Grant Lake Hydroelectric Project (FERC No. 13212)

Water Resources – Geomorphology
Final Report

Prepared for
Kenai Hydro, LLC

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Acronyms and Abbreviations

AEIDC	Arctic Environmental Information Data Center
cfs	cubic feet per second
DLA	Draft License Application
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
KHL	Kenai Hydro, LLC
LA	License Application
mm	millimeter
MW	megawatt
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NOI	Notice of Intent
OHWM	ordinary high water mark
PAD	Pre-Application Document
PM&E	protection, mitigation and enhancement
Project	Grant Lake Hydroelectric Project
USFS	U.S. Department of Agriculture, Forest Service
USGS	U.S. Department of the Interior, Geological Survey
WSE	water surface elevation

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1 INTRODUCTION

On August 6, 2009, Kenai Hydro, LLC (KHL) filed a Pre-Application Document (PAD; KHL 2009), along with a Notice of Intent (NOI) to file an application for an original license, for a combined Grant Lake/Falls Creek Project (Federal Energy Regulatory Commission [FERC] No. 13211/13212 ["Project" or "Grant Lake Project"]) under Part I of the Federal Power Act (FPA). On September 15, 2009, FERC approved the use of the Traditional Licensing Process (TLP) for development of the License Application (LA) and supporting materials. As described in more detail below, the Project has been modified to eliminate the diversion of water from Falls Creek to Grant Lake. The Project will be located near the community of Moose Pass, Alaska in the Kenai Peninsula Borough, approximately 25 miles north of Seward, Alaska and just east of the Seward Highway (State Route 9).

The Water Resources Study Plan (Plan) was designed to address information needs identified in the PAD, during the TLP public comment process, and through early scoping conducted by FERC. The following study report presents the results of the geomorphological components of the Plan along with previously existing information relative to the scope and context of potential effects of the Project. This information will be used to analyze Project impacts and propose protection, mitigation, and enhancement (PM&E) measures in the draft and final LA's for the Project.

The Project is located near the community of Moose Pass, approximately 25 miles north of Seward and just east of the Seward Highway. It lies within Section 13 of Township 4 North, Range 1 West; Sections 1, 2, 5, 6, 7, and 18 of Township 4 North, Range 1 East; and Sections 27, 28, 29, 31, 32, 33, 34, 35, and 36 of Township 5 North, Range 1 East, Seward Meridian (U.S. Geological Survey [USGS] Seward B-6 and B-7 Quadrangles).

The proposed Project would be composed of an intake structure at the outlet to Grant Lake, a tunnel, a surge tank, a penstock, and a powerhouse. It would also include a tailrace detention pond, a switchyard with disconnect switch and step-up transformer, and an overhead or underground transmission line. The preferred alternative would use approximately 15,900 acre-feet of water storage during operations between pool elevations of approximately 692 and up to 703 feet North American Vertical Datum of 1988 (NAVD 88)[1].

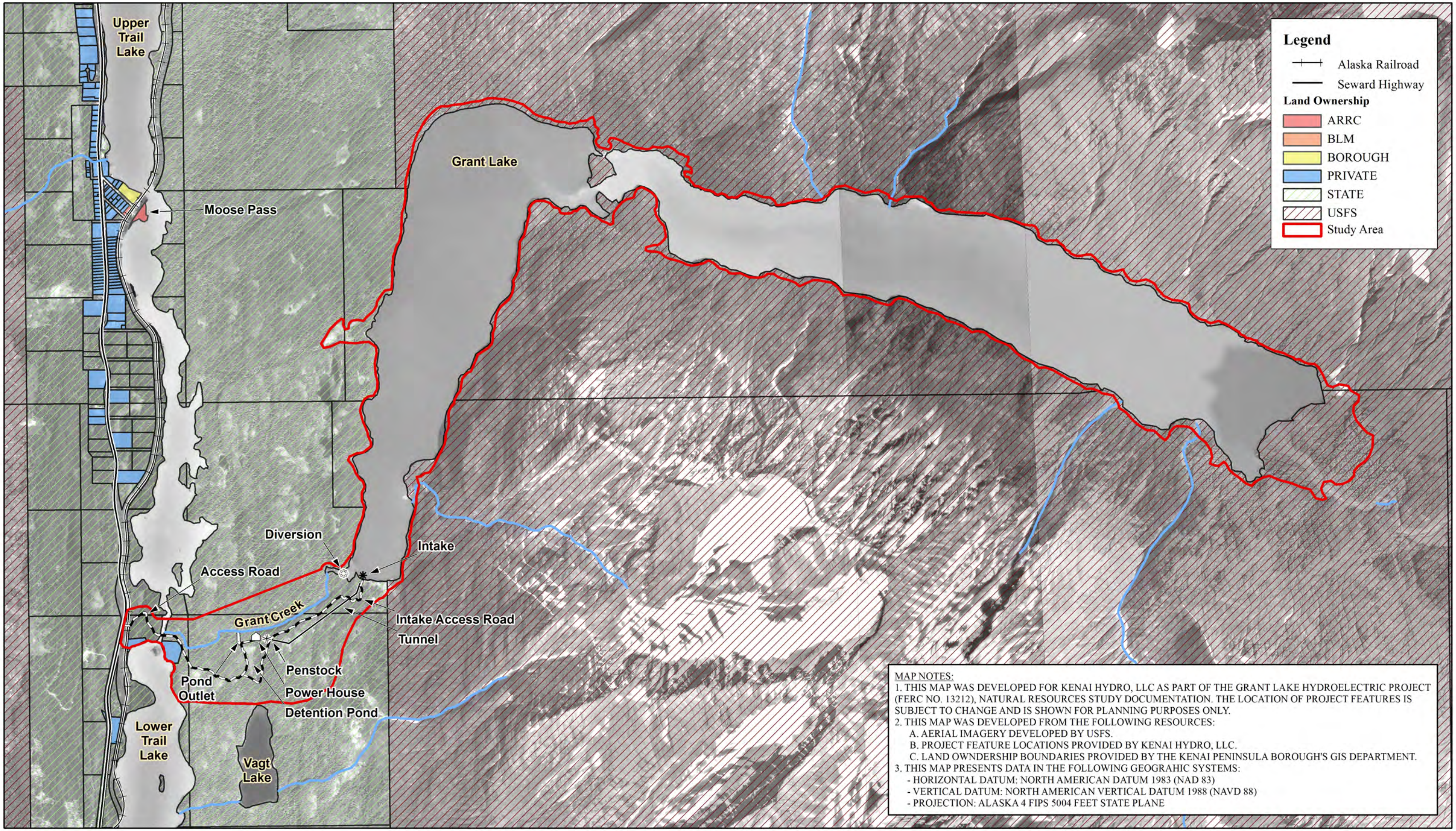
[1] The elevations provided in previous licensing and source documents are referenced to feet mean sea level in NGVD 29 [National Geodetic Vertical Datum of 1929] datum, a historical survey datum. The elevations presented in the Grant Lake natural resources study reports are referenced to feet NAVD 88 datum, which results in an approximate +5-foot conversion to the NGVD 29 elevation values.

An intake structure would be constructed approximately 500 feet east of the natural outlet of Grant Lake. An approximate 3,200-foot-long, 10-foot diameter horseshoe tunnel would convey water from the intake to directly above the powerhouse at about elevation 628 feet NAVD 88. At the outlet to the tunnel a 360-foot-long section of penstock will convey water to the powerhouse located at about elevation 531 feet NAVD 88. An off-stream detention pond will be created to provide a storage reservoir for flows generated during the rare instance when the units being used for emergency spinning reserve are needed to provide full load at maximum ramping rates. The tailrace would be located in order to minimize impacts to fish habitat by returning flows to Grant Creek upstream of the most productive fish habitat.

Two concepts are currently being evaluated for water control at the outlet of Grant Lake. The first option would consist of a natural lake outlet that would provide control of flows out of Grant Lake. A new low level outlet would be constructed on the south side of the natural outlet to release any required environmental flows when the lake is drawdown below the natural outlet level. The outlet works would consist of a 48-inch diameter pipe extending back into Grant Lake, a gate house, regulating gate, controls and associated monitoring equipment. The outlet would discharge into Grant Creek immediately below the natural lake outlet.

In the second option, a concrete gravity diversion structure would be constructed near the outlet of Grant Lake. The gravity diversion structure would raise the pool level by a maximum height of approximately 2 feet (from 703 to 705 feet NAVD 88), and the structure would have an overall width of approximately 120 feet. The center 60 feet of the structure would have an uncontrolled spillway section with a crest elevation at approximately 705 feet NAVD 88. Similar to the first option, a low level outlet would be constructed on the south side of the natural outlet to release any required environmental flows when the lake is drawn down below the natural outlet level. The outlet works would consist of a 48-inch diameter pipe extending back into Grant Lake, a gate house a regulating gate, controls, and associated monitoring equipment. The outlet would discharge into Grant Creek immediately below the diversion structure.

Figure 1.0-1 displays the global natural resources study area for the efforts undertaken in 2013 and 2014 along with the likely location of Project infrastructure and detail related to land ownership in and near the Project area. Further discussions related to specifics of the aforementioned Project infrastructure along with the need and/or feasibility of the diversion dam will take place with stakeholders in 2014 concurrent with the engineering feasibility work for the Project. Refined Project design information will be detailed in both the Draft License Application (DLA) and any other ancillary engineering documents related to Project development. The current design includes two Francis turbine generators with a combined rated capacity of approximately 5.0 megawatts (MW) with a total design flow of 385 cubic feet per second. Additional information about the Project can be found on the Project website: http://www.kenaihydro.com/index.php.



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Drawing Scale: 0 0.25 0.5 1 Miles

MCMILLEN, LLC

Developed For: Homer Electric Association, Inc. A Touchstone Energy Cooperative

GRANT LAKE HYDROELECTRIC PROJECT - FERC PROJECT #P-13212

GRANT LAKE NATURAL RESOURCES STUDY

Figure 1.0-1
Natural Resources Study Area

DESIGNED Jake Woodbury
DRAWN Jake Woodbury
CHECKED C. Warnock
ISSUED DATE 1/9/2014
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2 STUDY OBJECTIVES

The Grant Lake and Grant Creek Fluvial Geomorphology Study consisted of two independent study components: a Grant Lake shoreline erosion study and a Grant Creek spawning substrate recruitment study. The goals of the studies were to provide supporting information on the potential resource impacts of the Project that were identified during development of the PAD, public comment, and FERC scoping for the LA. The objectives of the studies are described below.

2.1. Grant Lake Shoreline Erosion Study

The primary study objective of the Grant Lake shoreline erosion study was to provide a basis for predicting and assessing potential lake shore erosion in Grant Lake as a result of general reservoir operations. Operations will affect the timing, duration and range of water surface elevations (WSE), and thus change the Grant Lake shoreline geomorphic conditions. The Grant Lake shore geomorphic study was a qualitative inventory of shoreline conditions that affect erosion potential based on professional judgment.

2.2. Grant Creek Spawning Substrate Recruitment Study

The primary objective of the Grant Creek spawning substrate recruitment study was to provide a basis for predicting and assessing potential changes to material movement, sedimentation, and gravel recruitment that may occur in Grant Creek with proposed operational management, especially as related to the long-term maintenance of fish spawning substrate. Operation of the Project would alter the flow regime and create a situation where some amount of flow will bypass the canyon reach. The Grant Creek spawning substrate study combines quantitative and qualitative elements.

3 STUDY AREA

The Project vicinity is near the town of Moose Pass, Alaska, approximately 25 miles north of Seward, just east of the Seward Highway (State Route 9). The specific geomorphology assessment study area includes Grant Lake shoreline and Grant Creek within the lower portion of the Grant Lake watershed.

3.1. Grant Lake Geomorphic Setting

Grant Lake is an approximately 6-mile long, 1,600 acre (2.5 square mile) lake located in a 68,000 acre (44 square mile) watershed within the Chugach Mountains of Kenai Range east of Moose Pass. Inlet Creek is the predominant stream in the upper portion of the watershed and drains melting alpine glaciers and snow from the nearby mountains into Grant Lake at the eastern end of the lake. Grant Lake itself sits in the lower portion of the watershed, capturing over 95 percent of the watershed area.

Grant Lake is located in a deep glacially-carved basin flanked by the high bedrock peaks of Lark and Solars Mountains. Grant Lake encompasses two almost separate bathymetric lake basins that are separated by a shallow submerged ridge at a narrow "neck" that connects the two basins at right angles (EBASCO 1984). The upper basin is oriented primarily east-west, whereas the lower basin is oriented primarily north-south. Much of the overall shoreline littoral zone is steep bedrock. The deepest point within the lower basin is approximately 262 feet deep and the upper basin is 283 feet deep (EBASCO 1984).

3.2. Grant Creek Geomorphic Conditions and Processes

The Grant Creek watershed occupies approximately 44 square miles with a majority of its watershed bound by the steep mountains of the Kenai Range. Grant Creek itself is approximately 5,800 feet long and flows west from the outlet of Grant Lake to the "narrows" between Upper and Lower Trail lakes. Grant Creek has a mean annual flow of 200 cubic feet per second (cfs), with an average gradient of 200 feet per mile. In its upper half, Grant Creek passes through a steep bedrock canyon with three substantial waterfalls. In its lower half, Grant Creek becomes less steep with boulder and cobble dominant alluvial substrate. Grant Creek is a high energy stream with a wide variability in flow regime.

4 METHODS

4.1. Methods to Evaluate Grant Lake Shoreline Erosion

The methods to conduct the shoreline erodibility assessment of Grant Lake consisted of both a desktop analysis using existing information and a field evaluation of conditions observed along the shoreline by boat at a relatively high lake stage (approximately 2 feet of water depth over the outlet to Grant Creek which is estimated to be 703 feet NAVD 88). For the field evaluation, it was assumed that the Project WSE would be approximately 3 to 5 feet higher than at the time of our site visit on August 24, 2013 assuming water depths at the invert would be a maximum of 3 to 5 feet deep. Minimum Project WSE would be 692 feet NAVD 88, or approximately 11 feet lower than at the time of our field visit. The desktop analysis utilized integrating previous studies and information, including bathymetric mapping, LiDAR, digital orthographic photos, and geologic mapping. Spatial information was evaluated and findings were mapped in a Geographic Information System (GIS). The analysis drew upon a number of assumptions as described below.

For conditions and impacts to the littoral zone at elevations that were submerged at the time of the field visit, it was assumed that the geomorphic units identified and mapped at the shoreline near the ordinary high water mark (OHWM) were the same in the submerged areas to at least the depth of the proposed managed WSE. The rationale for this assumption is that most of the steep shoreline was bedrock, or landforms that result from hill-slope process deposition (e.g. alluvial fan), continue downslope. In two instances, the landforms did not fit this model (at both distal ends of the lake), in these instances, the extent of geomorphic unit was inferred based upon the assumption that the unit continued in submerged areas to at least the bathymetric break in slope. In both instances, the bathymetric break in slope occurred below the proposed minimum WSE.

Methods

The erodibility assessment was initiated with a GIS desktop analysis. The analysis included remotely mapping the geomorphic features of the Grant Lake shoreline area. This was accomplished by evaluating a combination of spatial data sets in conjunction with historic studies and information and making an informed geological interpretation. The data sets that were used included:

- 2002 Aerial Photos of Grant Lake: USFS, 1996-2004, 2-5 meter, Black/White, UTM 6 NAD 27
- Google Earth oblique view aerial photos
- 4-foot contours generated from 2002 LiDAR using GIS: Aero-Metric Inc., 2008, 10-foot resolution, format: LiDAR point cloud data 1.1.
- Surface Geology Maps (EBASCO 1984)

The interpretation of landforms involved analysis of slope/relief, shape, contributing upland area, fluvial/non-fluvial influence, vegetation, texture and previous geological assessments. A "Geomorphic Unit" was developed based on geomorphic process for the landforms along the shoreline and each Geomorphic Unit was mapped within 200-foot buffer from the shoreline in GIS. The following Geomorphic Units were established for this analysis:

- Alluvial Deltaic Deposits
- Alluvial Fan Deposits
- Beach/Littoral Deposits
- Colluvial Deposits
- Landslide Deposits
- Bedrock

The depositional units were characterized based on typical sediment size and character of depositional material (layered strata versus massive consolidated strata, sorted versus unsorted sediment) with the rationale that smaller sediment size and layered strata were relatively more susceptible to erosion than larger sediment sizes and massive consolidated deposits. As a result, a relative erodibility of the geomorphic unit was generated such that the aforementioned units are listed from most susceptible to erosion to least susceptible. The geomorphic units in the area buffering the shoreline were field validated. Photographs of "type-sections" of geomorphic units are provided in Appendix 1. Mapping of geomorphic units is shown in Figure 4.1-1.

Wind generated waves are likely the predominant erosional process acting on the Grant Lake shoreline during present conditions. To evaluate the wind-generated wave erosion potential, an overlay of relative fetch potential was applied with the rationale that larger waves had more energy and were more effective at eroding the shoreline area than were smaller waves. Field observations of wave run-up potential were made during the boat-based survey and documented with photographs.

Evaluation

The evaluation was initiated by compiling all existing spatial information into a GIS-based platform. The geomorphic units were integrated with the fetch parameters to determine relative erodibility (Table 4.1-1). The resulting relative erodibility was mapped in GIS.

Table 4.1-1. Relative erodability integrating erosion susceptibility with wave energy potential.

Relative Fetch Distance	Geomorphic Unit					
	Alluvial Deltaic	Alluvial Fan	Beach	Colluvium	Landslide (bedrock)	Bedrock
Short	Moderate	Moderate	Moderate	Low	Low	Low
Medium	Moderate-High	Moderate-High	Moderate-High	Moderate-Low	Moderate-Low	Low
Long	High	High	High	Moderate	Moderate	Low

The integration of the relative erodibility susceptibility of the Geomorphic Units with the fetch distance to determine relative erodibility along the shoreline relies upon the following assumptions:

1. As the fetch increases the wave size increases, and therefore the wave-generated erosional processes increase with fetch
2. The geomorphology/geology within each mapped unit was assumed to be consistent throughout that individual unit.

In addition to wind-generated wave erosion potential, erosion due to changes in base elevation which could cause stream incision of streams that outlet along the shoreline during lower lake WSE conditions was considered.

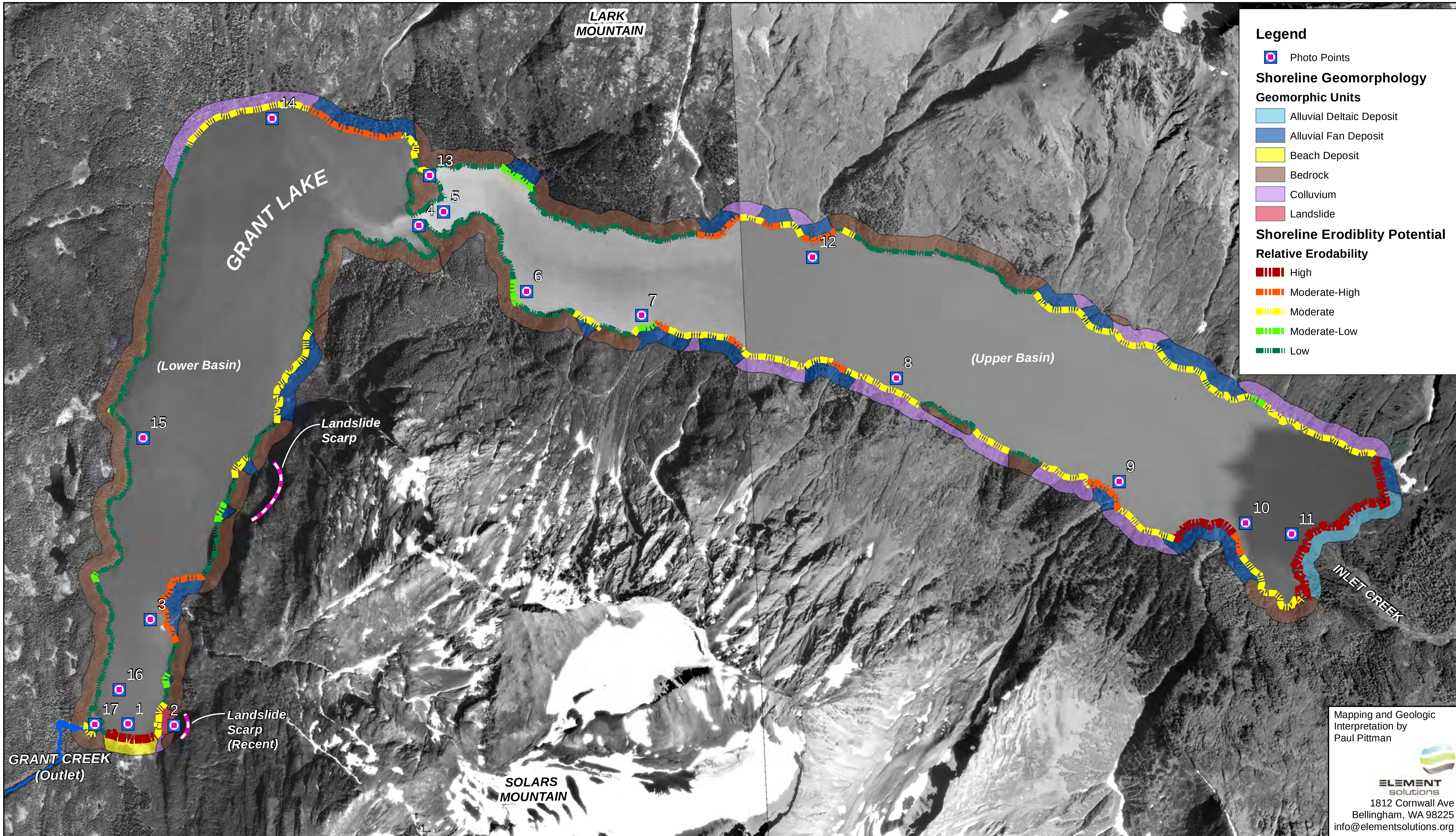
4.2. Methods to Evaluate Grant Creek Geomorphic Response

General Methods

The methods identified in the study plan to evaluate the sediment transport effecting salmon spawning substrate conditions following operational scenarios, included the following tasks:

1. assessment of the substrate at existing spawning areas including aspects of embeddedness and substrate size composition;
2. quantification of material transport conditions under the existing and projected flow regimes; and
3. qualitative geomorphic assessment of existing sediment supply conditions.

Figure 4.2-1 refers to the study area and sampling locations.



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GRANT LAKE NATURAL RESOURCES STUDY

FIGURE 4.1-1: GRANT LAKE GEOMORPHOLOGY RELATIVE SHORELINE EROSION

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FIGURE 4.1-1

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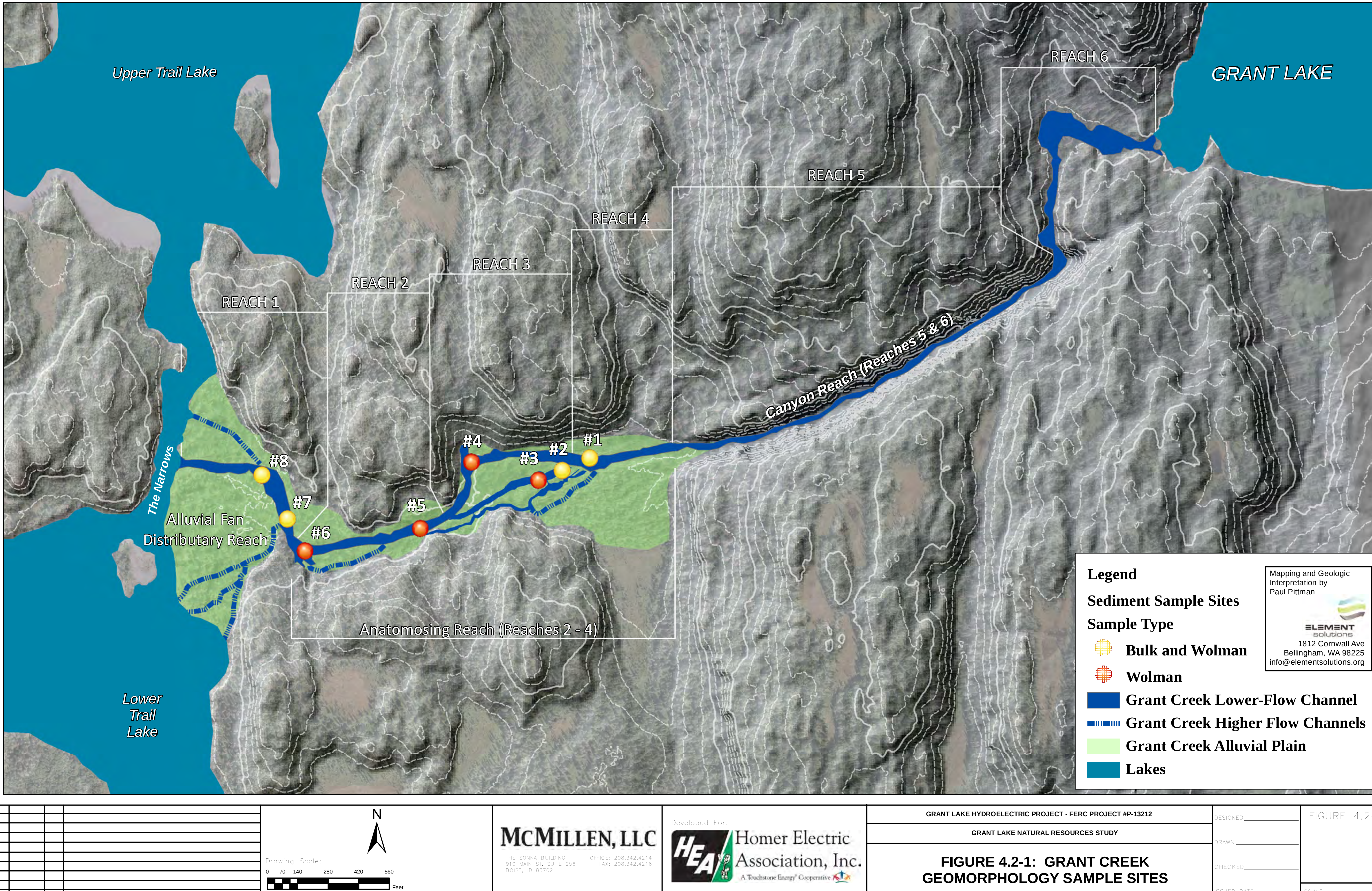

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FIGURE 4.2-1: GRANT CREEK GEOMORPHOLOGY SAMPLE SITES

DESIGNED ____
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FIGURE 4.2-1
SCALE:

Assumptions

The general operational scenario for the Project would result in bypassing some amount of flow from the canyon reach and the potential for an alteration of the natural flow regime. The specifics of the alteration cannot be detailed yet as ongoing work from an engineering feasibility standpoint and further discussions with stakeholders related to instream flows are needed prior to accurately defining the operational flow regime. What is certain is that the current natural flows would be modified as a result of Project operations and it is likely that peak flows would be decreased as a result of operations. For this assessment, in lieu of specific operational parameters that are yet to be worked out with stakeholders, an assumed operational peak flow of approximately 385 cfs (based upon general design parameters) was used.

The focus of this study was on the potential impacts to the spawning-size range of sediment. The following species of concern are documented to use Grant Creek for spawning: Chinook (*Oncorhynchus tshawytscha*), sockeye (*Oncorhynchus nerka*), coho (*Oncorhynchus kisutch*), rainbow trout (Salmo gairdneri *Oncorhynchus mykiss*) and Dolly Varden (*Salvelinus malma malma*). The range of documented preferred spawning sediment size classes that encompass these species can typically range from 5- 50 cm, with rainbow trout preferring the smaller substrate range and Chinook utilizing the larger substrate range (Russell 1974; Jones 1975; Suchanek et al. 1984; Milhous 1998; Bovee 1982; Swan 1989; Kondolf 1993). While these are the literature referenced "preferred" substrate size ranges, utilization of sediment sizes beyond this range does occur in reality. This is likely the case in Grant Creek, where sediment is typically larger than the stated preferred size classes. Although there is great variability in spawning substrate size preference between individual fish, different species and different river systems, the general size range is limited at the upper end by a substrate size that a particular fish has the physical ability to dislodge and at the lower range by a substrate size that reduces egg survivability during incubation. Substrate size alone is not a useful predictor of spawning potential (Geist and Dauble 1998).

Surface Sampling Methods

Surface sampling, also referred to as Wolman or frequency-by-numbers, was conducted on May 10, 2013 to characterize surface substrate size at various bedforms often utilized for spawning. Subsurface sampling methods utilized a random point sampling method to collect and measure surface sediment B-axis dimensions. Measurements were made using a Wolman template for a 100-stone count in areas of probable spawning. The grid spacing and measurement area was determined by field conditions such that the sample area was isotropic in the horizontal directions.

Subsurface Bulk Sampling Methods

Subsurface bulk sampling, also referred to as frequency-by-weight, was conducted on May 10, 2013 to characterize subsurface substrate size at anticipated spawning areas. Subsurface methods utilized field and laboratory sieving technics at four sampling sites in Reaches 1-4 downstream of the canyon to characterize subsurface conditions. The sampling sites were established at or near locations historic spawning or anticipated spawning at established instream flow monitoring sites in order to integrate the instream flow modeling outputs into the sediment transport equation. Based upon professional judgment, fewer sampling sites were needed due to the homogeneity of the substrate and field conditions. The sampling sites were spatially referenced for future monitoring.

Subsurface bulk samples were collected in areas assumed to have a high probability for salmon spawning based on the surface substrate size conditions and channel bed form (point or lateral bars that were immediately above the wetted channel margin at a flow of approximately 50 cfs). The surface armoring was removed as sample locations to the depth of at least one stone depth of the maximum surface stone diameter. Sieving many subsamples of a large sample volume was used to reduce bias and account for the large grain size observed at Grant Creek (Church et al. 1987). The largest grain size present in the sample is used as a basis for the sample volume following the reasoning that the largest particles will be the fewest in number and, therefore, least well represented. Because of the large grain sizes present at the site, it was infeasible to remove the full sample for laboratory measurement; therefore field sieving methods were used. The subsurface material was field sieved and weighed on site using the 2 percent criterion of Church et al. (1987) as the largest stone exceeded 90 mm which yielded individual sediment sample weights in excess of 450 pounds (200 kilograms). Sediment passing the 45 mm screen was sieved at a lab. A total of 4 bulk sample measurements were conducted in the Project reach.

Embeddedness Measuring Methods

The embeddedness sampling included measurements of approximately 50 stones of surface substrate of a particle size range that falls within the range of spawning substrate sizes for species using Grant Creek. Measurements of particle diameter (Dt) in the vertical direction and depth of embedment (De) were made of stones in the approximately D50 size class to achieve the Embeddedness Ratio. Embeddedness measurements were made at two sample sites in which Wolman counts were conducted.

Surface Marker Observation Methods

Surface marking methods were employed to field evaluate the presence or absence of sediment transport resulting from flows experienced in the 2013 season and to use to test sediment incipient motion calculations. Two areas of in situ surface substrate were marked at Sample Site 1 in which a Wolman Count and Bulk Sampling was performed. Substrate marking was accomplished by painting two one-meter square areas just above the low flow wetted margins adjacent to the Bulk Sample sites in situ conditions. These painted areas were inundated with higher flows (>100 cfs) and reevaluated following three months of high flow conditions to identify if thresholds of bed mobility were reached and compare to the modeling results.

Hydrology, Hydraulics and Incipient Motion Analysis Methods

Sediment transport analysis integrates the proposed maximum operation flows (385 cfs) and 2013 measurements of hydraulic characteristics at select sites utilizing the instream flow modeling outputs. Incipient motion particle size analysis was the method selected to determine the threshold of mobility for particles of various sizes given the proposed hydraulic condition.

Incipient motion particle size analysis was used to estimate the particle size that is anticipated to be transported at proposed operational flow (~350 cfs) and compare it to the spawning substrate size range to determine the impacts to the spawning substrate size range under the operational flow regime. A certain degree of sediment transport is necessary to maintain spawning substrate quality (Kondolf 1993). The incipient motion equation and literature-referenced calibration estimates were used to estimate the incipient motion particle size. The equation is:

$$\tau^* = \frac{\tau_o}{(\gamma_s - \gamma_w)\, D_s}$$

Where:

τ^* = Dimensionless Shield's parameter

τ_o = Channel bed shear, pounds per square foot (psf)

γ_s = Unit weight of sediment, assumed to be 165 pounds per cubic foot (pcf)

γ_w = Unit weight of water, 62.4 pcf

D_s = Size of sediment at incipient motion, feet

The values of the dimensionless Shield's parameter depend upon the size and shape of the substrate. A Shield's parameter value of 0.03 was considered for the Grant Creek calculation based on previous work by Inter-Fluve in the Cooper Lake Hydroelectric Project (FERC No. 2170; Inter-Fluve 2004) relicensing analyses, which referenced a study for small platy sediment forms (Mantz 1977). However, a range of different Shield parameter values were considered based upon the heterogeneity of the substrate shape and based on field observations and professional judgment.

Geomorphic Field Assessment

A qualitative geomorphic assessment of the sediment supply for Grant Creek was conducted on August 24, 2013. Analysis was based on observations from the field, understanding of the Grant Lake watershed, known geological conditions, and professional interpretation of observed geomorphic processes.

5 RESULTS

5.1. Grant Lake Shoreline Geomorphic Conditions and Processes Results

The results of the geomorphic shoreline mapping are shown on Figure 4.1-1. The shoreline conditions of Grant Lake are influenced by geologic conditions, geomorphic processes, and climate. Alluvial, colluvial and mass wasting processes, including avalanche, deliver sediment to the shoreline area and deposits of sediment locally bound the shoreline. The upper basin receives the dominant sediment load being transported to the lake via hill-slope and fluvial processes.

While most geologic and geomorphic processes effecting the littoral zone occur at relatively slow rates, evidence of large mass wasting events in Grant Lake were observed, which can create punctuated change along shorelines and stream channels, including rapid change in sediment supply, shoreline boundary changes, and large pressure generated waves, and erosion. It is hypothesized that the alluvial plain morphology of Grant Creek was influenced by a relatively recent landslide generated wave originating from Grant Lake. Large mass wasting events can have dramatic effect on the landscape.

<u>Natural Influences on Grant Lake WSEs and Littoral Conditions</u>

Grant Lake shoreline geomorphology is influenced by climate and seasonal variability. The lake remains ice free for approximately half of the year. During the ice-free period, WSEs fluctuate in response to snow melt, glacial melt, and precipitation. Wind generated wave processes erode, rework, deposit, and transport sediment in the littoral zone during the ice-free periods. The narrow confined valleys flanking the lake control wind direction and intensity. Wind direction from east or west will have the greatest effect on the upper lake basin whereas this wind direction will have little effect on the lower lake basin. Conversely, wind directions from north or south will have the greatest effect on the lower lake basin and only negligible effect on the upper lake basin. Because the lake orientation is divided by a 90 degree “bend” approximately mid-point, the effective maximum fetch is only approximately 3-miles. The largest wind-generated waves will be at the shorelines at the end of the fetch runs. The near shore bathymetric conditions also effect wave height and run up potential.

The highest WSEs typically occur in the summer months when snow melt and precipitation probability are highest or episodically in fall when transient snow and precipitation occur. WSE of Grant Lake is controlled by the Grant Creek outlet elevation (703 feet NAVD 88) and the hydrologic inputs from the watershed. The ordinary high WSE of the lake is at approximately 703 feet NAVD 88 based on previous estimates (EBASCO 1984). The OHWM has apparent elevation increases where wind generated wave run up occurs, including at the outlet at Grant Creek.

Grant Lake WSE is lowest in the winter months when the watershed is frozen, virtually halting hydrologic input. During ice-on conditions, the effect of wind generated waves is likely negligible except during ice break-up conditions. Anecdotal information would suggest that the lake WSE can fluctuate by several feet between high and low water. It is not known if the WSE drops below the elevation of the outlet control. If so, it is possible that some continued outlet of water occurs from the fractured or jointed bedrock present at the outlet. The presence of hydraulic loss at the outlet sill would also explain the fairly steady low flow rates observed in Grant Creek throughout the winter months when hydrologic inputs into Grant Creek are negligible.

<u>Project Operations Influencing Grant Lake WSEs</u>

Two design alternatives that affect the Grant Lake WSEs are being considered; one that allows for approximately 11 feet of WSE fluctuation but maintains the existing outlet elevation, and one that increases the outlet elevation by 2 feet and allows for 13 feet of WSE fluctuation. For this analysis, the more extreme of the two alternatives was considered since it will have the greatest influence on shoreline geomorphology. Table 5.1-1 provides a summary of the proposed operational changes to WSE.

The alternative to raise the natural outlet invert by 2 feet would be accomplished by constructing a concrete gravity diversion structure at the outlet of Grant Lake. The gravity diversion structure would raise the pool level by a maximum height of approximately 2 feet, and the structure would have an overall width of approximately 120 feet. The center 60 feet of the structure would have an uncontrolled spillway section with a crest elevation estimated at approximately 705 feet NAVD 88. A low level outlet would be constructed on the south side of the natural outlet to release any required environmental flows when the lake is drawn down below the natural outlet level. The outlet works would consist of a 48-inch diameter pipe extending back into Grant Lake, a gate house a regulating gate, controls, and associated monitoring equipment. The outlet would discharge into Grant Creek immediately below the diversion structure.

The primary release of water from Grant Lake for hydroelectric generation would be a concrete intake tower structure located approximately 500 feet east of the natural outlet of Grant Lake and adjacent to the shore. The intake would allow for drawdown of Grant Lake to elevation of approximately 692 feet NAVD 88. The intake can be designed to allow the Project to draw water near the surface at various levels of storage, if deemed necessary.

5.2. Grant Creek Geomorphic Conditions and Assessment Results

5.2.1. Grant Creek Geomorphic Setting and Conditions

The Grant Lake watershed is situated on the Kenai Peninsula within the Kenai Mountain Range. Metasedimentary and Metavolcanic rocks from the Valdez Group (Mesozoic Era) dominate the bedrock geology of the Grant Lake watershed and the Project area (Tysdal and Case 1979). The Valdez group within the watershed is composed primarily of greywacke, slate, and sandy slates (EBASCO 1984). The watershed has several faults and fracture zones that cut through it (Hartman and Johnson 1978; EBASCO 1984).

The most recent and prevailing influence on the geomorphology of the Grant Lake Watershed was the Pleistocene glaciations. Major continental glaciers have occupied portions of Kenai Peninsula at least four times over the past 1.6 million, the most recent ending approximately 11,000 years ago. The most recent major glaciation was the Naptwne Glaciation which occurred in the late Pleistocene, ending in the early Holocene (approximately 11,000 years ago) (Wilson et al 2012). The Grant Lake Watershed has been influenced by continental glaciers for much of its glacial history however the most recent glacial stade, the Elemendorf Stade, included mostly advances of Alpine glaciers that were concurrent with the continental glaciers. These glacial stades and interglacial periods have greatly altered the landscape by eroding bedrock, carving out the lake basin, steepening the valley walls, and depositing minor amounts of sediments. Glaciers have, for the most part, retreated to the upper limits of the watershed and only a few small alpine glaciers and snow fields are present today.

Grant Creek drains Grant Lake. It is a steep mountain stream with several falls, a narrow canyon, and a steep alluvial plain (Figures 4.2-1 and 5.2-1). In its upper half, the stream passes through a narrow bedrock canyon with three substantial waterfalls. The lower half of Grant Creek is a broader alluvial plain with a decreased stream gradient. It is likely that a faulting zone has facilitated the development of Grant Creek and the deep canyon that is associated with it. Grant Creek follows the Grant Creek Fault which has likely caused a shearing zone that has weakened the rock in this area and allowed the erosive power of Grant Creek flows to quicken the erosion of the canyon (EBASCO 1984). Additional linear features have also been identified in the watershed and several of these features are located on the ridgeline just west of Grant Lake and are in line with the abandoned relict drainage outlets that were formed when the lake level was higher. Grant Lake is in the process of lowering as it erodes the outlet sill and continues to incise the canyon.

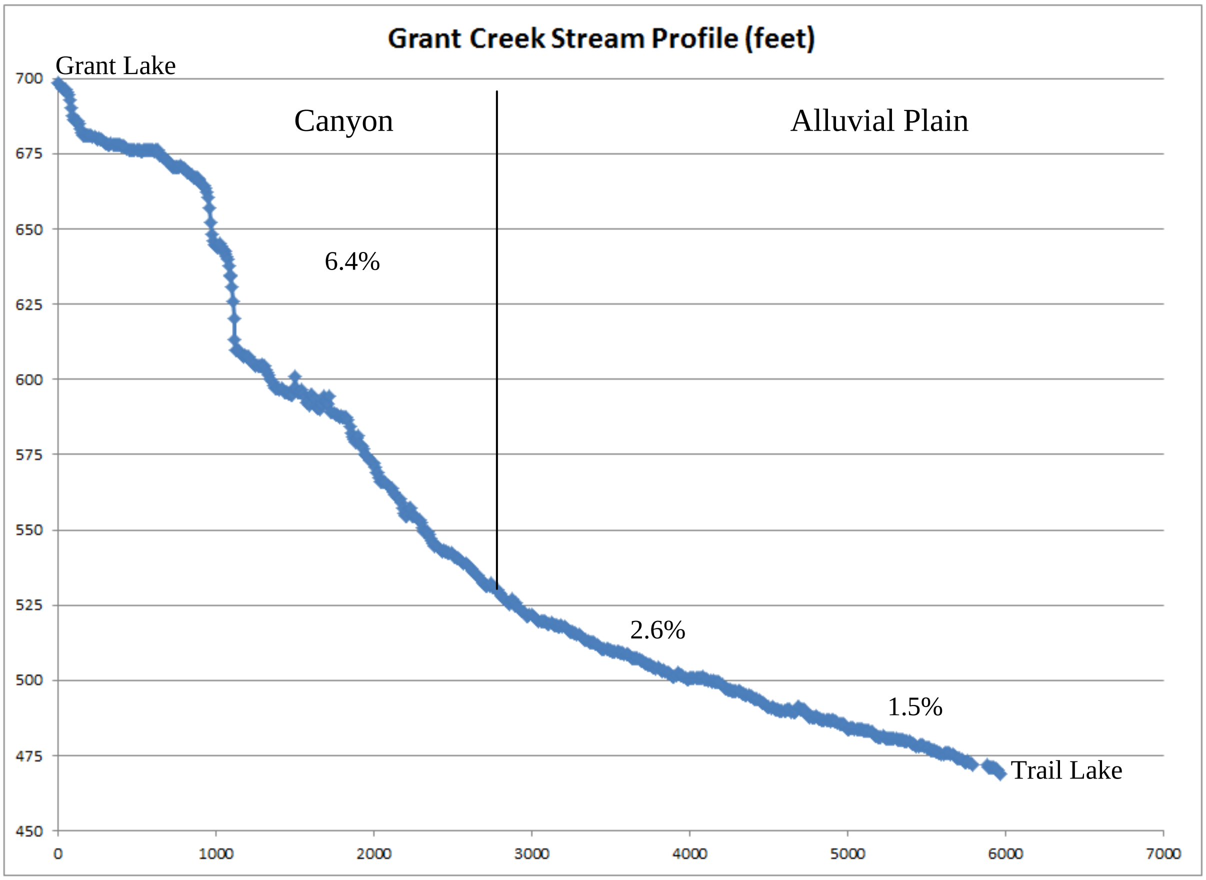


Figure 5.2-1. Grant Creek stream profile generated from LiDAR (2002). Vertical axis is in feet NAVD 88 and horizontal axis is in feet as measured from the outlet at Grant Creek.

Geomorphic interpretation of the alluvial plain landform indicates that relatively large hydrologic event(s) that are much larger than the historically observed hydrology have occurred and formed the broader alluvial plain. Substantial channel "rill" and fan topography near the canyon outlet and large alluvial transported boulders across a broad alluvial fan suggests a massive flow with sediment transport and deposition. The scale of the event(s) that formed the alluvial plain is likely substantially larger than snow-melt/rain flows where the largest recorded flow was 2,140 cfs (EBASCO 1984). It is hypothesized that the “event” was the result of an impact to Grant Lake that sent a surge of water over the Grant Creek outlet at the south end of Grant Lake. The event could have been a landslide or earthquake initiated seiche or an ice-jam dam break flood. The presence of very large sediment particles in the channel and on the alluvial plain that are beyond the transport capacity of the observed stream are relict of this event.

The alluvial plain channel has predominant substrate size that ranges from boulder to cobble and decreases from boulder-dominant substrate into a cobble-dominant substrate in the downstream direction (EBASCO 1984). The Grant Creek alluvial plain is bound by bedrock topography. The alluvial plain stream channel is approximately 25 feet at bankfull width on average, whereas the width of the alluvial plain is substantially larger than the bankfull and active channel which suggests that Grant Creek has historically occupied and eroded the alluvial plain margins.

Three generalized geomorphic channel form reaches currently exist in Grant Creek; the Canyon Reach, the Anastomosing Reach, and the Alluvial Fan Distributary Reach. The Canyon Reach (Reaches 5 and 6) is a confined bedrock channel and the primary source of sediment recruitment for Grant Creek. The channel in this section is steep and bedrock lined with limited sediment storage, both in volume and temporal duration. Most sediment is stored in the Canyon Reach sediment wedges formed behind boulder obstructions. Extremely large flows are capable of mobilizing these wedges and net incision into the bedrock is the trend. A series of headcuts (falls) are migrating up the stream in the direction of Grant Lake. In geologic time, these headcuts will migrate to Grant Lake and the lake water surface will drop to the new control elevation.

The Anastomosing Reach is within the partially confined alluvial plain and is net depositional zone with periods of incision occurring during low sediment input rates. Loss in hydraulic confinement and a change in gradient allow for sediment deposition within this reach when sediment input rates are high and transport capacity is low. It is anticipated that these conditions are episodic and driven by upper watershed conditions (hydrologic or geologic events) coinciding with a large sediment supply stored within the canyon reach. A low flow, primary channel carries the predominant flow and a series of side channel and floodplain channels are wetted at various flow conditions. The anastomosing reach changes relatively rapidly in both horizontal and vertical orientation depending upon the sediment load and is a more dynamic geomorphic reach than the Canyon Reach. Horizontal movements result from either lateral channel erosion or avulsion. It is anticipated the alluvial deposits overlay a bedrock base and that there is a robust hyporheic-ground water interaction, and that there is minimal hydrologic loss in this reach. The Anastomosing Reach channel and bedforms are sensitive to changes in flow regime and sediment load. Loss of side channel connectivity will result in a single thread channel, which decreases hydraulic complexity, concentrates stream power, and often results in increased channel incision.

The Alluvial Fan Distributary Reach is an unconfined, net depositional reach. Distributary channel networks that disperse flow to Lower Trail Lake and the Narrows are accessed at a wide range of flows. The Alluvial Fan Distributary Reach is likely the most dynamic reach in Grant Creek with respect to horizontal and vertical channel movements and avulsions. The reach is very sensitive to disturbances, particularly sediment supply and flow regime changes. Hydraulic complexity in The Alluvial Fan reach is hydraulically less complex than the Anastomosing Reach and it is probable that there is a slight hydrologic loss experienced in this reach.

The Anastomosing Reach of Grant Creek likely provides the greatest overall ecological function and salmonid productivity relative to the other reaches. The rationale for this hypothesis is that the reach has:

- the greatest hydraulic complexity;
- the greatest wetted channel length at moderate flows
- a more balanced wetted perimeter to depth at moderate flows;
- a higher probability of maintaining low and hyporheic connectivity in the winter;
- is more stable than the Alluvial Fan Reach; and
- lower velocity and stream power than the Canyon Reach.

Sediment Supply and Transport Influences on Grant Creek Geomorphology

A small amount of suspend and dissolved sediment load from the upper watershed reaches Grant Creek. However, Grant Lake acts to arrest all bedload sediment transport from the upper watershed area. Therefore, the sediment supply for Grant Creek, excluding the throughput suspended sediment load, is the canyon reach. With the majority of the sediment source for Grant Creek being derived from the canyon walls, the geological formations present along this length of stream channel play a critical role. The primary process for generating new bedload sediment in Grant Creek are the erosional forces that incise the canyon causing wall undermining and mass wasting (rock fall) from the canyon walls and exposing the geology to freeze-thaw and other surface erosion processes.

While Grant Creek within the alluvial plain exhibits net deposition over time, it is under "normal" hydrologic conditions a supply limited stream, meaning that the sediment transport capacity of the stream is greater than the sediment supply to the stream. A supply limited stream tends to migrate less laterally and vertically than a transport limited stream, and channel form is more "stable". Supply limited streams also tend to be armored, incised, and exhibit a straight versus meandering channel form.

Sediment Form Influences on Grant Creek Geomorphology

Of the three geological formations present along the creek channel, the greywacke is the more resistant rock type, whereas the sandy slate and slate are more friable and tend to supply the majority of sediment to the stream bed. The greywacke units control the base elevation in Grant Lake by creating the outlet sills and forming waterfalls. In time, erosion of the greywacke and head-cut retreat of the canyon would lower Grant Lake.

The sediment being recruited to Grant Creek is angular, with the slate having a "platy" particle morphology (A-axis and B-axis are similar, disproportionately small C-axis) and the greywacke having long "blocky or brick-like" particle morphology (large A-axis, similar disproportionately small B and C-axes). The high stream power in the canyon and the relatively short transport distance from the sediment source in the canyon to the depositional areas downstream results in relatively large grain size with high degree of angularity of the particles compared to other streams of similar discharge with a greater spatial extent of bedload sediment inputs. Blocky and platy sediment morphologies with the same B-axes dimensions have different volumes (think of a dinner plate versus a watermelon that both have similar B-axis diameter), and therefore a different surface area to mass, which effects transport characteristics. Angular sediment also transports across the channel bed (rolling and saltating) and entrains differently than does rounded. The particle morphology of Grant Creek likely increases the armoring qualities of the bed and thus adds to the overall stability of the channel form.

Hydrologic Influences on Grant Creek Sediment Transport and Geomorphology

The hydrology of Grant Creek is predominantly driven by the cycle of melting snow and precipitation in the summer and frozen watershed conditions in the winter. Historic hydrologic monitoring was conducted by a U.S. Department of the Interior, Geological Survey (USGS) operated gage between 1947 and 1959 and subsequent modeling indicates that Grant Creek has a mean annual flow of ~198 cfs (AEIDC 1983). Grant Creek was gauged in the spring of 2013 and a flow range of approximately 16 to 1,005 cfs was documented. The months of June through August typically produce the highest mean monthly flows (approximately 450 to 500 cfs) (AEIDC 1983). The highest measured flow was 2,140 cfs (EBASCO 1984). Recurrence intervals have not been calculated for this watershed.

It is the bankfull and peak flows that dominate the fluvial geomorphic processes at Grant Creek. The stream bed is comprised of large sediment particles and the bed is armored, so only the larger flows are able to mobilize the bed armoring, transport sediment en masse, and reorganize bedforms. The sustained flows offered by snow melt conditions allow for a longer duration of time for which to organize the substrate, construct and arrange the geomorphic channel bed structures, and allow channel form development.

A larger, but unmonitored hydrologic event likely occurred on Grant Creek in September 2012 when many other gauged streams in the vicinity of Grant Creek experienced flows of record. Some residual high water marks on Grant Creek were observed which showed that the 2012 event was larger than the highest 2013 flow. Using the existing stage gage and rating curve to estimate the flows, the 2012 flow was likely between approximately 1,500 and 2,000 cfs. The September 2012 flow was short duration and occurred late in the season and winter conditions set in soon after, therefore reducing the amount of time for flows following the event to process the transported sediment and adapt to the modified channel bed forms. As a result, the 2013 higher flow season responded to the disturbances from the 2012 event and there were several channel changes, including recapture of some floodplain channels, an avulsion, and partial abandonment of previously occupied low flow channels. The primary driver for these changes was likely a redistribution of bedload sediment and localized vertical channel bed changes, which affected localized WSEs. The observation shows that the channel form and bed forms and the interaction with the floodplain and floodplain side channels are dynamic, and thus habitat that relies on the availability, extent, and quality of substrate are related to sediment transport processes.

Non-climate driven hydrologic events likely occur within Grant Creek. The Grant Creek watershed is within an active seismic area and a large scale landslide, avalanche or earthquake caused seiche could occur. In the event that a large scale landslide did occur and deliver large volumes of material rapidly into Grant Lake, then large waves or seiches could propagate throughout the lake basin and into Grant Creek. It is probable that the hydrograph from one of these events, although brief in nature, would be substantially greater in magnitude than climate driven hydrographs.

5.2.2. Quantitative Sediment Characterization Summary

The Grant Creek channel bed is vertically stratified with at least two distinct layers; armored or pavement layer, and subsurface (Table 5.2-1). A sub-pavement layer was not distinct. The surface is highly armored which is enhanced by angular particle forms and the surface has low embeddedness and is relatively low in fine grained sediment. The subsurface is well-graded cobble and gravel with sand and nominal fines (less than 1 percent of sediment by volume is 1 mm (medium sand) or smaller). The subsurface material is anticipated to be easily remobilized when the armoring is removed.

Table 5.2-1. Surface (Wolman grid) sampling (frequency-by-numbers) results.

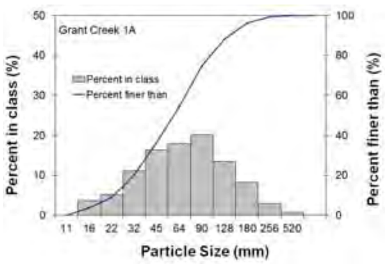
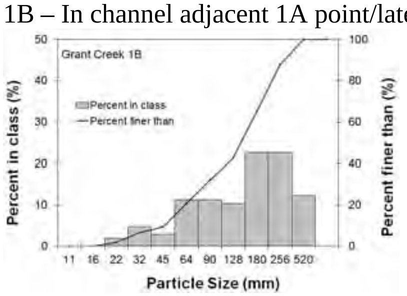
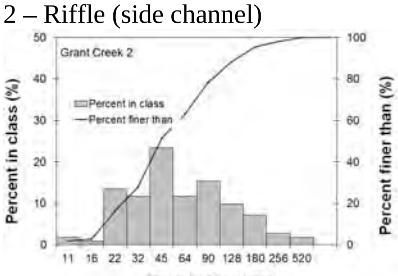
<table>
<tr><th>Sample ID - Description</th><th>Diameter Statics</th><th>Size (mm)</th></tr>
<tr><td rowspan="4">1A - Point/lateral bar

</td><td>D16</td><td>30</td></tr>
<tr><td>D50</td><td>59</td></tr>
<tr><td>D84</td><td>115</td></tr>
<tr><td>D-Maximum</td><td>>520</td></tr>
<tr><td rowspan="4">1B – In channel adjacent 1A point/lateral bar

</td><td>D16</td><td>55</td></tr>
<tr><td>D50</td><td>154</td></tr>
<tr><td>D84</td><td>524</td></tr>
<tr><td>D-Maximum</td><td>>600</td></tr>
<tr><td rowspan="4">2 – Riffle (side channel)

</td><td>D16</td><td>16</td></tr>
<tr><td>D50</td><td>48</td></tr>
<tr><td>D84</td><td>110</td></tr>
<tr><td>D-Maximum</td><td>>520</td></tr>
</table>

Table 5.2-1, continued…

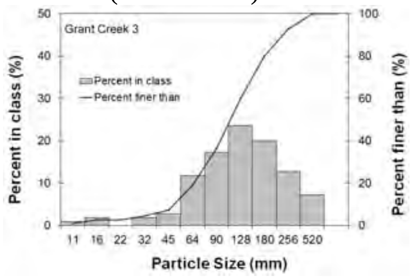
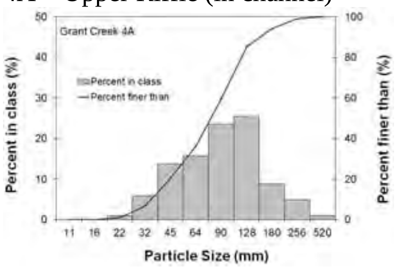
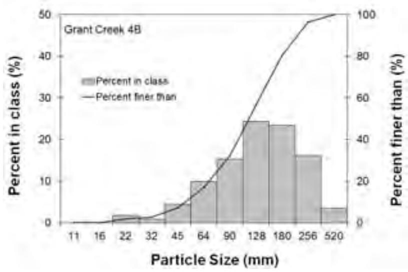
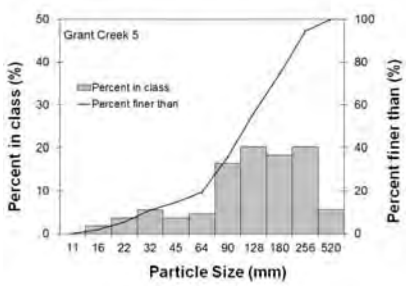
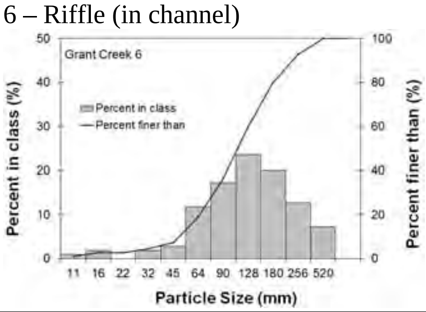
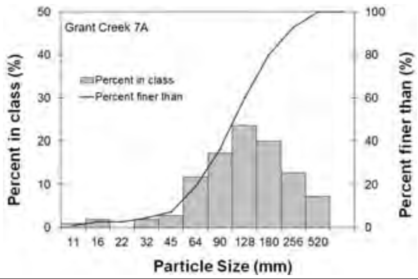
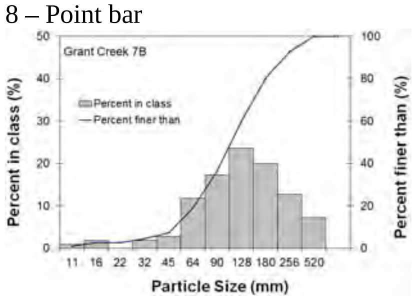
3 – Glide (side channel) 	D16	58
	D50	118
	D84	183
	D-Maximum	>520
4A – Upper Riffle (in channel) 	D16	40
	D50	78
	D84	122
	D-Maximum	>520
4B – Lower Riffle (in channel) 	D16	62
	D50	133
	D84	190
	D-Maximum	>520
5 – Run (in channel) 	D16	51
	D50	121
	D84	209
	D-Maximum	>520
6 – Riffle (in channel) 	D16	49
	D50	111
	D84	177
	D-Maximum	>520

Table 5.2-1, continued…

7 – Point bar 	D16	35
	D50	77
	D84	145
	D-Maximum	>256
8 – Point bar 	D16	51
	D50	83
	D84	151
	D-Maximum	>520

<u>Surface Analysis Results Summary</u>

In summary, the wetted low-flow channel areas are substantially coarser and more armored than are the lateral and point bars (Table 5.2-2). No trend in surface sediment decrease moving in the downstream direction was observed. It is hypothesized that local hydraulics and the two distinct particle forms (platy and blocky) influences particle size to transport relationship and deposition more than channel gradient in this turbulent system. The instream D50 is generally larger than literature referenced "preferred" spawning substrate size; however, in the case of Grant Creek the spawning species are utilizing the areas with large, armored surface substrate.

Table 5.2-2. Subsurface volume (bulk) sampling (frequency-by-weight (volume)) results.

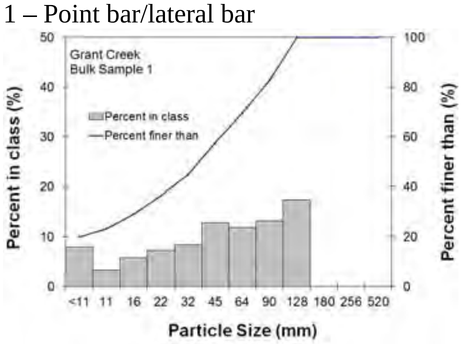
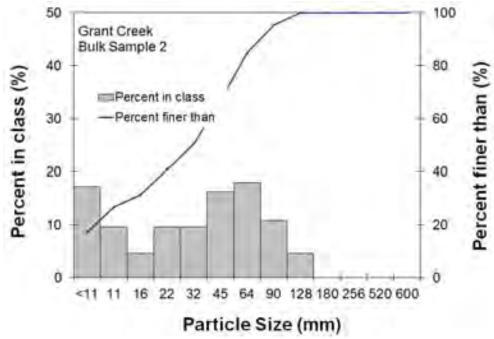
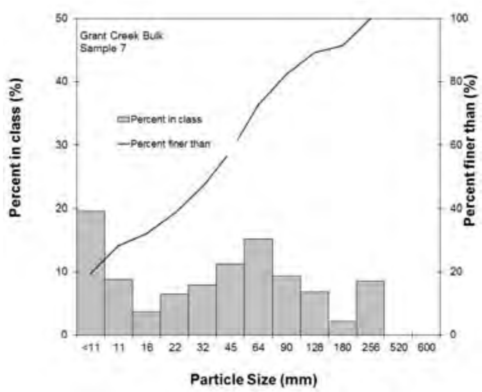
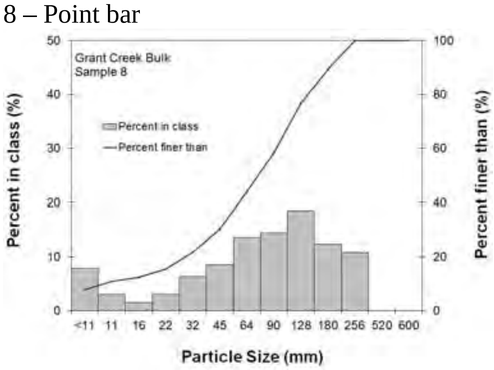
Sample ID - Description	Diameter Statics	Size (mm)
1 – Point bar/lateral bar 	D16	20
	D50	52
	D84	133
	D-Maximum	>128

Table 5.2-2, continued…

<table>
<tr><td rowspan="4">2 – Riffle in side channel
</td><td>D16</td><td>17</td></tr>
<tr><td>D50</td><td>21</td></tr>
<tr><td>D84</td><td>38</td></tr>
<tr><td>D-Maximum</td><td>>128</td></tr>
<tr><td rowspan="4">7 – Point bar
</td><td>D16</td><td>17</td></tr>
<tr><td>D50</td><td>28</td></tr>
<tr><td>D84</td><td>98</td></tr>
<tr><td>D-Maximum</td><td>>256</td></tr>
<tr><td rowspan="4">8 – Point bar
</td><td>D16</td><td>31</td></tr>
<tr><td>D50</td><td>74</td></tr>
<tr><td>D84</td><td>147</td></tr>
<tr><td>D-Maximum</td><td>>256</td></tr>
</table>

<u>Subsurface Analysis Results Summary</u>

The subsurface is less coarse than the surface, except at Sample Site 1, where the subsurface had a higher percentage by size class of large particles and yet a similar D50 size. It is hypothesized that the subsurface in Sample Site 1 represented a hyperconcentrated flow deposit as it lacked sorting and imbrication structure that was apparent in the other subsurface sample sites. Subsurface sediment was overall well-graded cobble and gravel with sand with minimal fines. Similar to the surface analysis, there was not a general trend in decreasing D50 particle size in the downstream direction because of the influence of localized hydraulics and relict hyperconcentrated lag deposits. It should be noted that inaccuracies in bulk sampling can be pronounced in bimodal distributions containing large clasts and where lag deposits from hyperconcentrated/dam outburst type alluvial deposits are found, as is the interpreted conditions of Grant Creek.

<u>Embedment Results</u>

Field observations of embeddedness resulting from fine-grained sediment deposition in the interstitial spaces of the surface armoring were found to be extremely low. The reasons for this are hypothesized to be that: the Grant Creek system is relatively starved of fine sediment and that the current flow regime transports most fines through the system as throughput, and the low sediment delivery rate and high flows result in armored condition.

General clast-to-clast embedment was difficult to measure because of the particle forms, particularly platy, and the generally well armored conditions. Qualitatively, clast-to-clast embedment appeared relatively high because of armoring. Because of the high percentage of imbricated platy sediment particles, there is low confidence in the values measured, and therefore it is our opinion that quantitative results are not reliable. However, it is not anticipated that the operational scenario will not increase the deposition of fines in the stream, therefore there should not be an increase in fines filling the interstitial spaces of the surface sediment within the spawning reach.

<u>Sediment Incipient Motion Analysis Results</u>

Grant Creek is an example of a complex system for the following reasons:

- Grant Creek is a high gradient, boulder dominated stream with turbulent flow. Bedform and channel bank irregularity, in addition to instream boulder and bedrock structures, create turbulence with secondary flow influences that can be much more influential on sediment transport than in planer bed conditions. Attempts to calculate or measure shear stress values in mountain rivers are complicated by the channel bed roughness and the associated turbulence and velocity fluctuations (Wohl, 2000).
- Sediment particle shapes are unique and vary from referenced calibrated models. The sediment shapes present in the Grant Creek are angular platy particles and angular blocky or "brick" shaped particles. These two shapes will each mobilize and transport differently relative to each other. These two shapes are different from the assumed particle shape used to develop and calibrate models, which are spherical shapes. Spherical particle shapes will have a different transport characteristic than either platy or brick shapes. In addition, each particle form will lay and organize differently on the channel bed and each has a different mass to B-axis ratio; therefore, incipient motion will be different for each particle represented in Grant Creek as well as different than predicted by equations developed using spherical models.
- Sediment transport rates at Grant Creek are very low. There are three phases of sediment transport associated with very low bedload transport rates, also known as marginal transport. Incipient motion and net transport rates in these systems are very sensitive to changing hydraulic conditions and bed material moves only partially; thus entrainment is size-selective (Hassan et al. 2005; Wilcock and McArdell 1993).
- The Grant Creek channel bed is locally armored. Sediment transport characteristics, specifically incipient particle motion, in armored gravel-bed rivers is often controlled by

patches of fine sediment and bedforms (e.g. Garcia et al. 1999). Bedload transport characteristics vary from the initiation of particle movement to the point when the breakup of the armor layer occurs when the channel becomes unstable at the reach scale.

- Inter-particle relationships are not represented in model assumptions, so hiding effect and "patches", which can have significant influence on particle movement are not considered.

A given particle will move only when the shear stress acting on it is greater than the resistance of the particle to movement. The magnitude of shear stress required to move a given particle is known as the critical shear stress. The resistance of the particles to movement, and thus its entrainment, will vary depending on its size, its size relative to surrounding particles, how it is oriented, and the degree to which it is embedded. The size of the particle will influence the weight of the particle. The size of the particles relative to surrounding particles will affect the amount of shear stress the particle is exposed to via the "hiding" factor. Orientation of the particle will affect the force required to roll the particle along the bed. Packing or embeddedness will affect the amount of shear stress that the particle is exposed to.

The substrate particle forms, as previously described, are distinctly different and literature supporting Shield parameter values for both platy and blocky particle forms is extremely limited. It is hypothesized that platy particle forms in a cohesionless, heterogeneous particle shape planer bed will mobilize in lower flows and be more easily entrained than will blocky particle forms of similar B-axis dimensions in the same flow conditions if the platy particles are loose and unorganized. However, if the platy sediment has become highly imbricated in a more homogeneous particle shape grouping, thus increasing particle-to-particle contact forces and decreasing fluid forces acting on a given surface area (skin friction), then the platy particle will require a higher flow to initiate mobilization than the blocky sediment. Based on the lack of strongly imbricated, homogenous surface present at Grant Creek, it is anticipate that the platy particles will be mobilized more easily than the long axis blocky particles. It should also be noted that Grant Creek channel bed is, for the most part, not planer, thus bed shear stress is primarily associated with form drag rather than skin friction on individual particles, which is the force that moves particles.

The incipient motion calculation estimated that the proposed maximum operational flow (385 cfs) will likely initiate mobilization of surface sediment within the preferred spawning substrate range (10 mm – 50 mm). At 385 cfs, it is anticipated that substrate mobility will be partial, limited to only smaller particles and that movement of particles will be intermittent, localized, and primarily from the deeper channel areas or where turbulence is high. Mobilization of particles will also depend upon the degree of armoring, bedform, and particle shape. Table 5.2-3 is a summary of the estimated upper particle size threshold being mobilized at 385 cfs.

Table 5.2-3. Summary of incipient motion calculations at 385 cfs.

Sample Site	τ(blocky)	τ(platy)	τb (pounds/sf)	Ds(blocky) mm	Ds(platy) mm	D50 surface mm	D50 subsurface mm
1	0.06	0.03	1.85	92	183	59	52
2	0.06	0.03	0.79	39	79	48	21
7	0.06	0.03	1.32	65	131	77	28
8	0.06	0.03	1.12	55	111	83	74
			Average	62.8	126	67	44

Field observations, marker analysis, and professional judgment would suggest that the predicted particle sizes are high for the platy particle forms using the Shield's parameter of 0.03. It also is possible that the values obtained for the blocky substrate are too high as well. These outputs predict that there would be substantial bedload movement at a 385 cfs flow. Very little bedload sediment transport appeared to be occurring at flows near the proposed operational flow. Additionally, flows near the proposed operational flow also coincided with spawning activity. The point bar at Sample Site 1 had only experienced minor sediment transport even with the 1000 cfs flows, so it is unlikely that widespread surface sediment breakup occurred at 1000 cfs flows. However, channel bed changes and resulting WSE changes occurred in 2013 occurred following the higher flows; therefore, some degree of local bedload transport does occur with flows between 350 cfs and 1,000 cfs.

Sediment Delivery Potential Results

Sediment delivery and transport in Grant Creek is divided between two transport characteristics; suspended sediment load and bedload sediment. Suspended sediment load passes through Grant Creek with very little deposition in the alluvial reach as a result of the steep stream gradient, turbulence and low sediment load. The primary source of suspended sediment is from the glacial headwaters. Much of the suspended sediment load settles out into Grant Lake. The suspended sediment that passes through Grant Lake is extremely fine and has a very low settling rate, which also decreases the potential for deposition to occur within Grant Creek.

There are four primary sources of bedload sediment in Grant Creek; lakeshore littoral sediment input, canyon reach input, channel bed and channel bank remobilization (bank erosion, incision), and mechanical breakdown of instream sediment during mobilization. Field investigation determined that the bedload sediment supply in Grant Creek is extremely limited and that the canyon is the predominant source of bedload sediment. Bedload sediment delivery arrives episodically, either from a rock fall within the canyon, or a littoral contribution resulting from a large wind storm occurring at high lake WSEs. Remobilization of channel bank and channel bed sediment can provide a sediment input to lower reaches, but does not recharge or replenish the whole stream system. Large hydrologic events are necessary to mobilize and transport sediment from the canyon and deliver the sediment to the lower reaches as well as to mechanically breakdown instream sediment.

6 CONCLUSIONS

6.1. Grant Lake Shoreline Erosion Study Conclusions

The analysis utilized methods prescribed in the Study Plan previously developed by KHL and resource agencies and finalized in March 2013. Since operational WSE changes have not yet been fully defined, the shoreline erosional change was difficult to completely determine. Additionally, because of the presence of snow and ice occurring during low WSE, it was not feasible to conduct a low lake WSE analysis. As a result, the analysis relied upon the previously described conditions and available information. Lastly, the geomorphic analysis does not include a geotechnical evaluation of existing slope stability or changes in slope stability resulting from changes in Grant Lake WSE.

The anticipated impacts to shoreline erosion potential from the proposed operational WSE fluctuation are likely to be relatively minor over the long term for the following reasons:

- Proposed operational conditions only increase the WSE fluctuation range by a maximum of 2 feet above existing natural lake WSE fluctuations
- Most of the change in WSE range is a decreased WSE that occurs in winter during ice-on conditions when wave and stream erosion processes are less active.
- The shoreline littoral area is predominantly bedrock or coarse, angular boulders with a low susceptibility to erosion.
- Influence of wind-generated waves in Grant Lake is not a substantial erosional process because the open fetch was limited to a maximum of approximately 3 miles, and therefore wind wave heights were limited. In the areas where fetch was greatest and bathymetric conditions favored high wave run up, only a slight increase in OHWM elevation demonstrating that maximum wind-wave heights were estimated to be a maximum of approximately 5 feet at Inlet Creek and 3 feet at Grant Creek outlet.
- In the areas where erosion potential was greatest, only minimal erosion; in part because of the depositional nature of the geomorphic units these areas and the apparent high depositional rate. With the exception of the Beach geomorphic unit, all other areas are actively delivering sediment to the shoreline area at rates that are greater than the erosion potential.
- It is anticipated the WSE fluctuations under proposed operational conditions will decrease the duration of time that the WSE holds at any one elevation, especially peak WSE levels, therefore decreasing the frequency of wave events occurring at any one elevation and reducing the effects of wave erosion at any one shoreline elevation.
- Because of the limited extent of littoral transport observed in the field, the effects on the Beach geomorphic unit and other isolated pocket beaches is anticipated to be relatively minor. It should be noted that an interruption of limited littoral-transported sediment supply to Grant Creek will occur following the construction of the gravity diversion structure (if this option is selected), but it is anticipated that the sediment volumes and delivery rates are relatively small and only occur episodically and likely infrequently.
- The impacts of erosion along the shoreline from an elevated lake WSE above the current OHWM will be most dramatic in the first few years as loose and fine grained sediment are "winnowed" from the shoreline deposits by wave action leaving behind an armored shore. In some areas shoreline retreat and temporary vertical bluffs are expected,

particularly in the more erodible alluvial deposits. This impact will be greatest in low-sloping shorelines, fine-grained depositional areas, and areas with greater fetch, Inlet Creek in particular will see the greatest shoreline changes. In addition, the vegetation along the shoreline that is functioning to bind soils and slopes together with root mass will lose this function as the vegetation in the inundated and dies. It is possible that the shoreline will take up to a decade to recover from the initial disturbance created by the increased WSE.

- The areas most susceptible to erosion from stream incision caused by decreases in base elevation are the alluvial deposits (Alluvial Deltaic and Alluvial Fan geomorphic units). The potential effects of channel incision will be the steepening of stream gradient, coarsening of streambed sediments, straightening of stream channels, decreased floodplain connectivity, increased instream flow velocities and depths, and bank steepening and retreat.

The potential for ice jams exists in Grant Lake, particularly at the narrow, shallow sill mid-way down the lake and at Grant Creek outlet. The temporary elevation increase of WSE and resulting shoreline erosion is possible during these potential episodes, as is the potential stream erosion in Grant Creek resulting from an ice jam break. While landslides and ice-jams can be significant geomorphic processes, the recurrence interval and magnitude is unknown, but likely infrequent.

The greatest ongoing potential for geomorphic impact is the potential incision of the inlet streams at the shoreline margin, Inlet Creek at the east end of the lake in particular. The effects of impact is lessened since these streams do not possess populations of any fish species other than the potential for the stickleback and sculpin known to be the only two species that inhabit Grant Lake. The degree of impact will be limited by the timing of high flows in combination with the extent and duration of low lake WSE conditions. As lake WSE increases, the probability and extent of stream incision impacts decreases.

6.2. Grant Creek Spawning Substrate Recruitment Study Conclusions

The analysis utilized methods prescribed in the Study Plan previously developed by KHL and resource agencies and finalized in March 2013. In general, bedload transport is not a simple exercise to measure or predict. There is a high degree of uncertainty and low degree in output confidence in uncalibrated bedload transport modeling. A collaborative approach to addressing these potential issues is recommended.

Grant Creek is a complex, steep stream that demonstrated a wide range of variability both with the substrate and bedform conditions and transport is not adequately captured using referenced Shield's parameter values (Yager 2012). Regardless, the proposed operational conditions have the potential to have a geomorphic response as summarized in Table 6.2-1.

Table 6.2-1. Potential geomorphic responses from Project operational conditions.

Proposed Change	Potential Geomorphic Response
Decreased frequency and magnitude of Grant Creek peak flows	• Reduced shear stress potential resulting in decreased net sediment transport potential • Decreased movement potential for large sediment material • Continued sediment transport of smaller and intermediate sediment sizes from the surface or subsurface following bioturbation (specifically spawning) • Decreased potential for armor remobilization • Increased relative armoring trend over time resulting from smaller particle "winnowing" (migrating in a downstream direction) • Decreased remobilization of sub-surface sediment except in spawning areas • Increased potential for channel stability (decreased lateral migration, net increase for channel incision potential) • Increased potential for development of a single-thread channel • Loss of floodplain connectivity • Decreased potential for scour and organization of depositional channel bed forms • Decreased bedform quantity and associated loss of hydraulic complexity • Decreased sediment supply resulting from lateral migration
Decreased frequency and duration of Grant Creek low flows	• Decreased potential for fine-grained sediment deposition
Flow bypass of the canyon reach	• Reduced sediment supply availability • Decreased ice-jam dam outburst potential • Decreased potential for slope instability in canyon reach • Decreased potential for bedrock outlet control degradation (erosion) and long-term Grant Lake WSE reduction

Of the potential geomorphic responses listed above, the following geomorphic responses are anticipated to have impacts to spawning substrate. Many of the geomorphic response and the resulting impacts to spawning substrate are anticipated to occur incrementally over time measured in years and decades. It is anticipated that there will be high potential for:

- An increased coarsening of surface bedload sediment as the sediment supply decreases from a bypass of the Canyon Reach and smaller surface sediment is transported out of the reach by operational flow. As a result, there is likely to be degradation spawning substrate quantity and quality resulting from this geomorphic response.
- Increased armoring and pavement depth in spawning areas as subsurface fines are mobilized and winnowed out of the system following bioturbation pavement breakup (from spawning). As a result, there is likely to be a degradation of spawning substrate quality resulting from this geomorphic response.
- Decreased geomorphic channel form complexity (loss of side-channel and floodplain connectivity, development of a single-thread channel) resulting from decreased sediment supply will increase primary channel incision and stream velocity. As a result, there will likely be a decrease in spawning substrate quantity resulting from this geomorphic response.
- Decreased quantity of channel bedforms (riffles and bars) resulting from decreased sediment supply and decreased sediment transport with a reduced flow regime. As a

result, there will likely be a decrease in hydraulic complexity that is expected to degrade spawning substrate quality and reduce its availability resulting from this geomorphic response.

It is the conclusion of this analysis that there will be an ecological impact related to the anticipated geomorphic responses resulting from operational conditions. There is a direct relationship between stream flow and sediment transport and aquatic habitat availability and quality (Pitlick and Wilcock 2001). Bedload sediment supply in combination with a variable flow regime creates and modifies channel bedforms, controls sediment transport and storage, affects surface texture through selective transport, influences channel migration, and has a direct influence on aquatic habitat. The flux rate of coarse material combined with high flow magnitude and duration create an important component of sediment mass balance and geomorphic response in a stream and modification of these variables and can have ecological significance both for salmonid spawning, juvenile rearing, and invertebrate production. While a variable flow regime is vital to creating and maintaining spawning substrate, it is possible that some moderation of the Grant Creek flow range under certain management scenarios could provide some positive impacts to redd survival.

Geomorphic bedform features create hydraulic processes that support ecologic function, in particular channel and bedform complexity create hydraulic conditions favorable for spawning and rearing habitat by creating interstitial flow pathways between surface water, hyporheic, and ground water zones (Geist et al. 1998). Geomorphic bedforms are created, organized and destroyed by flow variability, higher flows that mobilize bedforms are particularly important in this process. Salmonid spawning tends to occur at the transitions between pools and riffles associated with lateral bar deposition (Bjornn and Reiser 1991; Church and Jones 1982).

A management scenario that integrates some degree of flow variability to provide flows of sufficient peak and duration to enable spawning substrate mobilization and organization could be utilized to offset some of the impacts to substrate quality. Additionally, a management scenario that allows periodic, sediment flushing flows through the canyon reach could provide for recruitment and transport of the sediment necessary to maintain spawning substrate quantity in the lower reaches. This management scenario would have to be coordinated with reservoir level and habitat utilization period(s). Another alternative could be to develop a sediment nourishment program to replace the lost sediment recruitment opportunity created from the canyon bypass.

7 VARIANCES FROM FERC-APPROVED STUDY PLAN AND PROPOSED MODIFICATIONS

There were three variances from the FERC and agency-approved study plan that occurred in the geomorphology analysis. One is that a dataset for the embeddedness assessment task was not provided. The rationale for action was that unique field conditions made for non-reproducible results with high data uncertainty. The second was that the number of subsurface sampling sites and sample size and sieve methods was modified to fit actual field conditions. The sediment particle size was too great to remove the prescribed sample size and to have it processed by a lab.

The number of sample sites was decreased based on relative homogeneity of conditions observed and an unanticipated low quantity of gravel bars exposed at low flow.

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Appendix 1: Grant Lake Shoreline Geomorphology Site Photos

Note: Locations of photos are shown on Figure 4.1-1.

Geomorphic Unit "Type Sections" and Field Notes

Photo 1 (by P.Pittman, 8/24/2013): Grant Lake typical "*Beach Deposit*" Geomorphic Unit.

Field Note - WSE at visit is was approximately 2 feet over the Grant Creek outlet invert.at this location of the lake is approximately 3 -feet higher than the WSE at the time of the field visit and likely represents an apparent OHWM increased because of wave run up. The OHWM in protected areas of the lake was approximately 1 to 2 feet above the WSE at the time of the field visit. An increase in WSE of 2 feet will cause a shoreward retreat of the shoreline and vegetation loss below the OHWM.

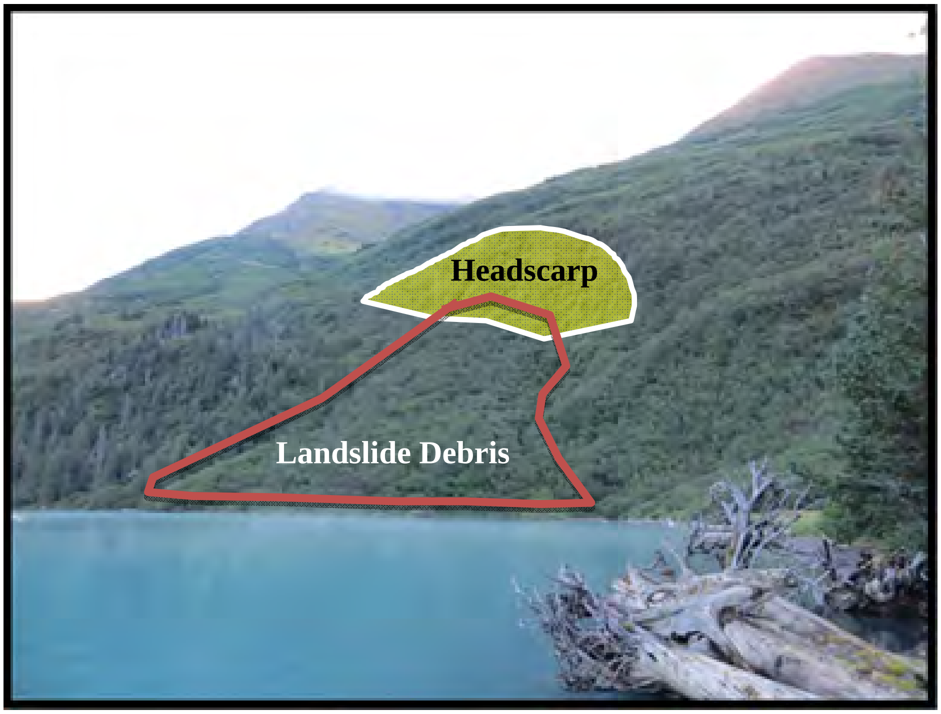

Photo 2 (by P.Pittman, 8/24/2013): Grant Lake typical "*Landslide*" Geomorphic Unit and field interpretation.

Photo 3 (by P.Pittman, 8/24/2013): Grant Lake typical "*Alluvial Fan Deposit*" Geomorphic Unit.

Photo 4 (by P.Pittman, 8/24/2013): Grant Lake typical "*Bedrock*" Geomorphic Unit.

Photo 5 (by P.Pittman, 8/24/2013): Grant Lake typical "*Bedrock*" Geomorphic Unit at the Grant

Field Note: Lake narrows between the upper basin and lower basin. At low WSE conditions, the gap will narrow and water depths will be 2-feet or less, and it is anticipated that the submerged topographic saddle is bedrock.

Photo 6 (by P.Pittman, 8/24/2013) Field Note: Grant Lake pocket beach along a bedrock shoreline.

Photo 7 (by P.Pittman, 8/24/2013): Grant Lake typical "*Alluvial Fan Deposit*" Geomorphic Unit showing contribution from both alluvial transport and avalanche activity.

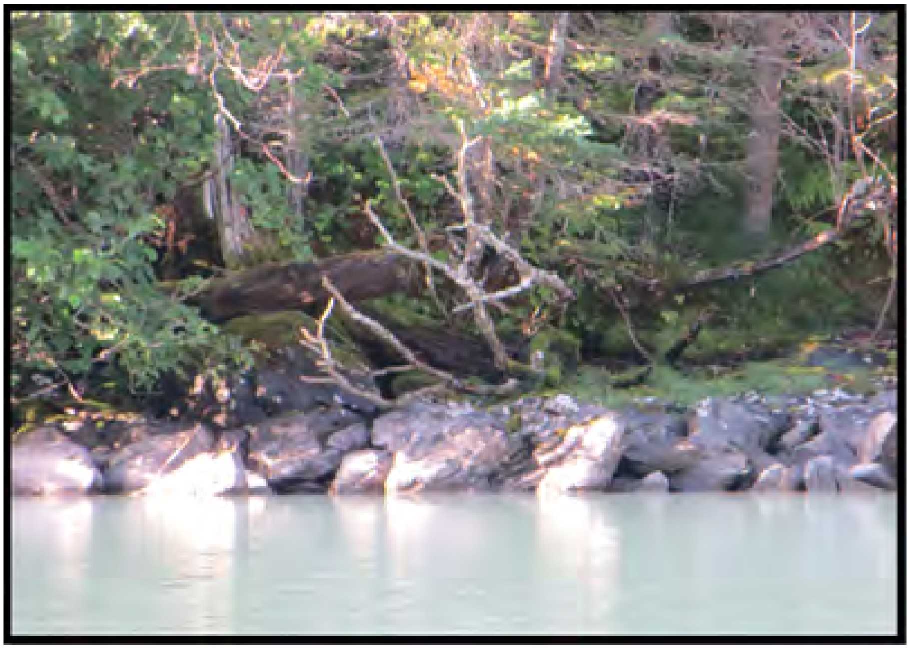

Photo 8 (by P.Pittman, 8/24/2013): Grant Lake typical "*Colluvium*" Geomorphic Unit.

Photo 9 (by P.Pittman, 8/24/2013): *Field Note* - Evidence of shoreline erosion occurring on an "*Alluvial Fan Deposit*" Geomorphic Unit.

Photo 10 (by P.Pittman, 8/24/2013): "*Alluvial Fan*" Geomorphic Unit.

Field Note - Streams along the Grant Lake shoreline are susceptible to WSE and incision, armoring, channel straightening, and loss of floodplain connectivity is anticipated with decreases in WSE, particularly if WSE remains low during high flow conditions.

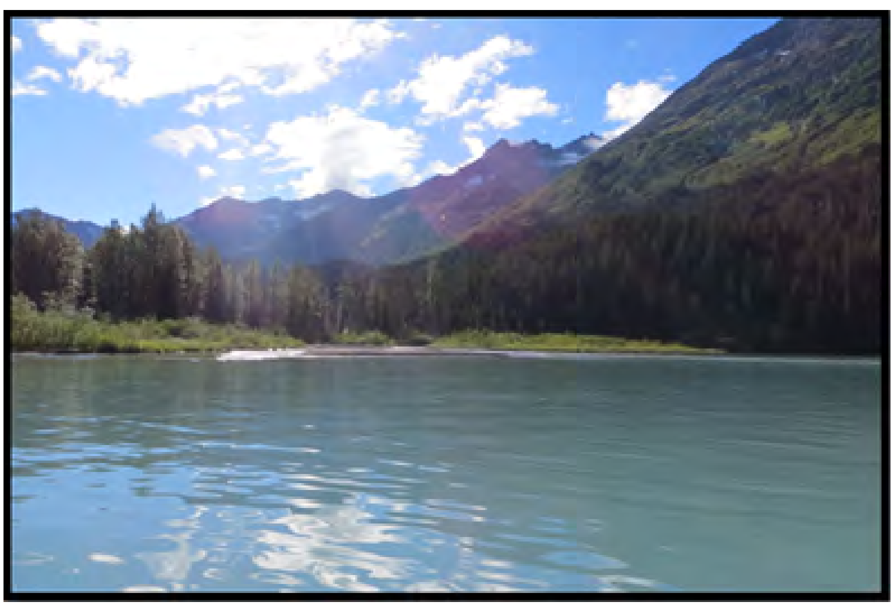

Photo 11 (by P.Pittman, 8/24/2013): Grant Lake typical "*Alluvial Deltaic*" Geomorphic Unit at Inlet Creek.

Photo 12 (by P.Pittman, 8/24/2013): *Field Note* - Interspersed alluvial fan and colluvium deposits dominate the shoreline of the Grant Lake upper basin.

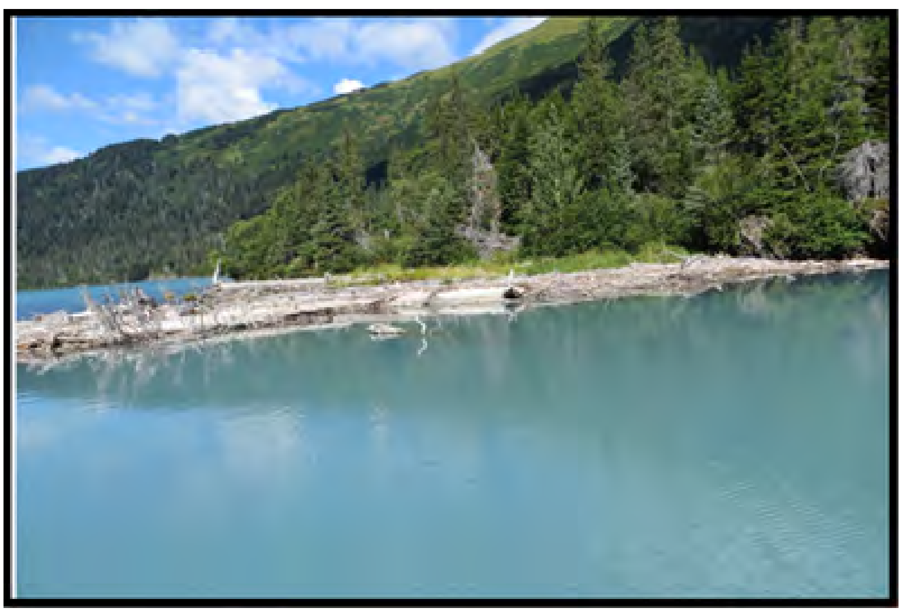

Photo 13 (by P.Pittman, 8/24/2013): *Field Note* - Accumulation of organic debris and forest encroachment at a shallow gap in the Grant Lake narrows between the upper and lower basin. This accumulated debris will likely be inundated and dislodged when the lake WSE is increased. During low WSE conditions, an isthmus will be exposed.

Photo 14 (by P.Pittman, 8/24/2013): *Field Note* - WSE increase cause a retreat of shoreline vegetation and temporary shoreward erosion will occur as a result of the loss of root strength and winnowing of finer sediments and soils. The erosion should self-mitigate once root strength and vegetation can reestablish in the disturbed areas.

Photo 15 (by P.Pittman, 8/24/2013): *Field Note* - Steep bedrock shorelines dominate the shoreline areas of the Grant Lake lower basin.

Photo 16 (by HDR, circa spring 2009): *Field Note* - Low WSE under natural conditions at the “Beach Deposit” Geomorphic Unit.

Photo 17A (by HDR, 6/10/2009)

Photos 17B (by HDR, 6/10/2009)

Photos 17A and 17B: *Field Note* - Grant Lake outlet at Grant Creek. Bedrock sill grade control visible beneath water (approximately 2 feet deep estimated at time of field visit.

Photo 17C (by HDR, circa spring 2009): *Field Note* - Grant Lake outlet at Grant Creek where the proposed gravity diversion structure will be constructed.

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