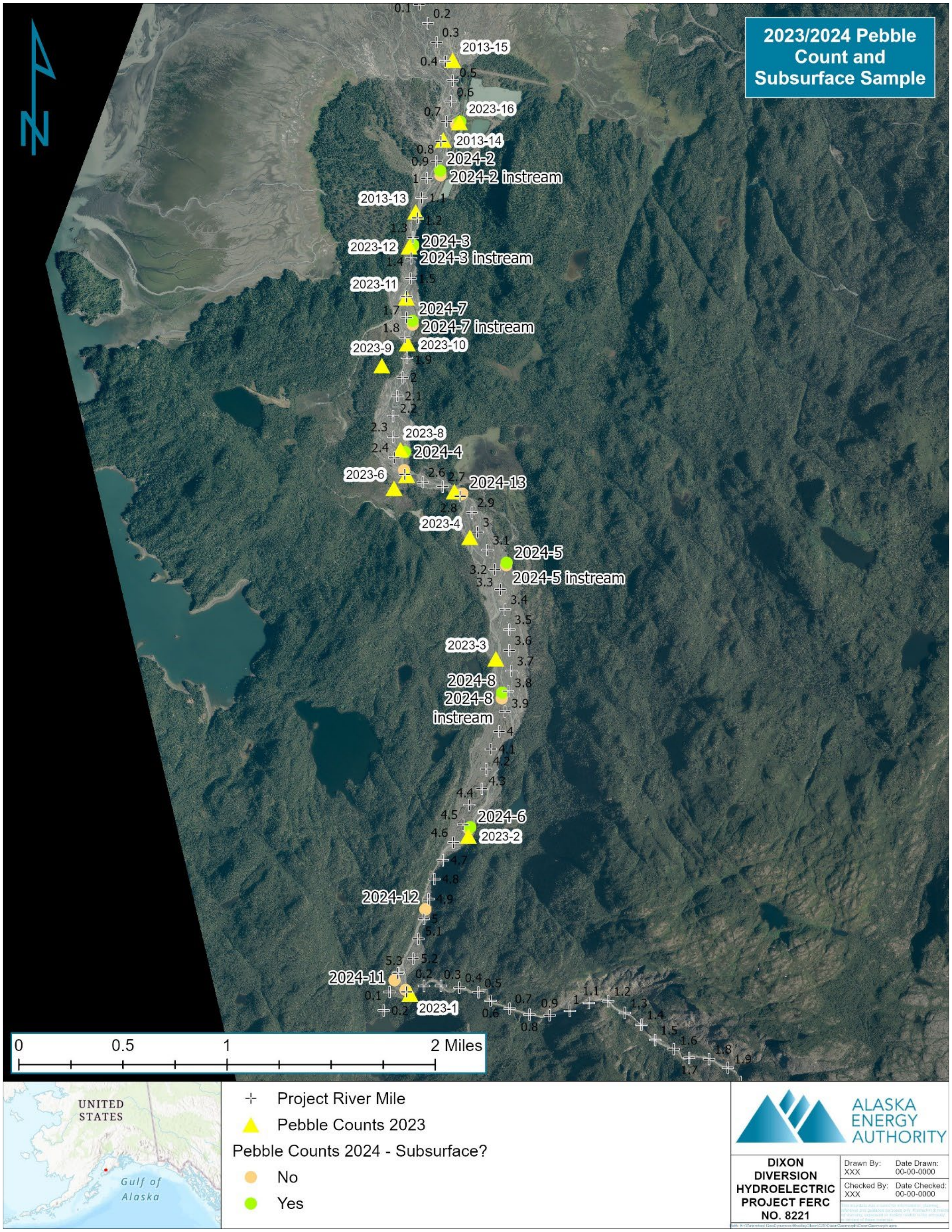


Figure 4-1 Martin River 2023/2024 pebble count and sub-surface sample locations.

4.3.2 Sub-surface Sampling

In 2024, sub-armor samples were taken at eight locations in conjunction with the 2024 pebble counts (Figure 4-1). For sub-surface samples, the surficial (armor) layer was scraped away to one median grain size depth over an approximately 25-40 square foot area. The sub-surface material was removed using a pickaxe and shovel and loaded into 5-gallon buckets. Each bucket was weighed and then sieved through a 32-mm sieve in the field. Clasts larger than 32 mm were separated into size classes (e.g., 32-45 mm, 45-64 mm, 64-90 mm, 90-128 mm, etc.) on a tarp. Total sample size varied depending upon the weight of the largest particle, with the 1 percent sample mass criteria of Church et al. (1987) being the goal sample size. If the largest class was extremely heavy (for example, the largest particle in sample 2024-6 was 16.9 kg which would have required a total sample size of 1690 kg), Church's 2-5 percent criteria was used.

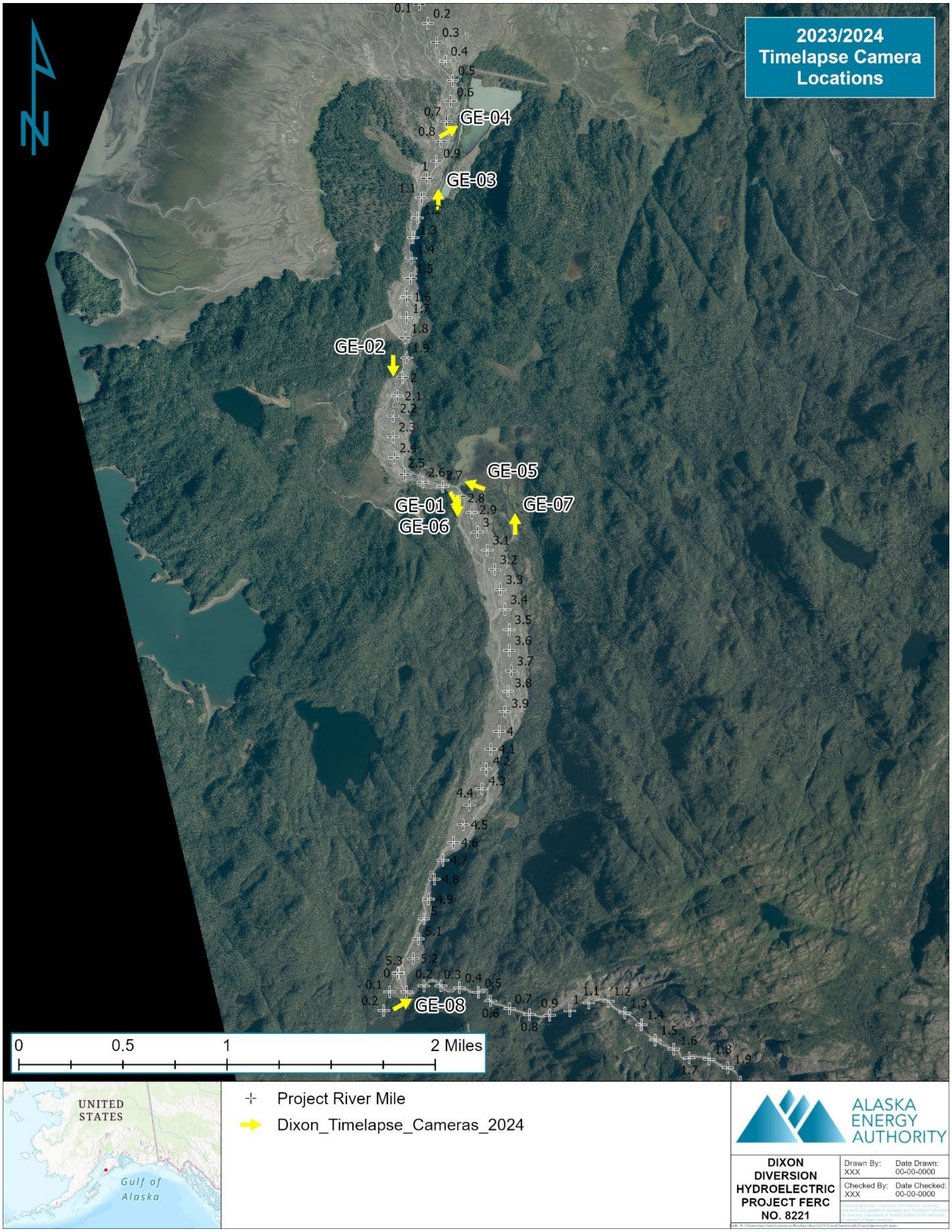
When the entire sample was field sieved, the clasts in each grain size were weighed and recorded on the data sheet. The remainder of the sample (finer than 32 mm) was weighed and then split with approximately 15-20 kg bagged and tagged to bring back for laboratory sieving. Laboratory sieving of the finer fraction sub-samples was conducted by Alaska Testlab in Anchorage, AK. Samples were dried and sieved through a series of sieves (32 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.065 mm) and the weight of sample retained on each sieve was recorded, along with the remaining fine fraction. The weights retained reported by the lab were multiplied by the ratio of total finer than 32 mm field weight/split weight and combined with the field weights of each particle size class to produce a complete particle size distribution for each sub-armor sample.

4.4 Timelapse Cameras

Timelapse cameras were deployed at three locations with a view of braided areas along the Martin River to record braid/sediment transport timing during 2023. In 2024, a total of eight timelapse cameras were deployed (Figure 4-2, Photo 4-1 through Photo 4-8). The 2024 deployment included locations with braided channels as well as locations with views of off-channel habitat and one location looking up the EFMR canyon.

The cameras were Brinno TLC 202 timelapse cameras in waterproof housing (with 1 gm desiccant pack) with mounting bracket. Each bracket was screwed to a 12-inch-long piece of 1-inch by 6-inch wooden board. The boards were attached to an appropriately sized tree by two tie-down straps. Cameras were set to take one photo per day at approximately noon in 2023 and three photos per day at 7 AM, 1 PM, and 7 PM in 2024. In 2023, cameras were installed on May 16, 2023, serviced (fresh batteries and micro-SD cards) on August 24, 2023 and removed on October 19, 2023. In 2024, cameras were installed on April 18, 2024. Cameras GE02, GE03, GE04, GE06, GE07, and GE08 were serviced on August 21, 2024 and Camera GE05 was removed on that day due to channel changes that made the location infeasible. Camera GE01 was not serviced in August due to channel changes that made the location unreachable under the flow conditions that day. All remaining cameras were removed on October 30, 2024.

The footage from each camera was viewed to determine dates when channel change occurred. Movement of braided river channels occurs when bedload transport takes place (Middleton et al. 2019). The dates with channel change were noted for each camera and correlated with gage height and/or flow measured at the USGS gage (USGS 15238951 EFMR at mouth near Homer, AK) and the RM1.9 constriction gage (DOWL 2024).



Note: Arrows show direction camera pointed.

Figure 4-2 Martin River 2023 and 2024 timelapse camera locations.

Photo 4-1 Martin River timelapse Camera GE01 view looking upstream, May 16, 2023 (top image) and April 18, 2024 (bottom image).

Photo 4-2 Martin River timelapse Camera GE02 view looking upstream, May 16, 2023 (top image) and April 18, 2024 (bottom image).

Photo 4-3 Martin River timelapse Camera GE03 view looking downstream, May 16, 2023 (top image) and April 18, 2024 (bottom image).

Photo 4-4 Martin River timelapse Camera GE04 view looking downstream April 18, 2024.

Photo 4-5 Martin River timelapse Camera GE05 view looking downstream April 18, 2024.

Photo 4-6 Martin River timelapse Camera GE06 view looking upstream April 18, 2024.

Photo 4-7 Martin River timelapse Camera GE07 view looking downstream April 18, 2024.

Photo 4-8 Martin River timelapse Camera GE08 view looking upstream April 18, 2024.

4.5 Sediment Transport and Deposition Patterns under Current and Potential Future Flow Regimes

Bedload transport in gravel-bedded rivers occurs when river flows are high enough to mobilize the armor (coarser, surficial) layer on the riverbed. Bedload transport is a function of shear stress acting on the gravel/cobble particles on the riverbed, and can be calculated based on river depth and velocity.

4.5.1 Sediment Transport Analysis Using 2Dimensional Hydraulic Model Output

The 2D hydraulic model (Kleinschmidt Associates 2025) was used to estimate river depth and velocity under five different peak flow scenarios. The model was run with the following flows:

- EFMR: 1,000 cfs, 2,000 cfs, 3,000 cfs, 4,000 cfs, 5,000 cfs
- WFMR: 10 cfs for all scenarios
- Mid-reach inflows: 1 cfs
- Other tributaries: 0 cfs

The critical diameter (diameter of the substrate that can be moved under given flow conditions) was computed for each cell in the 2D model output using the method described in Appendix B of EM 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) is 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)

The critical diameter was computed in ArcGIS Pro and used to produce maps showing critical diameter under the five flow scenarios. These maps were compared to surficial grain size data (pebble counts) collected during the field visits.

4.5.2 Comparison of Future Sediment Input and Transport Potential

Comparison of future sediment input and transport potential will be completed in 2025.

4.6 Synthesis of Hydraulic, Geomorphic, Riparian, and Aquatic Analyses: Potential Pathways of Change in River Valley Characteristics, Riparian Habitat, and Aquatic Habitat/Connectivity

Synthesis of hydraulic, geomorphic, riparian, and aquatic resource effects of proposed changes to Martin River flow regimes will be completed in 2025.

5.0 RESULTS

5.1 Geomorphic Reach Mapping and Channel Change Mapping from Historic Aerial Photographs

Delineation of geomorphic reaches along the Martin River is helpful to differentiate parts of the river with different gradient and confinement characteristics that are often correlated with varying responses of the channel to changes in water or sediment supply. Geomorphic mapping units are similar, but instead of linear features the map units are areas of the river valley that have had similar past geomorphic activity. For example, unvegetated alluvial areas indicate recent fluvial reworking while areas with vegetation of a similar height or age indicate the length of time since the river was active in those areas. The following sections describe geomorphic reaches and geomorphic map units based on recent conditions using the 2022 and 2024 aerial photographs, LiDAR, and field observations. Changes to geomorphic reaches downstream from RM 1.9 resulted from the August 2023 levee breach.

5.1.1 Geomorphic Reaches of the Martin River

Twelve different geomorphic reaches were delineated along the Martin River and EFMR from tidewater to the Dixon Glacier in both 2022 and 2024 (Table 5-1, Figure 5-1, Figure 5-3). Reaches that are constricted/confined by bedrock or steep valley walls generally have one or two channels; unconfined areas generally have multiple channels (Figure 5-2). The number of wetted channels in each unconfined reach varies depending on flow conditions; at higher flows, more channels are wetted while at lower flows only one or two channels may be wetted. Note that Geomorphic Reach 8, while unconfined by valley walls, was subdivided into two distinct sub-reaches; a downstream unconfined sub-reach with multiple channels and an upstream sub-reach that is currently confined by a high terrace. The upstream reach (8b) is currently incising into past deposits to create the confining terrace; this section of the river was not confined to a single channel on historical aerial photographs (see discussion in Section 5.1.3).

In 2022, average channel gradients in the geomorphic reaches were relatively consistent (0.6 to 0.8 percent) between the delta (Geomorphic Reach 1) and Geomorphic Reach 7 except for the slightly steeper Geomorphic Reach 5 constriction. Channel gradients gradually increased in the upstream direction from Geomorphic Reach 7 (0.8 percent) through Geomorphic Reach 9 (1.5 percent). The EFMR canyon (Geomorphic Reach 10) had an average gradient of 6.7 percent, with gradient increasing closer to the Dixon Glacier. Channel changes at the mouth of the Martin River in response to the August 2023 levee breach resulted in slight changes in channel gradient in Geomorphic Units 3 and 4.

Table 5-1 2022 and 2024 geomorphic reach characteristics.

Geo-morphic Reach No.	Reach Characteristics	2022 Length (ft)	2022 Average Gradient	2022 Braid Index	2024 Length (ft)	2024 Average Gradient
0	Tidewater	n/a	n/a	n/a	n/a	n/a
1	Delta	2,530	0.7%	4.0	3,145	0.7%
2	Levee	3,458	0.7%	10.6	2,447	0.7%
3	Constriction	1,365	0.6%	3.8	1,365	0.9%
4	Unconfined, left bank off-channel enters	2,114	0.8%	2.8	2,114	0.8%
5	Constriction	283	1.1%	1.6	283	0.7%
6	Unconfined; left bank off-channel area at upstream end	3,400	0.8%	6.2	3,400	0.8%
7	Moderately confined; right bank side channel enters	1,537	0.8%	6.0	1,537	0.8%
8a	Unconfined, multiple channels	5,536	1.2%	4.9	5,536	1.2%
8b	Unconfined single channel (constrained by high terrace)	3,820	1.2%	2.6	3,820	1.2%
9	Moderately confined single thread Red Lake outflow (WFMR) near upper end of reach	4,238	1.5%	1.1	4,238	1.5%
10	EFMR Canyon	19,671	6.7%	1	19,671	6.7%
11	Glacier	33,256	9.8%	n/a	33,256	9.8%

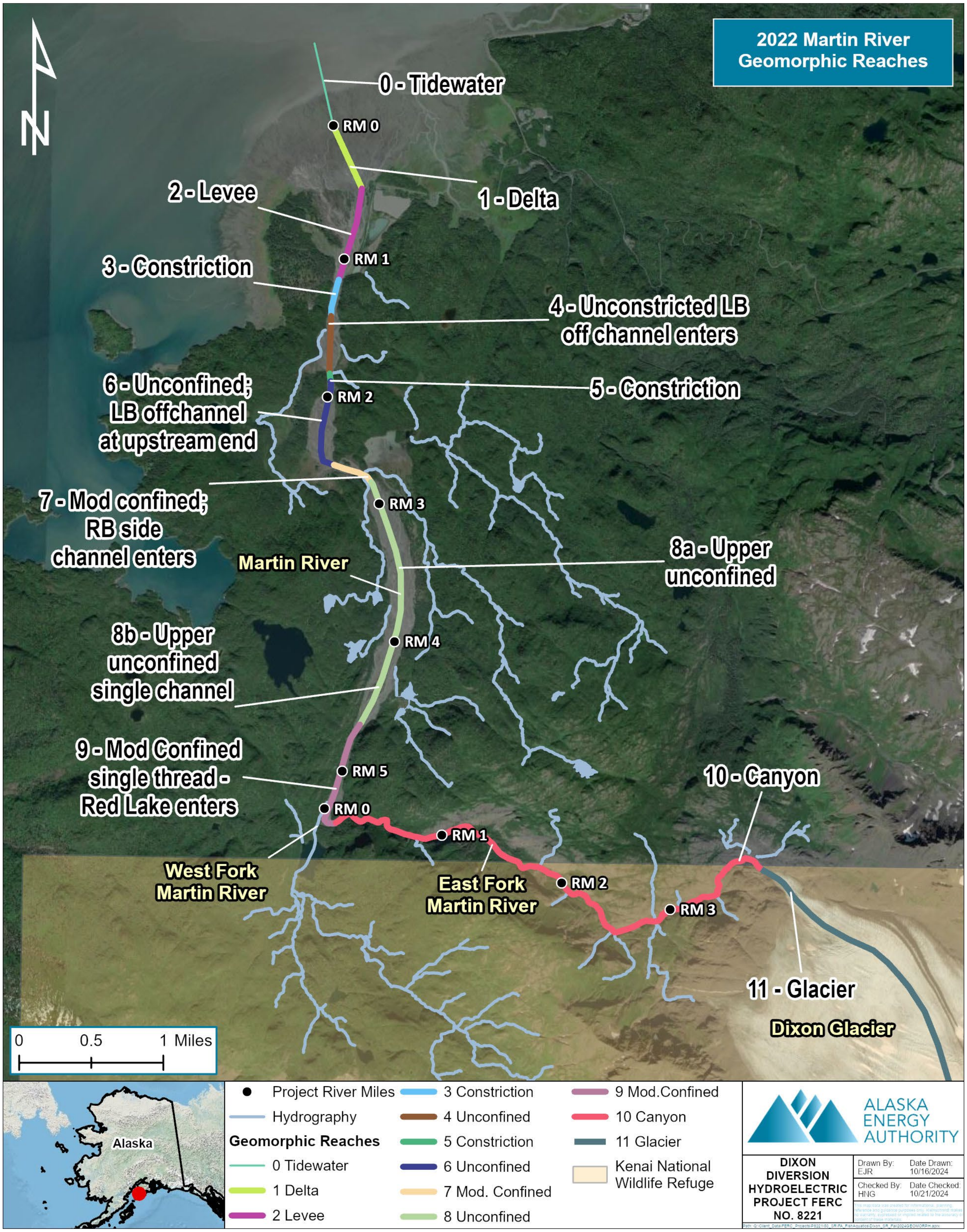


Figure 5-1 Martin River 2022 geomorphic reaches.

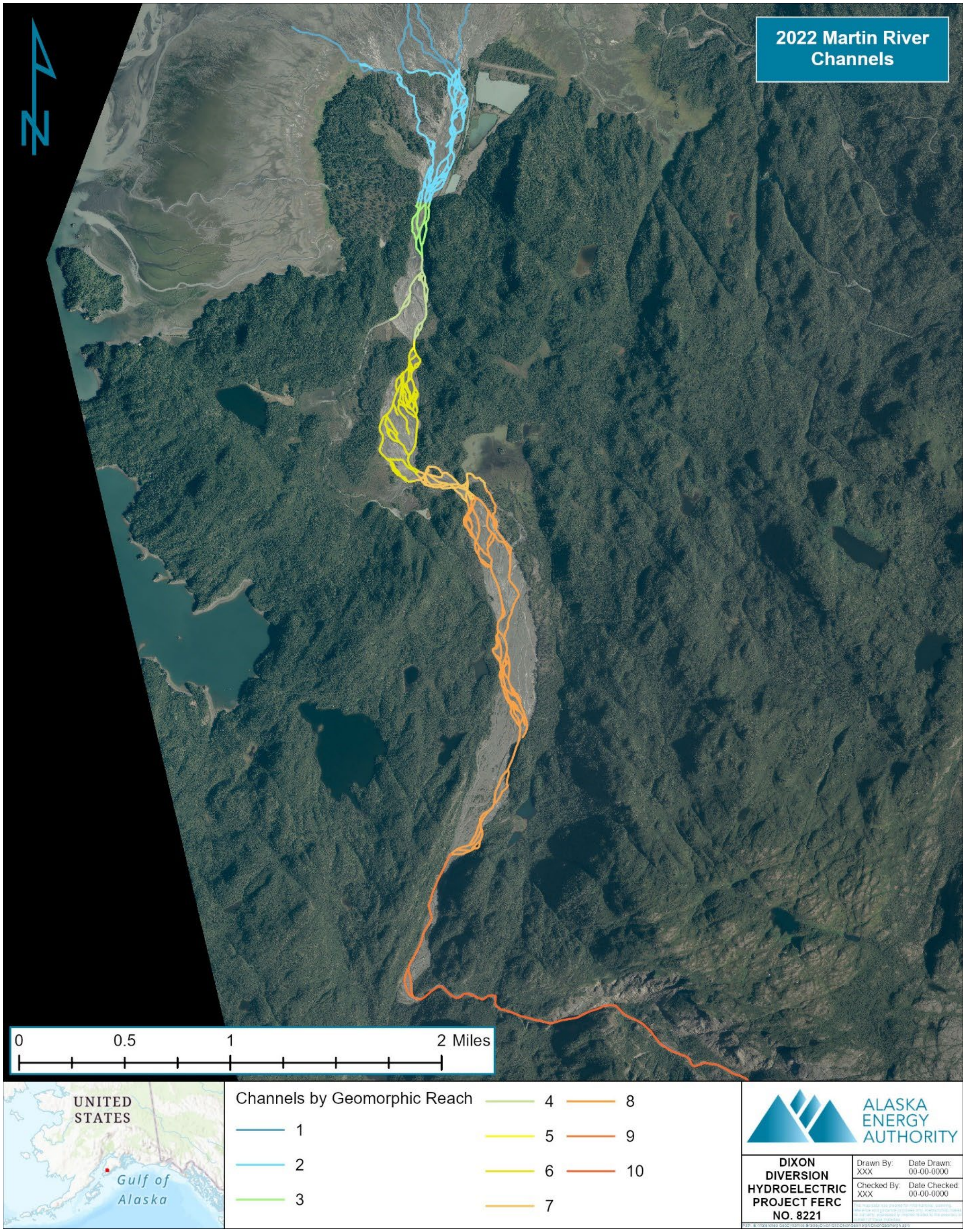


Figure 5-2 Martin River 2022 channels by geomorphic reach.

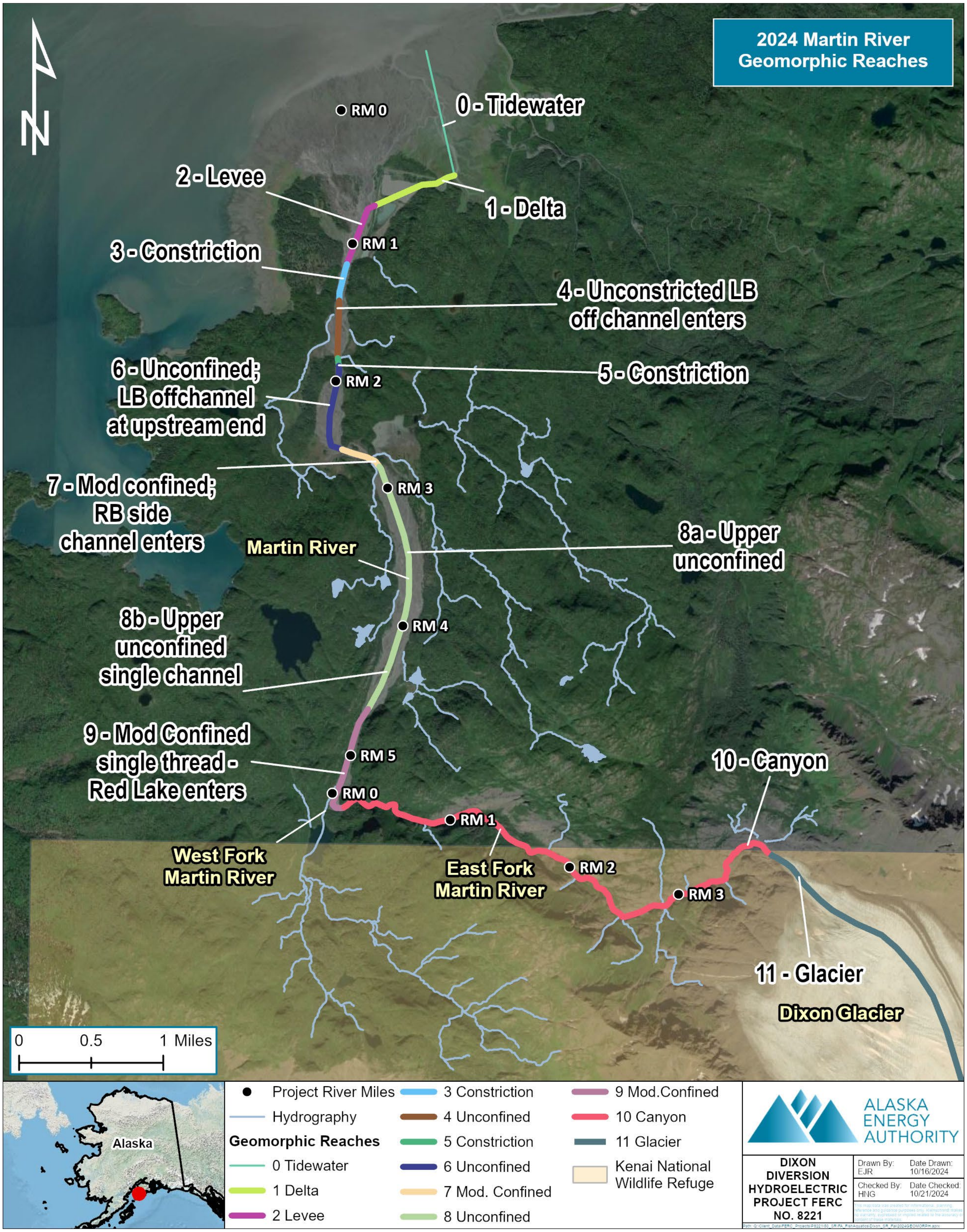


Figure 5-3 Martin River 2024 geomorphic reaches.

5.1.2 Geomorphic Units in the Martin River Valley

The Martin River valley is relatively flat bottomed with steep bedrock sidewalls as a result of the braided glacial river that has filled the valley with alluvial material. As the river fills one area of the valley bottom, the active channel moves into a different location in the valley bottom and the previously active area re-vegetates. The valley bottom was delineated into geomorphic units based on 2022 dominant geomorphic process or, in the case of forested valley bottom areas, vegetation height that is indicative of the length of time since the area was part of the active channel (Table 5-2 and Figure 5-4). Geomorphic Units were added to the river valley on the east side of the levee based on the 2024 aerial photographs and LiDAR based on conditions at the time of the aerial photographs (May 2024). Note that the river continues to evolve east of the levee breach, as discussed in Section 5.1.3.3.

The active channel Geomorphic Unit dominates the Martin River valley, with unvegetated alluvial deposits and an active braid plain up to 1,000 feet wide in unconfined areas of the valley.

At least five off-channel areas or tributaries and connecting channels (corridors) occur between RM 1.5 and the WFMR confluence. All of the off-channel/tributary areas except the left bank lakes at RM 3.4 show evidence of current or recent (past 50 years) activity from the mainstem river channel in the form of alluvial deposits or turbid water during high flow conditions.

There are three large, forested areas that have small active mainstem channels, primarily high flow channels: the left bank area at the mouth of the river that is part of the Martin River delta, and large areas on the right and left bank between RM 2 and RM 3 that connect to off-channel areas. Based on field observations, the river valley has recently been actively aggrading in the active channel adjacent to these locations which has resulted in fresh alluvium and small high flow channels through the forested areas.

Much of the remaining valley is in various stages of revegetation following past fluvial activity. Tree height and species are indicators of how recently these areas have been active and can provide insights into how frequently the Martin River re-occupies portions of the valley. Revegetation generally starts with forbs, alder, and cottonwood. Spruce regeneration follows. Cottonwood grows tall quickly; spruce grows more slowly.

Table 5-2 2022 and 2024 geomorphic units in the Martin River valley.

Geomorphic Unit Name	Characteristics	2022 Area (acres)	2024 Area (acres)
Tidelands	Areas that are primarily tidal in nature.	33	33
Active channel (2022)	Unvegetated (or very sparsely vegetated) alluvial areas indicative of relatively recent fluvial action.	605	623
Off-channel habitat or tributaries	Ponds or wetlands that are connected to the active channel area but do not currently show signs of recent mainstem re-working (some off-channel areas receive high flows from the Martin River, some areas are only connected by channels flowing out of the off-channel habitat and maintain relatively low turbidity water). Includes WFMR/Red Lake	80	98
Off-channel/tributary connectivity corridor	Small channels that connect off-channel/tributary habitat with the main channel.	4	4
Forested with small active high flow channels	Primarily forested area that contains one or multiple Dixon River channels; these channels are wetted primarily under high flow conditions.	395	406
Vegetated (to 5 ft high)	Vegetated valley bottom with shrubs/trees up to 5 feet high.	33	33
Vegetated (to 10 ft high)	Vegetated valley bottom with shrubs/trees up to 10 feet high.	4	6
Vegetated (to 15 ft high)	Vegetated valley bottom with shrubs/trees up to 15 feet high.	16	16
Vegetated (to 20 ft high)	Vegetated valley bottom with shrubs/trees up to 20 feet high.	18	18
Vegetated (to 30 ft high)	Vegetated valley bottom with shrubs/trees up to 30 feet high.	2	2
Vegetated (to 40 ft high)	Vegetated valley bottom with shrubs/trees up to 40 feet high.	37	37
Vegetated (to 50 ft high)	Vegetated valley bottom with shrubs/trees up to 50 feet high.	55	55

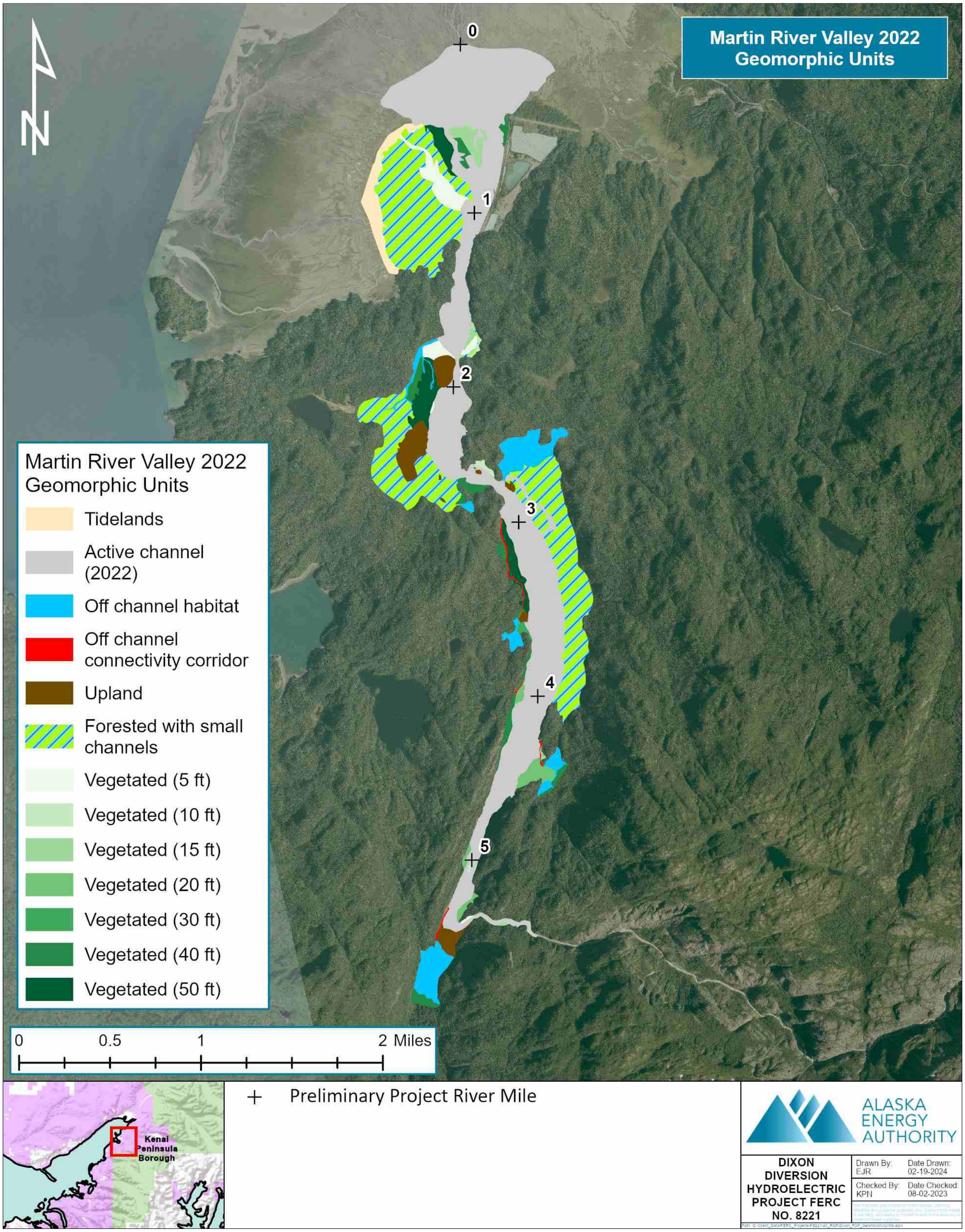


Figure 5-4 2022 Martin River valley geomorphic units.

5.1.3 Historical Aerial Photograph Mapping of the Martin River Valley

An overview of historical aerial photographs from 1950 through present (Table 4-1, above) yielded the following observations which are examined in greater detail in the following sections:

- The Dixon Glacier has been progressively retreating since the 1952 aerials (and likely since the late 1800s Little Ice Age Maximum). There were large areas of unvegetated and unconsolidated deposits in the EFMR valley that were eroding in the 1952 photos.
- The Martin River downstream from the EFMR canyon has been active across much of the valley, with the active channel occupying different parts of the valley, off-channel areas, and river delta through the years.
- The Martin River has been aggrading differently in the various reaches of the channel through time (e.g., aggradation rates are not necessarily constant throughout the river in space or time).
- The general characteristics of geomorphic reaches (e.g., single or multi-channel) have been relatively constant since 1950 except for Geomorphic Reach 8b which was a multi-channel reach prior to at least 1996. This suggests downcutting in Geomorphic Reach 8b that created the constraining terrace occurred after 1996.
- The Martin River aggraded enough to overtop and erode the right bank levee at the former borrow pit/mitigation ponds near the mouth of the river in 2023. The river has been adjusting to this change by building a delta into the former borrow pit/mitigation ponds.

5.1.3.1 Glacial Extent and Sediment Sources

The Martin River is a braided river, indicating that the sediment supply to the river far exceeds the ability of the river to transport the sediment load. To understand past and potential future changes to the river valley and channel form, it is important to evaluate sediment source areas and changes to sediment loading through time. Timescales important for river geomorphology and sediment transport are over centuries and decades as well as annual variations. The Dixon Glacier and Martin River watershed are the sediment source areas of the Martin River.

While there are no studies of the Dixon Glacier itself, research on the nearby Grewingk Glacier show that following the late Pleistocene glacial maximum, Kenai Peninsula glaciers began retreating during a warming period around 11,000 years ago (Wiles and Calkin 1990, Reger et al. 2008, LaBrecque and Kaufmann 2016). Following multiple re-advances and retreats in the early Holocene, the glaciers appear to have retreated to near their present positions by approximately 600 A.D. The Little Ice Age saw advance of the Kenai Peninsula glaciers, with the Grewingk Glacier advancing 2-3 miles from its present terminus between about 1400-1850 A.D., followed by retreat from the late 1800s to present.

Aerial photograph analysis of the primary eastern terminus of the Dixon Glacier shows it has been receding, with a retreat of 7,622 feet (1.4 miles) between 1952 and 2022 (average 109 feet/year; Figure 5-5 and Figure 5-6). The 1952-2022 retreat rates have not been steady, but this could be influenced by the topography of the canyon at the toe of the glacier; there are several very steep and constrained waterfall areas that result in differential ice thicknesses and toe widths (narrow tongue vs. wider terminus) that affect retreat rates.

The smaller, western lobe of the glacier has also been retreating; when the western terminus retreats above the current topographic divide between the eastern and western lobes, there will be no flow into the Martin River from the western lobe outlet stream. Instead, all flow from the Dixon Glacier will come from the outlet stream emanating from the eastern lobe.

If it is assumed that this average retreat rate can be applied to the retreat of the Dixon Glacier since the Little Ice Age Maximum (late 1800s), it would put the terminus of the Dixon Glacier approximately 3 miles downvalley from the present terminus. This is consistent with the Little Ice Age Maximum advance of the Grewingk Glacier.

Using the 3-mile downvalley estimate as a starting point, the 2022 LiDAR was evaluated for topographic evidence of the Little Ice Age Maximum of the Dixon Glacier, either moraines or erosional features consistent with glacial activity. A prominent series of moraine features was observed trending north of the present Dixon Glacier that connected to distinct erosional features in the Martin River canyon and moraines and erosional features in the upper Red Lake valley. This estimated position of the Dixon Glacier at the Little Ice Age Maximum is shown in Figure 5-5 as a dashed black line and a dashed blue line on Figure 5-6.

The importance of this Little Ice Age Maximum is the resulting source of sediment to the Martin River as discussed below.

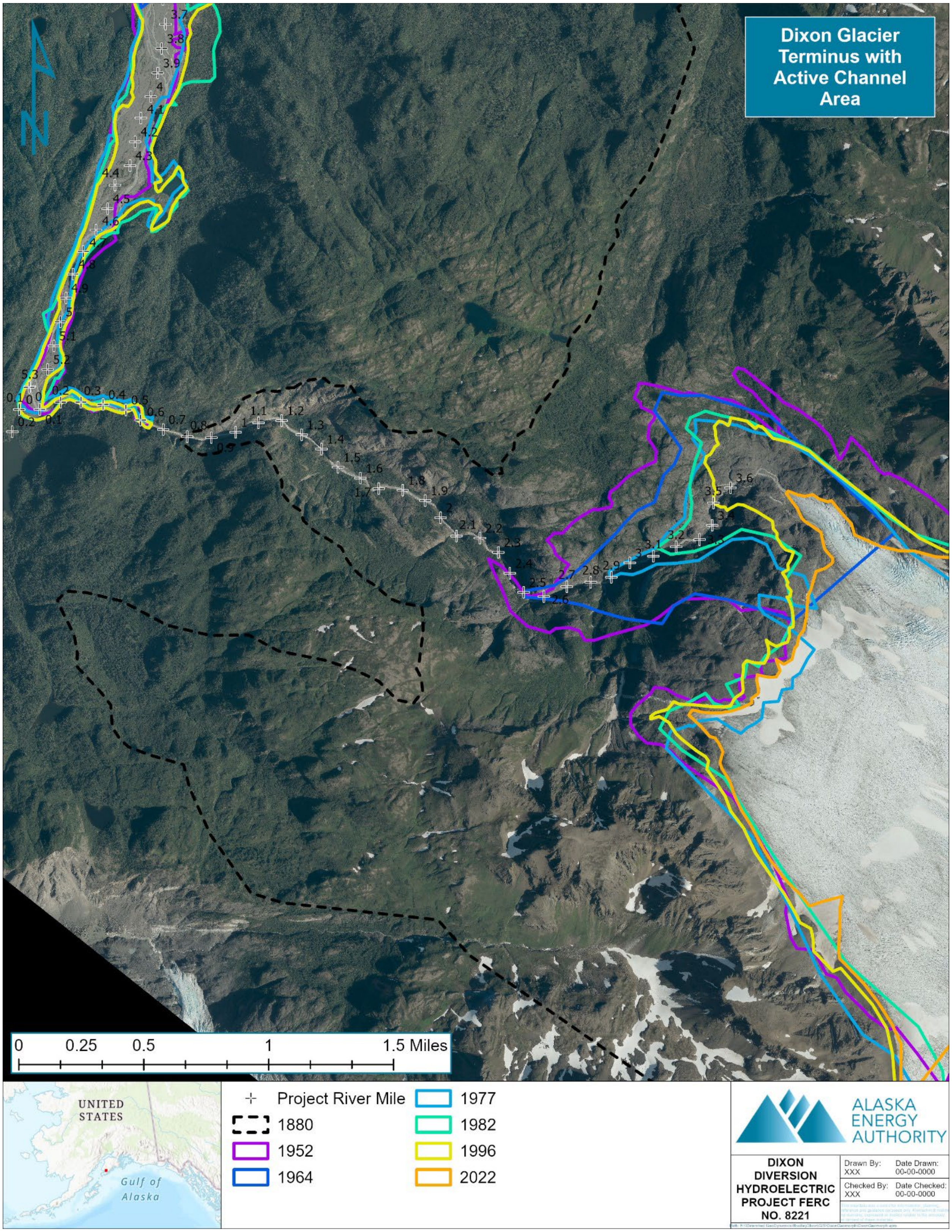


Figure 5-5 Dixon Glacier terminus positions Little Ice Age Maximum about 1880 through 2022.

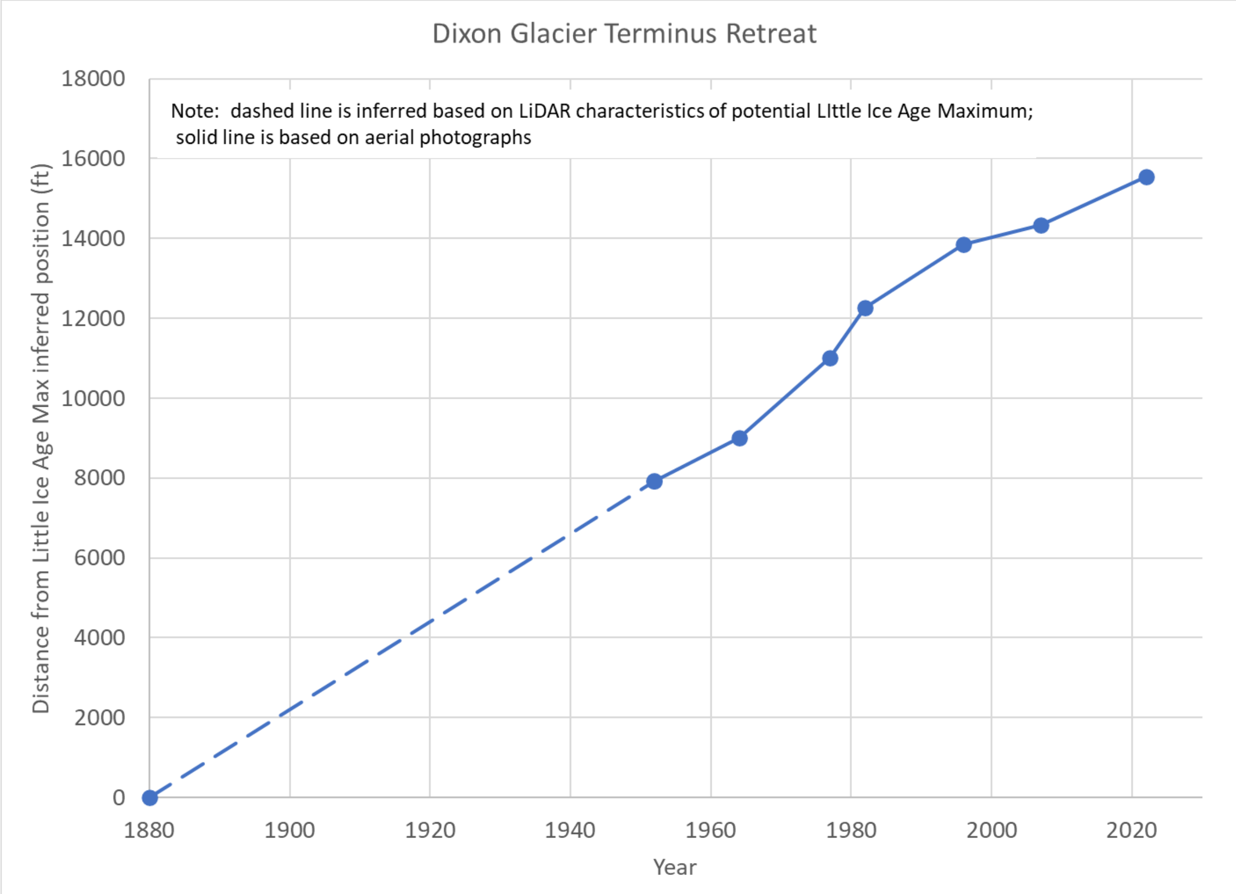


Figure 5-6 Dixon Glacier terminus retreat, late 1800s to 2022.

5.1.3.1.1 Martin River Sediment Sources

There are no direct measurements of sediment output from the Dixon Glacier. Measurements of basal erosion on other Alaskan glaciers range from 10 to 100 mm/year (Hallet et al. 1996). If it is assumed that over the long term, sediment output from the 59-acre Dixon Glacier is constant and falls within these basal erosion rates, average total sediment output (suspended load plus bedload) could range from 3,100 – 31,000 cubic yards/year. Of course, actual sediment output varies from year to year, but this calculation provides an estimate of potential sediment input from the Dixon Glacier outflow. Again, there are no data from the Dixon Glacier to provide guidance for partitioning the total sediment output into fine-grained (suspended load) and coarse-grained sediment (bedload). Data from other glacier systems is sparce and suggest that underlying bedrock characteristics such as hardness and composition affect the ratio, but total sediment load ranges from 10 to 50 percent bedload with the remainder suspended load. Increased sediment discharge during glacier retreat has been suggested by (Delaney and Adhikari

2020), so sediment yields from the Dixon Glacier outflow will likely remain similar to yields since the Little Ice Age Maximum.

In addition to sediment supply from Dixon Glacier outflow, sediment is supplied to the Martin River from the rest of the watershed. There are no large tributaries that supply sediment to the river (the majority of sediment from the WFMR valley is trapped in Red Lake), and no large landslides or other major sources of sediment were observed in the mainstem Martin River valley. However, there is evidence of large sediment sources within the footprint of the Little Ice Age Maximum of the Dixon Glacier in the EFMR valley.

The 1952 and 1964 aerial imagery shows large areas of unvegetated sediment between EFMR RM 0.9 and RM 2.2 in the EFMR valley with gullies and landslide scars and a wide, sediment-rich river in what is now the canyon (Figure 5-7). The 2022 LiDAR data further corroborates this interpretation of abundant sediment yield from unconsolidated, formerly sub-glacial sediment deposits between EFMR RM 0.9 and 2.2. A large, left bank, 3,500-square foot landslide scar is also evident on the LiDAR between EFMR RM 0.6 and 0.7; this landslide has a 250-foot-high headscarp. These features are still eroding on the 1964 aerial imagery, and then at least partially vegetated on the next available aerial image (1977, Figure 5-8) and the river is a narrower, single-thread channel, similar to conditions in the EFMR today (Figure 5-9). These images suggest that between the Little Ice Age Maximum and the mid 1900s, a large amount of sediment was supplied to the Martin River from erosion of unconsolidated sediment in the EFMR valley. Based on the glacial retreat rate shown Figure 5-6, it is likely that this sediment source area was exposed to maximum erosion (following glacial retreat and prior to revegetation) between about 1920 and 1965. The volume of sediment supplied from this source is difficult to calculate exactly since the pre-erosion topography is not known but based on elevational differences in the landslide and surrounding areas and in the sub-glacial deposit areas, up to 12,000,000 cubic yards of material could have been supplied to the Martin River over the 45-year period. This value will be compared to estimated aggradation volumes in the Martin River valley in subsequent sections.

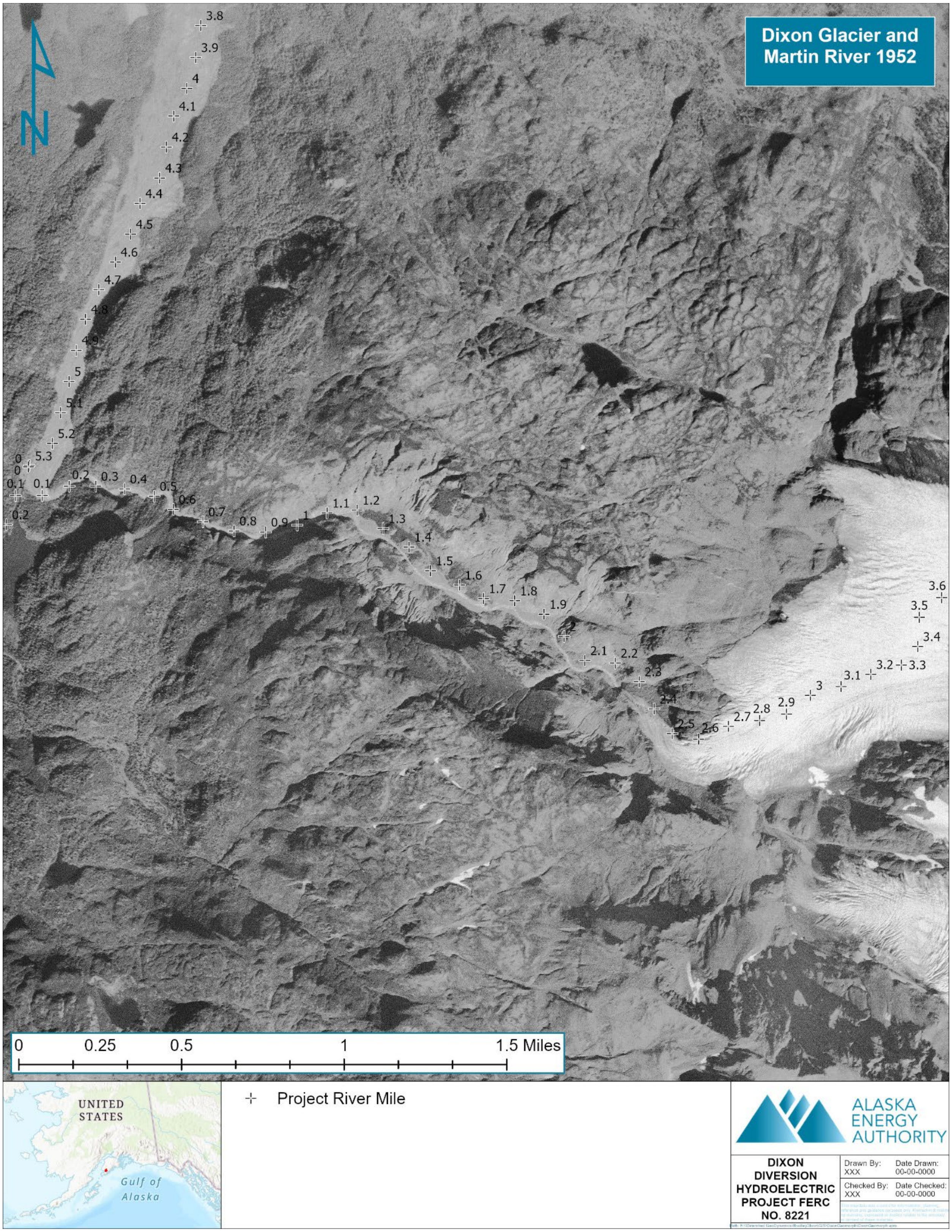


Figure 5-7 Dixon Glacier, East Fork Martin River, and upper Martin River 1952.

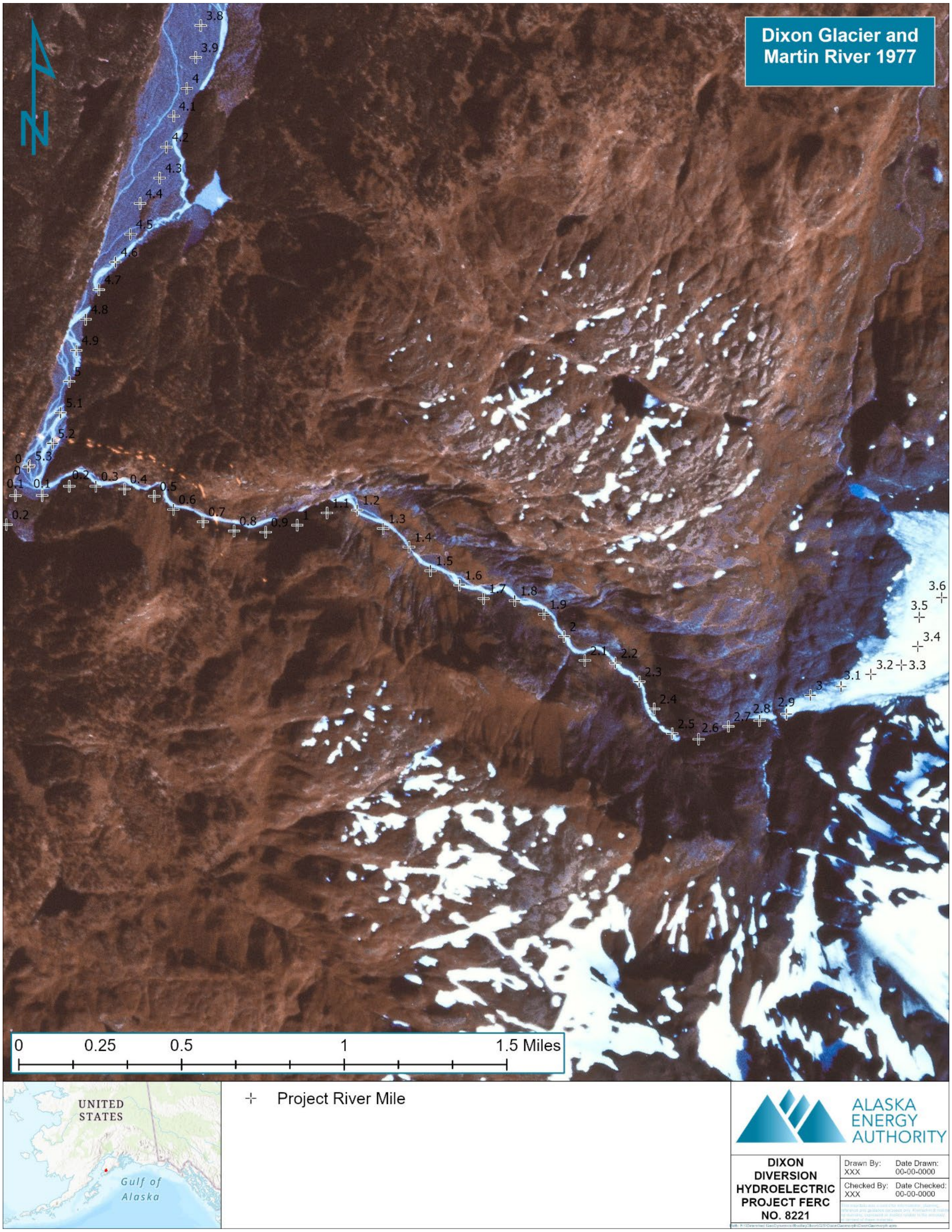


Figure 5-8 Dixon Glacier, East Fork Martin River, and Martin River 1977.

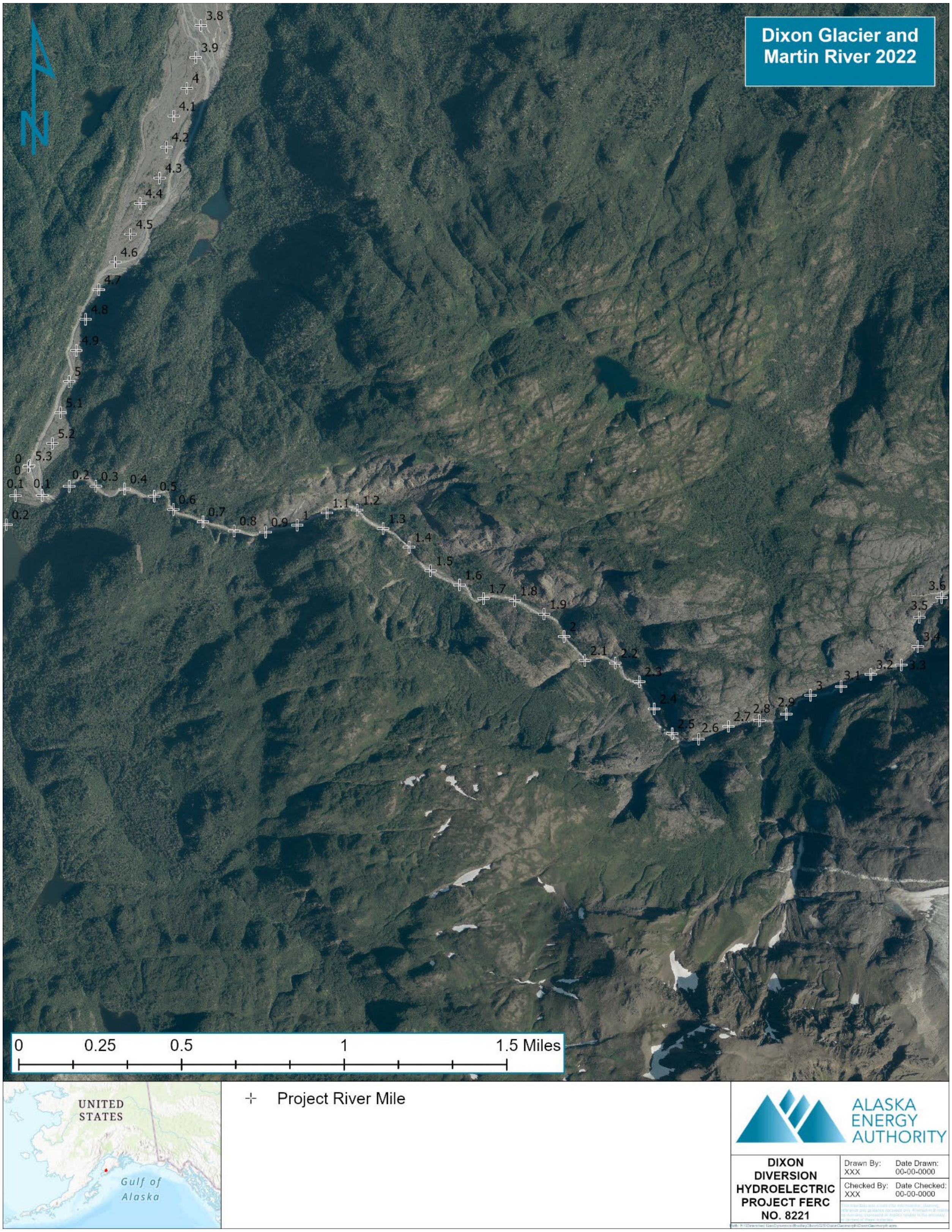


Figure 5-9 Dixon Glacier, East Fork Martin River, and upper Martin River 2022.

5.1.3.2 Martin River Channel and Valley Evolution

As discussed in previous sections, the Martin River is a braided river with a high sediment load from the current Dixon Glacier outflow as well as large episodic inputs of sediment from erosion of past glacial deposits in the EFMR watershed. It is hypothesized that these large episodic sediment inputs occurred between approximately 1920 through the mid-1960s following retreat of the Dixon Glacier after the Little Ice Age Maximum. Based on field and aerial photograph observations, it appears that this large sediment input has been progressively moving downstream over the past century. Researchers in gravel bed rivers suggest that large episodic sediment inputs (sediment “slugs”) diffuse as they move downstream, with finer-grained sediment moving more rapidly and coarser-grained sediment more slowly (Beechie 2001, Cui et al. 2003, James 2010, Nelson and Dubé 2016). Typical response time for rivers to return to pre-slug conditions is decades to centuries depending upon the side of the sediment slug and specific river dynamics.

Field observations of indicators of rapid aggradation in the Martin River valley include large buried trees in growth position in the middle of the Martin River valley, particularly in geomorphic reaches 8a and 8b (between RM 3 and 4.5; see Photo 5-1) and near the mouth of the river suggest periods of rapid aggradation in the past. The buried trees near RM 4.4 are particularly interesting because they show that a mature forest existed in the middle of the Martin River valley in the past, relatively rapid aggradation of at least 7-8 feet that buried the trees and protected the stumps from erosion, and subsequent incision of a similar amount exposed them. Field observations of river valley margins in 2023 and 2024 also showed indicators of aggradation, with valley-margin vegetation buried in recent gravel resulting in tree death, new channels into the left bank off-channel areas at RM 2.5 and RM 1.2, and overtopping of the right bank levee near the mouth of the river in late 2023 (see Section 5.1.3.3 for detailed discussion of August 2023 levee breach).

Photo 5-1 Buried trees in growth position near Martin River RM 4.4, photo taken looking upstream, May 22, 2023.

Observations of channel and valley evolution on the 1950s to present aerial photography further corroborates the field evidence of valley aggradation progressing downstream.

Off-Channel Habitat (OCH) RM4.3R (right): The 1952 aerial photographs show that the Martin River was not connected to the OCH RM 4.3R, with a band of relatively mature forest between the active (unvegetated) valley area and the OCH (Figure 5-10). By 1977, the river had aggraded and shifted toward the OCH, depositing sediment in a fan that reached the OCH right bank pond and split it into two ponds, killed part of the forest band, and allowed turbid mainstem water into the ponds. The 1982 aerial photographs show further development of the fan, no evidence of the former forested band, and a shift of the main channel back towards the middle of the valley.

Interestingly, this forest band is in the same location as the exposed stumps shown in Photo 5-1), suggesting that at least 7-8 feet of aggradation occurred between 1952-1982. The 1996-2022 aerial photographs show that the main channel no longer connected to the OCH RM4.3R ponds, and riparian vegetation was beginning to grow on the former fan. By 2022 the river had incised, and is likely still a few feet above the pre-1952 elevation forest in this area based on the buried tree stump elevations.

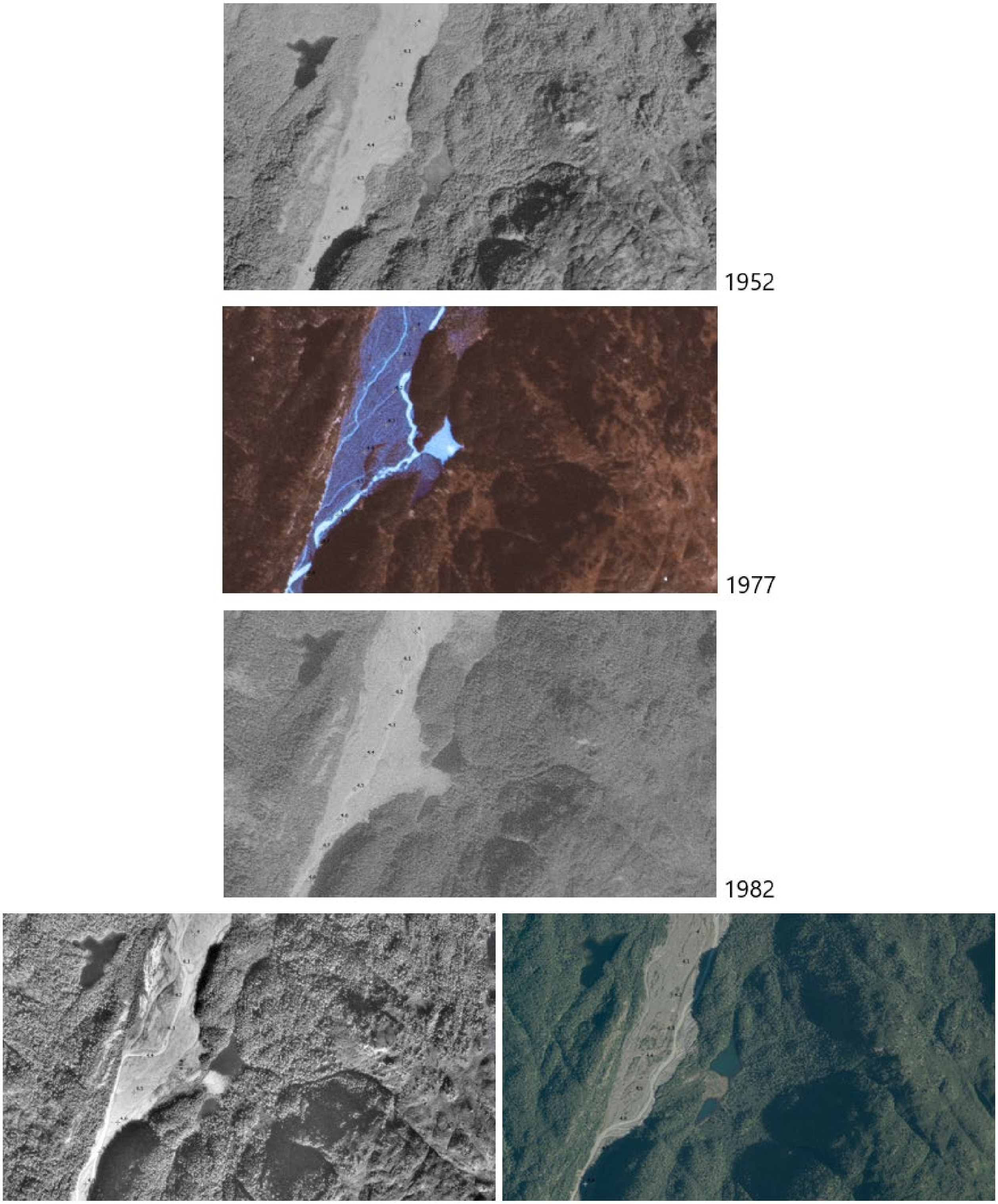


Figure 5-10 Evolution of Martin River RM 4.3 right off-channel habitat.

Unconfined Geomorphic Reaches 8a (RM 2.85-RM 3.9) and 6 (RM 1.9-2.55): In unconfined valley areas, changes in the active valley width (unvegetated valley width) through time can indicate changes in sediment deposition rates. Increases in sediment deposition (aggradation) can correspond with a valley widening response as sediment encroaches upon vegetation on valley margins. Conversely, decreases in active valley width can correspond to decreases in deposition rates or downcutting as vegetation can become re-established. Measurements of active valley width in Geomorphic Reach 8a show that active valley width increased through the mid-1980s then decreased through 2022 (Figure 5-11). The next unconfined geomorphic reach downstream (Reach 6) shows an increase in active valley width since the late 1970s through present (Figure 5-12).

The aerial photograph analysis, combined with field observations, suggests that the large sediment input that is inferred to have come from the EFMR valley between 1920 and 1964 has been progressively working downstream, with deposition around RM 4.3 in the 1970-1980 period (followed by channel incision in this area), deposition in the RM 2.8-3.9 area through the mid-1980s, and deposition in the RM 1.9-2.5 area from the 1980-1990 period through present. Assuming an average of 5 feet of aggradation in the active channel geomorphic units downstream from the EFMR/WFMR confluence in the last 100 years, a total of 4.6 million cubic yards of sediment is estimated to have accumulated in the valley over the last century. The accumulated material includes boulder, cobble, gravel, and sand-sized particles; the majority of finer sediment (silt/clay; glacial flour) would have been transported as suspended load through the Martin River into Kachemak Bay. The 4.6 million cubic yards of accumulation is a reasonable estimate when compared to the estimated 12 million cubic yards of sediment input from the EFMR valley and 3,000-30,000 cubic yards/year sediment input from the Dixon Glacier. These sediment input estimates include both coarse- and fine-grained sediment; the majority of the fine-grained sediment would have been transported through the river without being deposited.

The following section discusses aggradation at the mouth of the river and changes that have taken place since the 2023 levee breach.

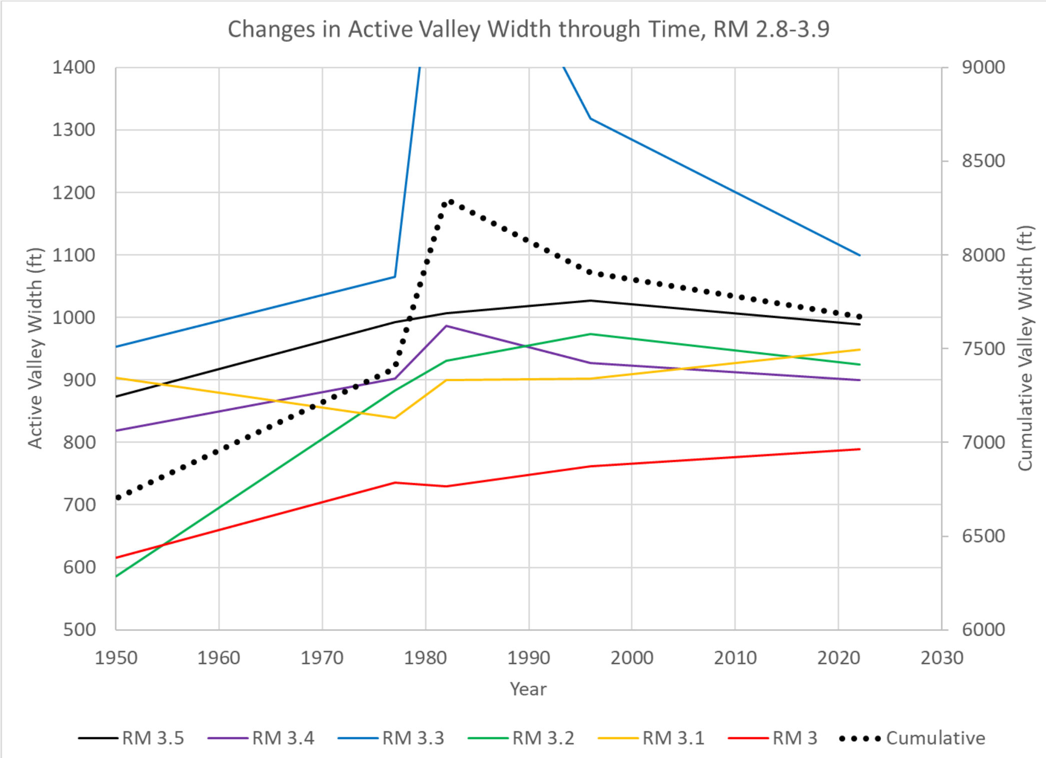


Figure 5-11 Temporal changes in active valley width, Martin River RM 2.8-3.9.

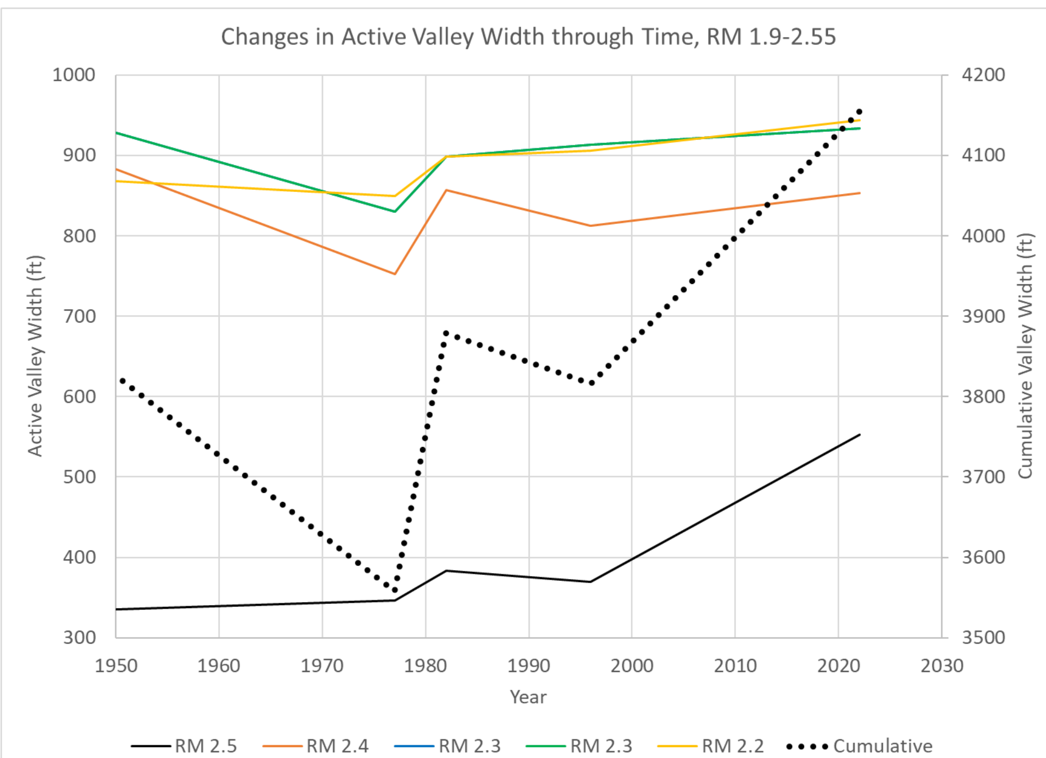


Figure 5-12 Temporal changes in active valley width, Martin River RM 1.9-2.55.

5.1.3.3 Evolution of the Martin River Following the August 2023 Levee Breach

The mouth of the Martin River has built a large, arcuate delta into Kachemak Bay. Prior to construction of a constraining, right-bank levee in the 1980s, the river position across the delta shifted as sediment was deposited and the delta aggraded. Construction of the right bank levee constrained the river and deposition areas to westward of the levee.

The right bank levee was constructed to separate the river from borrow pits that were dug to supply material used during construction of the Bradley Lake Hydroelectric Project in the 1980s. The levee spanned the east side of the Martin River delta from the airstrip at approximately RM 0.4 to a bedrock constriction near RM 1.1. The borrow pits were rehabilitated for fish spawning and rearing ponds in 1991 by the Alaska Energy Authority (AEA). As-built drawings of the borrow pits/levee (dated March 12, 1992) show the top of the levee was approximately five feet higher than the river at the breach location at time of construction, and borrow pits were dug 15 to 35 feet deep (Figure 5-14 and Figure 5-15). The levee was constructed with rip rap armoring on the river side but filled and topped with native material. It was anticipated that the Martin River would aggrade and eventually breach the levee based on assessments at the time (Parry and Seaman 1994).

As anticipated, the Martin River aggraded following construction of the levee. During reconnaissance site visits at high flow levels in 2022, a minor amount of flow from the river was overtopping the levee in the vicinity of the middle of the three ponds (approximately RM 0.2), the location where levee breaching occurred in 2023. The right bank levee was overtopped and breached by the river at the beginning of August 2023 (Figure 5-13). Based on satellite imagery from July and August 2023, the breach occurred between July 31 and August 2, 2023. It is hypothesized that the levee overtopped and river flow over the top and back side of the levee was forceful enough to erode the fill on the back side of the levee, leading to eventual undercutting of the protective rip rap on the river side of the levee and breaching of the levee (Photo 5-2). Pieces of rip rap were observed in the newly cut channel downstream from the breach location. Assuming 5 feet of aggradation in the 32 years between construction and overtopping yields an average aggradation rate of 0.16 feet/year.

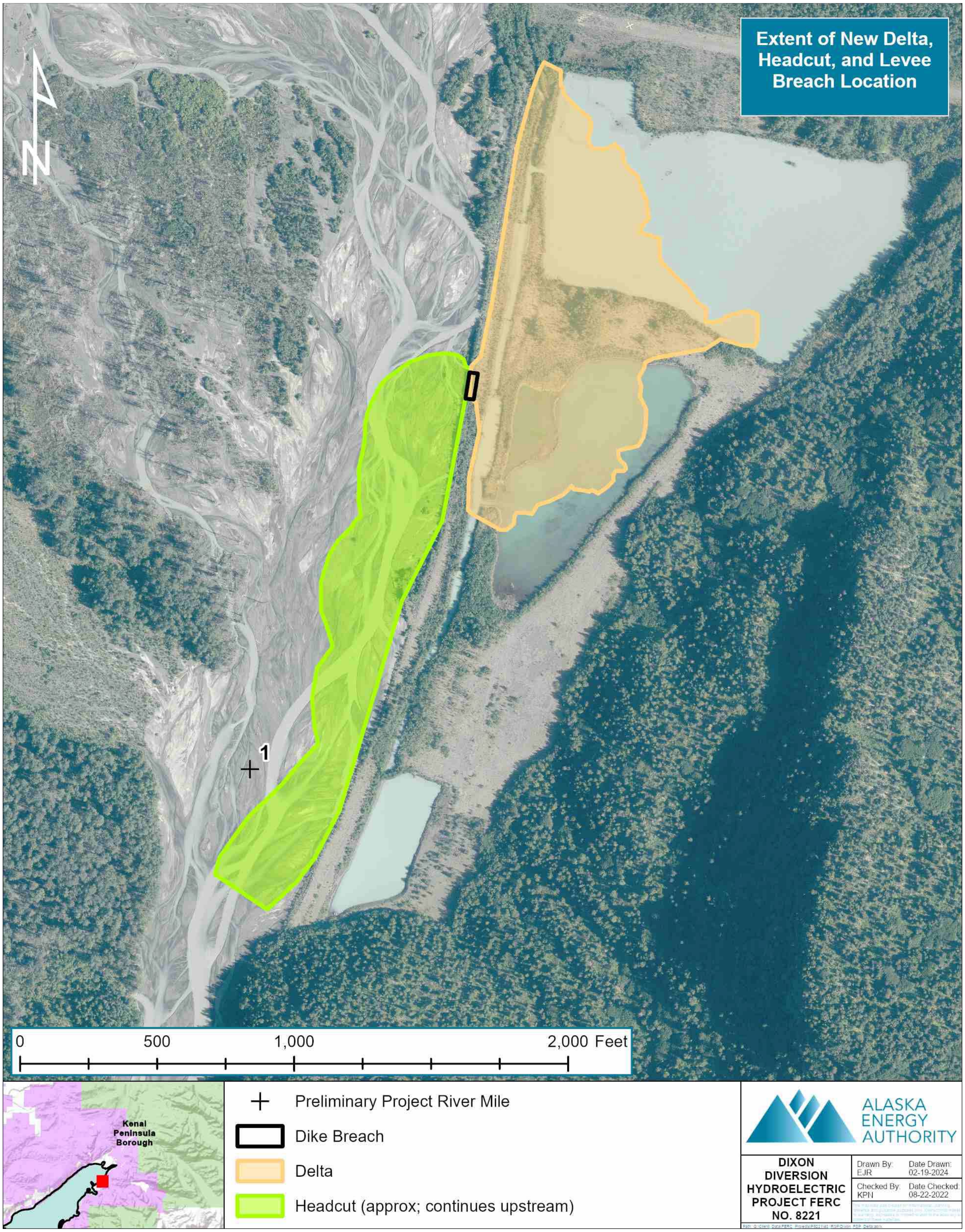


Figure 5-13 Extent of new delta, headcut, and levee breach location near the mouth of the Martin River, November 2023.

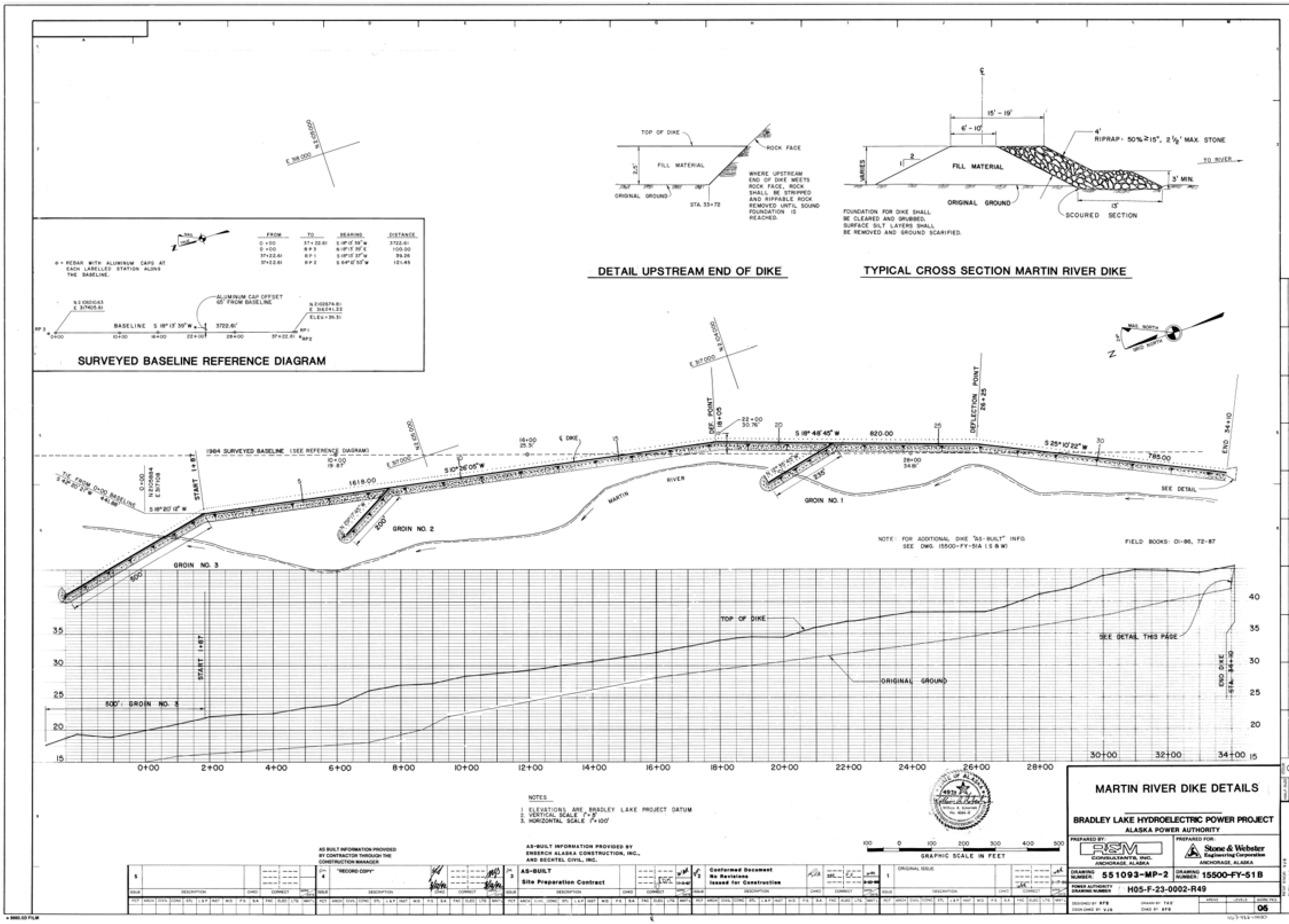


Figure 5-14 As-built drawing of Martin River levee.

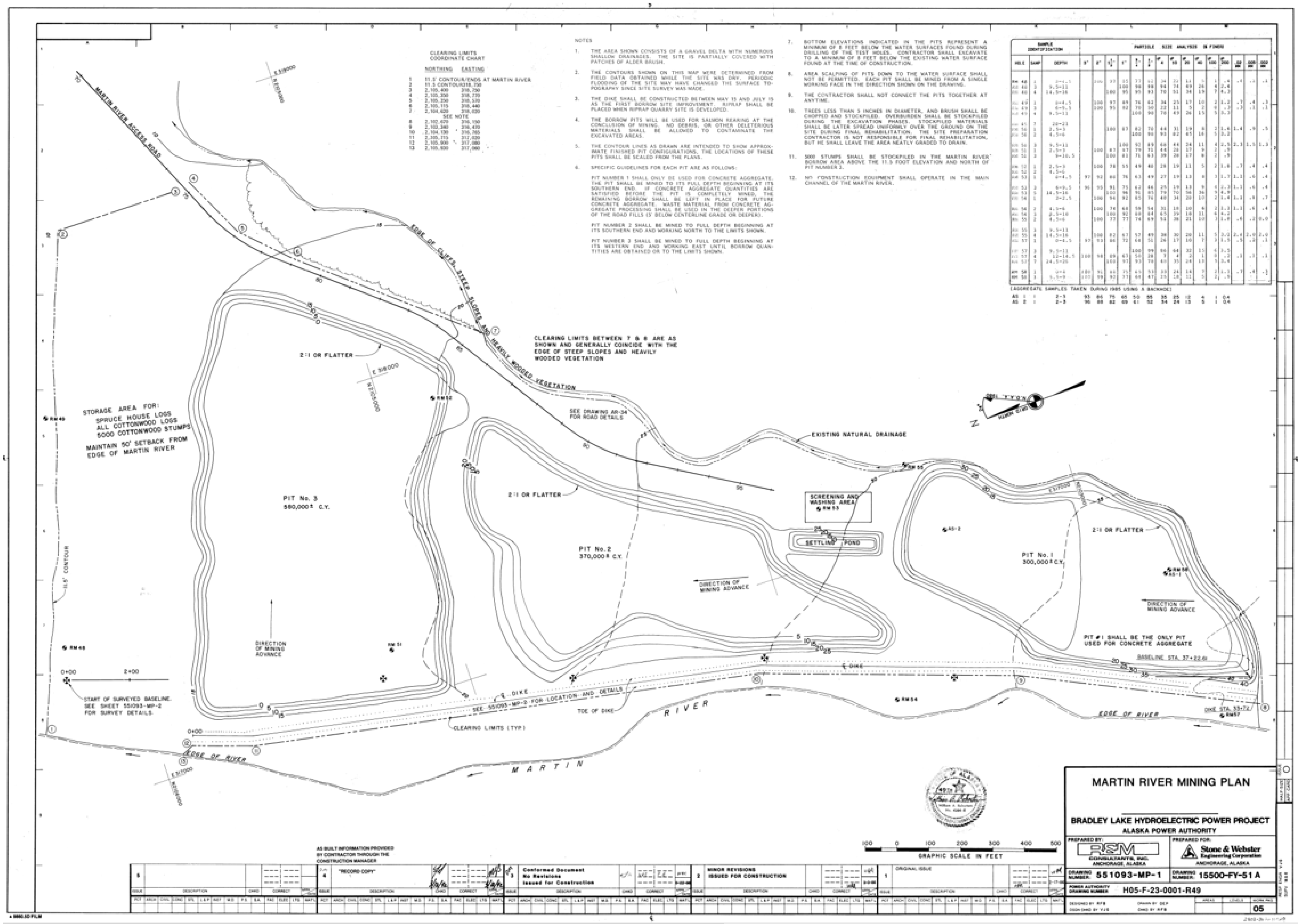


Figure 5-15 As-built drawing of Martin River mining plan (ponds).

Photo 5-2 Cross-section of levee at breach location, November 2, 2023.

Since August 2, 2023, all flow from the Martin River flows through the levee breach, into the mitigation ponds, and out a low point at the northeast corner of the largest (northern) pond into Kachemak Bay (Photo 5-3, Photo 5-4, and Photo 5-5). The river has been building a delta into the ponds, with up to 15- to 35-foot-deep accumulations in some areas (as of November 2023) assuming the northern-most ponds were originally dug 15 to 35 feet below grade as shown on the as-built drawings. As of November 2023, the delta covered approximately 19.5 acres. Coho Salmon adults were observed in the ponds and just upstream of the levee breach during the November 2023 site visit, indicating that they were able to utilize and traverse the new river channel. In November 2023, the bottom of the channel was approximately 10-12 feet below the top of the levee at the breach location. Upstream from the levee breach, the river has been eroding and headcutting as it adjusts to the new base level.

Photo 5-3 Extent of deposition in mitigation ponds; new Martin River outlet to tidewater (top right), November 2, 2023.

Photo 5-4 New outlet of Martin River looking upstream from tidewater to the northeast corner of the lowermost mitigation pond, November 2, 2023.

Photo 5-5 Mid-channel bar just downstream from levee breach (pebble count 2023-16 location), looking downstream, November 2, 2023.

Aerial imagery and LiDAR was acquired in May 2024 and showed the extent of the delta building at the mouth of the Martin River compared to 2022 conditions as well as the headcutting upstream from the breach location (Figure 5-16 and Figure 5-17). The difference between the 2024 and 2022 LiDAR is shown in Figure 5-18 with aggradation in red and erosion in green. Note that the former mitigation ponds are shown as erosion (blue/green); this is because the 2024 LiDAR captured the elevation of the bottom of the ponds and the 2022 LiDAR captured the surface elevation of the ponds – the difference shown is water depth in the ponds.

Field observations during May-October 2024 showed that the delta continued to aggrade into the former mitigation ponds. The high flow in August 2024 accelerated this delta building as well as headcutting upstream of the levee breach. Additional erosion of the northern levee edge occurred and was captured on the timelapse cameras (see images in Section 5.4 and Appendix A). It was estimated that the levee breach increased from 100 feet wide to approximately 200 feet wide during the high flow event.

As of the end of October 2024, the river had filled both northern mitigation ponds with sediment and had cut a wider channel through both the levee and the eastern pond/river outlet (Photo 5-6). There was evidence of multiple channels flowing across the airfield. The river will continue to aggrade in the former pond area over the next few decades.

Photo 5-6 Martin River mouth looking downstream from levee breach, October 30, 2024.

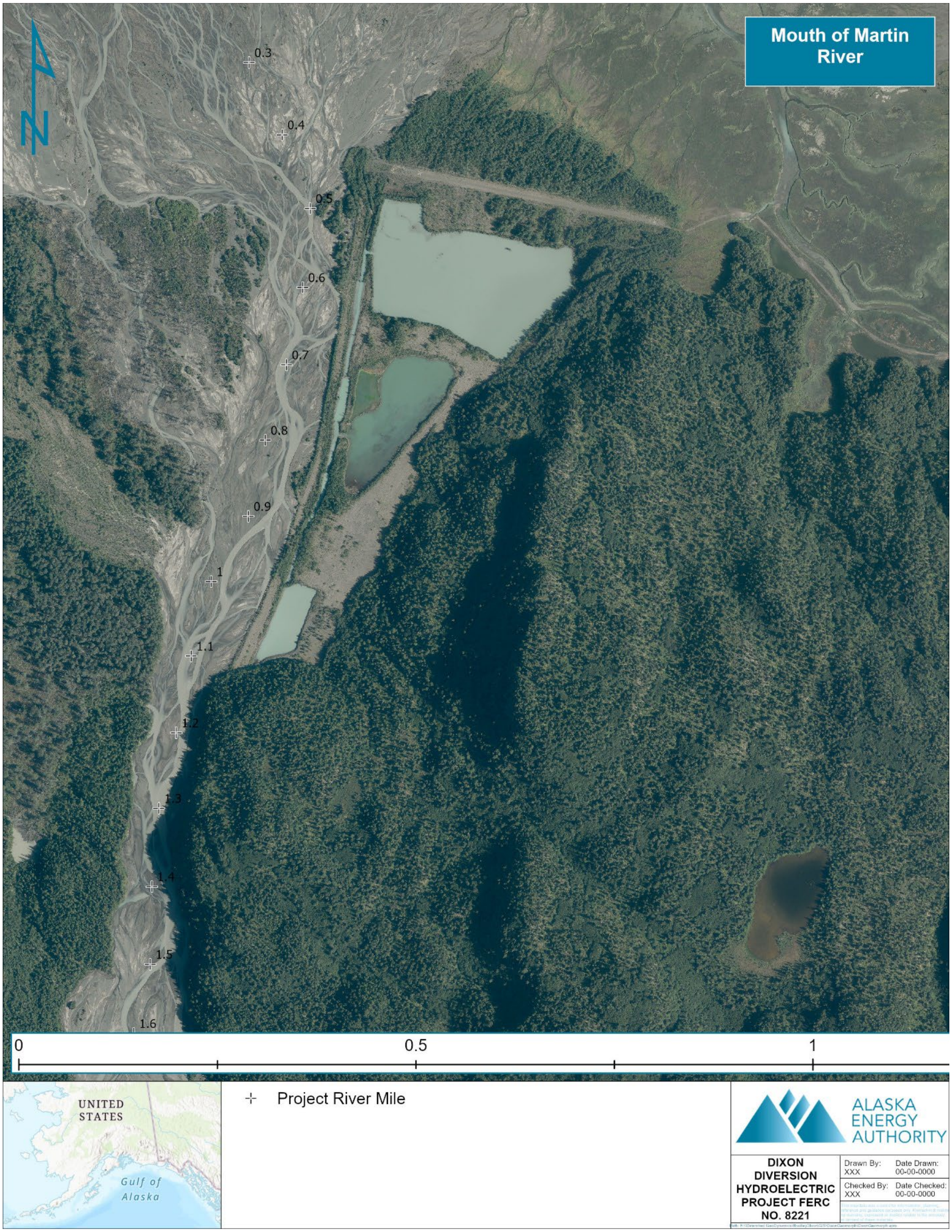


Figure 5-16 Mouth of the Martin River, 2022.

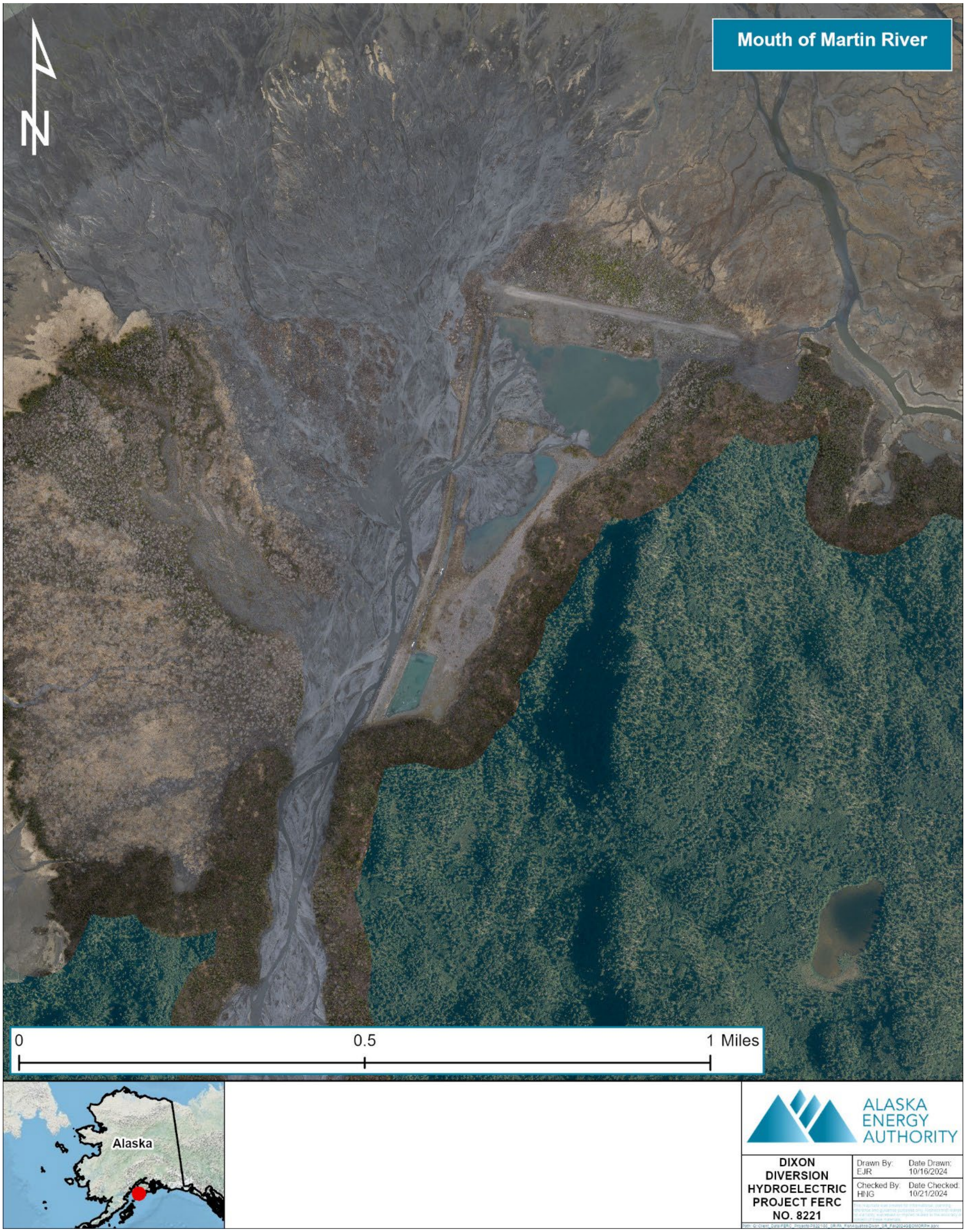


Figure 5-17 Mouth of the Martin River, 2024.

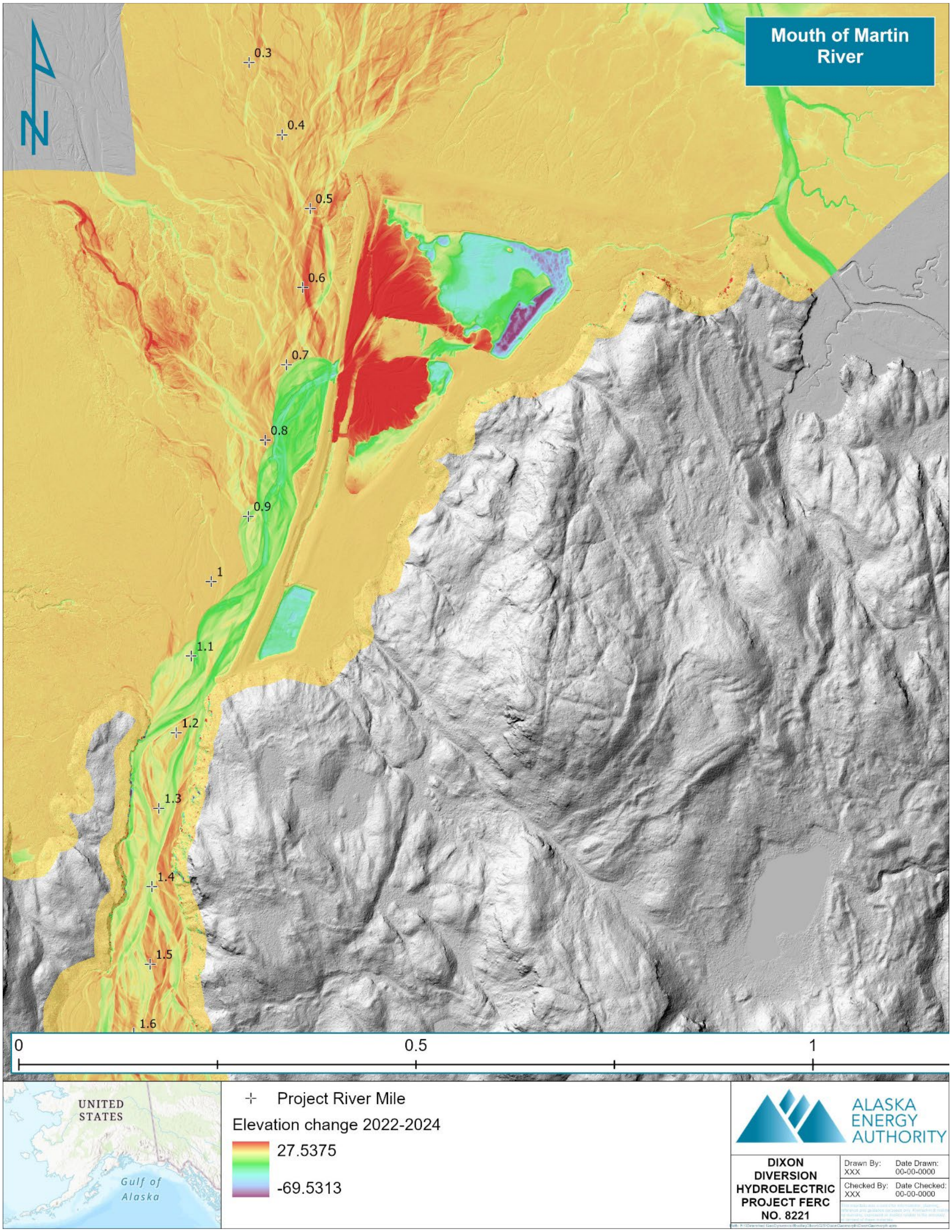


Figure 5-18 Elevation changes at the mouth of the Martin River, 2022-2024.

5.2 Field Visit Observations

MAY 16, 2023

- Main channel flow was low/clear. Substrate in most of main channel (from tidewater to EFMR canyon) was cobble/gravel dominated and generally coarsened upstream. Substrate suitable for spawning fish was observed in most main channel areas.
- Changes to channel locations (braids) have occurred since aerial photographs (7/28/2022) and LiDAR (10/13/2022) were flown in some areas indicating river flows in the time between aerials/LiDAR and LiDAR/freeze-up were high enough to transport bedload material.

MAY 22-24, 2023

- Evidence of very high sediment loading from Dixon Glacier (or glacial deposits) to the Martin River. The entire Martin River valley mapped as "active channel 2022" in Geomorphic Reach 2 through 8a is aggrading as evidenced by sediment deposition along all active channel Geomorphic Unit margins covering tree trunks resulting in dying vegetation. Old, buried trees (in grown position) observed throughout valley. Fresh gravel/cobble deposition into vegetated areas on left bank in Geomorphic Reach 6 and 2 (likely last fall, has only a few scattered leaves on surface from last autumn's leaf fall).
- Past deposition in Geomorphic Reach 8b (lightly vegetated bars) is currently incising; 5- to 6-foot incision depths to top of banks, uncovering buried cottonwood stumps in middle of channel.
- Outlet of left bank off-channel open water area in Geomorphic Reach 8a was checked via helicopter – will be adjusted in GIS/map.
- Main channel flow has shifted to right bank side channel at downstream end of Geomorphic Reach 8a, deposition of small to medium gravel in channel is controlling water level in large off-channel open water area on right bank.
- Deposition in the Martin River valley/fan has blocked the outlet to the former spawning channel/mitigation pond drainage near the mouth of the river. The ponds currently drain to the east toward the Battle Creek estuary over a shallow lip. This likely affects fish passage into/out of ponds.
- Gravel deposition in Martin River fan extends out to tidewater and the boundary between river and tidewater can be delineated based on color change on aerials (light gray gravel to organic sand).

NOVEMBER 2, 2023

- Main channel flow was low/fairly clear.

- The Martin River eroded an approximately 100-foot-wide section of the existing levee; likely mechanism was aggradation on the river side of the levee, overtopping of levee during high flows, and erosion of the pond-side (unprotected) portions of the levee which then undercut rip rap protection on river side of levee. Depth of erosion from top of dike to bottom of channel on November 2, 2023 approximately 10-12 feet (based on estimated water depth in channel). Observations of levee cut showed rip rap blanket on river side, smaller fill material on pond side.
- Extensive gravel, sand, cobble deposits in middle and lower pond areas (deposits cover 19.5 acres).
- Extensive headcut upstream from dike breach (total extent of headcut not delineated). Width of headcut up to 350 feet.

APRIL 18, 2024

- Main channel flow was fairly high and slightly turbid from rains and associated snowmelt. River about 1 foot higher than previous day based on USGS gage at EFMR/WFMR confluence. Turbidity was tan/brown color indicating surface runoff rather than glacial melt.

APRIL 27-29 AND MAY 7, 2024

- Main channel flow was low and clear allowing pebble counts to be taken within the wetted channel of the Martin River.
- Incidental wildlife observations (tracks and scat or animals): black bear, brown bear with cub, moose, wolf, coyote, river otter, bald eagles

AUGUST 21, 2024

- The August 7, 2024 high flow event resulted in major river channel changes in the Martin River.
- Mainstem flows had been extremely high and turbid throughout the river and appeared to result in overall channel incision in many areas based on observations (no elevation measurements were made).
- The high mainstem flows resulted in incursion of turbid mainstem water into all off-channel ponds and channels during the high flow event; all off-channel ponds (including Red Lake) were still very turbid during the August 21 field visit even though mainstem flow was no longer entering the ponds (except for RM 2.8R pond).
- Mainstem flow at the exit of the canyon (EFMR/WFMR confluence) had been extremely high and overflowed into the West Fork Martin River and backwatered into Red Lake. The EFMR is now split into two channels at this location. One high water mark GPS point was taken.

- The OCH 4.2R pond was very turbid and had evidence of past inflow and sediment deposition from the mainstem.
- On August 21, turbid mainstem flow (via side channels) was flowing into the large off-channel right bank RM 2.8 pond. Turbid mainstem water was seen accessing the OCH 2.8R channels near approximately RM 3.1 and RM 3.6 (see video). The pond was extremely turbid, and much smaller in size than previously observed. It is hypothesized that deposition of fines on the south side of the pond where the tributary channels enter as well as incision in the mainstem that appears to have dropped the hydraulic control of the pond outlet approximately 1-2 feet has resulted in a smaller pond area. A pair of swans was still using the pond and a large moose was observed.
- Incision of the mainstem channel was observed in many locations where we were on the ground, including near RM 2.8, RM 1.9 (downstream from the constriction), and near and upstream from the levee breach.
- The river had eroded approximately 100 additional feet of levee on the north side of the breach and totally filled in the two downstream mitigation ponds (the upstream pond was not filled).
- The river through the ponds appears to be a relatively consistent gradient (no large drops).
- The new river outlet from the ponds has widened and looks like an established single channel (formerly was multiple channels through the trees).
- The airstrip was covered with additional fine sediment.
- It appeared that at some point during the high flow event, at least a small amount of flow went down the former delta.
- Several videos and still photos of the river were taken and are available on the project SharePoint site.
- Incidental wildlife observed: one large moose, a pair of swans, and other waterflows near/in RM 2.8R pond; one set of recent very large brown bear tracks near RM 2.8, many older black bear tracks along river in many locations; lots of coyote and river otter tracks in most locations.

OCTOBER 30, 2024

- All mainstem and tributary flows were low and clear.
- There was approximately 6 inches of snow on the ground; air temperature was cold in the morning (mid 20s degrees Fahrenheit) and there was ice forming on ponds and locations where streamflow was low.

- Continued incision of the mainstem channel was observed downstream of the constriction.
- The new delta downstream from the levee breach continues to aggrade. Channels have formed across the old airstrip and flow to saltwater.
- Incidental wildlife observed: waterfowl in RM 4.3R OCH pond; one set of recent very large brown bear tracks in the snow that went from the RM4.3R OCH water quality site downstream to at least RM 2.8, coyote and river otter tracks in locations downstream from RM 3. Eagles at the constriction. Large salmonid in WFMR near water quality site.

5.3 Pebble Counts and Sub-surface Sampling

River substrate provides habitat for fish and aquatic organisms and channel roughness that influences hydraulic conditions. Gravel- and cobble-bedded rivers exhibit a coarser armor layer that forms as finer-grained material (generally sand and fine gravel) are selectively removed following bedload transport events. The sub-armor layer is representative of the mix of material that moves during bedload transport events; the surficial armor layer represents the substrate that influences aquatic habitat and hydraulics. Both surficial pebble counts and sub-surface sediment samples were taken along the Martin River in 2023 and 2024 to help characterize aquatic substrate and provide information for hydraulic modeling and sediment transport calculations (Figure 4-1 above shows locations of sample sites). Grain size distribution data for the surficial pebble counts are shown in Table 5-3 through Table 5-5, Figure 5-19, and Figure 5-20. Grain size distribution data for the sub-surface samples are shown in Table 5-6, Figure 5-21 and Figure 5-22.

Surficial grain size generally decreased in a downstream direction, with the median (D_{50}) grain size ranging from 231 mm at the outlet of the EFMR canyon to 17 mm in the delta near sea level. Substrate is primarily gravel and cobble downstream from RM 4 with cobble, gravel and boulder upstream from RM 4.

Sub-surface material is remarkably uniform along the sampled areas of the river, from RM 0.7 to RM 3.8, with the median (D_{50}) grain size ranging from 17-20 mm, and is primarily gravel-sized with some sand and cobble.

The grain size data suggest that the majority of boulder and the largest cobble material that are transported down the EFMR canyon are deposited close to the mouth of the canyon, upstream of approximately RM 4.5. Downstream of approximately RM 4.5, bedload material (e.g., sub-surface material) is relatively uniform, but surficial substrate continues to fine in a downstream direction to approximately RM 2.5 and is fairly uniform downstream of RM 2.5.

Table 5-3 Martin River 2023 river bar pebble count summary statistics.

Sample No.	2023-1	2023-2	2023-3	2023-4	2023-5	2023-6	2023-7	2023-8	2023-9	2023-10	2023-11	2023-12	2023-13	2023-14	2023-15	2023-16
River Mile	EFMR 0.2	4.55	3.65	3.00	2.75	2.50	2.50	2.35	1.95	1.85	1.60	1.35	1.18	0.80	0.40	0.7
Geomorphic Reach	9/10	8b	8a	8a	7	Side Channel	6/7	6	Side Channel	5	4	3	3	2	1	New Delta at Levee Breach
Grain Size (mm)																
D_{16}	86	64	34	31	50	13	25	17	13	23	9	14	8	11	8	11
Median – D_{50}	231	119	68	55	84	27	49	30	23	43	18	25	16	20	17	33
D_{84}	481	250	132	87	143	50	83	47	51	75	40	51	43	36	31	64
D_{90}	542	299	156	100	160	56	90	54	64	84	47	67	55	43	40	74
Percent in Grain Size Category																
Sand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
Gravel	10%	16%	46%	65%	31%	97%	65%	98%	90%	75%	96%	88%	94%	96%	98%	82%
Cobble	44%	69%	54%	35%	69%	3%	35%	2%	10%	25%	4%	12%	6%	4%	2%	16%
Boulder	47%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 5-4 Martin River 2024 river bar pebble count summary statistics.

Sample No.	2024-1	2024-2	2024-3	2024-4	2024-5	2024-6	2024-7	2024-8
River Mile	0.70	1.00	1.25	2.45	3.15	4.50	1.70	3.80
Geomorphic Reach	2 – levee breach	2	3	5	8a	8b	4	8a
Grain Size (mm)								
D_{16}	14	19	18	19	20	30	15	21
Median – D_{50}	31	41	35	41	44	69	35	42
D_{84}	60	61	70	74	74	124	72	79
D_{90}	71	69	80	83	83	197	80	87
Percent in Grain Size Category								
Sand	0%	0%	0%	0%	0%	0%	0%	0%
Gravel	87%	88%	80%	77%	76%	45%	78%	72%
Cobble	13%	12%	20%	23%	24%	48%	22%	28%
Boulder	0%	0%	0%	0%	0%	7%	0%	0%

Table 5-5 Martin River 2024 instream pebble count summary statistics.

Sample No.	2024-1	2024-2	2024-3	2024-5	2024-6	2024-7	2024-8	2024-10	2024-11	2024-12	2024-13	2024-14	2024-15
River Mile	0.70	1.00	1.25	3.15	4.50	1.70	3.80	EFMR 0.15	WFMR 0.05	5	2.8	2.8 side channel	2.5
Geomorphic Reach	2 – levee breach	2	3	8a	8b	4	8a	9	WFMR	9	6	6	5
Grain Size (mm)													
D_{16}	23	14	28	20	24	16	15	19	40	53	19	9	34
Median – D_{50}	46	32	66	65	73	46	41	97	96	144	43	16	68
D_{84}	87	55	102	118	166	87	91	342	194	397	89	37	114
D_{90}	100	67	113	132	221	99	111	422	272	461	107	43	125
Percent in Grain Size Category													
Sand	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Gravel	80%	98%	58%	60%	49%	71%	73%	37%	28%	19%	67%	100%	46%
Cobble	39%	12%	64%	60%	56%	37%	28%	43%	61%	49%	33%	0%	54%
Boulder	0%	0%	0%	1%	8%	0%	3%	20%	11%	32%	1%	0%	0%

Table 5-6 Martin River 2024 sub-surface sample summary statistics.

Sample No.	2024-1	2024-2	2024-3	2024-4	2024-5	2024-6	2024-7	2024-8
River Mile	0.70	1.00	1.25	2.45	3.15	4.50	1.70	3.80
Geomorphic Reach	2 – levee breach	2	3	5	8a	8b	4	8a
Grain Size (mm)								
D_{16}	2	3	3	1	2	2	2	2
Median – D_{50}	18	19	19	18	18	20	19	17
D_{84}	59	64	55	56	58	104	74	44
D_{90}	78	81	70	72	86	142	98	61
Percent in Grain Size Category								
Sand	16%	12%	12%	28%	16%	12%	12%	16%
Gravel	69%	72%	76%	59%	70%	63%	68%	75%
Cobble	15%	16%	12%	13%	15%	23%	20%	9%
Boulder	0%	0%	0%	0%	0%	2%	0%	0%

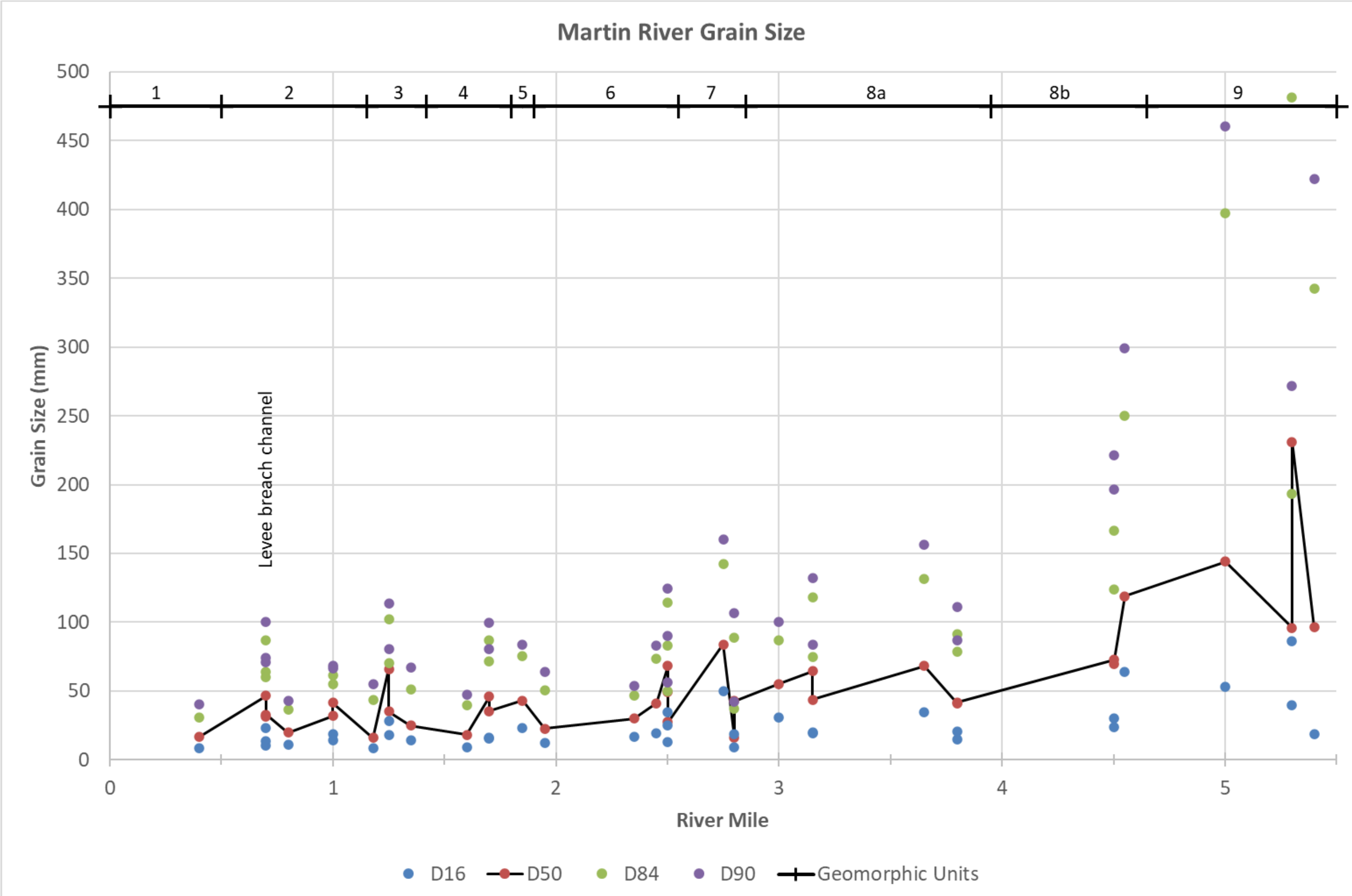


Figure 5-19 Martin River longitudinal variations in surficial grain size.

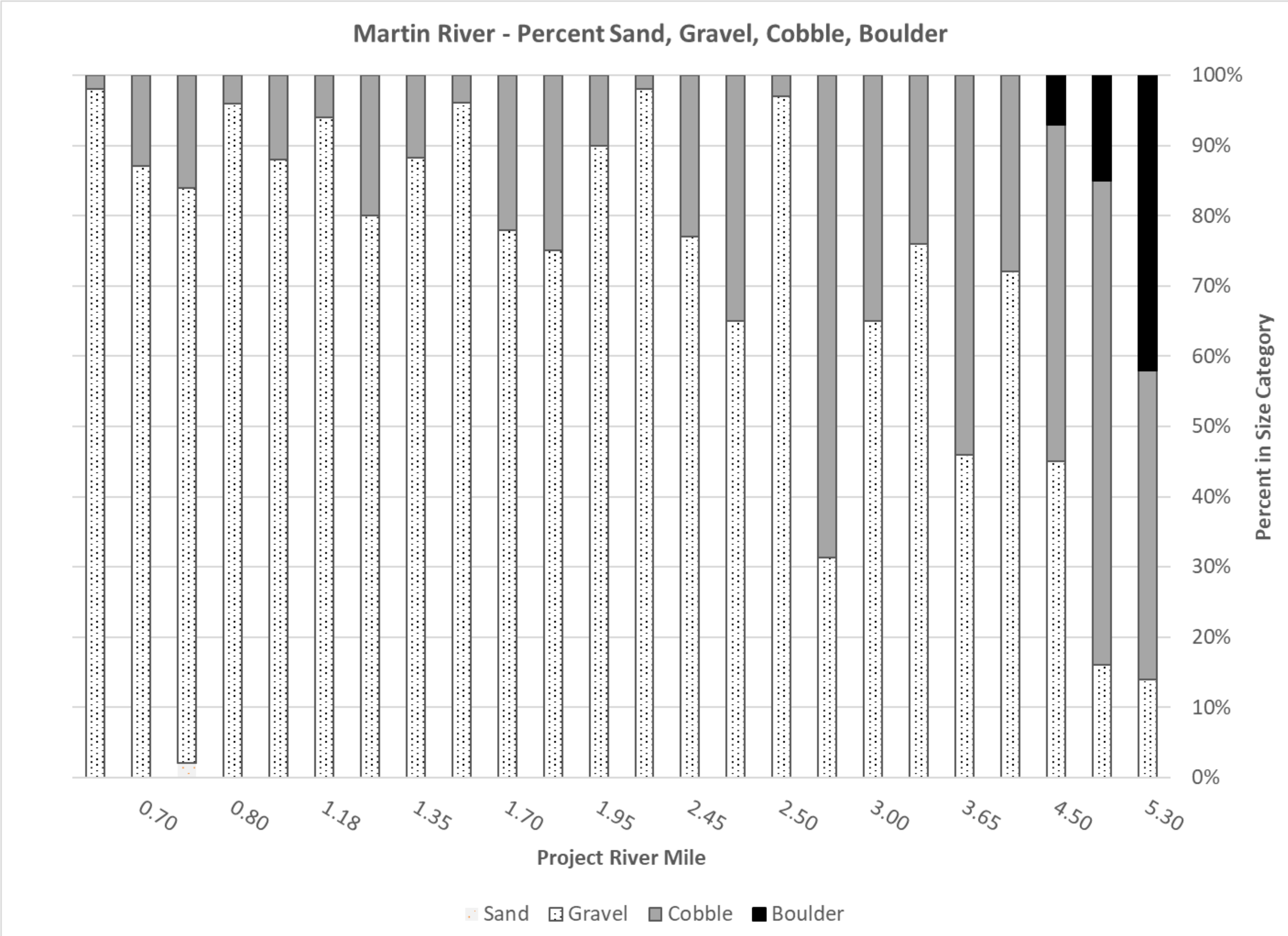


Figure 5-20 Martin River percent sand, gravel, cobble, and boulder in surficial pebble counts.

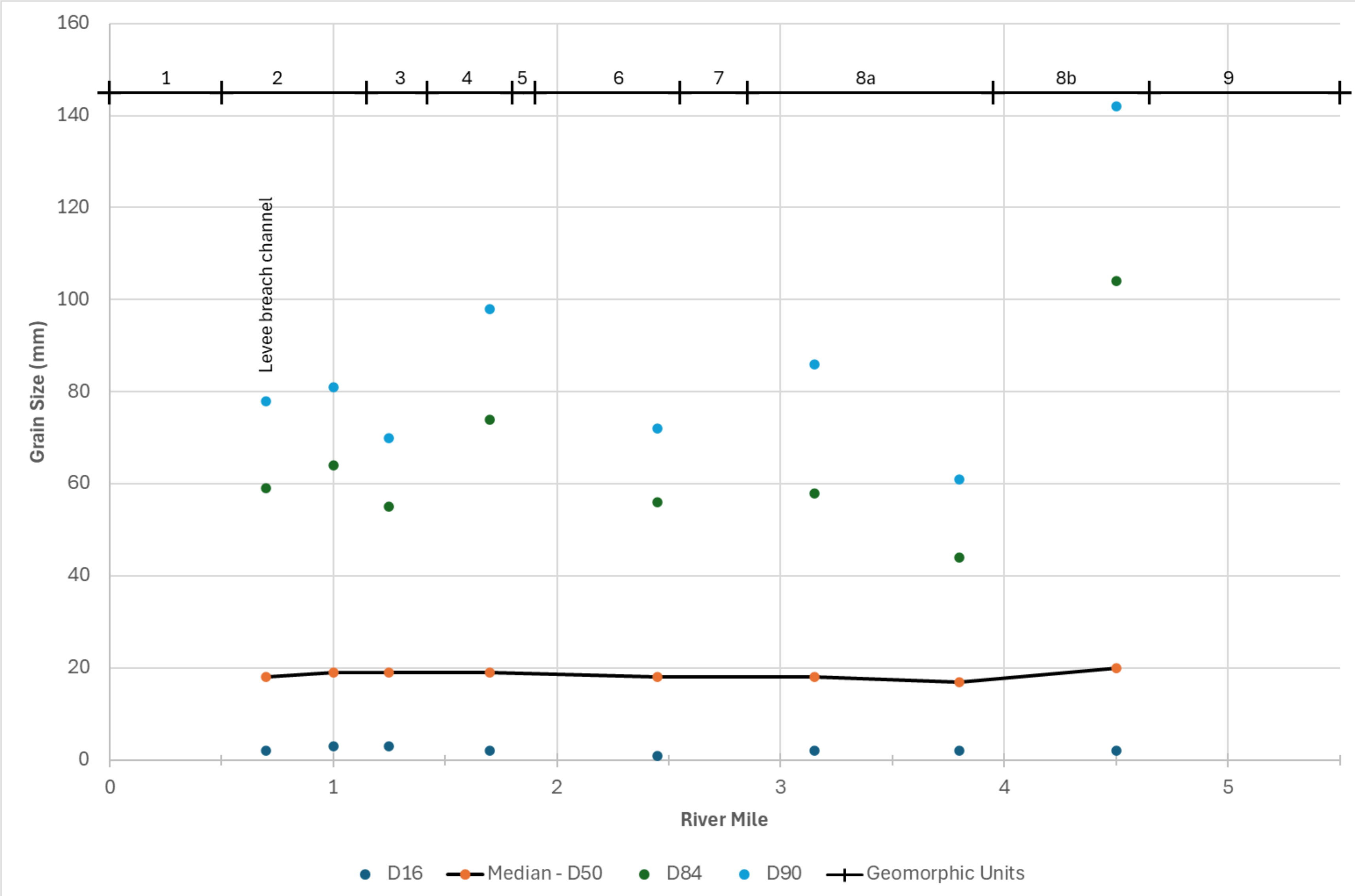


Figure 5-21 Martin River longitudinal variations in sub-surface sample grain size.

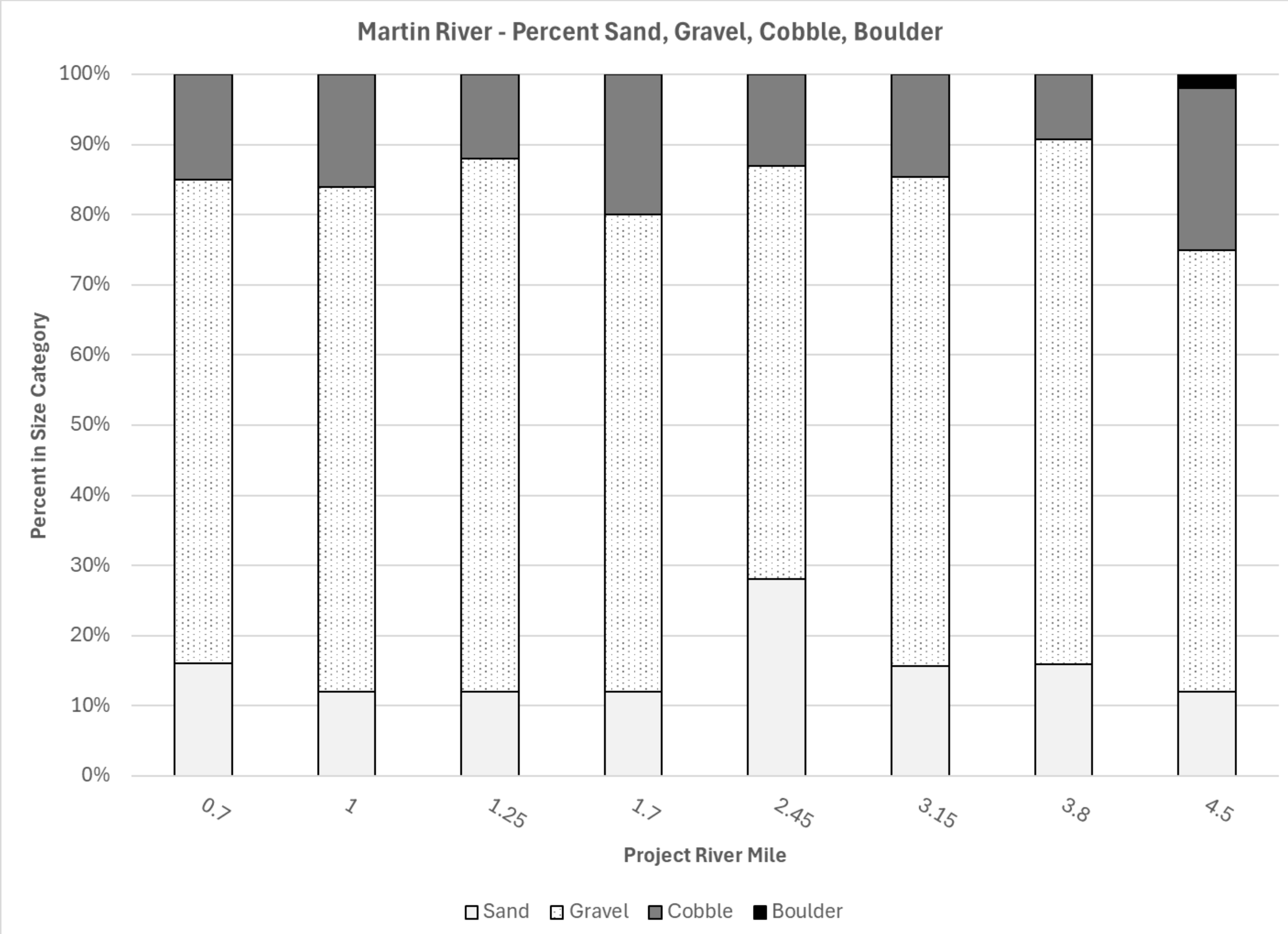


Figure 5-22 Martin River percent sand, gravel, cobble, and boulder in sub-surface samples.

5.4 Timelapse Camera Analysis

Timelapse camera images from the three cameras that were deployed along braided sections of the Martin River showed change during at least eight high flow events in 2023 and six high flow events in 2024 (Table 5-7 and Table 5-8, Figure 5-23 and Figure 5-24). Channel changes (e.g., shifts in channel locations) in braided river systems occur when flows are high enough to transport bedload sediment (Middleton et al. 2019).

Table 5-7 2023 dates with channel change on timelapse camera footage.

Date	USGS 15238951 Stage (ft) PROVISIONAL	USGS 15238951 flow (cfs) ESTIMATED	Camera Designation		
			GE 01 (RM 2.8)	GE 02 (RM 2)	GE 03 (RM 1.1
6/24/2023	6.30	1,184	X	X	
6/25/2023	6.44	1,457	X	X	
6/26/2023	6.27	1,148		X	X
6/27/2023	6.28	1,164		X	
6/28/2023	6.20	1,027		X	
7/3/2023	6.34	1,184			X
7/6/2023	6.30	1,185		X	X
7/7/2023	6.36	1,309		X	
7/16/2023	6.64	1,943			X
7/17/2023	6.45	1,486			X
7/22/2023	6.22	1,058		X	
7/28/2023	6.44	1,452			X
7/29/2023	6.49	1,562	X	X	
7/30/2023	6.18	994		X	
8/6/2023	6.52	1,645		X	X
8/7/2023	6.7	2,108	X	X	
8/12/2023	6.61	1,844			X
8/14/2023	6.39	1,352	X		
8/21/2023	5.91	655			X
8/25/2023	6.62	1,875	X	X	
8/27/2023	6.72	2,154			X
8/29/2023	6.86	2,598		X	X
8/31/2023	6.7	2,100		X	X
9/16/2023	6.27	1,146		X	X

Table 5-8 2024 dates with channel change on timelapse camera footage.

Date	USGS 15238951 Stage (ft) PROVISIONAL	Flow at Constriction (PRM 1.9, cfs)	Camera Designation					
			GE 01 (RM 2.8)	GE 02 (RM 2)	GE 03 (RM 1.1)	GE 04 (RM 0.7)	GE 05 (RM 2.7)	GE 08 (EFMR RM 0.15)
7/12/2024	6.8	1,369	X	n/a	X	X	X	
8/7/2024	10.2	4,209	X	X	X	X	X	X
8/12/2024	6.9	1,130				X	n/a	
8/18/2024	7.2	1,352			X	X	n/a	
9/5/2024	7.6	1,280	X	X	X	X	n/a	
9/13/2024	7.0	1,337		X	X	X	n/a	

Notes: - n/a indicates camera was not deployed or not functioning on these dates.
- Channel change at Camera GE 08 may have occurred on other dates, but the single channel was full all summer and changes could not be discerned.
- Cameras GE 06 and GE 07 were deployed in side channels/tributaries for aquatic habitat study purposes and are not included in this table.

In 2023, the upstream-most camera (GE 01) showed the least amount of channel change; this may have been due to the camera location that primarily showed a secondary, left bank channel that had less flow than the main channel (Photo 4-1 above). The GE 02 and GE 03 cameras both showed frequent channel changes (during at least eight different high flow events) during the 2023 flow season, consistent with braided glacial river dynamics. In addition, images from the GE 03 camera (Photo 4-3 above) showed channel incision, bank erosion, and resulting base level changes on August through October images following the downstream right bank levee breach.

In 2024, there were fewer observed instances of channel change at the timelapse cameras, likely due to the flow hydrograph that stayed relatively high from the large peak flow in early August through mid-September, making it difficult to discern channel change due to water covering the river bars. However, channel change was observed during one to six different high flow events at the various cameras (Table 5-8).

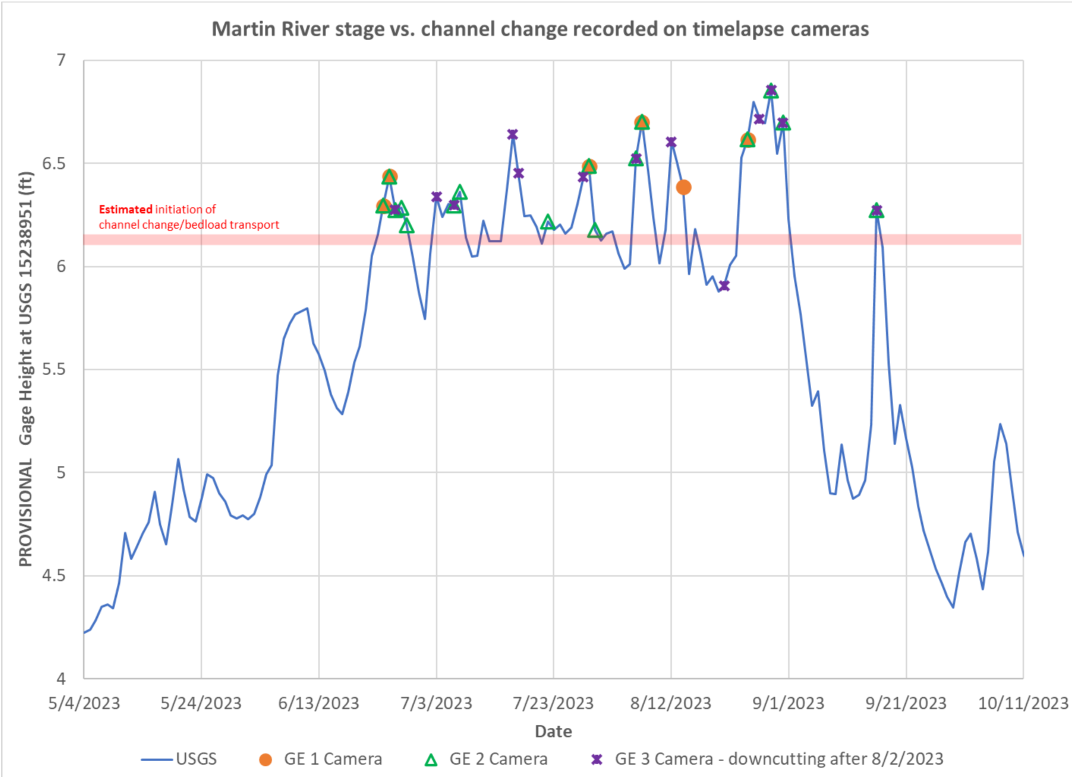


Figure 5-23 Martin River stage versus channel change 2023.

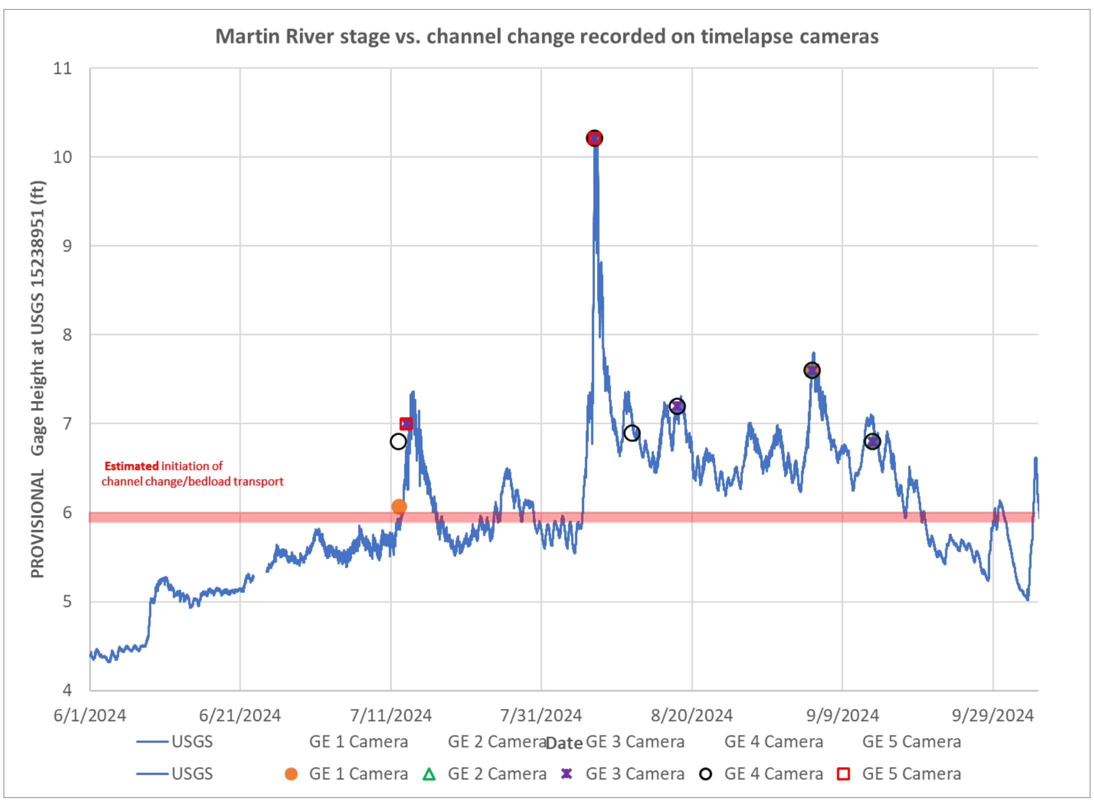


Figure 5-24 Martin River stage versus channel change 2024.

The provisional USGS gage heights (USGS Gage No. 15238951) were compared for each date that had channel change in 2023 and 2024 and showed that in general, flow events corresponding to gage heights above about 6 feet resulted in channel change (Figure 5-23 and Figure 5-24). Based on rating curves for the constriction gage near Martin River RM 1.9 on the dates when channel change was noted in 2023 and 2024, it appears that a flow of approximately 1,000 cfs is needed to mobilize bedload and induce channel change in the braided areas of the Martin River. Higher flow is needed to mobilize sediment in the lower end of the EFMR canyon due to the large boulders on the bed; channel change was observed following an estimated flow of approximately 4,200 cfs, but there are not enough instances of flows between 2,000 and 4,200 cfs to discern the threshold for bedload movement in the lower canyon.

The August 7, 2024 peak flow event resulted in major changes in the Martin River channel. The peak gage height and flow are estimated due to equipment issues during the large peak, but flow was estimated to be 4,200 cfs at the gage at the RM 1.9 constriction. The flow was large enough to completely fill the canyon at the mouth of the EFMR (Camera GE 08) and spanned much of the valley at other camera locations. Representative before, during and/or after photos of the flood are included in Appendix A.

5.5 Sediment Transport and Deposition Patterns

A discussion of sediment deposition and erosion patterns in the Martin River through time is included in Section 5.1.3.2 and 5.5 above. This section describes and quantifies deposition and erosion locations and volumes between the October 2022 and May 2024 LiDAR data acquisition dates, essentially quantifying the net volume of sediment erosion, transport, and deposition during 2023.

Elevation changes between the 2022 and 2024 LiDAR in the Martin River valley are shown on Figure 5-25 and Figure 5-26. Areas of aggradation (deposition) appear in red tones on the figures and areas of degradation (erosion) appear in green tones. Yellow tones indicate little topographic change. Note that the 2022 LiDAR elevation data show the top water surface of rivers and ponds whereas the 2024 LiDAR includes bathymetric data and shows the bottom of rivers and ponds. Therefore, river channels and ponds appear in green/blue/purple colors indicating water depth rather than erosion.

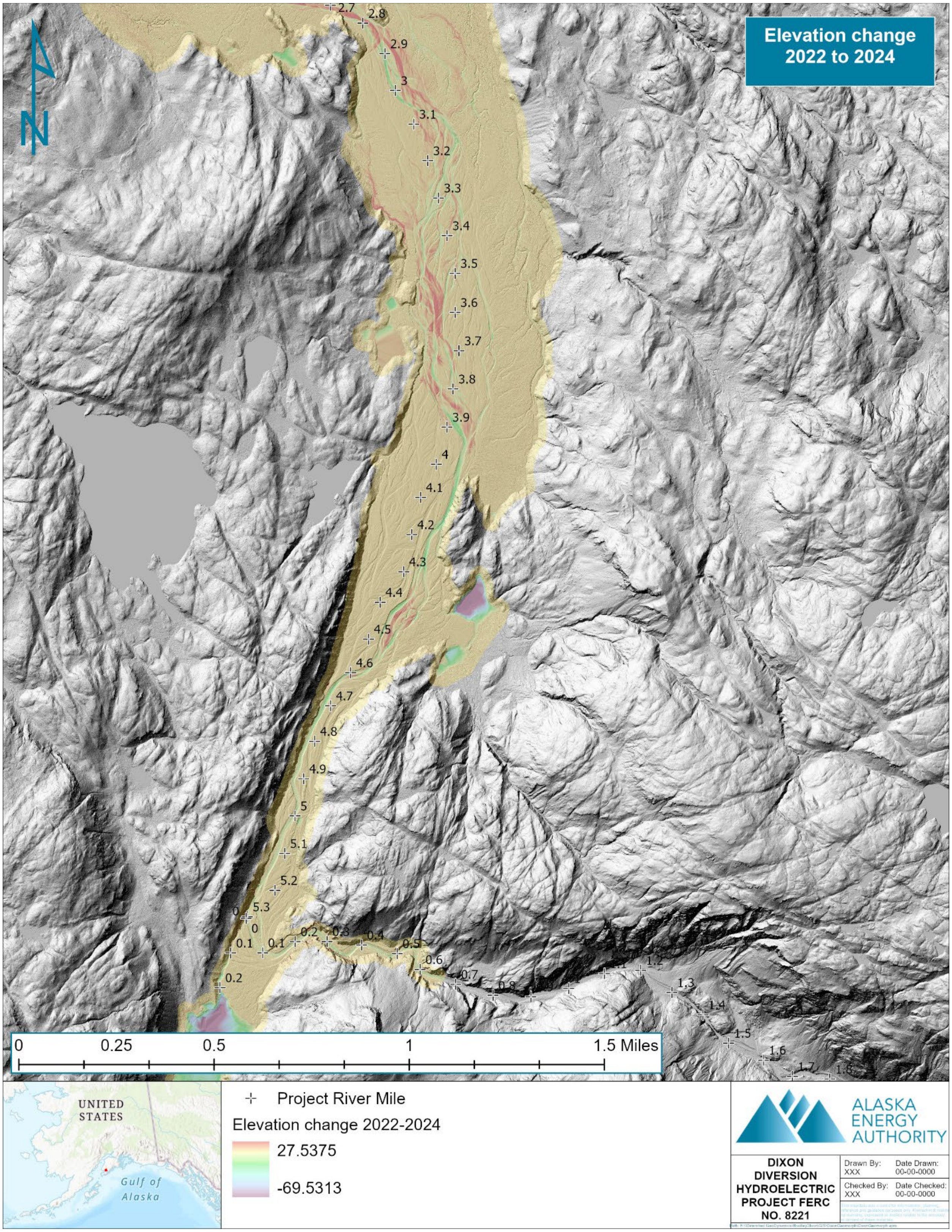


Figure 5-25 Martin River upper valley elevation changes 2022 to 2024.

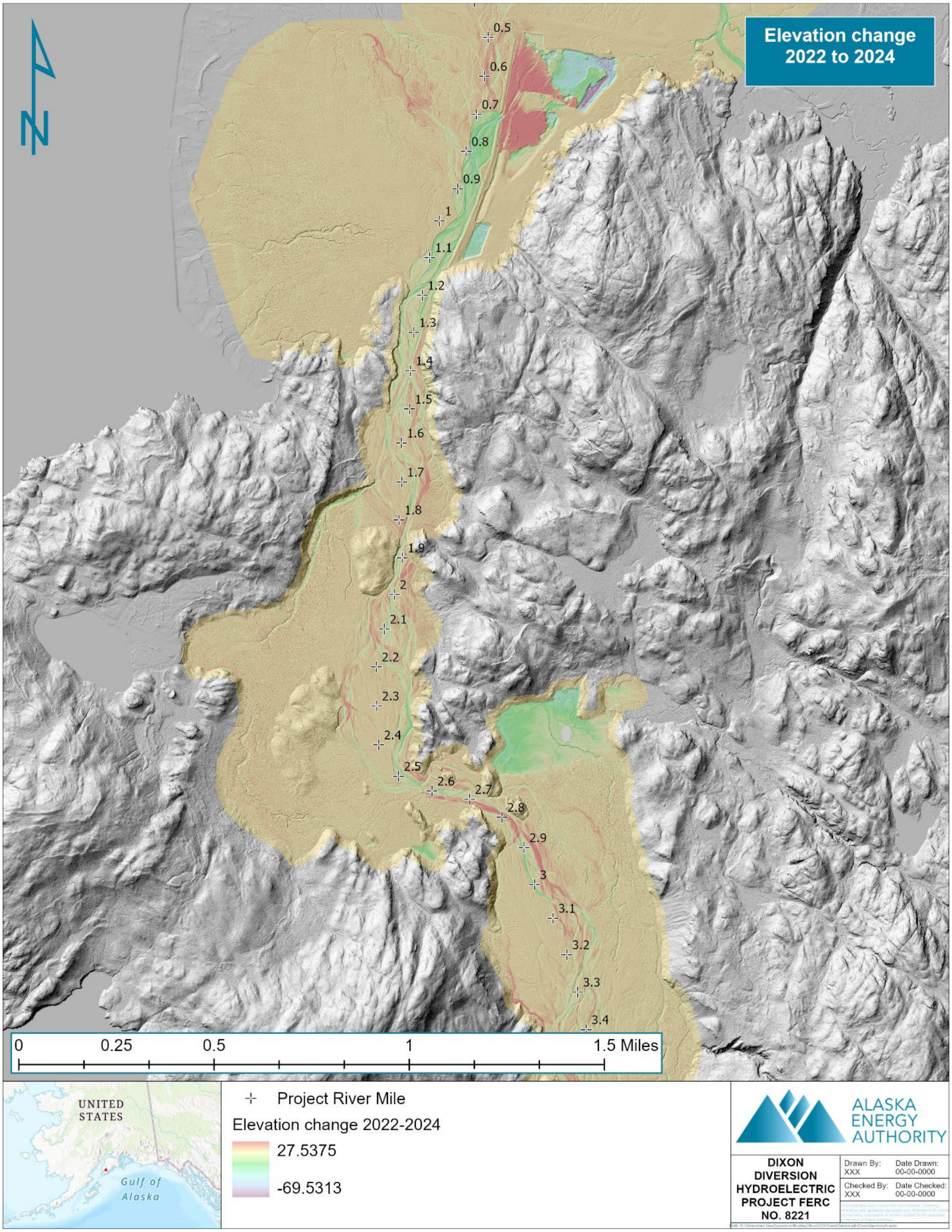


Figure 5-26 Martin River lower valley elevation changes 2022 to 2024.

The 2022-2024 comparison shows little change upstream from RM 4.5, discrete areas of deposition and erosion representing migration of the braided river channels between RM 2.5-4.5, and more diffuse erosion and deposition between RM 1.2-2.5. Downstream from RM 1.2, the net channel incision resulting from the drop in base level following the August 2023 right bank levee breach is shown, along with deposition in the former delta area near RM 0.5-0.7 that presumably occurred prior to the levee breach, and deposition in two lobes in the former lower and middle mitigation ponds east of the levee breach.

The 2024-2022 net change in topography in the Martin River active channel/valley was summed by geomorphic unit to show trends in sediment deposition or erosion along the river valley (Figure 5-27). The net change shows a small amount of net erosion in the upper, confined areas of the river (geomorphic units 8b and 9; upstream from RM 3.9), net deposition as the valley widens and the river spreads out in geomorphic unit 8a, minor net changes through RM 1.4, channel erosion in response to the headcut upstream from the levee breach in geomorphic units 2 and 3, and a large amount of deposition in the new delta that built into the former mitigation ponds. Note also that there was net deposition in the former delta area (labeled "old delta" on the figure) between the October 2022 LiDAR acquisition and the early August 2023 levee breach; an average of 0.12 feet of aggradation if spread across the entire old delta area. This rate is consistent with the long-term estimate of 0.16 feet/year of aggradation in the delta area as discussed in Section 5.1.3.2.

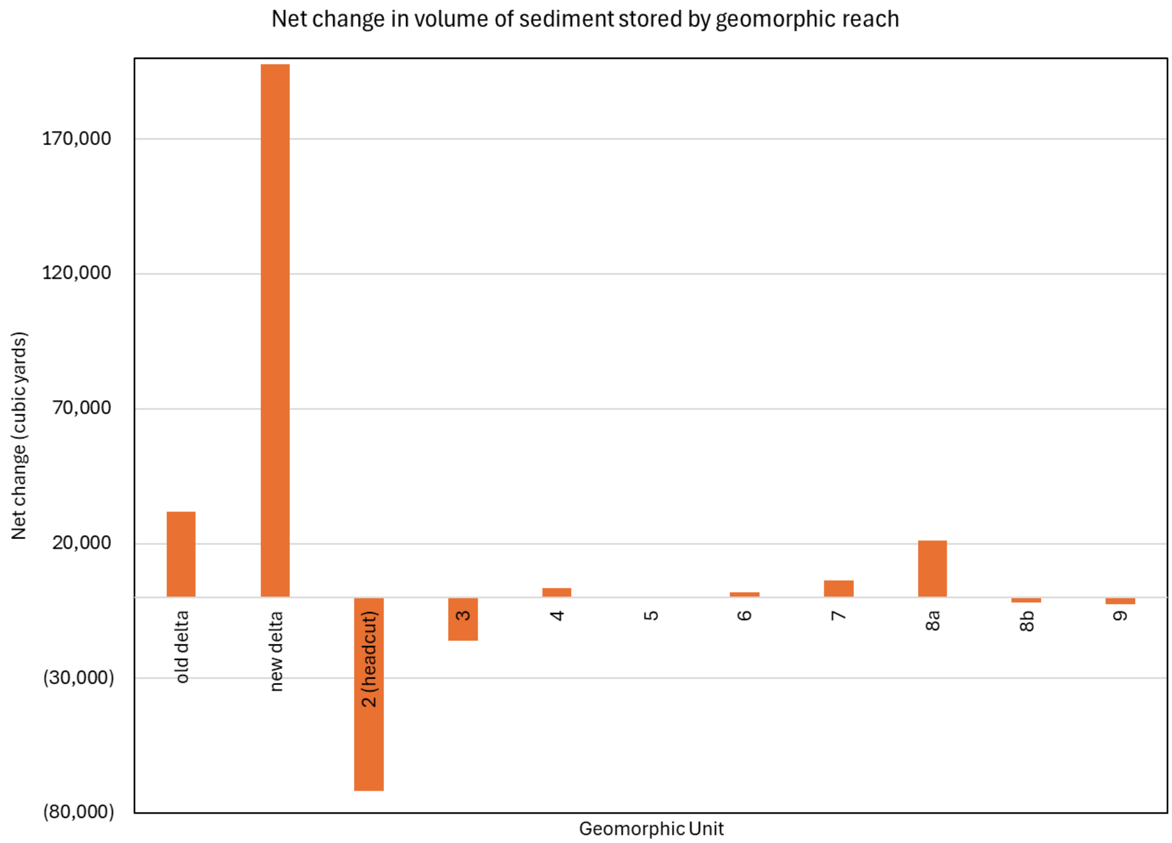


Figure 5-27 Net change in volume of sediment stored in the Martin River active channel/valley by geomorphic reach, October 2022-May 2024.

5.6 Sediment Transport Analysis using 2Dimensional Hydraulic Model Output

The output from the 2D HEC-RAS hydraulic model representative of May 2024 topographic conditions was used to predict the critical grain diameter, e.g., the size of particles that could be entrained by flows of 1,000-5,000 cfs. These predicted grain sizes indicate the diameter of particles that could theoretically be eroded from the bed of the river at each model cell location under the modeled flow.

Examples of the critical grain diameter analysis for the upper Martin River, near the EFMR and WFMR confluence for 1,000 and 5,000 cfs are shown in Figure 5-28 and Figure 5-29, and for the mouth of Martin River in Figure 5-30 and Figure 5-31. As expected, critical grain diameter in confined and higher gradient areas is larger (cobble to boulder-sized) in the upper river areas than in downstream, unconfined areas. Areas where the model predicts smaller critical grain diameter downstream from areas of larger critical grain diameter, indicative of areas where deposition could be expected, are similar to those areas where deposition occurred in the 2022-2024 LiDAR comparison (Figure 5-25 and Figure 5-26 in previous section).

The predicted critical grain diameter under the 1,000 cfs modeled flow was compared with the median (D_{50}) substrate size collected along the river in May 2024, the same timeframe as the 2D hydraulic model topography was collected (see pebble count data in Section 5.3). In almost all locations, the substrate D_{50} was similar to the predicted critical grain size, further validating the predictive ability of the 2D model analysis.

The 2D model analysis will be used in 2025 to help determine changes to sediment transport patterns under potential future flow regimes.

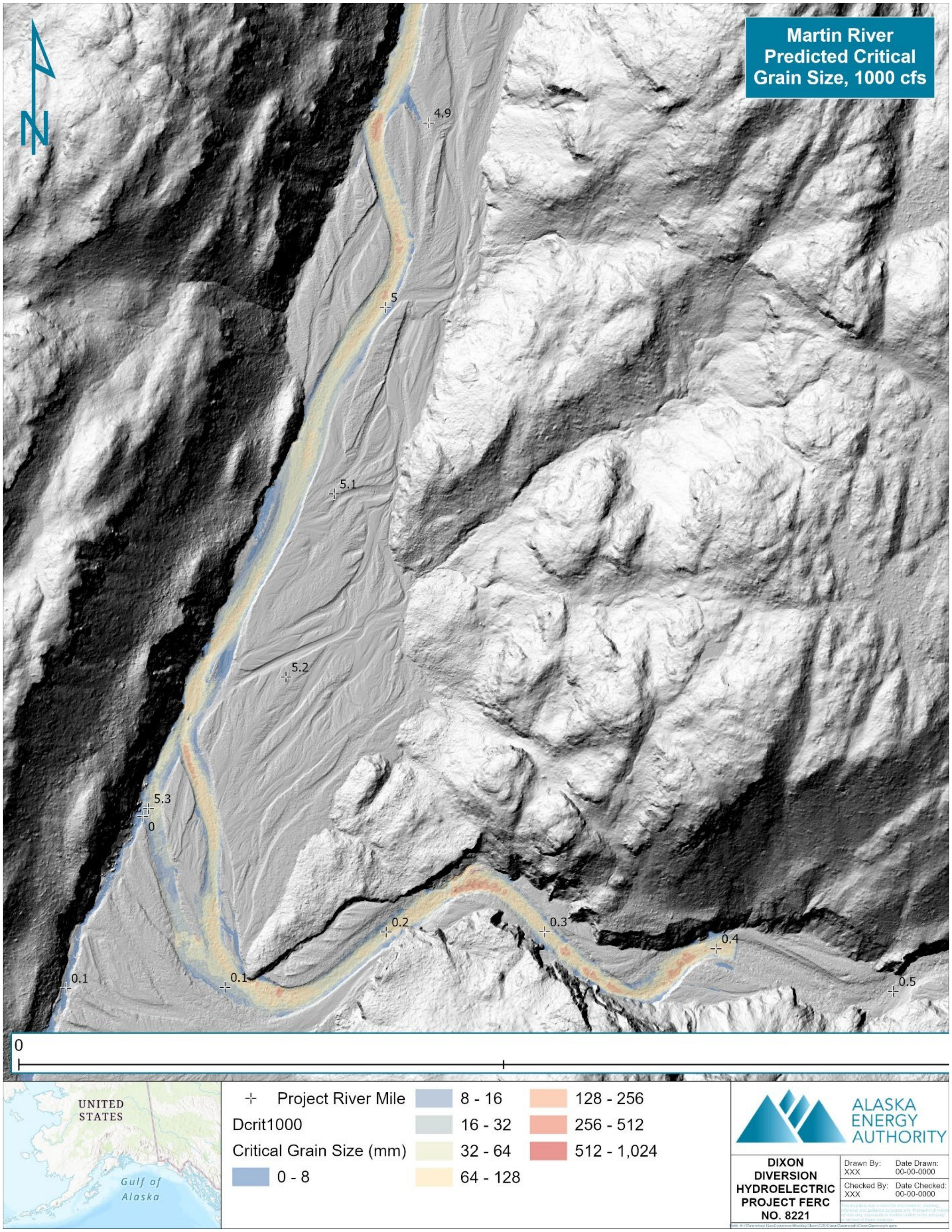


Figure 5-28 Critical grain diameter, 1,000 cfs, upper Martin River.

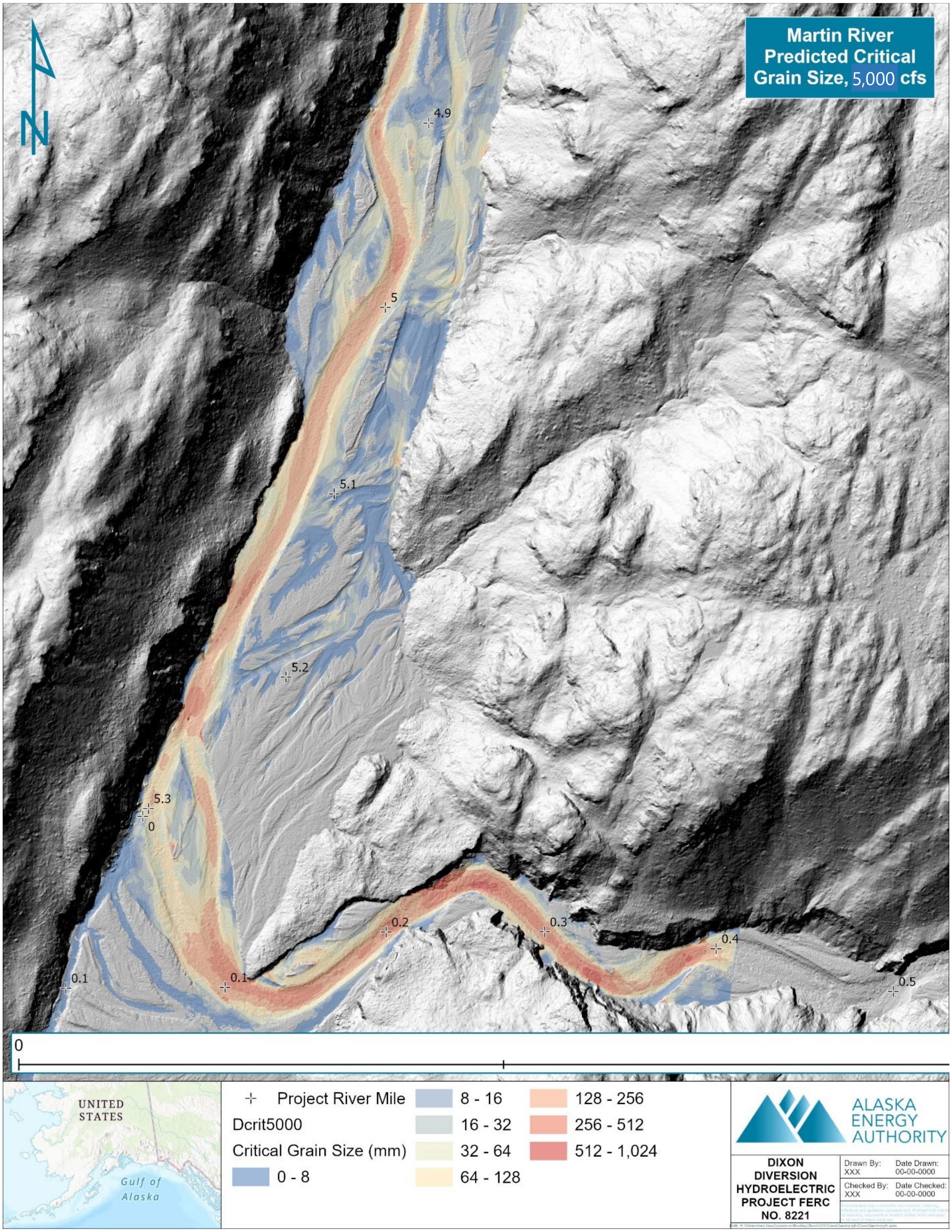


Figure 5-29 Critical grain diameter, 5,000 cfs, upper Martin River.

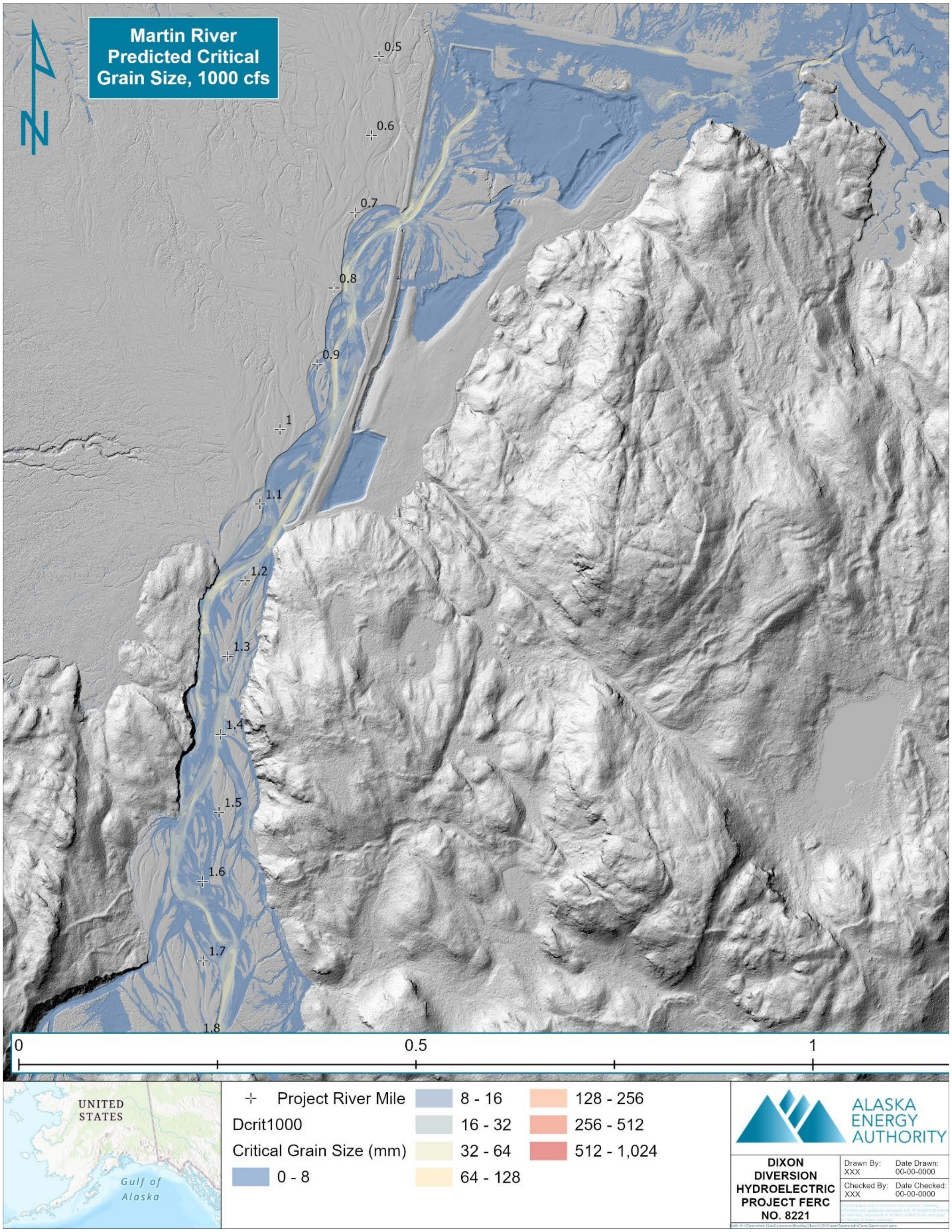


Figure 5-30 Critical grain diameter, 1,000 cfs, mouth of Martin River.

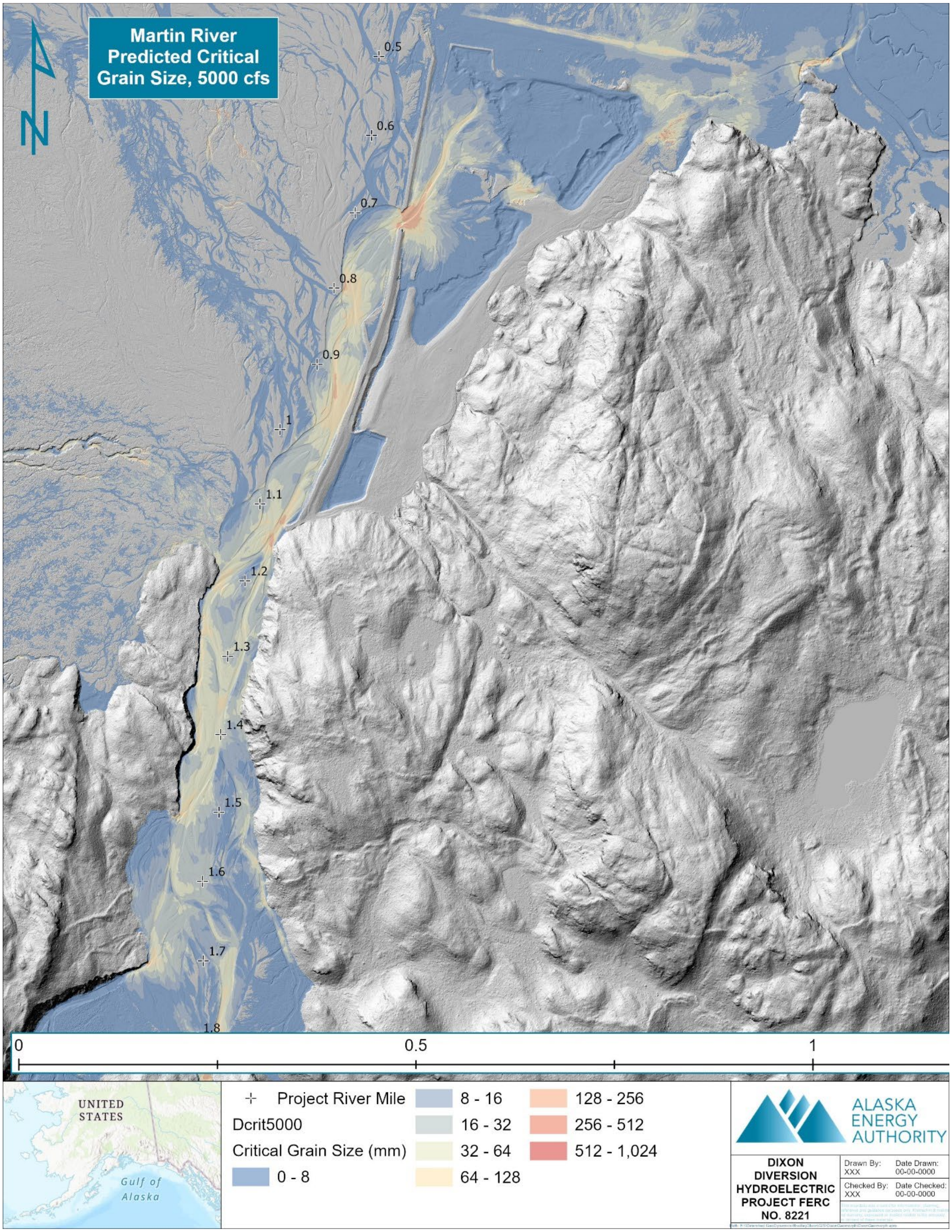


Figure 5-31 Critical grain diameter, 5,000 cfs, mouth of Martin River.

6.0 DISCUSSION

The Martin River is a braided glacial river with a very high sediment load. Channel gradient is fairly consistent from the mouth to the EFMR canyon, with a slight increase in gradient upstream from RM 2.5. Substrate is primarily gravel and cobble downstream from RM 4 with cobble, gravel and boulder upstream from RM 4 and in the moderately confined Geomorphic Reach 7.

The river has been actively aggrading. The braided channels migrate and bedload transport occurs multiple times per flow season (June through August), particularly in unconfined reaches. It is estimated that bedload transport downstream from the EFMR/WFMR confluence occurs when flows reach approximately 1,000 cfs. Current off-channel habitat areas were part of the active channel in the past and will likely be part of the active channel in the future as the river migrates across the valley bottom.

Aerial photograph analysis suggests that a large episodic input of sediment occurred from the early- to mid-1900s following retreat of the Dixon Glacier Little Ice Age Maximum. This resulted in a sediment “slug” that has been moving and diffusing down the Martin River valley. As the sediment slug has moved down the valley, 5-7 feet of aggradation has occurred across the entire valley, followed by slow channel incision. It is anticipated that the sediment slug will continue to move through the lower valley for the next few decades before the river reaches a quasi-equilibrium with sediment and water input primarily coming from the Dixon Glacier.

In addition to the aggradation and subsequent incision caused by the sediment slug, the levee breach near the mouth of the river in August 2023 has been and will continue to affect channel dynamics as the river adjusts to the new base level. The levee breach resulted in aggradation in the right bank mitigation ponds as a delta builds into the ponds and headcutting upstream of the breach location as the river adjusts to the new channel configuration. Channel adjustment related to the breach will continue for years to decades until a new, more stable base level is reached.

Knowledge of the past and current geomorphology and sediment input and transport dynamics of the Martin River, along with the 2D sediment transport analysis provide tools to understand potential future changes to the river under both unaltered conditions and with potential water withdrawals proposed for the Dixon Diversion Project. While the 2D hydraulic modeling and result are a “snapshot in time” of conditions in a very active braided river valley with mobile, shifting channels, the historic analysis of channel changes and likely future conditions provides a broader understanding of potential changes to river dynamics in the future and the validity of the “snapshot in time” approach to modeling the Martin River.

7.0 STUDY STATUS AND SCHEDULE

This report summarizes data collection and analyses completed in 2023 and 2024 and describes historic and existing geomorphic and sediment transport conditions in the Martin River. Analyses of potential changes associated with diversion of part of the Martin River flow into Bradley Lake will take place in 2025 and will include these tasks:

- Comparison of sediment input and transport potential under potential future flow regimes
- Synthesis of hydraulic, geomorphic, riparian, and aquatic analyses

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Appendix A

Representative Timelapse Camera Images of August 7, 2024 Peak Flow

Camera views before, during, and/or after peak flow event
(Note that the date/time stamp is shown on each photo)

Camera GE 08, mouth of EFMR canyon looking upstream.

Camera GE 08, mouth of EFMR canyon, looking upstream.

Camera GE 01, RM 2.9, looking upstream.

Camera GE 05, RM 2.75 right bank side channel, looking downstream.

Camera GE 04, RM 2, looking downstream.

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Camera GE 04, RM 2, looking downstream.