ATTACHMENT 3: PRELIMINARY RESERVOIR SLOPE STABILITY ASSESSMENT

SUSITNA-WATANA HYDRO

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Preliminary Reservoir Slope Stability Assessment

AEA11-022

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ACRONYMS AND ABBREVIATIONS

Acres	Acres American Incorporated
AEA	Alaska Energy Authority
AEIC	Alaska Earthquake Information Center
bgs	below ground surface
El.	Elevation in feet
FERC	Federal Energy Regulatory Commission
GAI	Golder Associates Incorporated
H:V	horizontal, vertical
ICOLD	International Committee on Large Dams
INSAR	Interferometric Synthetic Aperture Radar
LiDAR	Laser Detection and Ranging
Ma	million years from the present
MatSu	Matanuska-Susitna Borough
m	meters
mi	miles
msl	mean sea level
pcf	pounds per cubic foot
psf	pounds per square foot
psi	pound-force per square inch
TM	Technical Memorandum
WCC	Woodward-Clyde Consultants

EXECUTIVE SUMMARY

The proposed Susitna-Watana dam is a hydroelectric project being planned by the Alaska Energy Authority (AEA) within the Railbelt area of south-central Alaska that will create a large reservoir 42 miles in length. This technical memorandum presents the methodology and results derived from a desktop study performed to assess future reservoir rim erosion and stability in support of engineering feasibility studies and preparation of the license application to the Federal Energy Regulatory Commission (FERC).

The preliminary reservoir rim stability assessment utilized recently acquired LiDAR (Laser Detection and Ranging) and ISFAR (Interferometric Synthetic Aperture Radar) imagery, the results of previous field investigations, the recent update of the terrain unit analysis (Golder, 2013), and interpretations from aerial imagery to examine the landscape for evidence of active/recent and/or historical slope movement and erosion (e.g., slides, flows, solifluction). Areas of active and historical slope movement and erosion were identified and the likely dominant mechanisms of slope movement, erosion, and failure modes and mechanisms that could occur during reservoir operation were evaluated. The assessment of future slope movement and erosion, post-impoundment, was conducted along the rim of the proposed reservoir and was based on geologic and topographic factors (e.g., lithology, unconsolidated sediments, permafrost, slope angle and aspect) and other conditions.

The reservoir rim stability evaluation identified several potential modes of slope erosion and failure that could occur along slopes of the proposed reservoir margin, primarily within and adjacent to the drawdown zone, including:

- Beach Formation and Erosion
- Solifluction / Skin Flows
- Bimodal Flows
- Debris Flows / Earth Flows
- Translational Slides.
- Rotational Slides
- Rock Toppling

Geomorphic evaluation of the reservoir area indicated that bi-modal and debris flows, with progressive erosion from thawing permafrost within slopes, are the primary agents in active and historical slope movement and erosion within the proposed reservoir area. These movements are generally shallow as

they occur within the active layer of the soil profile, and move with a slow to moderate rate of movement.

As part of this preliminary assessment, two representative areas of active slope movement, characterized by translational slides along the Susitna River valley, were evaluated. Geotechnical parameters (e.g., shear strength) for the mapped geologic units used in preliminary stability analyses were developed from geotechnical data obtained during previous site investigations in the proposed dam site area. The models were run with a number of different loading conditions to evaluate the effects of reservoir drawdown, and develop a better understanding for stability categorization along the reservoir shoreline.

This desktop evaluation found that slope movement due to the reservoir or reservoir operation will generally be confined to near shore areas. No geomorphic evidence was found within the reservoir area of a large scale, rapid movement landslide that would have had the potential to create a large impulse wave within the reservoir. Additionally, no evidence was found that would indicate that large-scale landslides or slope failures, either alone or in aggregate, will cause a significant environmental impact due to the reservoir or reservoir operation.

This study is intended to provide a preliminary and qualitative look at the slopes surrounding the proposed reservoir, and to guide future geologic and geotechnical investigations. Geologic reconnaissance was not performed as part of this study. Recommendations for future work include geologic mapping along the reservoir, drilling and laboratory testing, installation of subsurface and surface monitoring equipment, and continued visual observation.

1. INTRODUCTION

The proposed Susitna-Watana dam and reservoir are part of a hydroelectric power development project planned to be constructed on the upper Susitna River near River Mile 184, in the Fog Lakes region of the Talkeetna Mountains of south-central Alaska. The proposed hydroelectric plan for the Watana site is a 735 feet high roller-compacted concrete (RCC) dam and surface powerhouse. The Watana reservoir will have a normal maximum operating level of elevation (El.) 2050 feet above mean sea level (msl) and be approximately 42 miles in length with a total surface area of approximately 23,500 acres (**Figure 1**). The total volume of the reservoir is planned to be 5.2 million acre feet. During operation, the potential maximum reservoir drawdown will be up to 200 feet, resulting in a minimum operating level of El. 1,850 feet msl.

1.1 Objectives

A critical aspect of the safe construction and operation of the dam and facilities is related to the stability of the slopes surrounding the reservoir during construction and under operating conditions. Large slope failures in proximity to the dam could cause damage to structures or potentially impact the safe operation of the project. Alternatively, large slope failures within the reservoir impoundment can induce impulse waves that can overwhelm the structure and cause damage to the facility. This technical memorandum presents the methodology implemented and results obtained from an evaluation of the reservoir rim stability and erosion based on the anticipated reservoir operating conditions and loading.

The objectives of this study are to:

- provide a preliminary assessment of the potential for a major landslide or slope failure that could threaten or negatively impact the safety or safe operation of the dam and/or associated critical facilities;
- evaluate the potential for large-scale landslides or slope movements and erosion in the reservoir area that either alone or in aggregate, may create a significant environmental impact, if the operation and presence of the reservoir is determined to be a primary causative factor; and
- establish baseline slope conditions around the reservoir, including a catalogue of active and historical slope mass movement and failures, and classification of various types of slope erosion and failure modes in order to determine the mechanisms and parameters influencing slope development and stability in the study area.

1.2 Scope of Work

The scope for this evaluation includes completion of a desktop geomorphic characterization and compilation/characterization of areas with evidence of active or very recent slope movements as well as areas where there is evidence of historical or ancient slope failure. The results of this characterization were used in evaluation of reservoir slope stability and erosion during reservoir inundation and operation. These activities included a review of results from two previous investigations completed in the early 1980’s, and mapping and assessment of areas for evaluation of potentially significant stability issues. These evaluations were accomplished using:

- available project topographic maps;
- newly available high-resolution geospatial data and aerial imagery of the reservoir area;
- updated terrain unit analysis maps using bare-earth backgrounds; and
- limit equilibrium slope stability modeling software (SLOPE/W by GEO-SLOPE International).

A preliminary assessment of slope stability and erosion potential has been made based on the current project physical parameters, reservoir maximum and minimum operational levels, as well as geologic conditions, e.g., lithology, groundwater conditions, extent of permafrost, topographic conditions such as slope angle and aspect, and vegetation.

Previous investigations in the 1980s (Acres, 1981, 1982a) considered a reservoir normal mean operating level of El. 2,185 feet msl (Stage III) with a potential maximum drawdown of 170 feet to a minimum operation elevation of El. 2,015 feet msl. As currently proposed, the Watana reservoir will operate at a maximum elevation of El. 2,050 feet msl, with a potential drawdown of up to 200 feet annually, to a minimum operational elevation of El. 1,850 feet msl.

The range of reservoir elevations will intersect different regions of the reservoir slopes along the Susitna River and Watana Creek areas. These slope regions have variable slope angles and aspect, geologic conditions, lithology, extent of permafrost, and groundwater conditions than were previously evaluated during the 1980’s investigations. Although the modes of failure presented in previous evaluations are still considered applicable in many cases, the anticipated annual drawdown of up to 200 feet may significantly increase the hydrostatic loading on the valley slopes, especially along steeper slopes expected along the reservoir shoreline at this lower elevation.

Currently on the slopes above the river, evidence of shallow landslides, and the presence of discontinuous permafrost imply that some slope movement and erosion will also occur during reservoir filling. The thawing of frozen soils will add to the complexity and sensitivity of the slopes in stability evaluations and in predicting the conditions of the slopes after impoundment.

By incorporating and building on the results of the Acres studies (1981, 1982a), and utilizing updated terrain unit maps projected onto bare-earth terrain models from the LiDAR and INSAR data, this preliminary evaluation is intended to provide updated assessments and interpretations on areas of potential slope movement and erosion. High resolution aerial photographs obtained during the LiDAR acquisition were used to update the terrain unit interpretation and to delineate areas of very recent slope movement and erosion (Golder, 2013).

1.3 Previous Work – 1981 and 1982 Slope Stability Evaluations

Previous reservoir stability investigations for the proposed Watana reservoir evaluated the landscape based on aerial photography, terrain unit analysis, and limited field reconnaissance along the extent of the proposed shoreline (Acres, 1981, 1982a). The presence or evidence of slope failure (or movement) was identified at various locations in addition to areas underlain by frozen soils, i.e., discontinuous permafrost. From this information, modes of potential slope failure were defined along reaches of the proposed reservoir. Slopes in the reservoir that could potentially be subject to movement, deformation or failure were classified by one or more slope models defined for the study after an evaluation of reservoir geology.

The 1981 Stability evaluation was included as Appendix K in Volume 2 of the 1980-1981 Geotechnical Report (Acres, 1981). This qualitative evaluation considered the geology conditions (terrain units), changes in the groundwater regime due to initial impoundment and reservoir fluctuation during operation, the thawing of frozen soils and topographic factors (e.g., slope angle and aspect) in order to develop a “best estimate” in identifying areas in the reservoir that would be subject to future beaching, erosion, and slope movement. The evaluation considered the types and locations of slope movement and failure that were present along the reservoir to develop modes of potential slope movement and failure expected once the reservoir filled.

For the evaluation of the Watana reservoir, four general slope failure modes were identified, along with variations of each, including beaching, flows and slides. Potentially unstable slopes were classified based on aerial photo interpretation and limited field reconnaissance, into one or more modes as to the type of failure that may occur along reaches of the reservoir rim or shoreline. Existing mass wasting slope movement and failures along with areas underlain by discontinuous permafrost were also delineated. The 1981 evaluation was preliminary and qualitative in nature.

The 1982 Reservoir Slope Stability Report (Acres 1982a) was included as part of the Task 2 – Survey and Site Facilities portion under subtask 2.15 – Slope Stability and Erosion Studies Closeout Report. Building on the 1981 assessment, the 1982 reservoir slope stability evaluation incorporated some general modeling to examine cases considering groundwater changes, permafrost thaw, and rapid drawdown. The examined cases considered the slopes in the different conditions under which they will exist:

- the original slope above the reservoir level,
- below reservoir level,
- partially submerged slopes, and
- thawing permafrost along slopes.

The cases were examined as infinite slope, and assumed seepage parallel to the slope. Groundwater was assumed to be generally parallel to slope, and that it would rise with the level of the reservoir.

The examined cases showed that the first two cases, un-submerged and submerged slopes showed identical factors of safety, with no additional instability issues. Partial submergence – raising the groundwater table or drawdown of the reservoir –indicated a reduction in the factor of safety. Cohesive materials were more stable than non-cohesive materials in submerged conditions; however, with the introduction of slope parallel seepage forces, the degree of instability was not as great as a cohesionless material.

The permafrost case modeled the depth of thaw along a slope and showed that the stability of a thawing slope is dependent on geotechnical parameters of the slope materials (cohesion, slope failure angle, and coefficient of consolidation for the material) rather than its thermal conditions. Excess pore pressures generated during thaw would give rise to shallow slides on relatively flat slopes.

Both evaluations catalogued areas of active slope failure and areas of permafrost which were delineated on topographic plates along reservoir area. Potential slope movement that might be expected along certain reaches was delineated as well.

2. GEOLOGIC SETTING OF THE RESERVOIR AREA

2.1 Bedrock Geology

The proposed Watana Dam and Reservoir area are located within the Talkeetna Mountain physiographic province of the Talkeetna block in south-central Alaska (**Figure 1**). The headwaters of the Susitna River are located in the mountains north of the Copper River basin, northwest of the Talkeetna Mountains, and the river flows westward through the Copper River basin and Talkeetna Range toward the Susitna Basin to the southwest.

The area is underlain by bedrock which is comprised of a sequence of Cretaceous shale (regionally metamorphosed to argillite) and lithic greywacke sandstone of the Kahiltna assemblage (Csejtey et al., 1978). The Kahiltna assemblage is regionally intruded by small bodies of Paleocene granites, and granodiorites with minor diorite (Csejtey et al., 1978), between 53.2 Ma (1 Ma = 1 million years) to 64 Ma during the late stages of accretionary tectonics from terrains that drifted northwestward and sutured onto the North American plate (Csejtey, 1978). Diorite and quartz diorite bedrock underlies the reservoir at the dam site and upstream for a short distance (Acres, 1982). Further upstream, the reservoir is underlain by Paleozoic and Cretaceous meta-sedimentary bedrock. Other bedrock units include Paleocene to Miocene subaerial volcanic rocks and related shallow intrusives (WCC, 1980), including andesite porphyry, mafic to felsic dikes, and basalt flows (Acres, 1982). The Talkeetna suture zone is a terrain bounding structure associated with the Late-Cretaceous and Early Tertiary accretion of the Talkeetna and Wrangelia Terrains. The Talkeetna suture trends northeast-southwest and extends along Watana Creek north of the Susitna River. Folded and faulted Tertiary sedimentary bedrock units exposed along Watana creek are elongated along the trend of the suture zone, and underlie Quaternary glacial sediments (Csejtey, et. al., 1978).

2.2 Surficial Geology

The Watana Reservoir and adjacent slopes are characterized by a relatively narrow, V-shaped, stream-cut valley that is inset below a broad, gently sloping, previously glaciated basin. During the late Quaternary, advancing glaciers from the Chugach, Alaska, Wrangell, and southern Talkeetna ranges flowed out of their respective valleys to coalesce and form large piedmont glaciers, which spread across the basin floors. Merging glaciers from different ranges converged and blocked river drainage paths creating an extensive system of pro-glacial lakes (Wahrhaftig, 1965). Piedmont glaciers of the Wrangell and Chugach Mountains merged and dammed the ancestral Copper River, creating an extensive lake in the Copper River Basin, and glaciers flowing south from the Alaska Range periodically blocked drainage paths of the upper Susitna River, forming an extensive lake which covered a large portion of the project area (Acres, 1981). Continued glacial advancement filled in basins and eliminated the lakes. At glacial maximum, during the Wisconsin Glaciation, the entire area was completely covered in ice. Subsequent glacial advances during the late Quaternary repeated this process, but to a more diminished extent with each advance. During glacial retreat, lakes would again form, but continued melting eliminated the ice dams allowing sometimes rapid outflow (Acres, 1981). Interglacial periods are characterized by fluvial entrenching of the Susitna and Copper Rivers and their tributaries.

Late Quaternary glacial deposits overlie bedrock throughout much of the area, and bedrock units are exposed along much of the lower canyon walls and crop out in isolated areas in the upper canyon slopes and in the broad basin area away from the main Susitna river channel. Along much of the reservoir area, the upper slopes of the reservoir and the broad flats above the Susitna River valley are covered by a sequence of glacial till, outwash, and lacustrine deposits. The upper elevation and 200 foot drawdown zone for the reservoir will overlie, or lap onto, on Quaternary glacial deposits along much of the length of the reservoir, and on bedrock slopes for smaller portions of the reservoir perimeter. Glacial deposits were investigated in the 1980's along the north side of the proposed reservoir near the dam site to evaluate their potential as construction material sources (Acres, 1982; Harza-Ebasco, 1984). Four major depositional units were identified in the dam site area and include basal and ablation till, outwash, and lacustrine deposits:

- Basal till was deposited as glaciers spread across the project area depositing a sheet of gravelly, sandy, and silty till. The till varies in thickness from greater than 100 feet, exposed along incised slopes, to thin layers draped over bedrock. Basal tills are generally overconsolidated, and contain subangular to angular striated gravel and cobbles supported in a fine grained matrix (i.e., higher silt and clay content) and low permeability. Basal till has been mapped extensively throughout the reservoir area and is the dominant surficial unit exposed along the slopes on both the north and south shore of the reservoir. In general, distribution of permafrost throughout the basal till is discontinuous.
- Ablation till generally overlies lacustrine sediments between Tsusena and Deadman creeks along the north side of the Susitna River. These sediments represent the extent of the last major advance of glacial ice into the project area. The ablation till was deposited as sheets, and has more pronounced hummocky topography. The unit contains cobbles and boulders, with less fines, and a somewhat higher permeability than the basal till. In general, the distribution of permafrost in this deposit is sporadic to discontinuous.
- Outwash deposits generally consist primarily of subrounded and striated gravels and sands, crudely sorted, with higher permeabilities. These deposits primarily crop out above Deadman Creek. These deposits typically do not contain permafrost.
- Lacustrine deposits overly the basal till and represent deposition in lakes formed during the retreat of glaciers. In the Watana Creek area, they are typically less than 20 feet in thickness, and cover much of the area upstream along the Susitna River to the Copper River Lowland to the east.

Lacustrine deposits are generally of low permeability and comprised of fine to medium grained silt and sands, often stratified and sorted, with occasional gravel or cobble (drop stones),. Distribution of permafrost throughout the lacustrine deposits is discontinuous to continuous.

Landslides, including shallow slides and flows, occur throughout the proposed reservoir area. Evaluation of active and historical areas of slope instability indicates that most areas of instability are initiated within and predominantly comprised of the basal till, or basal till overlain with lacustrine deposits. The predominant mode of slope movement along the river valley of both current and historical landslides appears to be bi-modal flow resulting from progressive thawing of permafrost. Slope aspect, discussed below, is a key factor in slope movement and erosion along the Susitna River valley and its tributaries.

3. EVALUATION METHODOLOGY

The potential for movement of soil and rock slopes adjacent to the reservoir after impoundment was evaluated using newly available high resolution LiDAR data (North Susitna Bare Earth), and 1 foot ortho-rectified aerial photography. Current and previous slope instability as evidenced by flows and slides, as well as their aspect and slope angle were delineated. On-screen digitization of areas was performed from LiDAR data, imagery, terrain unit map overlays (digitized from previous reports (Acres, 1981b) and as revised by Golder (2013) using the new elevation and imagery data), elevation data, and related slope data derived from geospatial analysis of the elevation data. Overlay and layer analysis was used to extract certain terrain units of interest that were delineated by Golder and calculate areas and sub areas by MWH through area calculations using ArcGIS 10.1. Slope angles were calculated across the available LiDAR extent (shown in **Figure 2**) using ArcGIS and the spatial analysis extension, and were grouped in 5º increments.

This information, in addition to soil and rock conditions throughout the reservoir and the upper and lower limits were used to identify potential types and zones of slope instability influenced by reservoir impoundment and operation. Field reconnaissance to observe the geologic conditions, current and historical slope movement and erosion, and to field check interpretations made herein were not performed as part of this preliminary assessment of potential reservoir slope stability.

3.1 Factors Affecting Slope Stability

Factors affecting the stability of the slopes were evaluated and compared with the slope angle delineated using GIS modeling and the Terrain Unit Maps and geology along the drawdown area to assess modes of failure that may apply along reaches of the reservoir. Areas of potential instability were delineated considering both slope angle and geology along each reach, and are presented in an overview (**Figure 3**).

Several parameters were used to recreate conditions along the reservoir margin to evaluate potential instability along the shoreline across the entire reservoir operating drawdown zone. These are discussed below and include reservoir operating levels and potential drawdown, slope angle, slope aspect, groundwater, unfrozen and frozen ground conditions (extent of permafrost), and geology and the characteristics of geologic units encountered along the proposed reservoir shoreline.

3.1.1. Reservoir Operating Levels

As currently proposed, the Watana reservoir will operate at a maximum elevation of El. 2,050 feet msl, with a potential drawdown of up to 200 feet to a minimum operational elevation of El. 1,850 feet msl.

Early studies for the Watana site had considered a reservoir maximum operating level of El. 2,185 feet msl with a potential drawdown of 170 feet to a minimum operation elevation of El. 2,015 feet msl.

3.1.2. Slope Angle

The Susitna River has incised a narrow, steep-walled, east-west valley up to 800-feet deep into the broad Fog Lakes upland formed by repeated Late Quaternary glaciations. Near the dam site, slope angles along the north side of the river valley average approximately 25º (2H:1V) above the river level, at about El. 1,450 feet, for approximately 600 feet, flattening out to a maximum elevation of 2,350 feet. Slopes along the south side of the river are generally steeper and rise from the river at a slope of about 35º (1.4H:1V), and shallow out to 18º (3H:1V) or less to approximately El. 2,600 feet.

As a generalization, for coarse grained low-cohesion or cohesionless soils, the stable slope angle is generally equal to the effective friction angle at low groundwater conditions. Changes in groundwater levels can have a major influence/effect on the stability of slopes (e.g. high infiltration, rapid drawdown). During rapid drawdown, in low permeability materials such as the basal till, pore pressures drop slowly, and without the stabilizing force of the reservoir water pressure along the slope face. At high groundwater conditions, the stable slope angle is approximately half the effective friction angle (Abramson, 2002). Delineation of slope angles along the reservoir margin in addition to geologic units allows for rapid assessment of potential instability areas along the reservoir. Within the reservoir drawdown area, slope angles, including soil and rock slopes, ranged from near horizontal to vertical. Basal till and basal till with overlying lacustrine sediments have a mean slope angle of 15º within the drawdown area.

3.1.3. Slope Aspect

Aspect and incoming solar radiation are another key factor for slope movement within areas of glacial deposition. Areas with south or southeastern facing slopes typically contain more active and historical slope movement than slopes with north or northwest facing exposures. Failures along south facing slopes are predominantly bimodal flows, as a result of increased permafrost thawing. Along Watana Creek and its tributaries, the northwest side of the drainage is dominated by sometimes large progressive bimodal flows, while the southeastern side contains fewer, smaller translational slides. Along the Susitna River valley, north oriented slopes exhibit solifluction along gentle slopes overlain by basal till above the river, with sparse bimodal flows along the steeper slopes. Along the north side of the valley, on south facing slopes, larger failures can be seen including bimodal flows, as well as rotational slides indicating a likely thicker active layer above permanently frozen ground, i.e., discontinuous permafrost.

3.1.4. Groundwater

The groundwater regime around the reservoir is poorly understood, and likely complicated by the variable and complex sequence of glacial sediments, the presence of discontinuous permafrost, aquicludes, perched water, and confined aquifers. In the relict channel area north and adjacent to the proposed dam site, which was investigated during early 1980's site characterization (e.g., Acres 1981, 1982), perched water conditions exist locally above impervious and low permeability units including the basal till (Acres 1982). Test pits and borings performed during the 1980 to 1981 investigation in the relict channel and Borrow Site D encountered water within the upper 10 feet of the ground surface, which appeared to be perched on top of impervious or semipervious basal till. Borings that did not encounter water may be related to the penetration of frozen soils or coarser permeable gravels (Acres 1981).

3.1.5. Permafrost

The site for the Watana Reservoir lies within a zone characterized by presence of discontinuous permafrost, with a mean annual temperature very close to freezing, approximately -1.5 degrees Celsius (Acres, 1981a, 1982). The presence and extent of permafrost within the reservoir area is largely interpreted based on reconnaissance mapping, drilling, and instrumentation data from thermistors installed in boreholes drilled at the dam site, the relict channel area and Borrow D locations. The characterization of ground thermal conditions in the dam site area was extrapolated over the reservoir area as part of the terrain unit analysis (Acres 1981b). In general, sporadic permafrost was encountered within borings, though permafrost was present in basal till at depths of 70 to 140 feet, with the deepest permafrost detected at a depth of 240 feet (DR-22).

The active zone averages about 10 to 15 feet, but may reach depths as much as 22 feet locally (Acres 1982). Most visible ice is confined to the annual frost zone in upper stratigraphic units. Basal till contains localized ice lenses, locally comprising up to 50 percent of the sample volume. Average ground temperature encountered at depth during drilling, with the exception of several frozen shallow holes was between approximately 0.5ºC to 1.5ºC.

3.1.6. Geologic Conditions and Engineering Properties of Materials

Along the valley, glacial or talus deposits overlie bedrock units exposed along much of the lower canyon walls. For nearly the entire reservoir area, the upper slopes of the reservoir and the broad flats adjacent to the Susitna River are covered by glacial and lacustrine deposits. The drawdown zone for the reservoir will primarily be in contact with glacial deposits along much of the length of the reservoir (**Figure 4**).

Borings drilled in the Borrow D and relict channel areas during the 1982 investigation program encountered basal till in several locations (Acres 1982) (**Attachment 1**). Soil descriptions in the boring logs based on visual-manual procedures and laboratory grain size data identified the occurrence of a wide range of soil types including clayey gravel (GC)/clay with gravel (CL), clayey sand (SC), sandy gravel (GW) or sand with gravel (SW), silty sand with gravel (SM), clayey sand with gravel (SC), as well as silts and clays (ML-CL).

3.1.6.1. Basal Till Unit (Gtb)

Borings drilled in the Borrow D and Relict Channel areas during the 1982 investigation program encountered basal till in several locations (Acres 1982) (**Figure 5**). Field logs indicated that the glacial sediments are primarily composed of clayey gravel (GC) with sand and lean clay (CL) with gravel and sand. The material descriptions are typical for soil types encountered in tills, and laboratory tests were performed to confirm the field assessments of soil textures (**Attachment A**). Although multiple basal till units were encountered and defined during the Borrow D and Relict Channel investigations, no differentiation of these basal units has been made in the terrain unit maps of the reservoir area. This study therefore combined data from all described basal till units encountered within the borings to develop initial geotechnical parameters for the basal till. Of the 88 penetration tests performed during drilling, 59 went to refusal (**Attachment 1**). Twenty-nine uncorrected penetration tests in basal till units consisting of silts to gravels ranged from 7 to 116 blows per foot, indicating loose to highly compacted soils if no gravels are present, however, gravels within the soil will adversely affect the blow-counts to skew to a much higher value (see **Attachment 1 - Table A1-1** for sieve analyses). Twenty five of 29 N-values were greater than 30 blows per foot, indicating the predominance of dense soils and/or coarse gravel and cobbles. Penetration tests used a 2.5 inch inner diameter sampling tube with a 300 pound hammer dropped 30 inches. The following equation was used to correct the N-values (Burmeister, 1948, Clayton, 1990) for the diameter of the sampler, and hammer weight and efficiency:

$$N_{60} = N_R \left[\frac{2.0^2 in. - 1.375^2 in.}{Do^2 in. - Di^2 in.} \right] \frac{(W\ lbs) * (H\ in.)}{(140\ lbs) * (30\ in.)}$$

Where N_{60} is the corrected blow count, N_R is the raw blow count, *Do* is the outside diameter of the drive sampler, *Di* is the inner diameter of the sampler, *W* is the weight of the hammer, and *H* is the height of the hammer drop.

The unit weight of till and glacial outwash reported in published literature (Koloski et al., 1989; Edil et al., 2007; Mugg and Pham, 2010) is in the range of 114 to 140 pounds per cubic foot (pcf). For this project, an average unit weight of 130 pcf was assumed for use in the overburden correction of N-values. The following equation was also used to correct the N-values (Liao and Whitman, 1986) for overburden pressure assuming that the soils were predominantly granular:

$$C_N = (2116.22 \text{ psf}/\sigma_z')^{1/2}$$

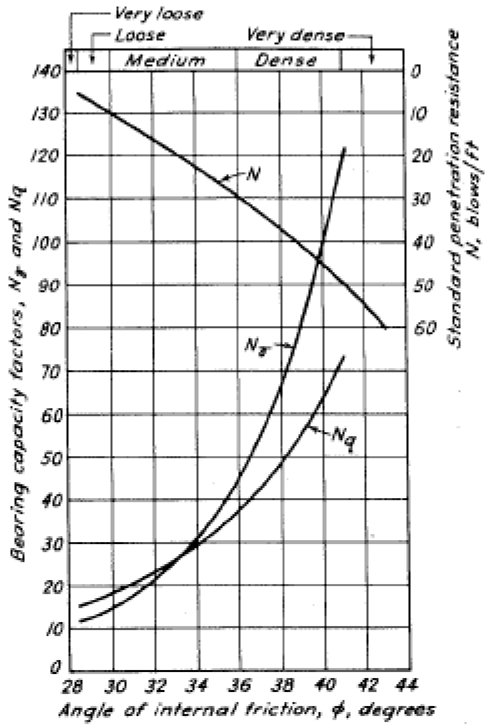
Where C_N is the corrected N value, and σ_z' is the overburden pressure.

The corrected N-values are in the range of 12 to 119 blows per foot, resulting in an angle of internal friction of 31 to 43 degrees as summarized in **Table 1.** The average ϕ-value is approximately 38 degrees.

Table 1 Estimated Angles of Internal Friction for Basal Till

Boring	Depth z	Uncorrected N Values	Energy Correction (N_{60})	Overburden Pressure	C_N	Corrected N $(N_{60})_1$	ϕ^1
	(feet)	Blows per foot	E_m	σz'		Blows per foot	°
AH-D-16A	29	64	89	3770	0.749	67	43
	34	69	96	4420	0.691	67	43
AH-D-16B	36	78	109	4680	0.672	73	43
	40	93	130	5200	0.637	83	43
	44	111	155	5720	0.608	94	43
AH-D-17	96	58	81	12480	0.411	33	36
	98	77	107	12740	0.407	44	40
AH-D-18	172	84	117	22360	0.307	36	37
	178	29	40	23140	0.302	12	31
AH-D-19	16	16	22	2080	1.008	22	34
	26	92	128	3380	0.791	101	43
	31	103	144	4030	0.724	104	43
	34	60	84	4420	0.691	58	42
	36	30	42	4680	0.672	28	35
	40	74	103	5200	0.637	66	43
AH-D-20	105	41	57	13650	0.393	23	34
AH-D-25	7	13	18	910	1.524	28	35
	9	7	10	1170	1.344	13	31
	14	79	110	1820	1.078	119	43
	25.5	25	35	3315	0.798	28	35
AH-D-28	18	44	61	2340	0.950	58	42
	20	35	49	2600	0.902	44	40
	22	28	39	2860	0.860	34	35
	24	35	49	3120	0.823	40	39
	26	60	84	3380	0.791	66	43
	34	111	155	4420	0.691	107	43
	36	116	162	4680	0.672	109	43
	45	107	149	5850	0.601	90	43
AH-D-30	99	90	126	12870	0.405	51	41

Notes:
1 Based on Peck et al. (1974) (see **Insert 1**);
2 Based on Hannigan et al. (1998) (see **Table 3**);
3 Blows per 30 centimeters.
4 Abbreviations: N = uncorrected SPT blow count; ϕ = angle of internal friction.



Insert 1: Relationship between Corrected N-values and ϕ-values (Peck at al., 1974, Figure 19.5)

Table 2 Relationship between Corrected N-values and ϕ-values (Hannigan et al., 1998, Table 4-5)

Description	Very Loose	Loose	Medium	Dense	Very Dense
Corrected N (1)	0 to 4	4 to 10	10 to 30	30 to 50	>50
ϕ (2) o	25 to 30	27 to 32	30 to 35	35 to 40	38 to 43

Notes:

1 SPT N-values are given in blows per foot;

2 Use larger values for granular material with 5% or less fine sand and silt.

The unit weight of tills published in literature (Koloski et al., 1989; Mugg and Pham, 2010) is in the range of 114 to 140 pcf. For this project, an average unit weight of 130 pcf was assumed for un-frozen glacial tills used in the models. An average unit weight of 140 pcf was assumed for frozen glacial till.

The angle of internal friction from available published data on tills, moraines and glacial outwash is in the range of 35° to 52° (Bishop, 1966; Koloski et al., 1989; Curry et al., 2009; Mugg and Pham, 2010) as summarized in Table 3. The average value is estimated to be approximately 35°. The effective cohesion intercept reported by these authors is zero to 4000 psf.

Table 3 Effective Shear Strength Parameters of Glacial Soils

Project	Soil Description	ϕ (°)	c (psf)	Reference
Research Project	Glacial till	36 (2)	0	Bishop (1966)
Compilation of Geotechnical Properties of Soils and Rocks Commonly Found in Washington	Till (SM, ML)	35 to 45 (3)	1000 to 4000	Koloski et al. (1989)
Research on Feegletscher Moraine, Valais, Switzerland	Moraine (sand with gravel and silt)	35 to 52 (2)	0	Curry et al. (2009)
Tacoma/Pierce County HOV Program, Washington	Glacial outwash and till (1)	45 (4)	0	Mugg and Pham (2010)

Notes:
1. Very dense clean (less than 10% fines) sands and gravels with occasional to frequent cobbles and boulders;
2. Measured in laboratory;
3. Based on field and laboratory tests;
4. Based on laboratory tests and empirical correlations.
5. Abbreviations: ϕ= angle of internal friction; c = effective cohesion intercept: NA = not available.

In this project, an initial angle of internal friction of 30° degrees and cohesion intercept of 100 pounds per square foot (psf) were conservatively assumed for the unfrozen glacial sediments. Frozen basal till were conservatively assumed to have an internal friction angle of 35° and a cohesion intercept of 1000. Sensitivity analyses (discussed below) were performed on existing (un-failed) slopes to refine these parameters.

3.1.6.2. Lacustrine Units (L)

Glaciolacustrine units, which overlie basal till units, were also encountered in the borings drilled in the Borrow D and Relict Channel areas during the 1982 investigation program (Acres 1982) (**Figure 5**). Lacustrine sediments are primarily composed of interbedded laminated clays (rock flour) and silt, with localized gravels and coarse sand (Acres 1982). Although multiple lacustrine units were encountered and defined during the Borrow D and Relict Channel investigations, no differentiation of these basal units has been made in the terrain unit maps of the reservoir area. For this study data was combined from all described lacustrine units encountered within the borings to develop initial geotechnical parameters lacustrine units. Of the 130 penetration tests performed during drilling, 54 went to refusal (**Attachment 1**). Seventy (70) uncorrected penetration tests in lacustrine units consisting of clays with gravels ranged from 8 to 135 blows per foot, indicating loose to highly compacted soil, if no gravels are present, however, gravels within the soil will adversely affect the blow-counts to skew much higher (see **Attachment 1 Table A1-2 for sieve analyses**). Thirty five (35) of 70 N-values were greater than 30 blows per foot, indicating the predominance of dense soils. Penetration tests used a 2.5 inch inner diameter sampling tube with a 300 pound hammer dropped 30 inches. Corrections for the diameter of the sampler, hammer weight and efficiency, and overburden were made using the methods described for the basal till, and are shown in **Attachment 1**.

The unit weight of glaciolacustrine sediments published in literature (Koloski et al., 1989) is in the range of 100 to 120 pcf. For this project, an average unit weight of 110 pcf was assumed for un-frozen glacial tills used in the models.

The corrected N-values were in the range of 8 to 104 blows per foot, resulting in an angle of internal friction of 31 to 43 degrees as summarized in **Attachment 1, Table A1-3.** The average ϕ-value is approximately 36 degrees.

3.2 Geotechnical Analyses

3.2.1. General

Static slope stability evaluations were performed using the geotechnical software SLOPE/W which is part of the Geo-Studio 2012, Version 8.0. SLOPE/W is a two-dimensional computer program which performs slope stability computations using the theory of limit equilibrium that satisfies both force and moment equilibrium. The analysis involves calculation of the factors of safety for potential shear failure surfaces. The factor of safety against shear failure is defined as the factor by which the shear strength of the soil must be reduced to bring the soil mass into a state of limiting equilibrium. The factor of safety is computed for all specified slip surfaces.

The Morgenstern-Price method which satisfies equilibrium of forces and moments acting on individual slices and allows specifying an inter-slice force function was selected to compute the factors of safety. The slices are created by dividing the sliding mass above the slip surface. The dividing planes between the slices are always vertical.

Circular or fully specified non-circular shear surfaces which satisfy both moment and force equilibrium can be analyzed. The analysis consists of an evaluation of multiple trial failure surfaces. Once the factors of safety are computed for all trial surfaces, the location of the critical shear surface can be selected.

A sensitivity analysis was performed using models of two existing landslides to determine the geologic configuration and failure mechanics. Representative profiles were generated using Spatial Analyst and 3D Analyst. Profiles were made along each slide and at a stable slope location adjacent to the active slide that was interpreted to resemble the configuration of the slope prior to failure. Comparisons of before and after slope profiles for each slide are shown in **Figure 6**, and profile locations are show in

Figure 12-2. The slopes were modeled using an approximately 20 foot thick layer of un-frozen basal till over approximately 200 feet of frozen till, on top of bedrock.

Slope D was chosen to represent typical shallow failures within the reservoir area, and was first modeled as a drained slope to develop parameters for a stable slope with a factor of safety of 1.0. Drained strength parameters were used for all materials. Slope E appears to represent a more deep seated rotational slump, and was modeled initially using fully-specified slip surface with a piezometric surface.

A summary of the strength values back calculated for the materials for the evaluated conditions are presented in **Table 4.** Bedrock was assumed to be impenetrable and the critical slip surfaces are not anticipated to intercept the bedrock due to its depth. For frozen glacial till, the material strength was changed to reflect higher cohesion of interstitial ice within the unit.

Table 4 Summary of Static Material Properties used in SLOPE/W

Material	Unit Weight (pcf)	ϕ (○)	c (psf)
Basal Till (unfrozen)	130 (1)	27 (1)	100 (1)
Basal Till (frozen)	140 (1)	30 (1)	925 (1)
Lacustrine	110 (1)	20 (1)	1000 (1)
Bedrock (2)	NA	NA	NA

Notes:
1 Derived from sensitivity analysis.
2 Bedrock as modeled in SLOPW/W is impenetrable and defines the limit of the possible failure surfaces.

3.2.2. Slide Cases Analyzed

Two cases were analyzed to evaluate the stability of the representative slopes: high reservoir conditions – 2050 feet reservoir elevation, and low reservoir operating conditions – 1850 feet reservoir elevation. Low reservoir conditions were modeled as rapid drawdown, in order to represent a "worst case" or conservative scenario. In fact, however, drawdown of 200 feet will not be rapid, and should normally occur gradually over several months during normal operation of the reservoir. This rate of drawdown should allow pore-water pressure to dissipate or be relieved within slopes to some degree, though this cannot be assured in all areas. Each of these cases was analyzed using active slides and adjacent slopes. The results of the cases modeled are presented in **Attachment 2**. A summary of the results and the computed factor of safety are presented in **Table 5**. Slope movement due to seismic loading was not evaluated for this study.

Table 5 Summary of Factors of Safety

Cases	Static Factor of Safety
Slope D – Case 1 – Initial, drained slope (existing)	1.0
Slope D – Case 2 – Reservoir Elevation 2050 feet	1.6
Slope D – Case 3 – Reservoir Elevation 1850 feet	0.6
Slope E – Case 1 – Initial, no lacustrine	1.1
Slope E – Case 1A – Initial, lacustrine sediments at bedrock interface	1.0
Slope E – Case 2 – Reservoir Elevation 2050 feet	1.3
Slope E – Case 3 – Reservoir Elevation 1850 feet	0.7

4. SLOPE STABILITY

4.1 Failure Modes and Mechanisms

Erosion along the reservoir shoreline will occur as a function of mass wasting processes, slope movement, and wave action from the reservoir. Beach erosion and creation will occur due to impoundment and ongoing reservoir operation. This and other modes of slope movement that are currently observed and/or likely to be encountered after impoundment are presented in **Figure 7** and described below:

- **Solifluction / Skin flow (Flow)** - Low angle slopes, saturated, poorly sorted deposits. Water within saturated surface soil layers is unable to penetrate underlying frozen soil layer, causing slow flowage down slopes of nearly negligible inclination.
- **Earthflow / Debris Flow / Bimodal** – Low to moderate angle slopes, unconsolidated, unfrozen materials. Reservoir fluctuation and groundwater saturate unconsolidated materials on hill slopes or stream channels. Generally form on hillsides, toes of slumps or heads of small gullies where groundwater seepage or surface runoff concentrates. Frozen material exposed at the head-scarp thaws and is transported away by mudflows that travel downslope (bimodal).
- **Translational (Block) Slides** – Block slides generally exhibit a somewhat coherent displacement and appearance of rigid body motion. These generally occur on mid to high angle slopes in frozen to sporadically frozen soils. Thawing within the active layer increases fluid pressure along frozen / unfrozen interface. Reservoir and groundwater fluctuations along slopes will increase thawing potential of slopes, possibly increasing pore water pressure during drawdown. Translational slides such as these may occur as very shallow slides, above the permafrost layer along the interface between the active layer and frozen layer, or somewhat deeper, along the base of the permafrost zone between the frozen zone and bedrock, within the unfrozen zone beneath the permafrost layer.
- **Rotational Slides** - High angle slopes, unfrozen, cohesive soils. Reservoir and groundwater fluctuation in soils will increase thaw zone and active layer. Over time, additional sliding may occur with extension of thaw zone into soil along reservoir margin.
- **Rock Toppling** - High angle rock slopes. Reservoir and groundwater level fluctuation increases frost wedging, inducing failure.
- **Beach Formation and Erosion** – Wave action can cause instability through sloughing or failure of an over-steepened back-slope. Beach erosion and formation can occur on all slopes, shallow to moderately steep.

Photographs of existing earthflow/bimodal flows and translational slides along the slopes of the Susitna River and Watana Creek are shown in **Figures 8-11**.

4.1.1. Groundwater

Under static loading conditions, movement along a slope generally occurs due to a change in groundwater conditions, including inundation of the area, thawing of permafrost, and/or seismic conditions (e.g. liquefaction). The groundwater table in the slopes adjacent to the reservoir will re-establish itself during reservoir inundation. The reservoir body will act as a stabilizing force against the slopes while in place. During drawdown of the reservoir over a short period of time, however, the stabilizing pressure is quickly removed, but the driving forces within the slope are relieved much more slowly. As a result, the pore-water pressure within the slopes above the reservoir level remain high while the buttressing effect of the reservoir water is removed, increasing the driving force or load on the slope (Abramson, 2002). Low permeability within the basal till and high pore water pressure may increase the likelihood of failure.

Drawdown of the reservoir will generally occur during the winter, as the reservoir freezes over with ice, and as the active layer in the soils begins to re-freeze. Drawdown of the reservoir during the winter is not considered rapid drawdown, as it will occur over several months, allowing pore water pressures to be relieved within the slope. However, drawdown will occur simultaneously with re-freezing of the upper layers of permafrost within the soil, possibly trapping water within the active zone between permafrost at depth at the base of the active layer, and the overlying layer as it begins to re-freeze, increasing pore water pressures in the slope. Ice from the surface of the reservoir will also be marooned along the shoreline as the water level drops, adding the weight of accumulated ice to the slopes.

4.1.2. Permafrost

The site for the Watana Reservoir lies within a zone of discontinuous permafrost, with a mean annual temperature very close to freezing, approximately -1.5 degrees Celsius (Acres, 1982). Permafrost along the slopes will generally thaw along the reservoir margin due to reservoir inundation. Permafrost above the maximum reservoir elevation will likely not be affected by reservoir inundation.

The depth of permafrost thawing within the slopes along the reservoir can be an indicator of the thickness of failure blocks. At its upper elevation, the reservoir will act as a stabilizing force against the slopes, however during drawdown, the groundwater regime will generally perch above frozen layers, increasing pore pressure, creating susceptible slopes along the interface of frozen and unfrozen soils. Although the increase in pore pressure above the frozen layers may increase the likelihood of slope instability, these failures are typically ‘thin’ blocks or flows limited to the active layer. In general, permafrost is distributed discontinuous in the basal till and the lacustrine deposits. The active layer delineated in the Relict Channel and Borrow D area is generally from 10 to 15 feet in depth (Acres, 1981).

Slope aspect and incoming solar radiation will continue to be a key factor especially along the south facing slopes of the Susitna River, and the southeast oriented slopes along Watana Creek and its tributaries. Thawing of permafrost along these slopes above the waterline of the reservoir may contribute to increased movement, although it may have a limiting effect on the thickness and volume of the movement. Along steeper, north facing slopes, the reservoir shoreline will generally be in contact with frozen basal tills. The erosion and thawing of ice-rich soils along the steeper slopes of the southern shoreline will increase the potential for slope movement in the form of shallow earthflows and slides.

Where the shoreline of the reservoir intersects steep bedrock cliffs, fluctuation of the reservoir and groundwater table accompanied by seasonal freezing and thawing will encourage frost jacking in joints in bedrock, potentially creating rock falls.

4.1.3. Seismic Loading

Seismic loading conditions were not evaluated as part of this study, however, due to the potential for earthquakes in the Project area, the adverse effect of ground shaking from seismic activity should be considered. Submerged and thawing slopes, and areas above the reservoir with relatively a high groundwater table may be susceptible to liquefaction during earthquakes. Liquefaction is a soil behavior phenomenon in which the soil undergoes a rapid loss in effective strength due to the due to the development of high excess pore water pressure generated by earthquake ground shaking. Soils that are most susceptible to liquefaction are clean, loose, uniformly graded, saturated, fine-grained sands or saturated soft to firm low plasticity silts that lie near the ground surface, within a depth usually considered to be less than 50 feet. Lacustrine sediments, which generally overlie basal till at the tops of slopes along the reservoir will generally be the most susceptible to liquefaction. The existence of these materials along the slope is generally limited, and will limit areas of instability due to seismic loading to areas of permafrost thaw, and areas above the reservoir in previously unfrozen soils.

5. ANTICIPATED RESERVOIR RIM CONDITIONS – PRELIMINARY

High resolution LiDAR maps and associated aerial imagery were examined to identify areas of active slope failure or slope movements. Terrain Unit Maps (Golder, 2013, Acres 1981) provided a geologic basis to determine which terrain units exhibit greater susceptibility to slope failure. For this study, approximately 20 landslides that appeared to be recently active, and numerous historical landslides were identified. An evaluation of active and historical slope failures as interpreted from LiDAR and aerial photographs indicates that most movement along the slopes of the proposed reservoir initiate within the basal till or basal till with overlying lacustrine layers (**Figure 12**). In general slope movements consist primarily of bimodal flows and debris flows, and to a lesser extent, shallow translational and rotational sides, and solifluction (**Figure 12**). On-going shallow progressive slope movement has continued to expand these unstable areas as loading is decreased at the base of the slopes. **Attachment A3** contains a summary of mass wasting, both active and historical slope movements, identified along the slopes of reservoir area.

In general, nearly all areas where basal till, or basal till overlain by lacustrine sediments along the reservoir are encountered within the drawdown area may be susceptible to slope movement of one kind or another during initial reservoir filling and normal operation. The basal till and basal till with overlying lacustrine sediments are encountered along approximately 60 percent of the reservoir drawdown area (**Figure 4**). Landslide deposits as delineated through the in the terrain unit analysis study (Golder 2013) make up another 5 percent of the drawdown zone (**Table 7**). Evaluation of the thickness, extent/distribution, and groundwater/permafrost conditions of the basal till is important to understanding the potential slope instabilities and erosion along the reservoir margin following filling.

Table 6 Proportion of 11,600 Acre Drawdown Area Comprised of Basal Till and Landslide Units

Unit	Total Acreage within Drawdown Area (acres)	Percentage of Drawdown Area (%)
Basal Till (Gtb), Lacustrine over Basal Till (L-Gtb)	6,920	59.7
Active and Inactive Landslide areas (Cl, Cl-i)	617	5

Along slopes of greater than approximately 20 degrees, there will be a potential for small, shallow slides and flows to occur. Water from spring runoff may further increase susceptibility of slopes to increased erosion. Areas of active and historical slope failures have the potential for re-activation, particularly during reservoir drawdown as the groundwater table adjusts to lower reservoir levels.

Areas immediately upstream of the proposed dam site, between the dam site and Deadman Creek, are generally located in areas where basal till or basal till overlain by lacustrine sediments will be encountered. During construction and initial filling, there may be a potential for increased slope movement that could impact or damage intakes and/or the outlet works. Active slope movement in this area is typically very shallow, occurring as solifluction or bimodal/debris flows, and there is no indication that large failures that could impede construction would occur during construction. In addition to shallow slope movement, the stability of temporary and permanent rock cut slopes will need to be assessed and adequate rock support installed to secure potential rock wedges and to avoid toppling failure. Continued observation of slopes throughout construction and initial reservoir impoundment will be important to assess potential hazards as the project progresses.

Results of the SLOPE/W models indicate increased potential slope movement within the basal till along slopes during rapid reservoir drawdown. Slope movement is more likely to occur on slopes greater than 20 degrees which are predominantly comprised of glacial sediments within the drawdown zone. As currently mapped, such conditions occur over a large portion of the reservoir area; however, it is possible that bedrock within the drawdown zone is significantly shallower than was assumed for this study.

Over continued operation, it can be expected that the slopes along the reservoir margin will eventually stabilize and reach a relative steady state. Beach formation and erosion from wave action along the shoreline will continue to actively work upon the shoreline, but the amount of active erosion will depend on the fetch available to generate wave action.

The potential for a large slide to occur and generate an impulse wave with the likelihood of overtopping the dam is generally considered to be very low, as wave generation of such a scale requires both a large volume of material at or above the reservoir rim, and rapid failure. For this to occur, a very high, steep slope, with a potentially unstable block of large volume would need to exist adjacent to the reservoir. High steep slopes above the reservoir are not present downstream of about river mile 200, approximately 16 miles upstream of the dam site. Upstream of river mile 200, large active or historical landslides with the potential volume of material required to generate a large wave were not observed. Upstream of approximately river mile 214, or about 30 miles upstream of the dam site, the reservoir will be relatively shallow, narrow, and meandering within the confines of the incised river valley. Waves generated by large slope movements along this reach would displace significantly less water, and likely dissipate before reaching the dam. Additionally, most observed slope movements in the area are typically of a relatively small volume, and occur as somewhat slower moving flows, which would not generate large impulse waves.

Environmental issues as a result of large-scale or aggregate slope movements within the reservoir are also considered to be very low.

- *Lower Reaches of Reservoir*

In the lower reaches of the reservoir area, between the dam site and Watana Creek, steep slopes of bedrock are overlain by thick accumulations of ablation till, outwash, and basal till deposits. Where the shoreline intersects bedrock cliffs, annual drawdown of the reservoir will contribute to frost wedging along the shoreline, creating rock falls. Where the shoreline intersects till deposits, the potential for slides or flows increases with slopes over approximately 15-20 degrees during annual drawdown. It is anticipated that most drawdown of the reservoir will occur during the winter and spring months. Freezing of the active zone may reduce pore water pressure within the active layer. Alternatively, drawdown during the winter freezing along the reservoir ground-surface interface may trap water within the soils and increase pore water pressure.

- *Watana Creek*
  Slope instability along the Watana Creek area generally occurs where permafrost in basal till, and basal till overlain by lacustrine sediments thaws, causing regressive bimodal flows. Areas above the reservoir operation elevation will continue to experience bimodal flows and debris/earth flows primarily from thawing permafrost. Along the shoreline, wave action will create beaches, or potentially undercut slopes along the shoreline which may subject slopes to further erosion. While Watana Creek remains an active area for continued slope movement, with continued bimodal flows from thawing permafrost, the potential for a large scale, rapid slope movement that would generate a wave with the likelihood of overtopping the dam appears remote, as the volume of material and speed of failure will not be sufficient to generate large impulse waves.
- *Upper Reaches of Reservoir*
  Upstream of the confluence of Watana Creek with the Susitna River, moderately inclined slopes are comprised primarily of colluvium overlying bedrock, in turn overlain by basal till and lacustrine sediments. Along this reach, the reservoir shoreline will generally intersect the mid-section of slopes along the river valley, mostly slopes comprised basal till. These slopes will generally be susceptible to flows from spring runoff, and beach creation and erosion from waves.

5.1 Recommendations

It is recommended that the slope conditions outlined in this report be further investigated during subsequent field programs to verify the interpretations made and to:

- Define geological material types and the geotechnical properties of each,
- Understand the groundwater conditions
- Further delineate the location of frozen soils
- Evaluate vegetation along slopes
- Develop a better understanding of failure mechanisms that control stability along the proposed reservoir slopes

- Consider seismicity and evidence of earthquake induced slope instability

Proposed field investigations should include:

- Geologic mapping of the reservoir area including active and inactive landslide areas, and delineation of springs;
- Field exploration and testing to include drilling, in situ permeability testing, and laboratory testing of soil samples ;
- Installation and monitoring of geotechnical instrumentation such as piezometers, inclinometers, and surface monuments;
- Analysis to estimate the possible influence of earthquake events on slope erosion and movement.
- The field investigations should place particular emphasis on the lower reservoir to just upstream of Watana Creek and the inundation of Watana Creek area, where considerable slope movement and erosion is presently occurring.

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FIGURES

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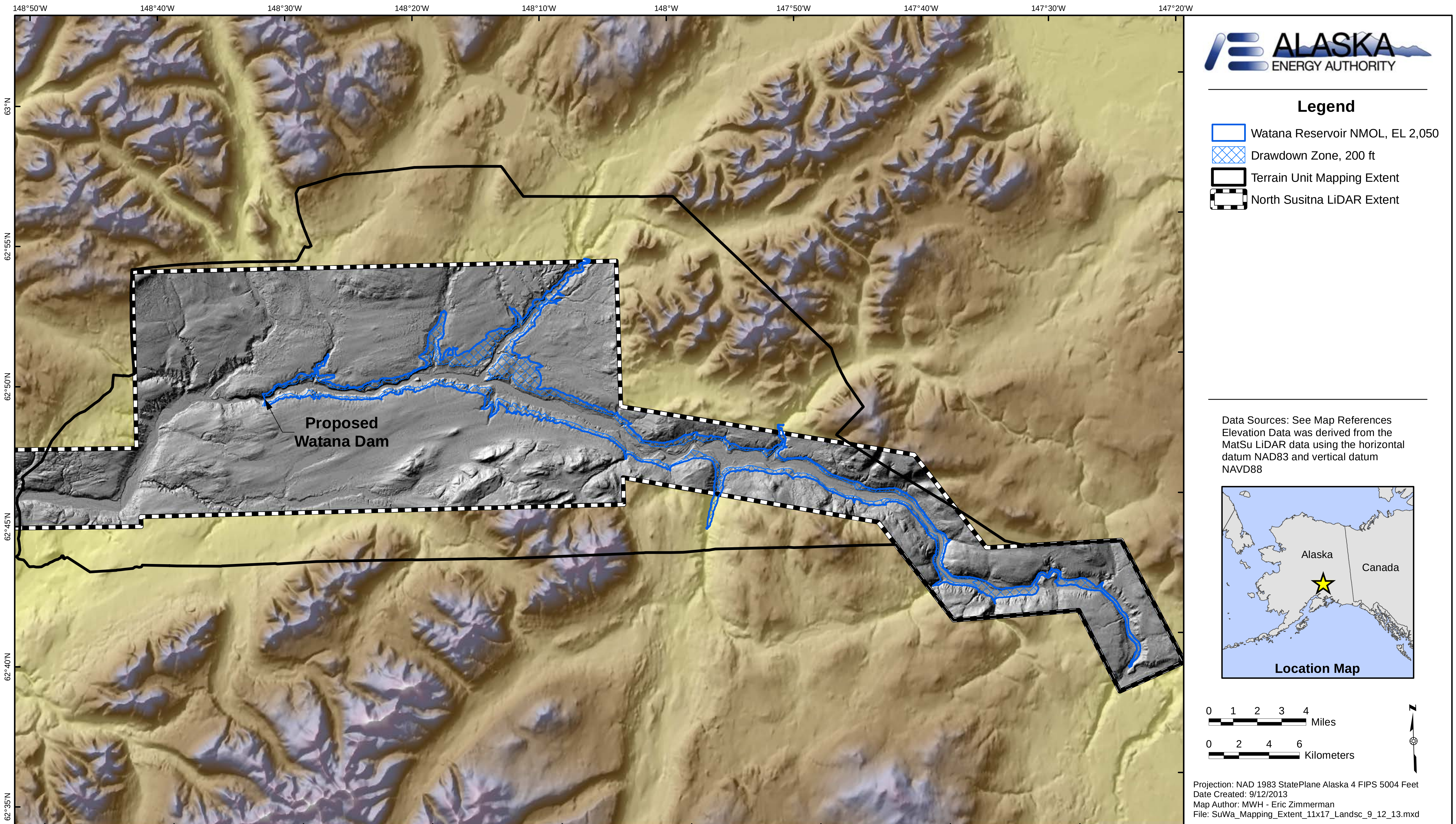
Site Location and Area of Investigation
Figure 1



LiDAR and Terrain Unit Map Coverage
Figure 2

Areas of Active or Recent Slope Movement
Figure 3

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Legend

- Watana Reservoir NMOL, EL 2,050
- Watana Reservoir MOL, EL 1,850
- Basal Till in Drawdown Area
- Basal Till
- Lacustrine Over Basal Till

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

0 1 2 3 4 Miles

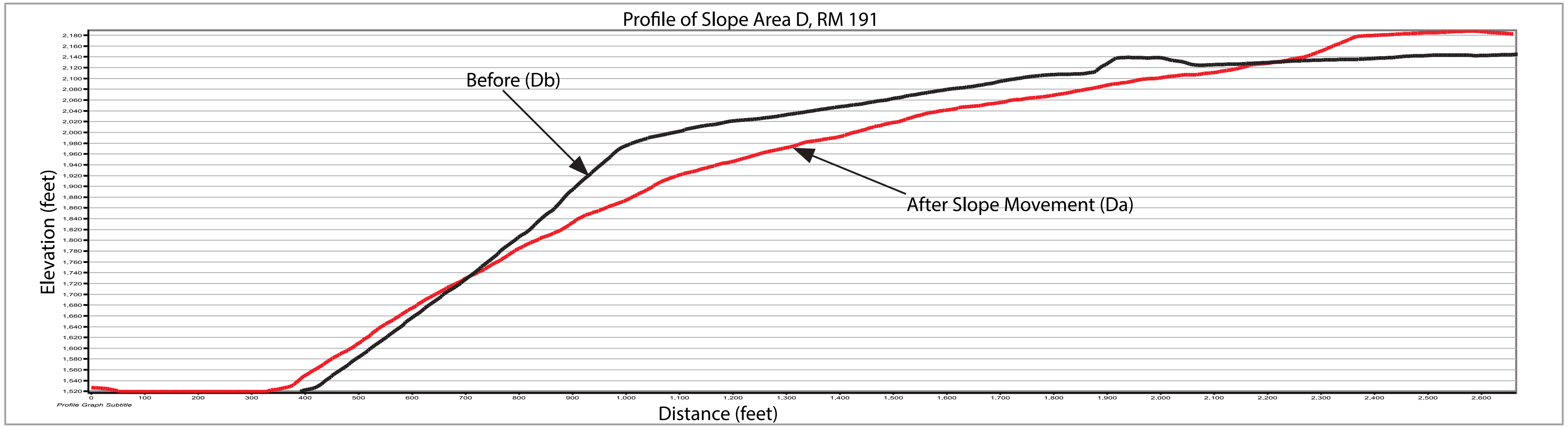
0 2 4 6 Kilometers

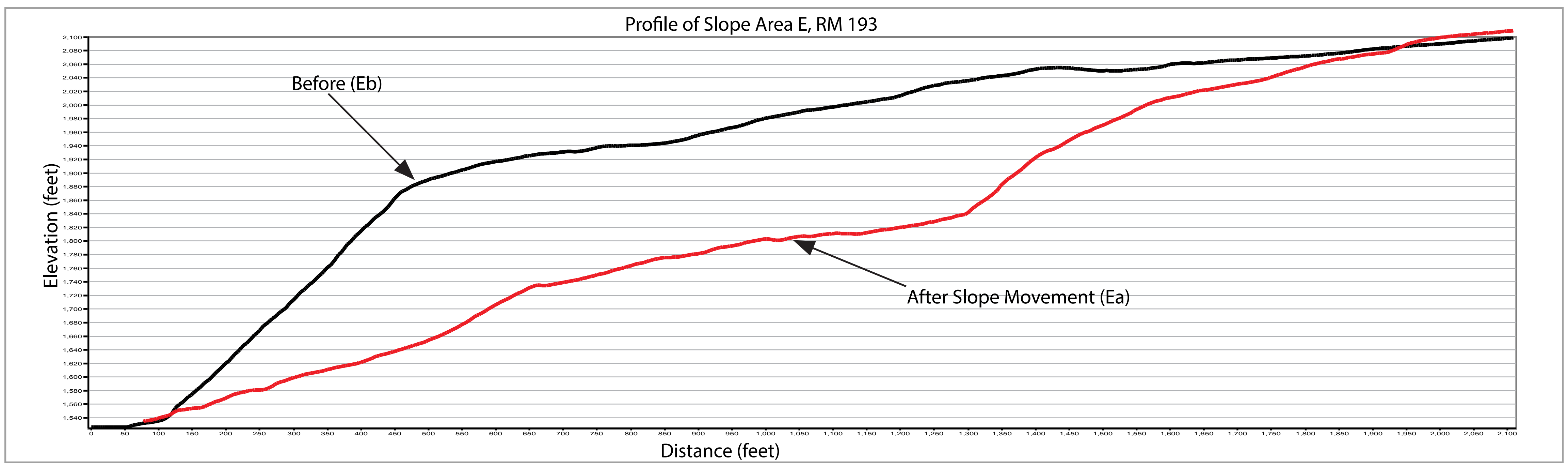
Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/13/2013
Map Author: MWH - Eric Zimmerman
File: SuWa_Reservoir_Drawdown_11x17_Landsc_9_12_13.mxd

Intersection of Basal Till Units with Drawdown Zone
Figure 4

Relict Channel / Borrow Area D Boring Locations

Figure 5





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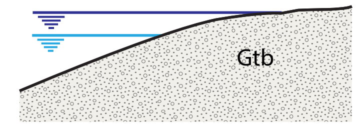
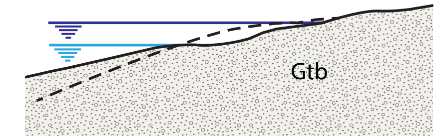
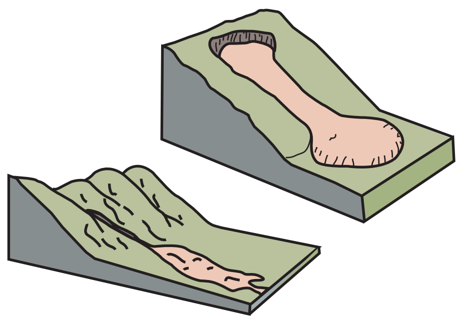
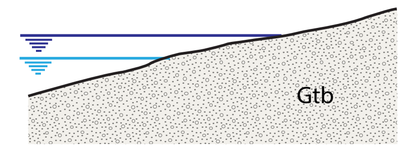
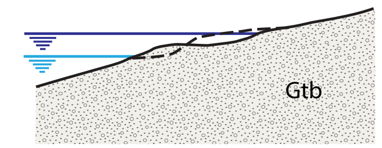
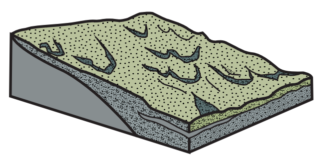
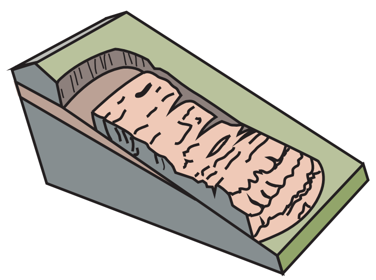
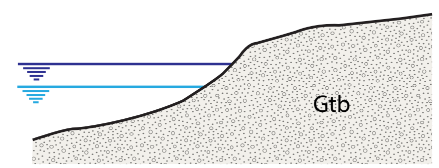
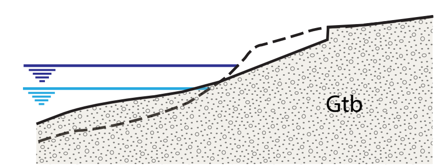
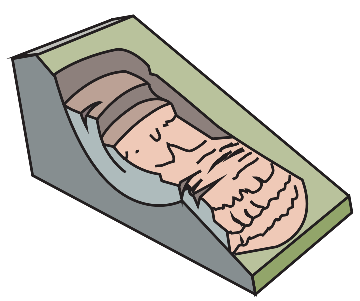
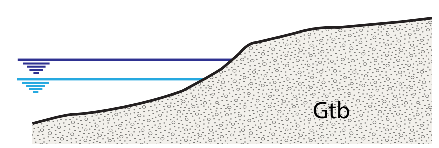
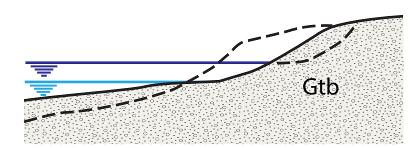
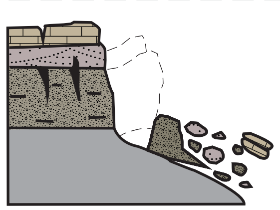
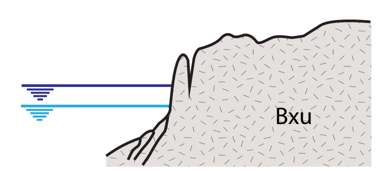
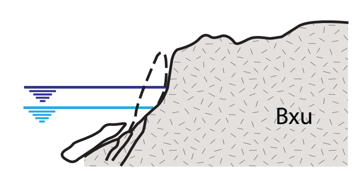
Note:

1. Scale is 1:1, no exaggeration.
2. Comparison of before and after profiles for slides D and E. Profiles were take along center of slide (Da and Ea), and along an intact slope adjacent to the slide (Db and Eb) as a proxy representative of the slope prior to slope movement.
3. Profile locations are shown in Figure 8-2.

Proposed Watana Reservoir Area - North Bank Slope Profiles
Figure 6

FAILURE MODE		DESCRIPTION	INITIAL SLOPE	AFTER SEVERAL YEARS
	B	Beach formation and erosion - All slopes. Wave action and reservoir fluctuation can cause instability through sloughing or failure of an over-steepened back-slope.		
	F1	Flow I (Bimodal Flow, Earthflow, Debris Flow) - Low to high angle slopes, shallow (~ <15 feet) unconsolidated or fine grained, frozen and unfrozen unfrozen materials. Reservoir fluctuation and groundwater saturate unconsolidated materials on hill slopes or stream channels. Generally form on hillsides, toes of slumps, or heads of small gullies where groundwater seepage or surface runoff concentrates. Frozen material thaws at the head-scarp and is transported away by mudflows that travel downslope (bimodal).		
	F2	Flow II (Solifluction/Gelifluction) - Low angle slopes, active layer, poorly sorted deposits. Water within saturated surface soil layer is unable to penetrate frozen layer, causing flow down slopes of nearly negligible slopes.		
	S1	Sliding I (Translational) - Mid to high angle slopes in frozen to sporadically frozen soils. Thawing within active layer increases fluid pressure along frozen / unfrozen interface. Reservoir and groundwater fluctuations along slopes will increase thawing potential of slopes, possibly increasing pore water pressure during drawdown.		
	S2	Sliding II (Rotational Slump) - High angle slopes, unfrozen, cohesive soils. Reservoir and groundwater fluctuation in soils will increase thaw zone and active layer. Over time, additional sliding may occur with extension of thaw zone into soil along reservoir margin.		
	R1	Rock Toppling - High angle rock slopes. Reservoir and groundwater level fluctuation increases frost wedging, inducing failure.		

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Legend

- Gtb — Basal Till
- Bxu — Bedrock - unweathered
- High Reservoir Level
- Low Reservoir Level

Slope Models and Failure Mechanisms
Figure 7

Figure 8. Earthflow / Bimodal Flow on South Abutment, adjacent to DH12-6 (Sheet 12-1).

Figure 9. Rotational Slide, Earth Slump, North Abutment, near RM 198,
Upstream of Confluence with Watana Creek (Sheet 12-7).

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Figure 10. Translational Slide on SW-facing Slope along Watana Creek (Sheet 12-5).

Figure 11. Translational Slide, Earth Block Slide of Frozen Ground, NE-facing Slope, Watana Creek (Sheet 12-6).

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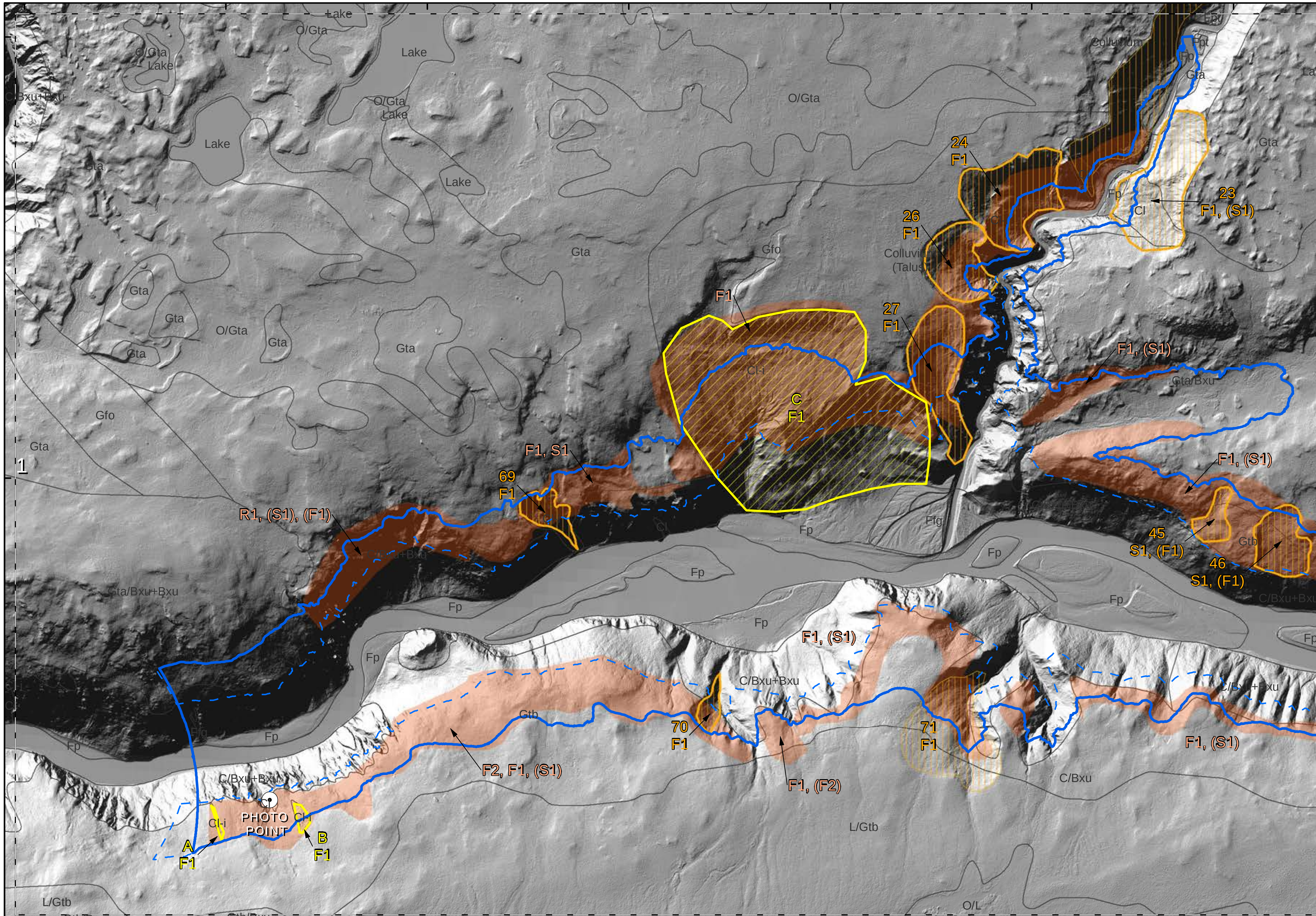

ALASKA ENERGY AUTHORITY

- Photo Point
- Cross-Section Line
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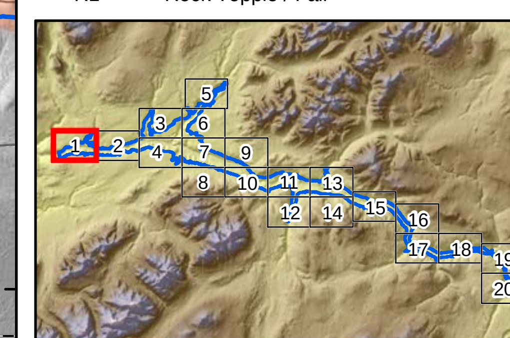
O	Organic deposits
C	Colluvial deposit
Cl	Active landslide
Cl-i	Inactive landslide
Cs	Solifluction deposits
Ffg	Granular alluvial fan
Fp	Floodplain
Fpt	Old Floodplain Terrace
GFo	Outwash
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
L	Lacustrine deposits
Gtb	Basal till
Bxu	Undifferentiated bedrock

Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

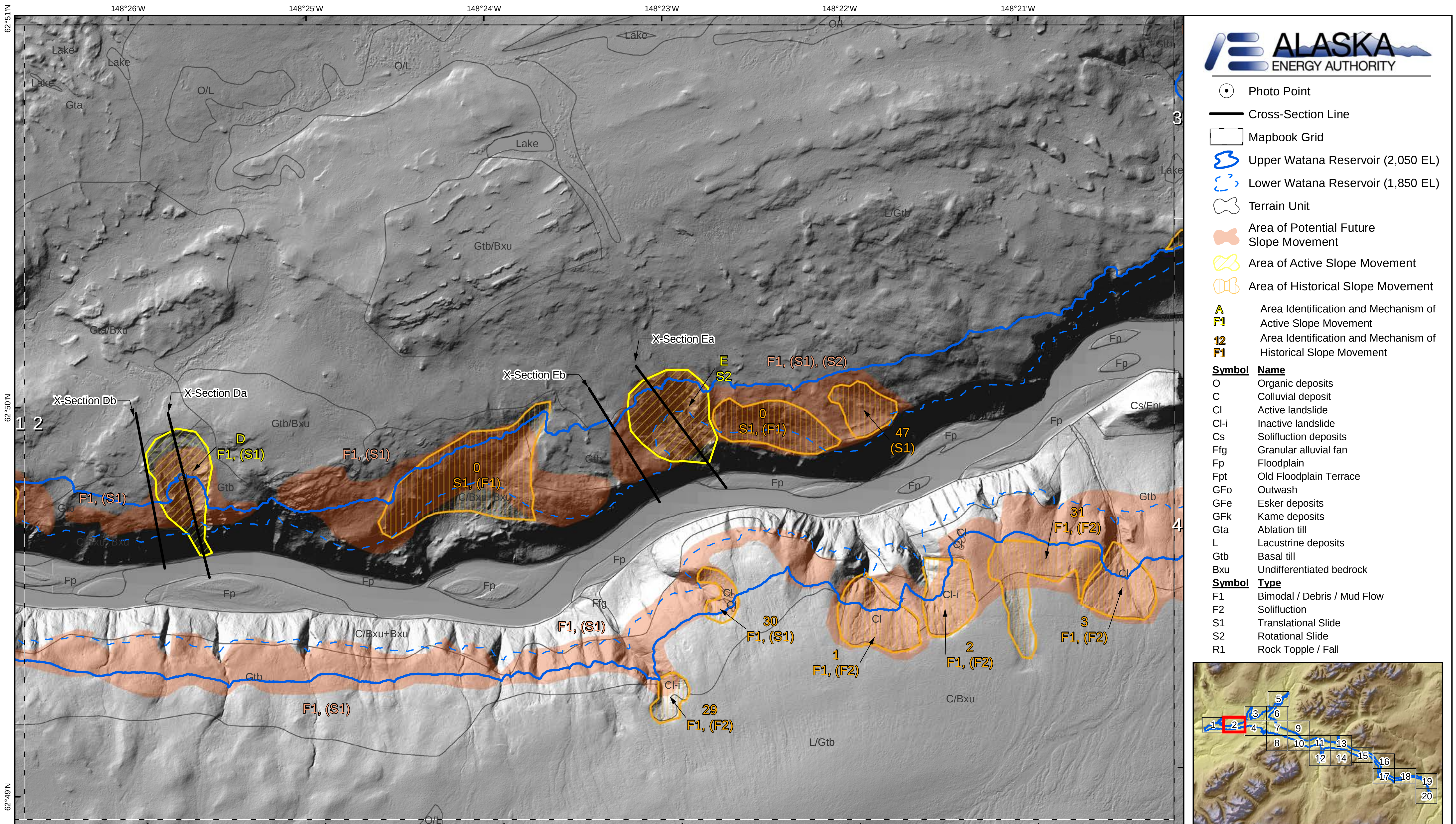
N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-1



Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-2

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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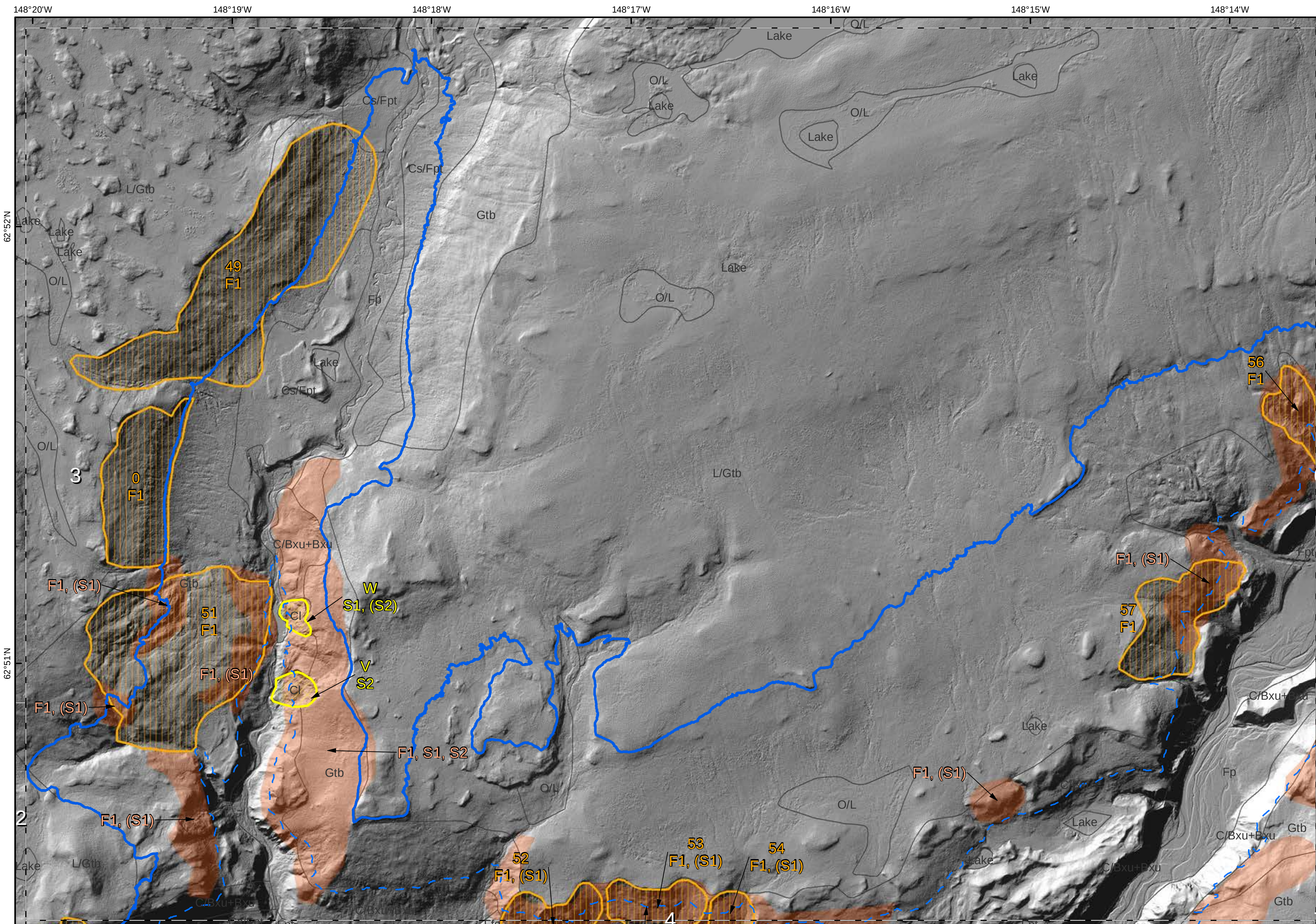

ALASKA ENERGY AUTHORITY

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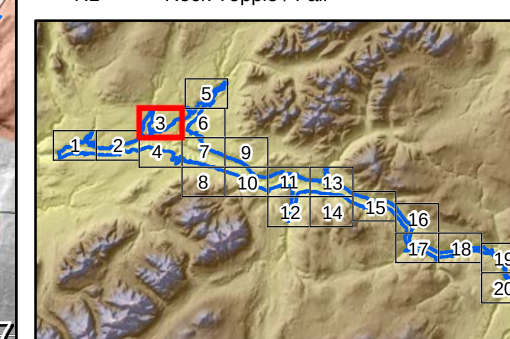
GFo	Outwash
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
L	Lacustrine deposits
Gtb	Basal till
Bxu	Undifferentiated bedrock

Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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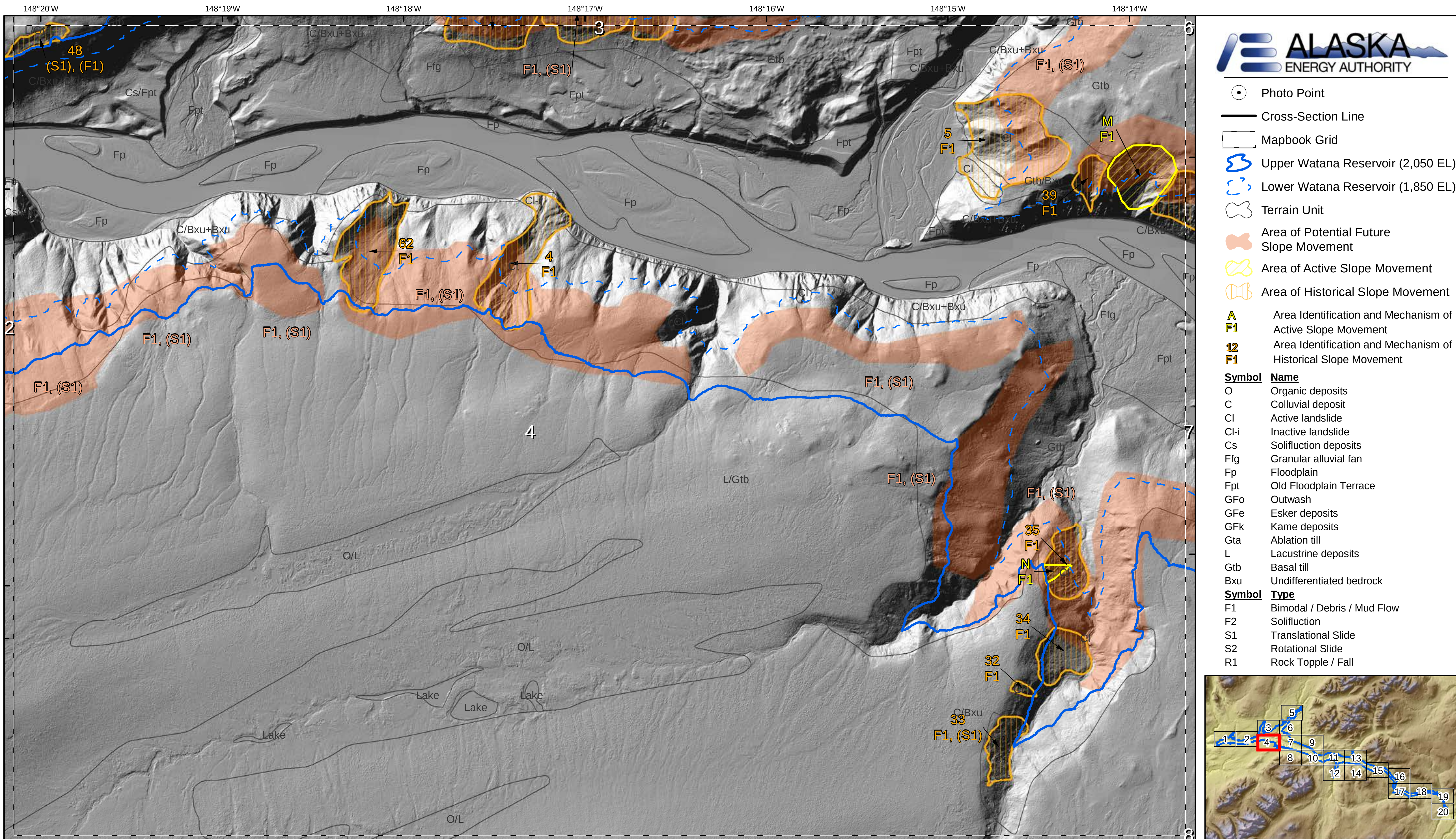
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-3



0 750 1,500 Feet
0 180 360 Meters

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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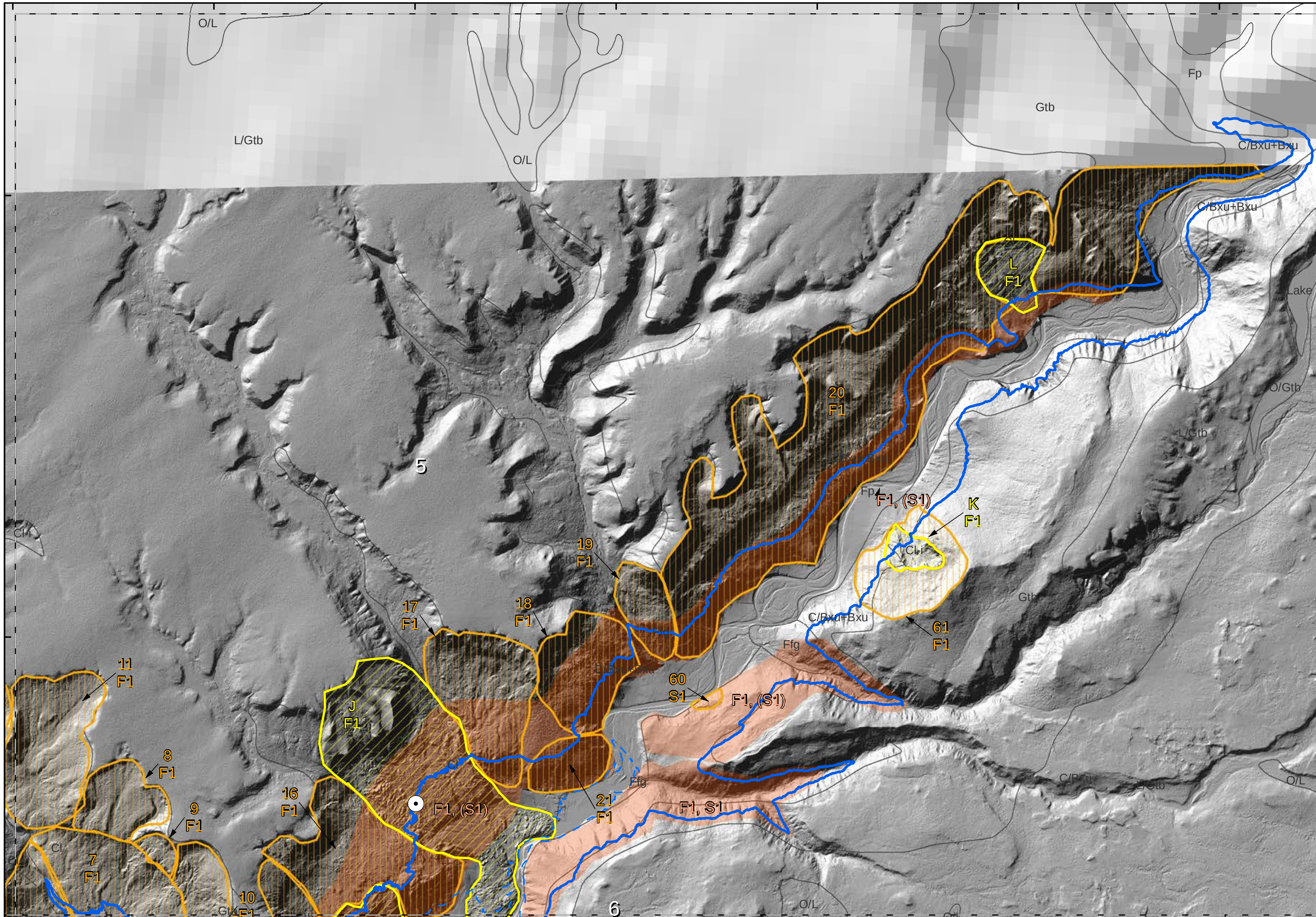
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-4



![ALASKA ENERGY AUTHORITY logo]

ALASKA ENERGY AUTHORITY

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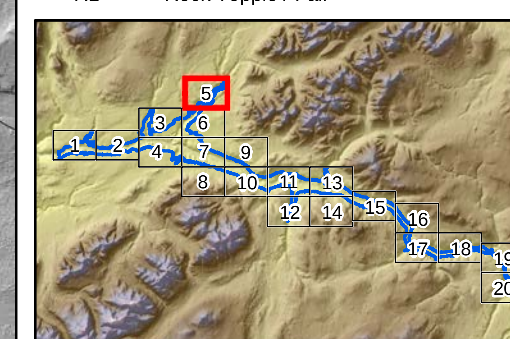
GFo	Outwash
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
L	Lacustrine deposits
Gtb	Basal till
Bxu	Undifferentiated bedrock

Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
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Data Sources: See Map References
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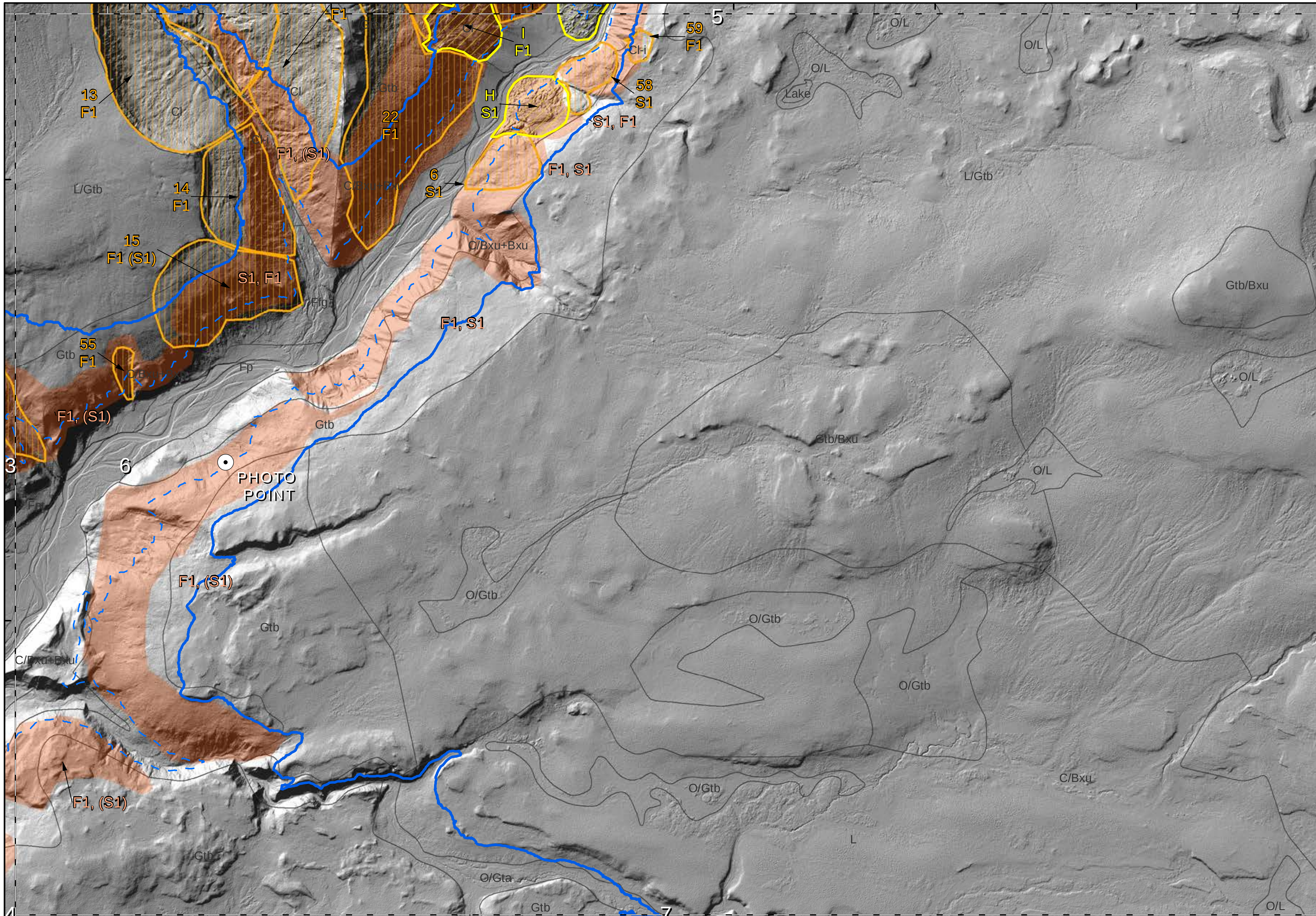
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-5



ALASKA ENERGY AUTHORITY

Photo Point
Cross-Section Line
Mapbook Grid
Upper Watana Reservoir (2,050 EL)
Lower Watana Reservoir (1,850 EL)
Terrain Unit
Area of Potential Future Slope Movement
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Area of Historical Slope Movement
A F1 Area Identification and Mechanism of Active Slope Movement
12 F1 Area Identification and Mechanism of Historical Slope Movement

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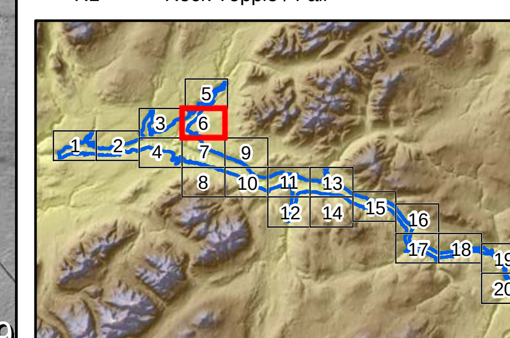
Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

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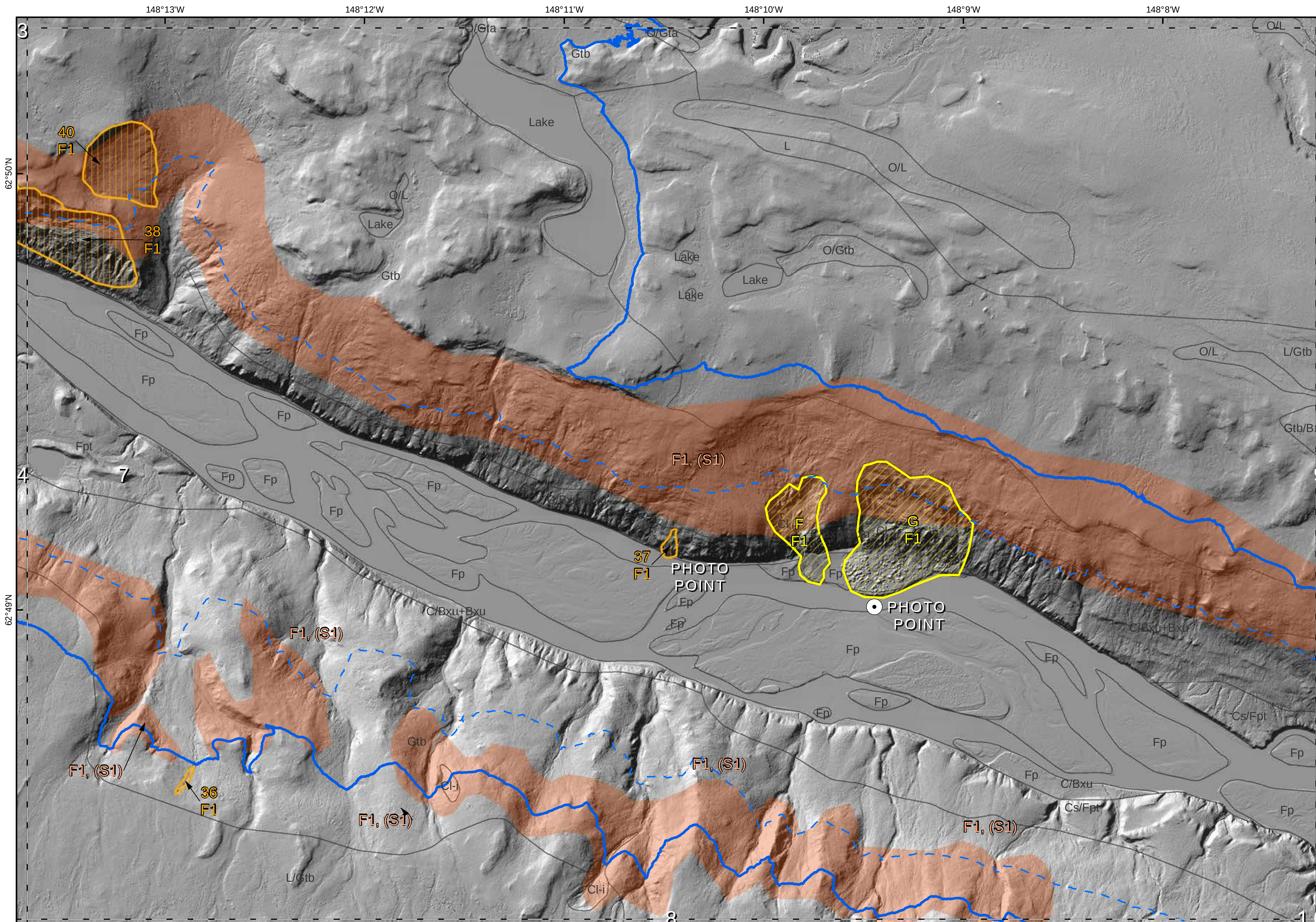
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-6



ALASKA ENERGY AUTHORITY

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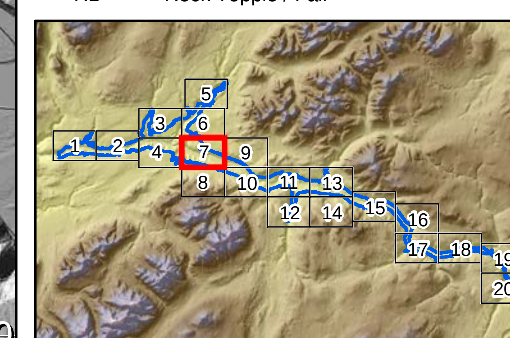
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
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File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

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Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-7

ALASKA ENERGY AUTHORITY

Photo Point

Cross-Section Line

Mapbook Grid

Upper Watana Reservoir (2,050 EL)

Lower Watana Reservoir (1,850 EL)

Terrain Unit

Area of Potential Future Slope Movement

Area of Active Slope Movement

Area of Historical Slope Movement

A F1 Area Identification and Mechanism of Active Slope Movement

12 F1 Area Identification and Mechanism of Historical Slope Movement

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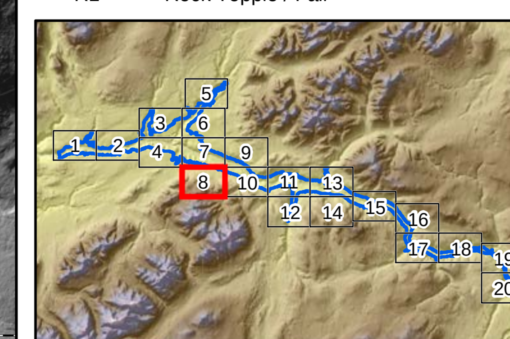

0 750 1,500 Feet

0 180 360 Meters

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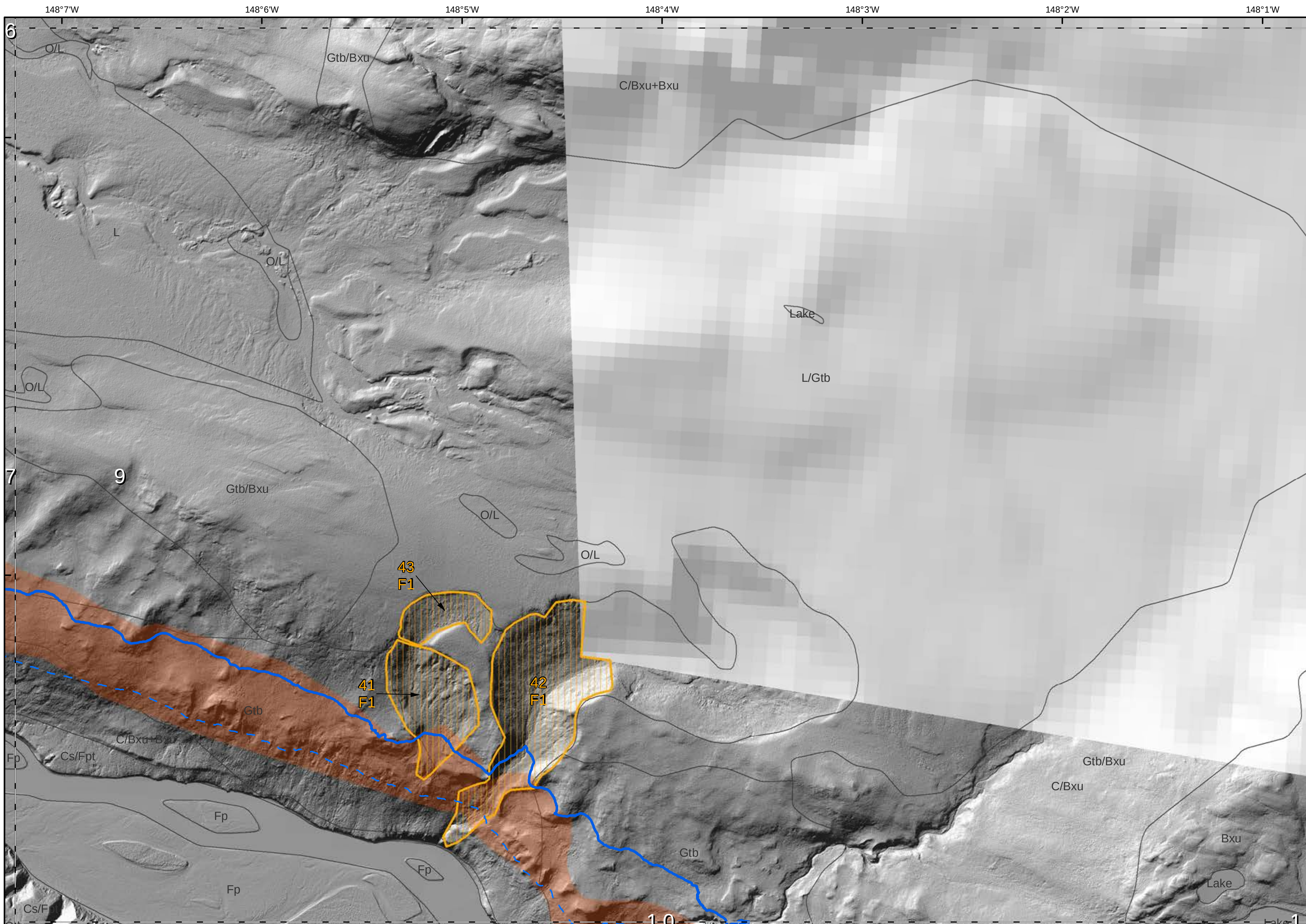
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-8



ALASKA ENERGY AUTHORITY

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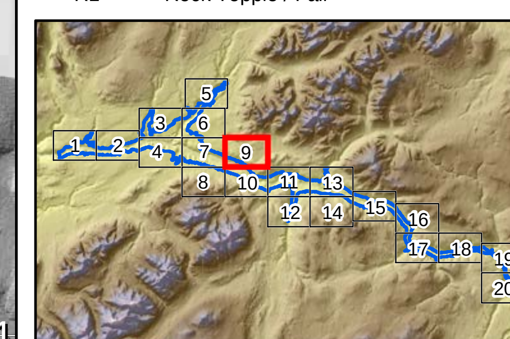

0 750 1,500 Feet

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N

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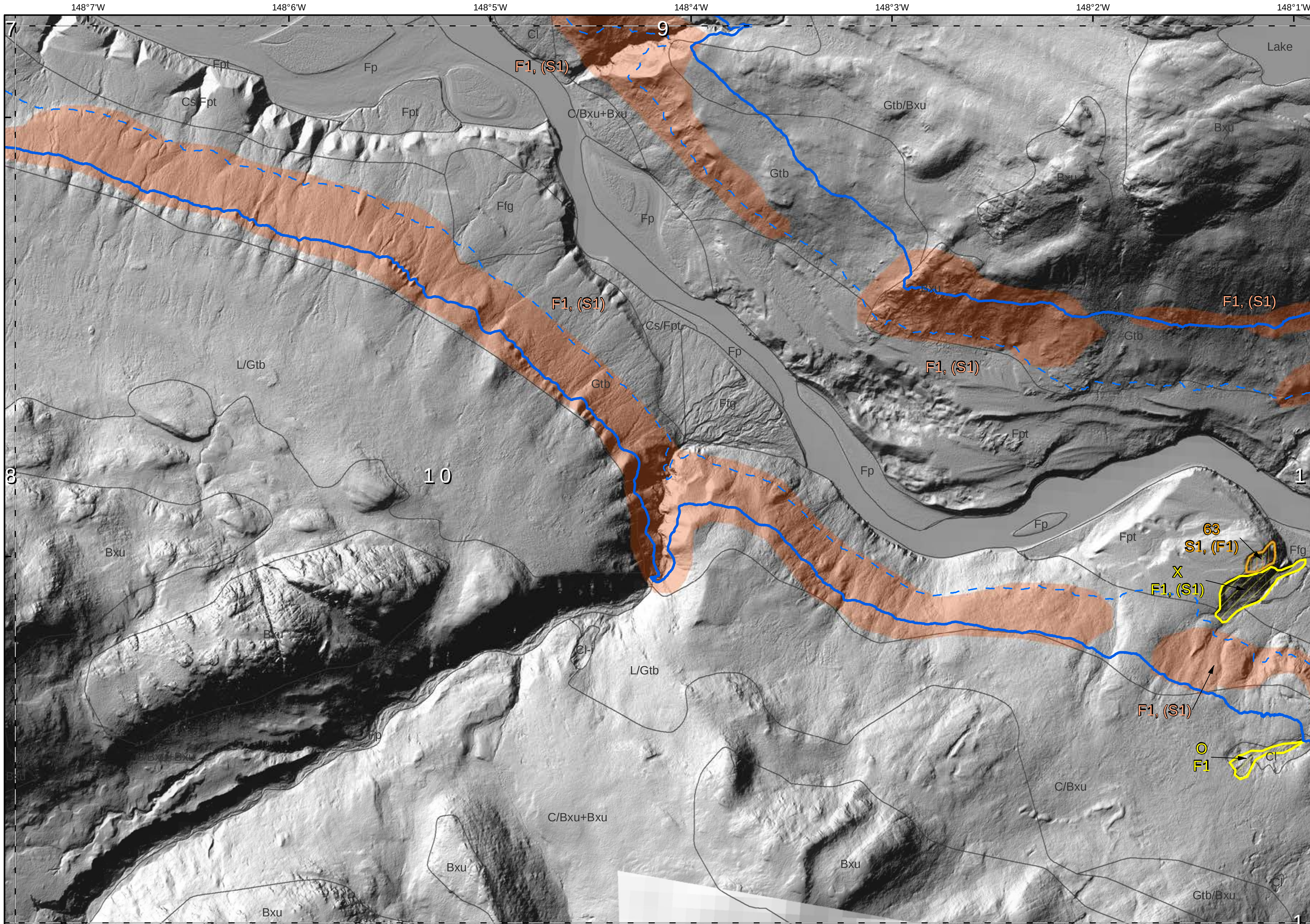
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-9



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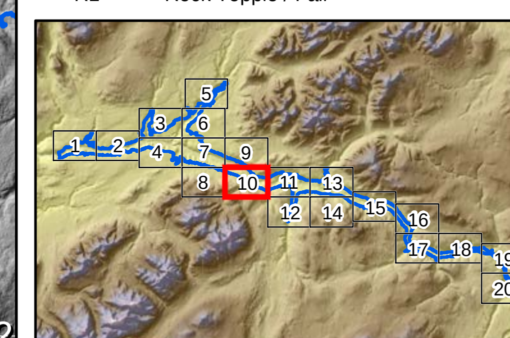

0 750 1,500 Feet

0 180 360 Meters

N

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File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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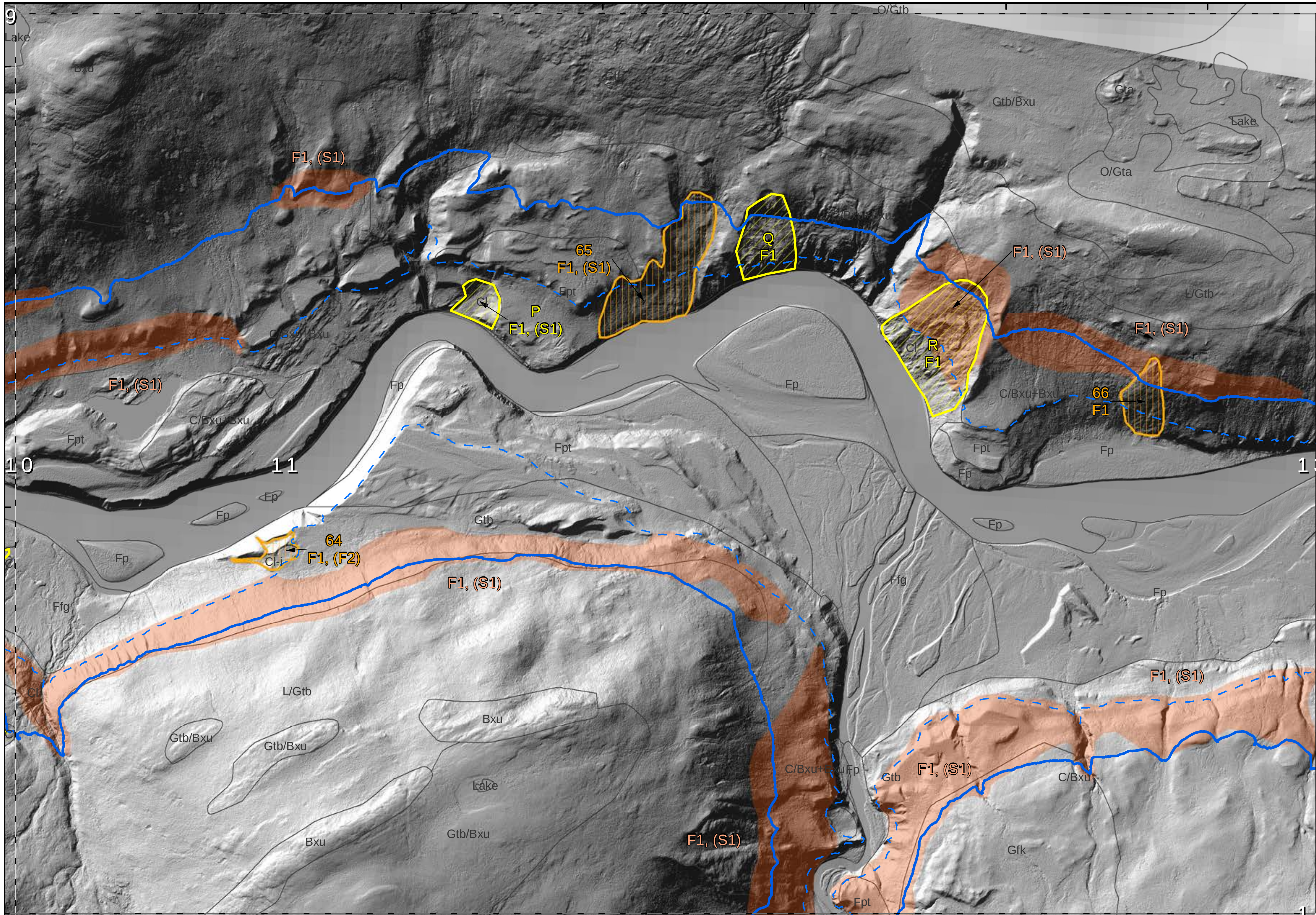
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-10



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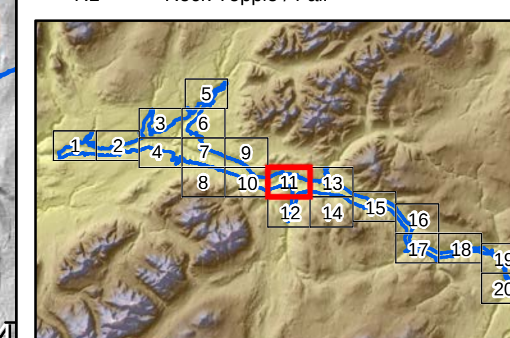
Symbol	Name
O	Organic deposits
C	Colluvial deposit
Cl	Active landslide
Cl-i	Inactive landslide
Cs	Solifluction deposits
Ffg	Granular alluvial fan
Fp	Floodplain
Fpt	Old Floodplain Terrace
GFo	Outwash
GFe	Esker deposits
GFk	Kame deposits
Gta	Ablation till
L	Lacustrine deposits
Gtb	Basal till
Bxu	Undifferentiated bedrock

Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

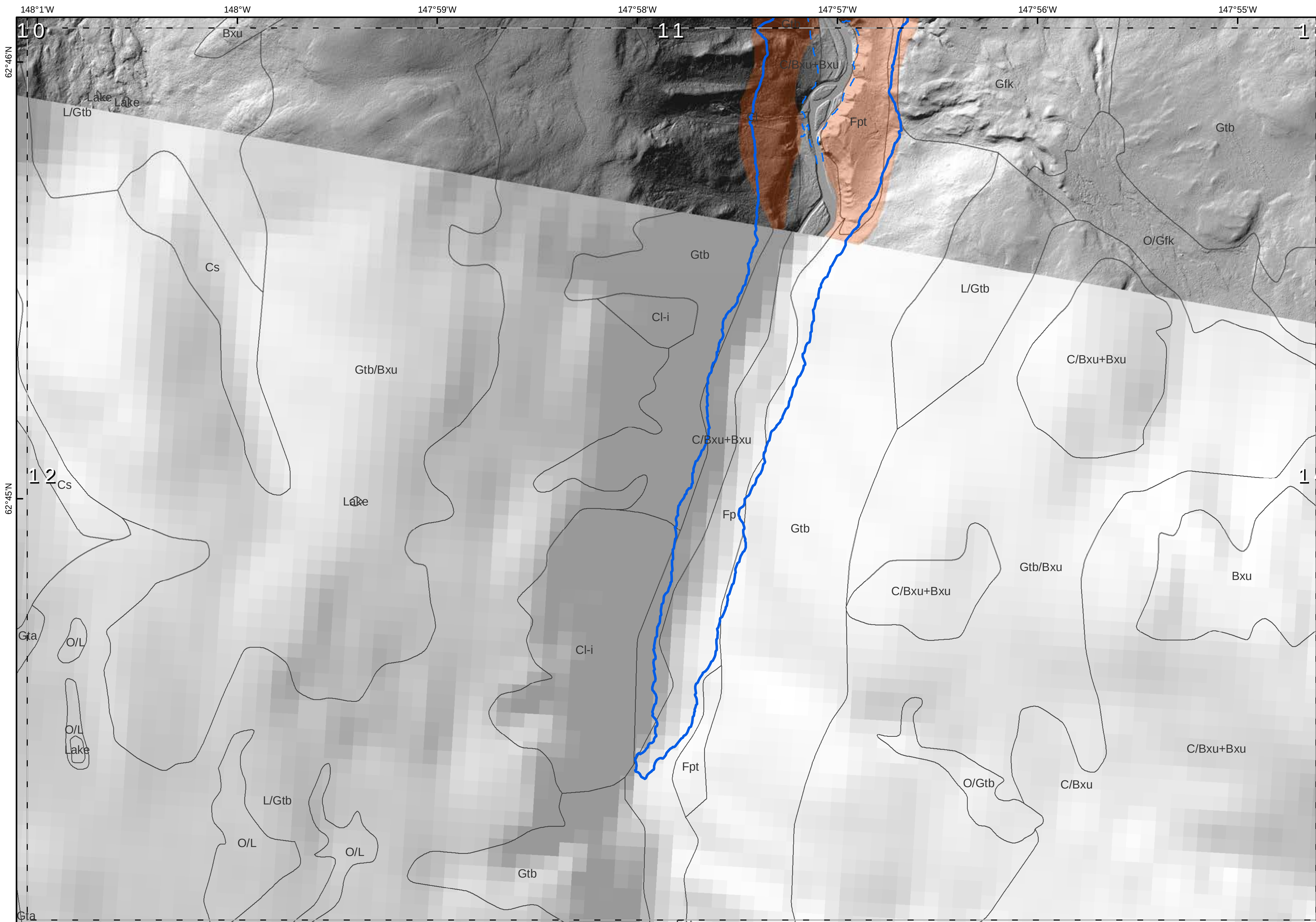
N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure12-11



ALASKA ENERGY AUTHORITY

- Photo Point
- Cross-Section Line
- Mapbook Grid
- Upper Watana Reservoir (2,050 EL)
- Lower Watana Reservoir (1,850 EL)
- Terrain Unit
- Area of Potential Future Slope Movement
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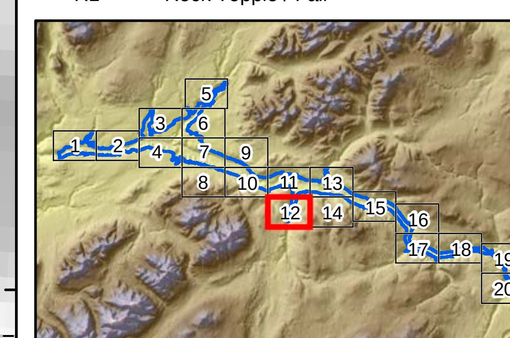
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

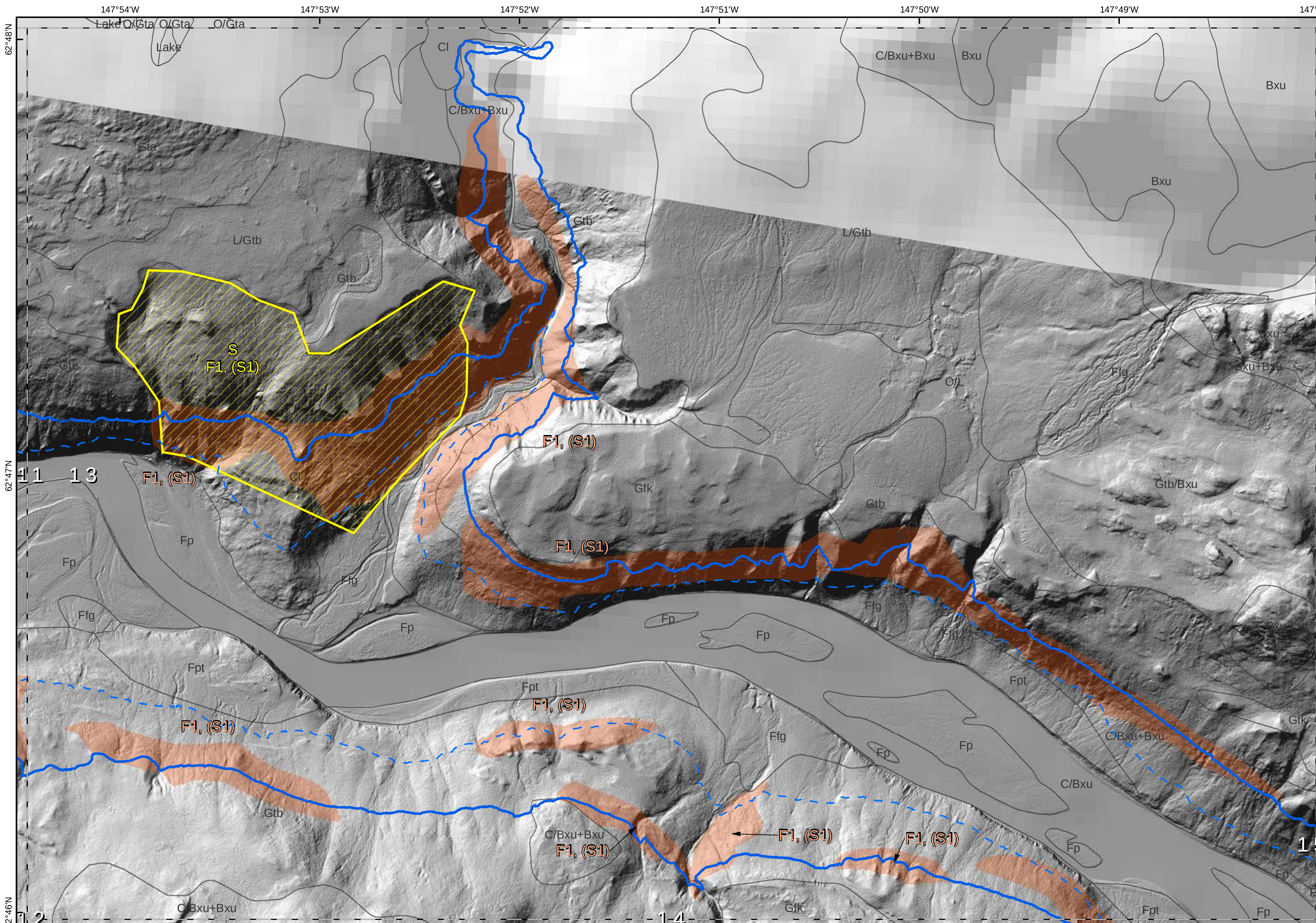
N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-12



ALASKA ENERGY AUTHORITY

- Photo Point
- Cross-Section Line
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- Upper Watana Reservoir (2,050 EL)
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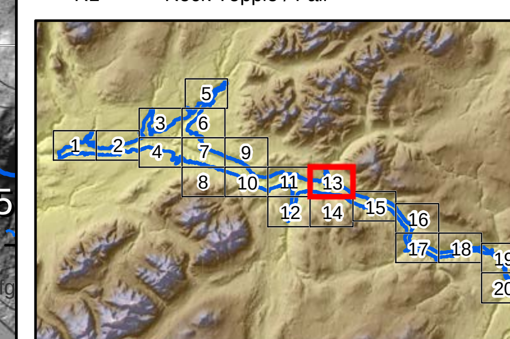
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

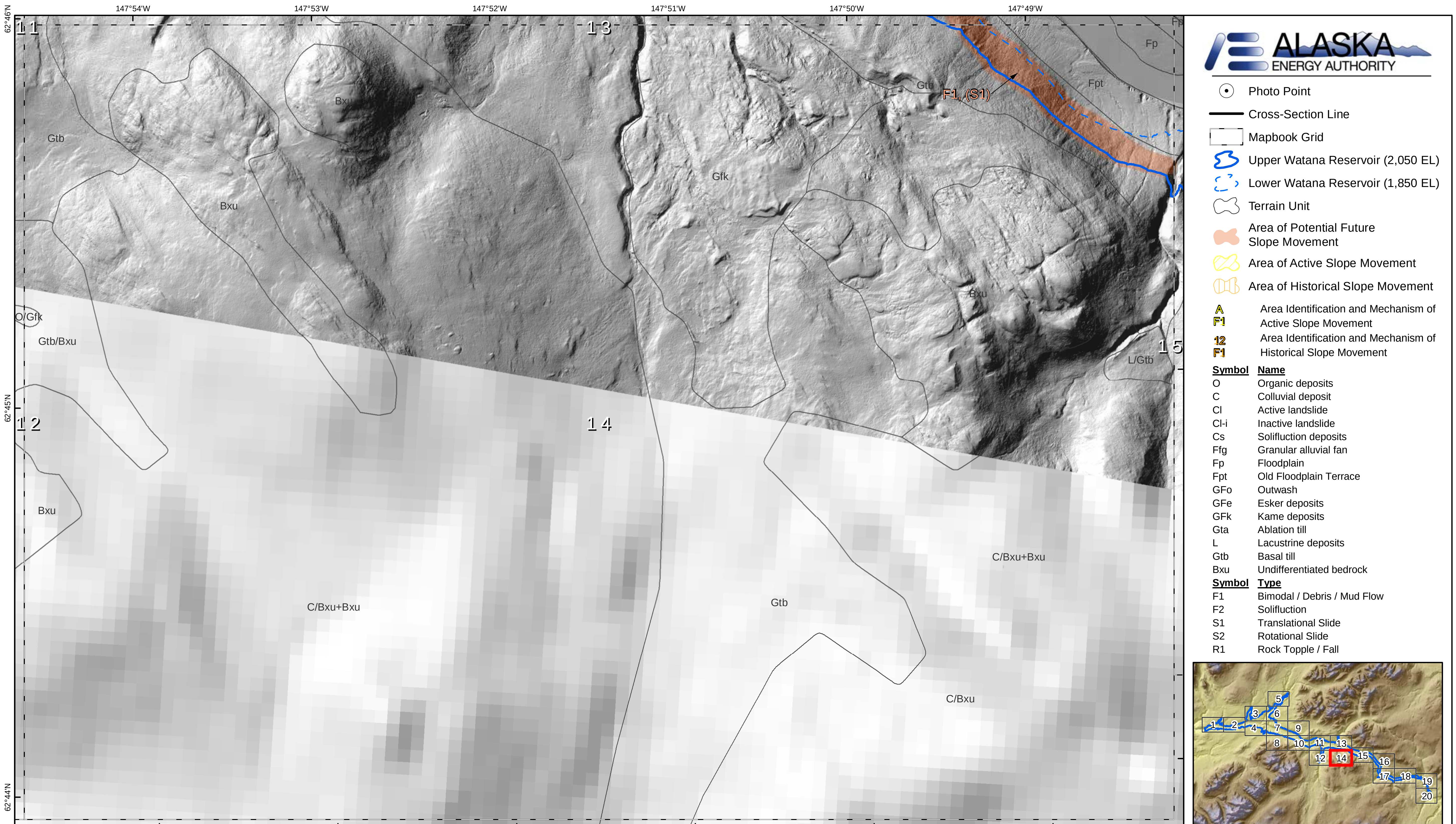
0 180 360 Meters

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-13

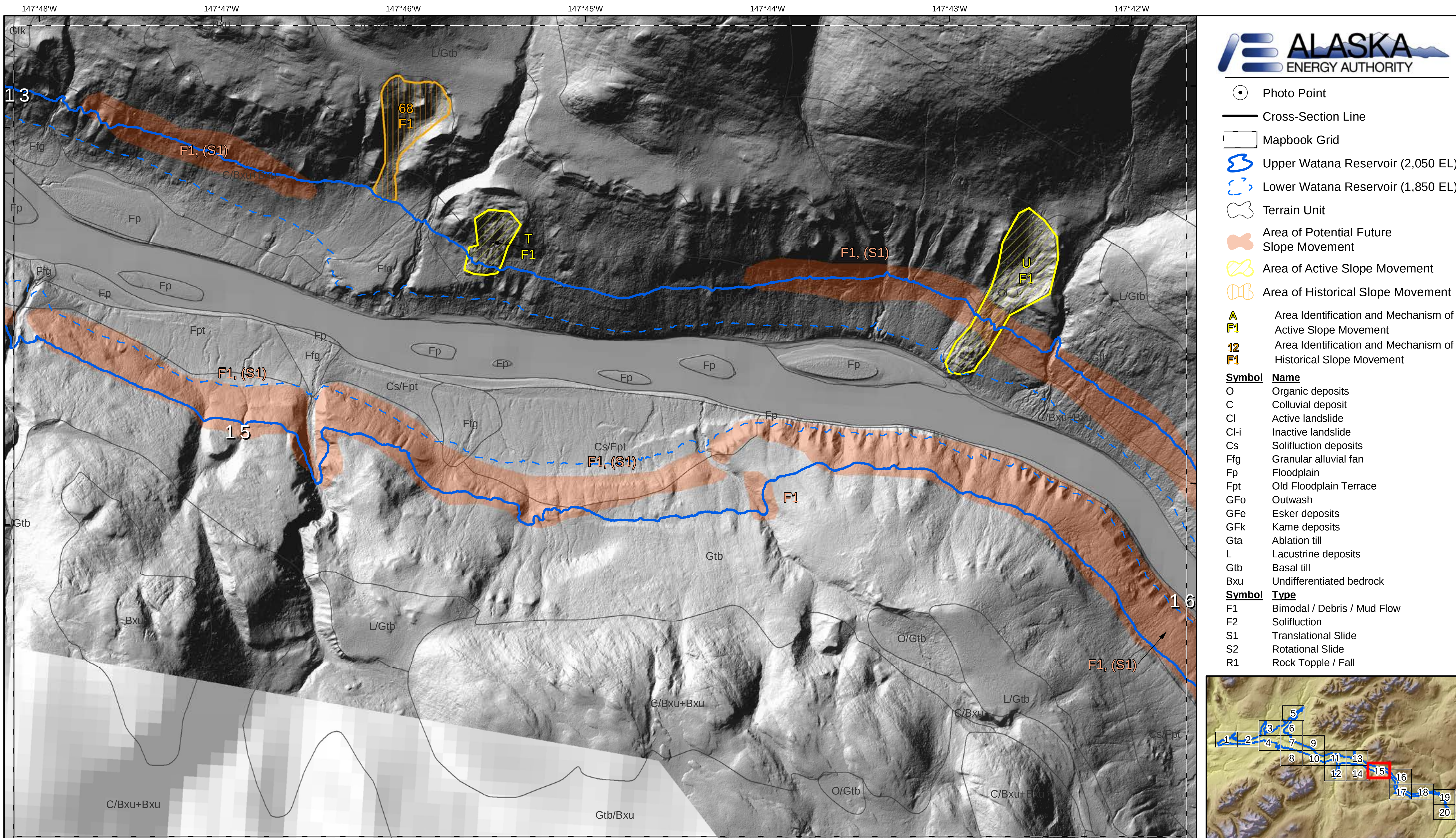


Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-14



0 750 1,500 Feet

0 180 360 Meters

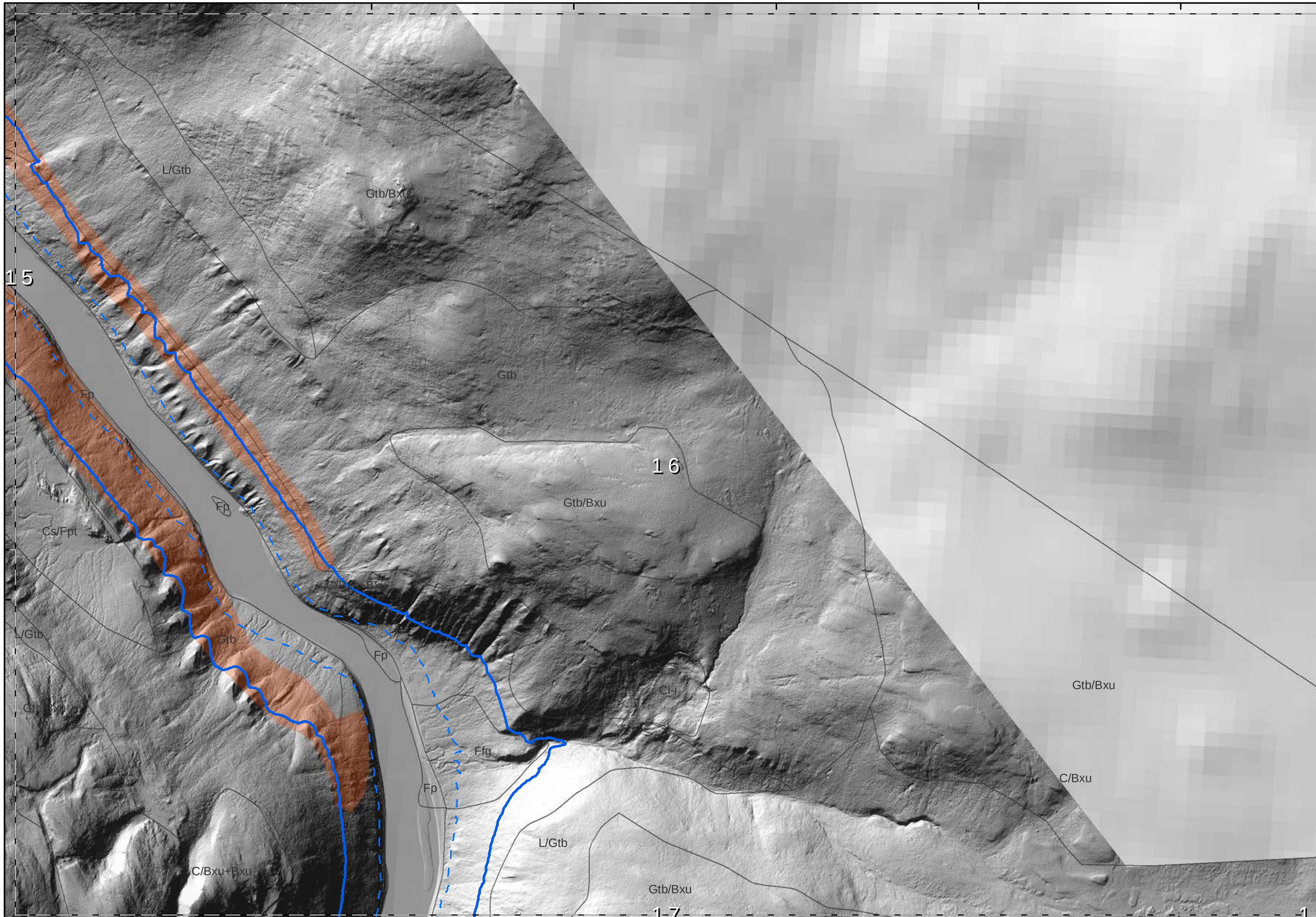
N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-15



ALASKA ENERGY AUTHORITY

- Photo Point
- Cross-Section Line
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- Upper Watana Reservoir (2,050 EL)
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Symbol	Type
F1	Bimodal / Debris / Mud Flow
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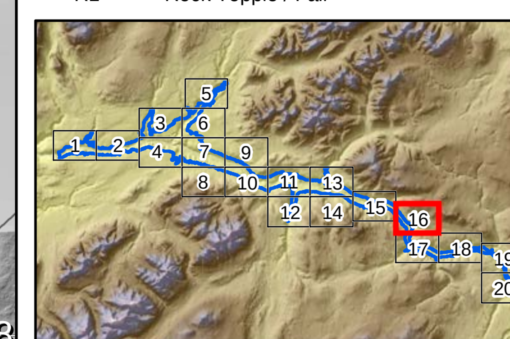


0 750 1,500 Feet

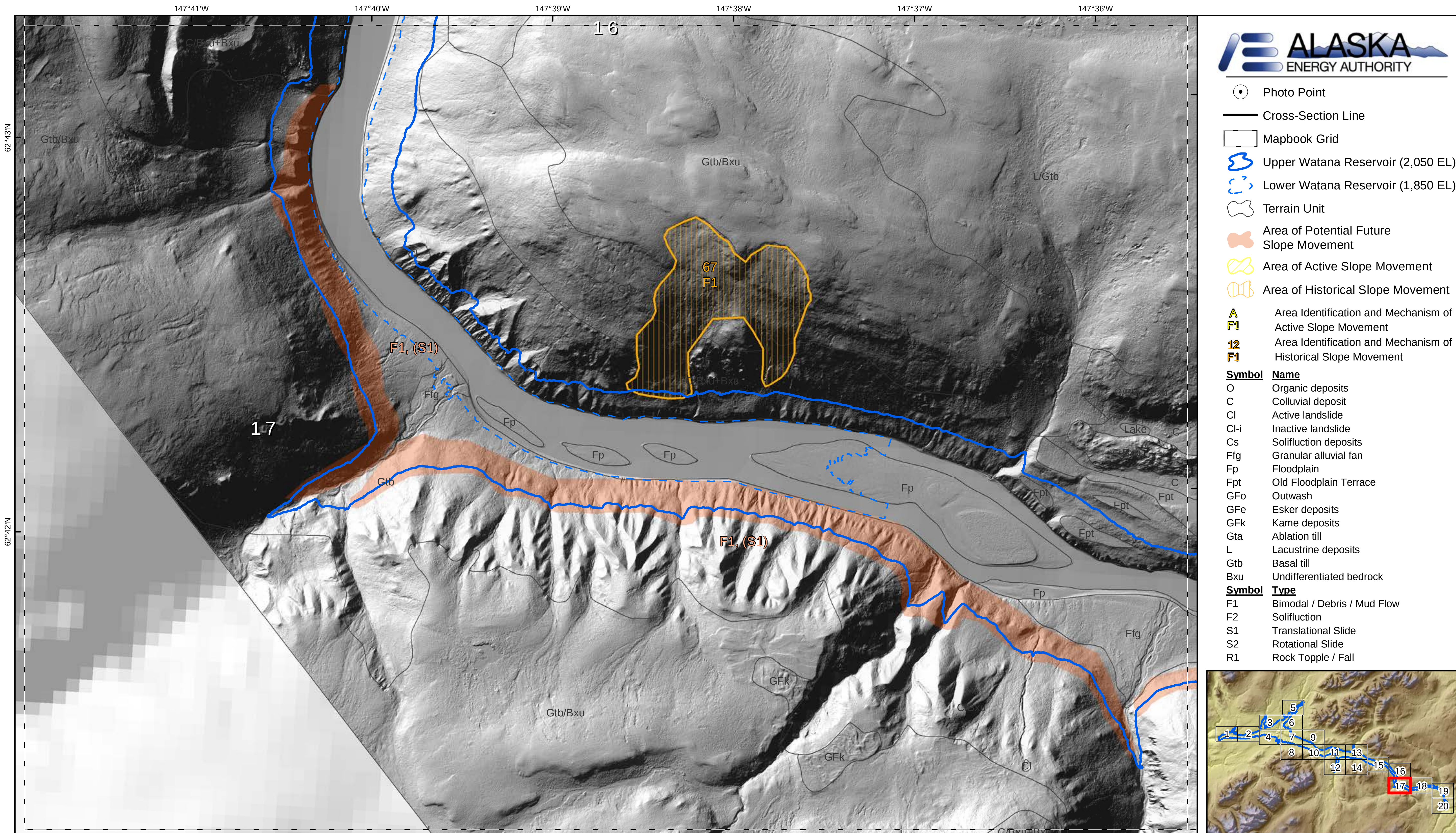
0 180 360 Meters

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88

Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-16



Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-17

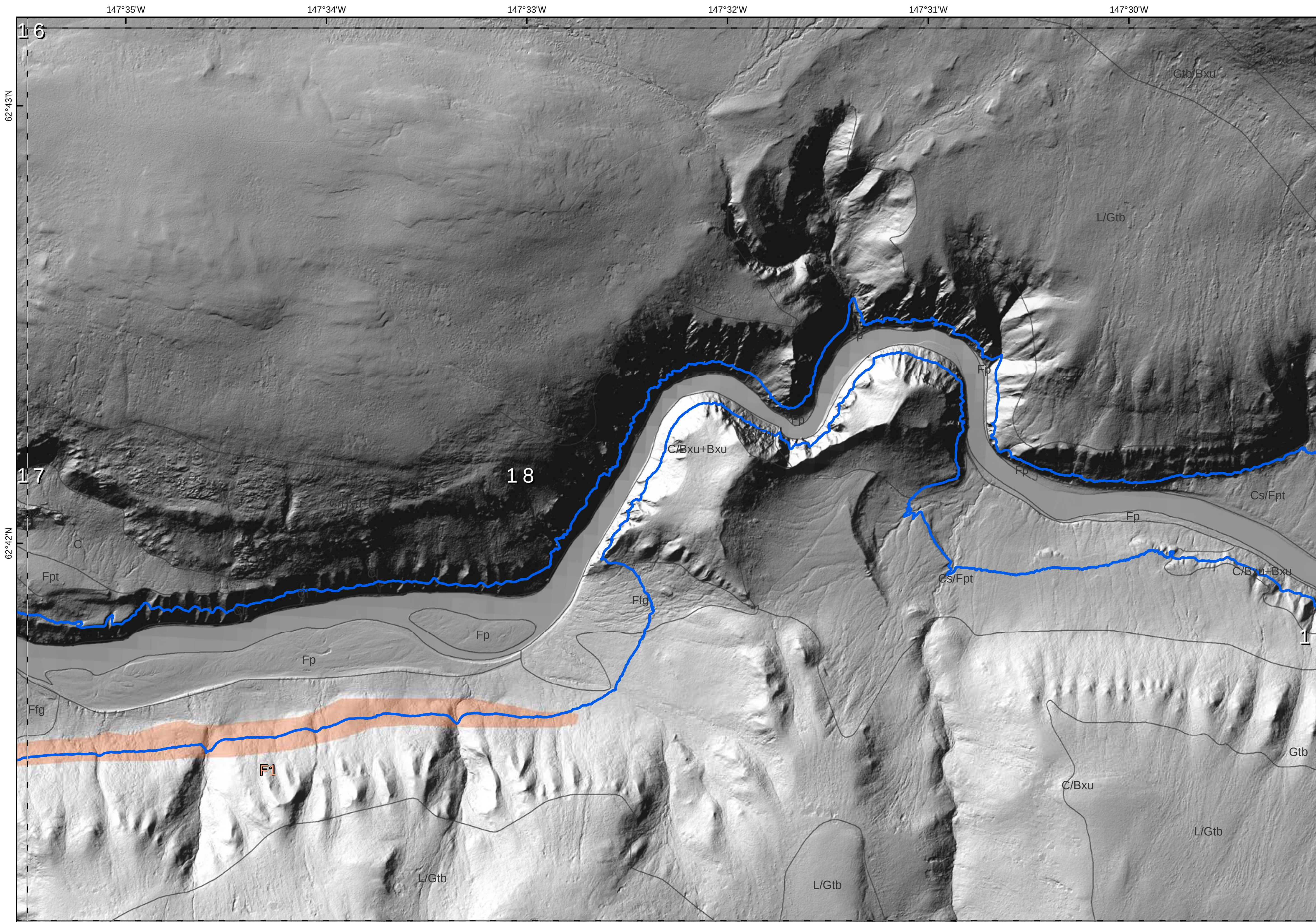
0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
Elevation Data was derived from the MatSu LiDAR data using the horizontal datum NAD83 and vertical datum NAVD88



ALASKA ENERGY AUTHORITY

- Photo Point
- Cross-Section Line
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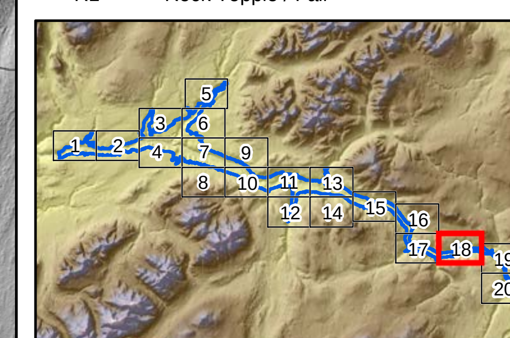
Symbol	Type
F1	Bimodal / Debris / Mud Flow
F2	Solifluction
S1	Translational Slide
S2	Rotational Slide
R1	Rock Topple / Fall



0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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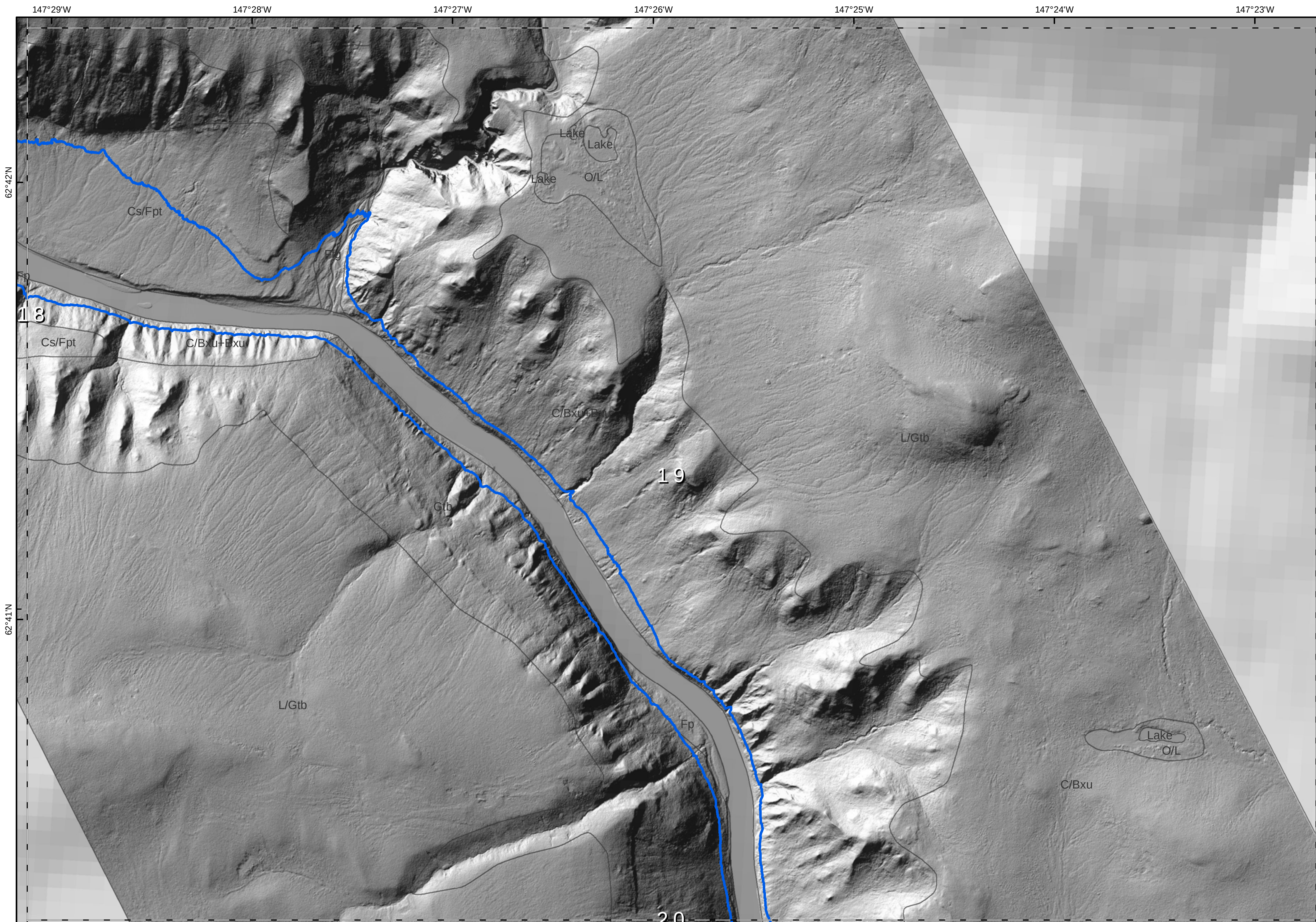
Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-18



ALASKA ENERGY AUTHORITY

- Photo Point
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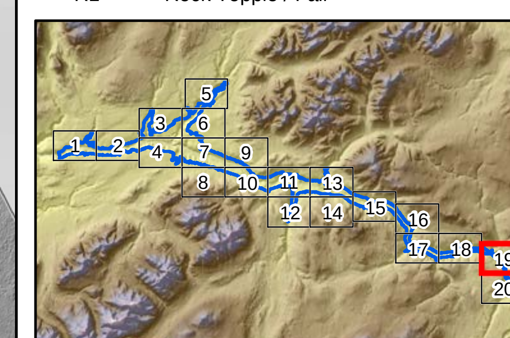

0 750 1,500 Feet

0 180 360 Meters

N

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-19

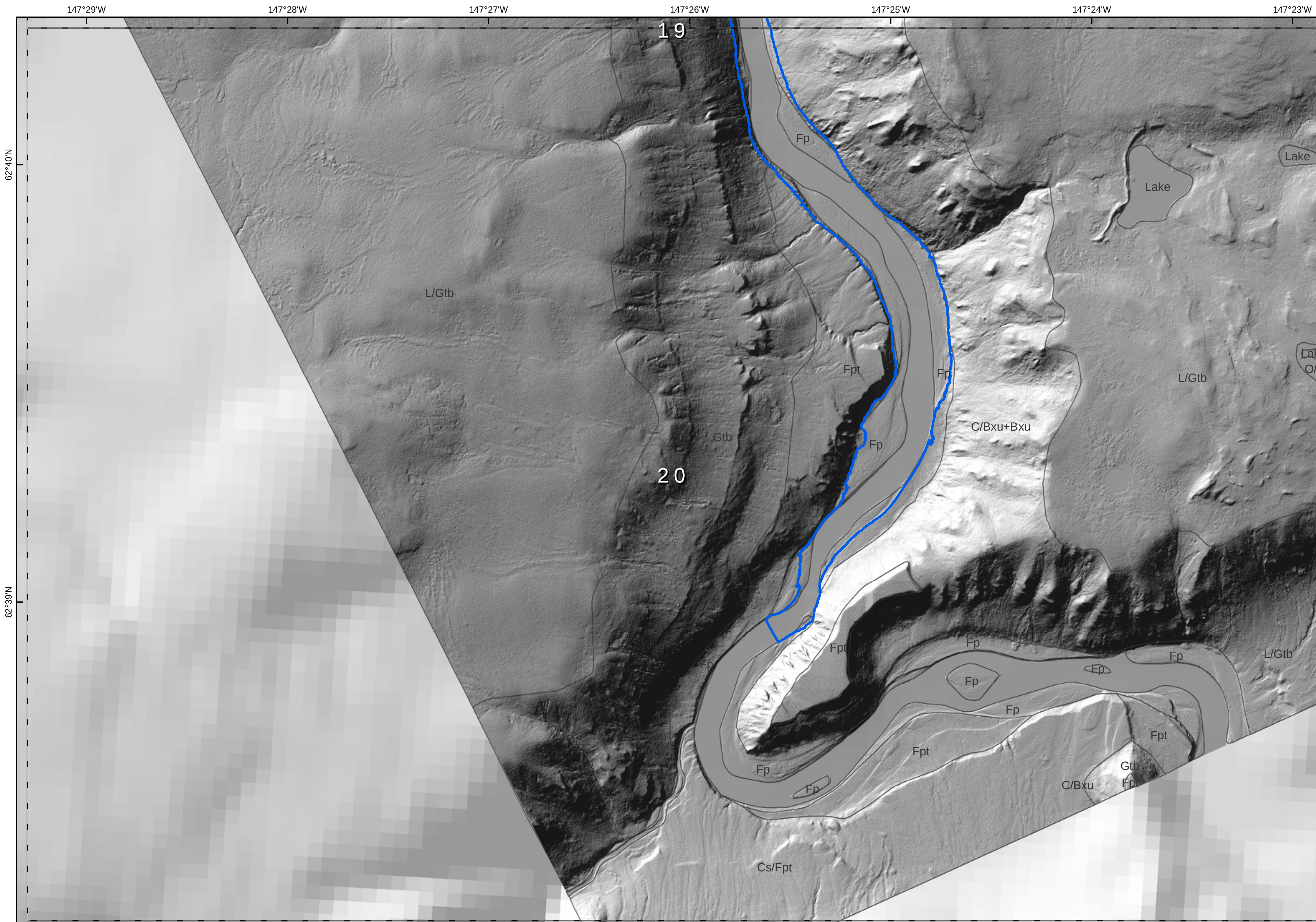

Photo Point

Cross-Section Line

Mapbook Grid

Upper Watana Reservoir (2,050 EL)

Lower Watana Reservoir (1,850 EL)

Terrain Unit

Area of Potential Future Slope Movement

Area of Active Slope Movement

Area of Historical Slope Movement

A F1 Area Identification and Mechanism of Active Slope Movement

12 F1 Area Identification and Mechanism of Historical Slope Movement

Symbol	Name
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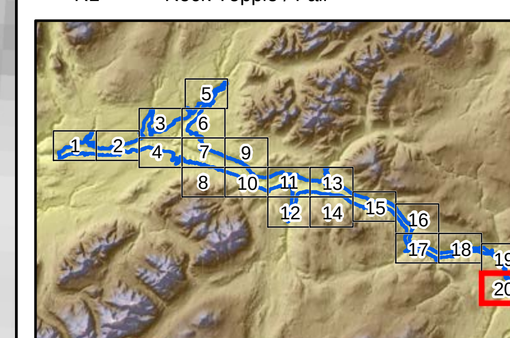

0 750 1,500 Feet

0 180 360 Meters

Projection: NAD 1983 StatePlane Alaska 4 FIPS 5004 Feet
Date Created: 9/17/2013
Map Author: MWH - Cory Bolen
File: SuWa_Cur_Instability_Mapbook_11x17_Landsc_8_28_13.mxd

Data Sources: See Map References
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Areas of Active, Historic, and Potential Slope Movement - Mapbook

Figure 12-20

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ATTACHMENTS

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Attachment 1

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Table A1-1: Basal Till Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Sample ID	Top Depth (feet)	Bottom Depth (feet)	Date	Soil Unit	USCS Classification	Sieve Analysis (%) Cobble (> 3")	Gravel (ret. on No. 4)	Sand (ret. on No. 200)	Silt/Clay (ret. on Pan)	Atterberg Limits LL	PL	PI	W_C (%)	Top Depth (feet)	Bottom Depth (feet)	SPT (blows / 6 inches) Test No.	1st	2nd	3rd	4th	N-Value	Hammer Energy Correction Em	Overburden Pressure	C_N	Corrected N
	28.2	28.6	8/15/1982	M	-	-	-	-	-	-	-	-	-	28.2	28.6	13	57/5				R				
16A-14A	29.5	30.0	8/15/1982	M	SM	0.0	20.0	41.0	39.0	-	-	-	11.7	29	31	14	17	29	35	41	64	89	3190	0.814	73
16A-14B	30.2	31.0	8/15/1982	M	CL-SC	0.0	7.0	44.0	49.0	-	-	-	13.0												
16A-15	31.0	31.9	8/15/1982	M	-	-	-	-	-	-	-	-	-	31	31.9	15	43	50/5			R				
16A-16	33.0	33.4	8/15/1982	M	-	-	-	-	-	-	-	-	-	33	33.4	16	55/5				R				
16A-17	34.0	36.0	8/15/1982	M	CL	0.0	27.0	12.0	61.0	33	20	13	-	34	36	17	30	24	45	62	69	96	3740	0.752	72
16B-18	36.0	38.0	8/15/1982	M	-	-	-	-	-	-	-	-	10.8	36	38	18	15	31	47	82	78	109	3960	0.731	79
16B-19	38.0	38.2	8/15/1982	M	-	-	-	-	-	-	-	-	13.7	38	38.2	19	N/A					0	4180	0.711	0
16B-20	38.2	39.0	8/15/1982	M	-	-	-	-	-	-	-	-	12.5	38.2	39.2	20	26	84			R				
16B-21A	40.0	42.0	8/15/1982	M	CL	0.0	16.0	24.0	60.0	-	-	-	11.5	40	42	21	5	38	55	89	93	130	4400	0.693	90
16B-21B	41.0	41.3	8/15/1982	M	ML	0.0	3.0	37.0	60.0	-	-	-	17.2	42	43.5	22	37	33	95		R				
16B-22	42.0	43.5	8/15/1982	M	CL	0.0	12.0	25.0	63.0	-	-	-	13.8	44	45.6	23	20	28	83	50/1	111	155	4840	0.661	102
17-35	94.0	95.2	8/15/1982	G'	SC	0.0	17.0	43.0	40.0	-	-	-	11.3	94	95.2	35	13	50	50/.2		R				
17-36	96.0	97.9	8/15/1982	G'	-	-	-	-	-	-	-	-	13.9	96	97.9	36	15	26	32	50/.4	58	81	10560	0.447	36
17-37	98.0	99.7	8/15/1982	G'	SC-CL	0.0	14.0	38.0	48.0	-	-	-	-	98	99.7	37	19	27	50	50/.2	77	107	10780	0.443	48
	100.0	101.3	8/15/1982	G'	-	-	-	-	-	-	-	-	13.6	100	101.3	38	19	46	50/.3		R				
17-39	102.0	102.8	8/15/1982	G'	SM-SC	0.0	13.0	45.0	42.0	-	-	-	-	102	102.8	39	44	50/.3			R				
18-42	132.0	132.8	8/14/1982	G'	-	-	-	-	-	-	-	-	-	132	132.8	42	58	85/4			R				
18-43	135.0	136.3	8/14/1982	G'	CL-CH	0.0	9.0	34.0	57.0	-	-	-	14.1	135	136.3	43	12	22			22	31	14850	0.377	12
	137.0	137.3	8/14/1982	G'	-	-	-	-	-	-	-	-	-	137	137.3	44	50/3				R				
	139.0	139.6	8/14/1982	G'	-	-	-	-	-	-	-	-	-	139	139.6	45	73	25/1			R				
	142.0	142.3	8/14/1982	G'	-	-	-	-	-	-	-	-	-	142	142.3	46	65/4				R				
18-47	143.0	143.5	8/14/1982	G'	-	-	-	-	-	-	-	-	-	143	143.5	47	100/6				R				
18-48	152.0	152.6	8/14/1982	G'	SC	0.0	19.0	28.0	53.0	-	-	-	12.0	152	152.6	48	32	50/1			R				
	155.0	155.9	8/14/1982	G'	-	-	-	-	-	-	-	-	-	155	155.9	49	7	50/5			R				
18-50	157.3	158.0	8/14/1982	G'	-	-	-	-	-	-	-	-	-	157.3	158.1	50	40	50/3			R				
18-51	160.0	160.4	8/14/1982	G'	-	0.0	10.0	49.0	41.0	-	-	-	9.3	160	160.4	51	62/5				R				
18-52	162.5	163.2	8/14/1982	G'	SM	-	-	-	-	-	-	-	7.8	162.5	162.7	52	31	50/.2			R				
18-53	166.0	166.6	8/14/1982	G'	CL-ML	0.0	8.0	38.0	54.0	-	-	-	15.8	166	166.7	53	52	30/1			R				
18-54	168.0	168.7	8/14/1982	G'	SC	0.0	16.0	38.0	46.0	-	-	-	10.4	168	168.8	54	17				0	0	18480	0.338	0
18-55	172.0	173.0	8/14/1982	G'	SM-SC	0.0	5.0	65.0	30.0	-	-	-	11.2	172	173	55	32	84			84	117	18920	0.334	39
18-56	176.0	177.3	8/14/1982	G'	ML-CL	0.0	9.0	24.0	67.0	-	-	-	18.1	176	177.3	56	17	14	55/4		R				
18-57	178.0	179.7	8/14/1982	G'	-	-	-	-	-	-	-	-	-	178	179.8	57	14	11	18	45/3	29	40	19580	0.329	13
18-58	180.0	181.3	8/14/1982	G'	ML-CL	0.0	18.0	23.0	59.0	-	-	-	13.5	181	181.3	58	80/4				0	0	19910	0.326	0
18-59	185.0	185.4	8/14/1982	G'	-	-	-	-	-	-	-	-	-	185	185.4	59	92/5				0	0	20350	0.322	0
19-8	16.0	17.8	8/16/1982	M	SC	0.0	24.0	42.0	34.0	-	-	-	13.0	16	17.8	8	7	4	12	50/.3	16	22	1760	1.096	24
19-9A	26.0	26.5	8/16/1982	M	SP	0.0	11.0	86.0	3.0	-	-	-	12.0	26	28	9	14	50	42	48	92	128	2860	0.860	110
19-9B	26.5	28.0	8/16/1982	M	SC-SM	0.0	13.0	43.0	44.0	-	-	-	10.9	28	28.8	10	18	50/.3			R				
19-10	28.0	28.8	8/16/1982	M	SC-SM	0.0	16.0	41.0	43.0	-	-	-	9.7	31	32.9	11	30	50	53	65/.4	103	144	3410	0.787	113
19-11	31.0	32.9	8/16/1982	M	SC-SM	0.0	18.0	39.0	43.0	19	15	4	10.2	34	35.8	12	12	18	42	50/.3	60	84	3740	0.752	63
19-12A	34.0	34.3	8/16/1982	M	GP	0.0	55.0	38.0	7.0	-	-	-	8.3	36	38	13	9	9	21	65	30	42	3960	0.731	31
19-12B	34.3	35.8	8/16/1982	M	SM-SC	0.0	14.0	46.0	40.0	-	-	-	8.6	38	38.3	14	50/.3				R				
19-13A	36.0	37.5	8/16/1982	M	SW-SM	0.0	31.0	62.0	7.0	-	-	-	11.6	40	42	15	21	39	35	48	74	103	4400	0.693	72
19-13B	37.5	38.0	8/16/1982	M	SC	0.0	30.0	38.0	32.0	-	-	-	6.1	43	44.3	16	9	45	70/.3		R				
19-15	40.0	42.0	8/16/1982	M	SM-SC	0.0	12.0	45.0	43.0	-	-	-	-	45	45.7	17	54	50.2			R				
19-16	43.0	44.3	8/16/1982	M	SM-SC	0.0	27.0	45.0	28.0	-	-	-	9.7	47	47.8	18	57	75/.3			R				
19-17	45.0	45.7	8/16/1982	M	SM-SC	0.0	34.0	35.0	31.0	-	-	-	8.6	49	49.8	19	75	60/.3			R				
19-18	47.0	47.8	8/16/1982	M	SM-SC	0.0	19.0	46.0	35.0	-	-	-	9.4	59	59.9	20	51	75/.4			R				
19-20	59.0	59.9	8/16/1982	M	SM-SC	0.0	30.0	46.0	24.0	-	-	-	8.0	61	61.4	21	50/.4				R				
19-22	65.0	65.7	8/16/1982	M	-	-	-	-	-	-	-	-	-	65	65.7	22	62	50/.2			R				
19-23	69.0	69.5	8/16/1982	M	SM-SC	0.0	32.0	44.0	24.0	-	-	-	7.4	69	69.5	23	70/.5				R				
20-39	105.0	107.0	9/4/1982	G'	ML	0.0	0.0	0.0	100.0	43	28	15	29.1	105	107	39	9	17	24	46	41	57	11550	0.428	24
20-40	109	110.3	9/4/1982	-	-	-	-	-	-	-	-	-	-	109	110.3	40	28	50	50/3		R				
20-41	111	111.6	9/4/1982	G'	ML	0.0	5.0	18.0	77.0	-	-	-	20.9	111	111.6	41	39	50/1			R				
20-42	113	114.2	9/4/1982	G'	ML	0.0	6.0	40.0	54.0	-	-	-	10.5	113	114.1	42	23	45	50/3		R				
21-42	101.0	101.3	9/2/1982	G'	SM-SC	0.0	27.0	36.0	37.0	-	-	-	-	101	101.3	42	75/.3				R				
21-43	104.0	401.2	9/2/1982	G'	CL	0.0	9.0	35.0	56.0	-	-	-	15.1	104	104.2	43	75/.2				R				

Table A1-1: Basal Till Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Sample ID	Top Depth (feet)	Bottom Depth (feet)	Date	Soil Unit	USCS Classification	Sieve Analysis (%)				Atterberg Limits			W_C (%)	Top Depth (feet)	Bottom Depth (feet)	SPT (blows / 6 inches)					N-Value	Hammer Energy Correction Em	Overburden Pressure	C_N	Corrected N
						Cobble (> 3")	Gravel (ret. on No. 4)	Sand (ret. on No. 200)	Silt/Clay (ret. on Pan)	LL	PL	PI				Test No.	1st	2nd	3rd	4th					
25-3	7.0	9.0	9/14/1982	G'	-	-	-	-	-	-	-	-	-	7	9	3	12	7	6	6	13	18	770	1.657	30
25-4	9.0	11.0	9/14/1982	G'	SC	0.0	22.0	41.0	37.0	-	-	-	14.5	9	11	4	8	4	3	2	7	10	990	1.461	14
25-5	11.0	11.7	9/14/1982	G'	-	-	-	-	-	-	-	-	-	11	11.7	5	7	30/2			R				
25-6	14.0	16.0	9/14/1982	G'	GM	0.0	52.0	37.0	11.0	-	-	-	5.8	14	16	6	52	45	34	43	79	110	1540	1.171	129
25-7	20.0	20.0	9/14/1982	G'	-	-	-	-	-	-	-	-	-	20		7	30/Ref.				R				
25-8	22.0	22.0	9/14/1982	G'	-	-	-	-	-	-	-	-	-	22		8	30/Ref.				R				
25-9	25.5	27.5	9/14/1982	G'	SP-SM	0.0	17.0	77.0	6.0	-	-	-	13.6	25.5	27.5	9	10	10	15	16	25	35	2805	0.868	30
28-9	18.0	20.0	9/21/1982	M	SC-CL	0.0	10.0	42.0	48.0	-	-	-	12.9	18	20	9	18	18	26	28	44	61	1980	1.033	63
28-10	20.0	22.0	9/21/1982	M	CL-CH	0.0	11.0	34.0	55.0	-	-	-	13.0	20	22	10	9	15	20	24	35	49	2200	0.980	48
28-11	22.0	24.0	9/21/1982	M	ML-CL	0.0	8.0	39.0	53.0	-	-	-	17.7	22	24	11	15	13	15	15	28	39	2420	0.934	37
28-12	24.0	26.0	9/21/1982	M	CL	0.0	10.0	25.0	65.0	-	-	-	13.9	24	26	12	9	14	21	30	35	49	2640	0.895	44
28-13	26.0	27.8	9/21/1982	M	CL	0.0	16.0	29.0	55.0	28	17	11	11.3	26	27.8	13	12	20	40	50/4	60	84	2860	0.860	72
28-14	28.0	28.2	9/21/1982	M	-	-	-	-	-	-	-	-	-	28	28.3	14	50/3				R				
28-15	32.0	32.2	9/21/1982	M	-	-	-	-	-	-	-	-	-	32	32.3	15	25/3				R				
28-16	34.0	35.8	9/21/1982	M	-	-	-	-	-	-	-	-	-	34	35.8	16	21	48	63	50/3	111	155	3740	0.752	116
28-17	36.0	38.0	9/21/1982	M	SC-CL	0.0	19.0	35.0	46.0	-	-	-	9.4	36	38	17	27	41	75	80	116	162	3960	0.731	118
28-18	40.0	41.3	9/21/1982	M	-	-	-	-	-	-	-	-	-	40	41.3	18	29	59	50/3		R				
28-19	44.0	44.2	9/21/1982	M	-	-	-	-	-	-	-	-	-												
28-20	45.0	47.0	9/21/1982	M	-	-	-	-	-	-	-	-	-	45	47	20	17	47	60	66	107	149	4950	0.653	98
30-21	74.0	74.3	9/25/1982	G'	-	-	-	-	-	-	-	-	-	74	74.3	21	100/3				R				
30-22	79.0	79.8	9/25/1982	G'	-	-	-	-	-	-	-	-	-	79	79.8	22	35	50/3			R				
30-23	84.0	84.8	9/25/1982	G'	-	-	-	-	-	-	-	-	-	84	84.8	23	40	50/4			R				
30-24	89.0	90.3	9/25/1982	G'	-	-	-	-	-	-	-	-	-	89	90.3	24	16	49	50/4		R				
30-25	99.0	100.0	9/25/1982	G'	-	-	-	-	-	-	-	-	-	99	100	25	21	90			90	126	10890	0.441	55

Notes: Soil Type:

M - Basal Till (Susitna Hydroelectric Project - 1982 Supplement to 1980-1981 Geotech Report Volume 1)

G' - Basal Till (Susitna Hydroelectric Project - 1982 Supplement to 1980-1981 Geotech Report Volume 1)

Table A1-2: Lacustrine Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Sample ID	Top Depth	Bottom Depth	Date	Soil Unit	USCS Classification	Sieve Analysis (%)				Atterberg Limits			W_C (%)	Top Depth (feet)	Bottom Depth (feet)	SPT (blows / 6 inches)					N-Value	Hammer Energy Correction Em	Overburden Pressure	C_N	Corrected N
						Cobble (> 3")	Gravel (ret. on No. 4)	Sand (ret. on No. 200)	Silt/Clay (ret. on Pan)	LL	PL	PI				Test No.	1st	2nd	3rd	4th					
15-15	35.5	37.0	8/3/1982	G	SM	-	-	-	-	-	-	-	23.1	35.5	37	15	7	10	11		21	29	3905	0.736	22
15-16	37.0	39.0	8/3/1982	G	SM	-	-	-	-	-	-	-	36.7	37	39	16	6	4	4	6	8	11	4070	0.721	8
15-17	39.0	41.0	8/3/1982	G	SM	-	-	-	-	-	-	-	38.5	39	41	17	4	4	5	8	9	13	4290	0.702	9
15-18	41.0	43.0	8/3/1982	G	SM	-	-	-	-	-	-	-	30.6	41	43	18	3	5	8	9	13	18	4510	0.685	12
15-19	43.0	45.0	8/3/1982	G	SM	-	-	-	-	-	-	-	39.7	43	45	19	3	5	6	8	11	15	4730	0.668	10
15-20	45.0	47.0	8/3/1982	G	SM	-	-	-	-	-	-	-	31.2	45	47	20	4	6	9	11	15	21	4950	0.653	14
15-21	47.0	49.0	8/3/1982	G	-	-	-	-	-	-	-	-	35.3	47	49	21	3	6	6	8	12	17	5170	0.639	11
15-22	49.0	51.0	8/3/1982	G	-	-	-	-	-	-	-	-	37.5	49	51	22	3	4	6	7	10	14	5390	0.626	9
15-23	51.0	53.0	8/3/1982	G	-	-	-	-	-	-	-	-	35.5	51	53	23	3	7	6	13	13	18	5610	0.614	11
15-24	53.0	55.0	8/3/1982	G	-	-	-	-	-	-	-	-	35.4	53	55	24	4	5	6	9	11	15	5830	0.602	9
15-25	55.0	57.0	8/3/1982	G	CH-MH	-	-	-	-	55	28	27	33.5	55	57	25	7	8	8	10	16	22	6050	0.591	13
15-26	57.0	59.0	8/3/1982	G	-	-	-	-	-	-	-	-	33.2	57	59	26	6	7	8	11	15	21	6270	0.581	12
15-27	59.0	61.0	8/3/1982	G	-	-	-	-	-	-	-	-	31.7	59	61	27	3	7	11	21	18	25	6490	0.571	14
15-28	61.0	63.0	8/3/1982	G	-	-	-	-	-	-	-	-	31.9	61	63	28	5	8	11	18	19	27	6710	0.561	15
15-29	63.0	65.0	8/3/1982	G	CH-MH	-	-	-	-	42	24	18	25.7	63	65	29	6	9	16	19	25	35	6930	0.552	19
15-30	65.0	67.0	8/3/1982	G	-	-	-	-	-	-	-	-	26.0	65	67	30	8	12	12	24	24	33	7150	0.544	18
15-31b	67.0	68.5	8/3/1982	G	-	-	-	-	-	-	-	-	20.0	67	69	31	8	12	16	24	28	39	7370	0.535	21
15-32	69.0	70.4	8/3/1982	G	-	-	-	-	-	-	-	-	22.9	69	70.4	32	7	15	50/.4		R				
16B-31B	58.9	59.3	8/15/1982	D'	SM-ML	0.0	1.0	50.0	49.0	-	-	-	20.9	58	59.8	31	16	32	41	50/4	73	102	6380	0.576	59
16B-32	60.5	61.3	8/15/1982	D'	ML	-	-	-	-	-	NP	-	-	60	61.3	32	38	37	60/4		R				
16B-33	62.4	62.8	8/15/1982	D'	ML	0.0	0.3	31.7	68.0	-	-	-	19.7	61.5	62.8	33	18	50	55/3		R				
16B-34	64.3	64.9	8/15/1982	D'	ML	0.0	4.0	22.0	74.0	-	-	-	17.9	63	65	34	41	63	72	61	135	188	6930	0.552	104
16B-35	65.3	66.9	8/15/1982	D'	ML	0.0	1.0	18.0	81.0	47	31	16	28.2	65	67	35	9	16	22	21	38	53	7150	0.544	29
16B-57	112.0	112.7	8/15/1982	G	SC	0.0	20.0	38.0	42.0	-	-	-	10.0	112	112.6	57	33	50/1			R				
16B-58	116.0	118.0	8/15/1982	G	MH-CH	0.0	0.0	2.0	98.0	52	29	33	29.3	116	118	58	11	14	18	26	32	45	12760	0.407	18
16B-59	118.0	120.0	8/15/1982	G	-	-	-	-	-	-	-	-	28.2	118	120	59	10	13	20	25	33	46	12980	0.403	19
16B-60	120.0	121.7	8/15/1982	G	-	-	-	-	-	-	-	-	28.9	120	121.6	60	N/A								
16B-61	124.0	126.0	8/15/1982	G	CL-CH	0.0	2.0	1.0	97.0	-	-	-	28.6	124	126	61	10	15	19	32	34	47	13640	0.394	19
16B-62	128.0	130.0	8/15/1982	G	-	-	-	-	-	-	-	-	-	128	130	62	10	15	25	38	40	56	14080	0.387	22
16B-63	132.0	133.5	8/15/1982	G	CH	0.0	0.0	0.0	100.0	52	28	24	34.1	132	133	63	10	13	23		36	50	14520	0.381	19
16B-64	136.0	137.5	8/15/1982	G	-	-	-	-	-	-	-	-	33.4	136	137.5	64	9	13	23		36	50	14960	0.376	19
16B-65	140.0	141.5	8/15/1982	G	CL-CH	0.0	0.0	0.0	100.0	-	-	-	30.6	140	141.5	65	10	16	19		35	49	15400	0.370	18
16B-66	144.0	145.5	8/15/1982	G	ML	-	-	-	-	31	25	6	28.1	144	145.5	66	10	14	22		36	50	15840	0.365	18
17-29	77.0	77.8	8/15/1982	G	CL	0.0	9.0	15.0	76.0	-	-	-	21.3	77	77.8	29	14	50/.3			R				
17-30a	80.0	81.0	8/15/1982	G	SC	0.0	16.0	43.0	41.0	-	-	-	13.7	80	81.7	30	25	35	45	50/.2	80	112	8800	0.490	55
17-30b	81.0	82.0	8/15/1982	G	SC	0.0	27.0	35.0	38.0	-	-	-	9.1												
17-31	85.0	86.9	8/15/1982	G	SC-CL	0.0	9.0	44.0	47.0	-	-	-	12.2	85	86.9	31	11	17	32	50/.4	49	68	9350	0.475	32
17-32	87.0	89.0	8/15/1982	G	-	-	-	-	-	-	-	-	-	87	89	32	30	32	29	34	61	85	9570	0.470	40
17-33	89.0	90.6	8/15/1982	G	-	-	-	-	-	-	-	-	-	89	90.6	33	17	25	49	50/.1	74	103	9790	0.465	48
17-53	185.0	186.8	8/15/1982	J'	CH	-	-	-	-	51	25	26	23.6	185	186.8	53	12	24	43	50/.3	67	93	20350	0.322	30
17-54	191.0	191.7	8/15/1982	J'	-	-	-	-	-	-	-	-	-												
18-9	25.0	27.0	8/3/1982	D'	CL-CH	0.0	8.0	27.0	65.0	-	-	-	15.5	25	27	9	10	19	23	27	42	59	2750	0.877	51
18-11	29.0	31.0	8/3/1982	D'	-	-	-	-	-	-	-	-	-	27	27.2	10	50/2				R		2970	0.844	
18-12	31.0	33.0	8/3/1982	D'	-	-	-	-	-	-	-	-	-	29	31	11	12	30	29	28	59	82	3190	0.814	67
18-13	33.0	35.0	8/3/1982	D'	GC-SC	0.0	49.0	25.0	26.0	-	-	-	9.8	31	33	12	11	39	15	22	54	75	3410	0.787	59
18-14	35.0	36.5	8/3/1982	D'	-	-	-	-	-	-	-	-	-	35	36.5	14	17	32	50/6		R				
18-15	37.0	38.4	8/3/1982	D'	CL-SC	0.0	17.0	33.0	50.0	-	-	-	11.5	37	38.4	15	16	37	50/5		R				
18-16	39.0	40.4	8/3/1982	D'	-	-	-	-	-	-	-	-	-	39	40.4	16	12	38	50/5		R				
18-17	41.0	43.0	8/3/1982	D'	CL	-	-	-	-	30	17	13	14.6	41	43	17	16	30	46	46	76	106	4510	0.685	73
18-18	43.0	45.0	8/3/1982	D'	CL	0.0	1.0	12.0	87.0	-	-	-	22.2	43	45	18	14	29	29	27	58	81	4730	0.668	54
18-26A	98.0	100.0	8/3/1982	G	CL-ML	0.0	2.0	39.0	59.0	-	-	-	18.0	98	100	26	25	46	34	51	80	112	10780	0.443	49
18-26B	98.0	100.0	8/14/1982	G	ML-CL	-	-	-	-	44	26	18	26.0												
18-27	100.0	100.9	8/14/1982	G	-	-	-	-	-	-	-	-	-	100	100.9	27	22	75/5			R				
18-28	102.0	103.0	8/14/1982	G	-	-	-	-	-	-	-	-	-	102	103	28	32	76			R				
18-29	104.0	104.5	8/14/1982	G	-	-	-	-	-	-	-	-	-	104	104.5	29	76/6				R				
18-30A	106.0	107.8	8/14/1982	G	ML-MH	0.0	1.0	2.0	97.0	-	-	-	22.7	106	197.8	30	13	13	31	60/4	44	61	11660	0.426	26

Table A1-2: Lacustrine Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Sample ID	Top Depth	Bottom Depth	Date	Soil Unit	USCS Classification	Sieve Analysis (%)				Atterberg Limits			W_C (%)	Top Depth (feet)	Bottom Depth (feet)	SPT (blows / 6 inches)					N-Value	Hammer Energy Correction Em	Overburden Pressure	C_N	Corrected N
						Cobble (> 3")	Gravel (ret. on No. 4)	Sand (ret. on No. 200)	Silt/Clay (ret. on Pan)	LL	PL	PI				Test No.	1st	2nd	3rd	4th					
18-30B	106.0	107.8	8/14/1982	G	ML-CL	-	-	-	-	27	20	7	14.7								0				
18-31	108.0	108.7	8/14/1982	G	-	-	-	-	-	-	-	-	-	108	108.7	31	45	50/2			R				
														110	111.2	32	17	63	50/2		R				
18-33A	112.0	113.7	8/14/1982	G	ML-MH	0.0	0.0	24.0	76.0	-	-	-	23.9	112	113.8	33	8	31	57	50/3	88	123	12320	0.414	51
18-33B	112.0	113.7	8/14/1982	G	SM	0.0	3.0	69.0	28.0	-	-	-	13.1												
18-34	114.0	116.0	8/14/1982	G	SP-SM	0.0	3.0	77.0	20.0	-	-	-	18.1	114	116	34	7	18	25	33	43	60	12540	0.411	25
18-35	116.0	118.0	8/14/1982	G	SM	0.0	3.0	55.0	42.0	-	-	-	17.5	116	118	35	12	50	54	80	104	145	12760	0.407	59
18-36	118.0	120.0	8/14/1982	G	SM	0.0	8.0	70.0	22.0	-	-	-	15.9	118	120	36	14	26	47	17	73	102	12980	0.403	41
														123	123.4	37	63/5				R				
18-38	125.0	125.4	8/14/1982	G	SM	0.0	41.0	38.0	21.0	-	-	-	6.0	125	125.4	38	75/5				R				
19-Run1a	164	169	8/16/1982	G	-	-	-	-	-	-	-	-	-												
19-Run1b	164	169	8/16/1982	G	CL-ML	0.0	3.0	14.0	83.0	-	-	-	28.5												
19-46	169.0	169.4	8/16/1982	G	CL-ML	0.0	2.0	3.0	95.0	-	-	-	-	169	169.4	46	80/.4				R				
19-47	171	172.5	8/16/1982	G	CL-ML	-	-	-	-	33	23	10	25.5	171	172.5	47	30	39	69/.5		R				
19-48	175	176.2	8/16/1982	G	ML-MH	0.0	2.0	24.0	74.0	-	-	-	18.6	175	176.2	48	39	55	50/.2		R				
19-49	177	178.5	8/16/1982	G	CL-ML	-	-	-	-	37	23	14	28.5	177	178.5	49	18	27	70/.5		R				
19-50	181	182.6	8/16/1982	G	CL	0.0	0.0	2.0	98.0	-	-	-	29.3	181	182.6	50	15	19	29	50/.1	48	67	19910	0.326	22
19-52	187	188.4	8/16/1982	G	ML	-	-	-	-	34	27	7	27.4	185	186.5	51	15	21	34		55	77	20350	0.322	25
														187	188.4	52	16	26	60/.4		R				
														191	191.4	53	59	50/.2			R				
19-54	193	193.8	8/16/1982	G	ML	0.0	0.0	1.0	99.0	-	-	-	27.6	193	193.8	54	23	50/.3			R				
20-25	64.0	65.1	9/4/1982	G	SM	0.0	16.0	63.0	21.0	-	-	-	13.0	64	65	25	25	63	50/2		R				
20-26	66.0	66.1	9/4/1982	-	-	-	-	-	-	-	-	-	-	66	66.2	26	50/2				R				
20-27	69.0	69.7	9/4/1982	G	CL-CH	0.0	9.0	35.0	56.0	-	-	-	13.0	69	69.8	27	46	50/3			R				
20-28	71.0	71.7	9/4/1982	G	CL-ML	0.0	6.0	38.0	56.0	-	-	-	15.5	71	71.8	28	21	50/3			R				
20-29	73.0	73.8	9/4/1982	-	-	-	-	-	-	-	-	-	-	73	73.8	29	40	50/4			R				
20-30	75.0	75.6	9/4/1982	G	-	-	-	-	-	-	-	-	-	75	75.7	30	32	50/4			R				
20-31	79.0	80.3	9/4/1982	G	SM	0.0	27.0	37.0	36.0	-	-	-	13.4	79	80.3	31	33	41	50/4		R				
20-32a	81.0	81.4	9/4/1982	G	GM-GC	0.0	54.0	22.0	24.0	-	-	-	8.2	81	83	32	17	18	27	37	45	63	8910	0.487	31
20-32b	81.4	83.0	9/4/1982	G	CL	0.0	9.0	20.0	71.0	-	-	-	18.1												
20-33	83.0	84.7	9/4/1982	G	CL-CH	0.0	18.0	15.0	67.0	-	-	-	16.1	83	84.8	33	13	26	41	50/3	67	93	9130	0.481	45
20-34	87.0	89.0	9/4/1982	G	CL-CH	0.0	5.0	36.0	59.0	-	-	-	15.8	87	89	34	34	21	34	64	55	77	9570	0.470	36
20-35	89.0	90.4	9/4/1982	G	ML	0.0	3.0	12.0	85.0	-	-	-	24.0	89	90.4	35	19	30	50/5		R				
20-36	93.0	95.0	9/4/1982	G	ML	0.0	0.0	0.0	100.0	-	-	-	30.2	93	95	36	19	18	23	44	41	57	10230	0.455	26
20-37	97.0	98.7	9/4/1982	G	ML	0.0	0.0	0.0	100.0	49	29	20	28.3	97	98.8	37	14	17	32	50/3	49	68	10670	0.445	30
20-38	101.0	103.0	9/4/1982	G	ML	0.0	0.0	2.0	98.0	47	29	18	29.1	101	102	38	9	6	23	27	29	40	11110	0.436	18
21-29	62.0	64.0	9/2/1982	G	ML-CL	-	-	-	-	37	25	12	21.8	62	64	29	17	25	31	58	56	78	6820	0.557	43
21-30	64.0	65.7	9/2/1982	G	ML-CL	0.0	0.0	3.0	97.0	-	-	-	25.1	64	65.7	30	14	20	41	50/.2	61	85	7040	0.548	47
21-31	66.0	68.0	9/2/1982	G	CL-ML	0.0	0.0	6.0	94.0	-	-	-	28.0	66	68	31	10	16	18	24	34	47	7260	0.540	26
21-32	68.0	70.0	9/2/1982	G	ML	0.0	0.0	1.0	99.0	-	-	-	26.0	68	70	32	16	25	47	51	72	100	7480	0.532	53
21-33	74.0	75.5	9/2/1982	G	CL	0.0	1.0	3.0	96.0	-	-	-	24.4	74	75.5	33	15	26	43		69	96	8140	0.510	49
21-34	78.0	79.5	9/2/1982	G	CL	0.0	0.0	26.0	74.0	-	-	-	16.8	78	79.5	34	19	33	53		86	120	8580	0.496	60
21-35	80.0	81.2	9/2/1982	G	CL	0.0	0.0	42.0	58.0	-	-	-	17.4	80	81.2	35	20	33	50/.2		R				
21-36	83.0	84.0	9/2/1982	-	-	-	-	-	-	-	-	-	-	83	84	36	43	71/.5			R				
21-37	85.0	85.4	9/2/1982	G	-	-	-	-	-	-	-	-	-	85	85.9	37	52	100/.4			R				
21-38A	87.0	87.7	9/2/1982	G	SM-SC	0.0	10.0	47.0	43.0	-	-	-	17.4	87	88.1	38	28	45	50/.1		R				
21-38B	87.7	88.1	9/2/1982	G	CH-MH	0.0	5.0	13.0	82.0	-	-	-	17.2												
21-39	89.0	91.0	9/2/1982	G	MH	-	-	-	-	51	30	21	30.0	89	91	39	10	19	21	23	40	56	9790	0.465	26
21-40	93.0	94.6	9/2/1982	G	MH	0.0	6.0	2.0	92.0	-	-	-	24.5	93	95	40	15	23	42	30/.1	65	91	10230	0.455	41
21-41A	98.0	99.0	9/2/1982	G	ML	0.0	0.0	2.0	98.0	38	28	10	28.8												
21-41B	99.0	99.3	9/2/1982	G	ML	0.0	0.0	6.0	94.0	33	28	5	19.4	98	99.3	41	11	16	50/.3		R				
23-32	92.5	93.7	9/7/1982	G	SM-ML	0.0	18.0	38.0	44.0	-	-	-	13.2	92.5	93.8	32	22	52	50/3		R				
23-33	95.0	96.3	9/7/1982	G	SM	0.0	26.0	64.0	10.0	-	-	-	12.5	95	96.3	33	37	66	50/4		R				
23-34	98.0	99.4	9/7/1982	G	SM	0.0	26.0	62.0	12.0	-	-	-	11.1	98	99.4	34	48	62	50/5		R				
23-35	100.0	102.0	9/7/1982	G	SM	0.0	15.0	72.0	13.0	-	-	-	11.7	100	102	35	15	31	47	63	78	109	11000	0.438	48
23-36	103.0	104.3	9/7/1982	G	SM	0.0	23.0	60.0	17.0	-	-	-	14.6	103	104.3	36	26	61	50/4		R				

Table A1-2: Lacustrine Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Sample ID	Top Depth	Bottom Depth	Date	Soil Unit	USCS Classification	Sieve Analysis (%)				Atterberg Limits			W_C (%)	Top Depth (feet)	Bottom Depth (feet)	SPT (blows / 6 inches)					N-Value	Hammer Energy Correction Em	Overburden Pressure	C_N	Corrected N
						Cobble (> 3")	Gravel (ret. on No. 4)	Sand (ret. on No. 200)	Silt/Clay (ret. on Pan)	LL	PL	PI				Test No.	1st	2nd	3rd	4th					
23-37A	107.0	108.8	9/7/1982	G	-	-	-	-	-	-	-	-	-	107	108.8	37	14	34	63	50/4	97	135	11770	0.424	57
23-37B	107.0	108.8	9/7/1982	G	SM	0.0	1.0	83.0	16.0	-	-	-	23.6												
23-38	109.0	109.8	9/7/1982	G	SM	0.0	2.0	73.0	25.0	-	-	-	21.8	109	109.8	38	38	50/4			R				
23-39	111.0	112.3	9/7/1982	G	SM	0.0	0.1	70.9	29.0	-	-	-	22.3	111	112.3	39	36	55	50/4		R				
23-40	113.0	114.3	9/7/1982	G	SP-SM	0.0	0.0	87.0	13.0	-	-	-	24.4	113	114.3	40	27	46	50/4		R				
23-41	118.0	119.3	9/7/1982	G	SM	0.0	1.0	73.0	26.0	-	-	-	24.9	118	119.3	41	29	50	50/3		R				
23-42	122.0	123.3	9/7/1982	G	SM	0.0	0.0	75.0	25.0	-	-	-	22.4	122	123.3	42	22	53	50/3		R				
23-43	126.0	127.2	9/7/1982	G	ML	0.0	1.0	12.0	87.0	-	-	-	22.4	126	127.2	43	24	51	50/2		R				
23-44	128.0	129.2	9/7/1982	G	ML	0.0	3.0	17.0	80.0	-	-	-	21.4	128	129.2	44	23	56	50/2		R				
23-45	130.0	131.3	9/7/1982	G	ML	0.0	0.3	7.7	92.0	-	-	-	22.9	130	131.3	45	21	40	50/3		R				
23-46	132.0	133.3	9/7/1982	G	ML	0.0	1.0	40.0	59.0	-	-	-	21.3	132	133.3	46	21	51	50/3		R				
23-47	136.0	137.0	9/7/1982	G	ML	0.0	5.0	19.0	76.0	-	-	-	20.0	136	137	47	24	96			96	134	14960	0.376	50
23-48	140.0	141.0	9/7/1982	G	ML	0.0	5.0	19.0	76.0	-	-	-	19.4	140	141	48	24	93			93	130	15400	0.370	48
23-49	144.0	145.2	9/7/1982	G	ML-CL	0.0	1.0	24.0	75.0	-	-	-	22.2	144	145.2	49	16	42	50/2		R				
23-50	146.0	147.2	9/7/1982	G	ML	0.0	1.0	12.0	87.0	-	-	-	24.1	146	147.2	50	16	31	50/2		R				
23-51	148.0	149.2	9/7/1982	G	ML	0.0	1.0	4.0	95.0	23	24	-1	25.5	148	149.2	51	22	38	50/2		R				
23-52	152.0	153.0	9/7/1982	G	ML	0.0	0.0	9.0	91.0	-	-	-	21.0	152	153	52	10	94			94	131	16720	0.356	47
23-53	156.0	156.7	9/7/1982	G	ML	0.0	0.0	30.0	70.0	-	-	-	23.1	156	156.7	53	44	50/2			R				
26-17	78.0	79.5	9/15/1982	G	ML-CL	0.0	1.0	7.0	92.0	42	29	13	25.8	78	79.5	17	12	21	62		83	116	8580	0.496	57
27-13	60.0	61.2	9/30/1982	D'	SM-SC	0.0	11.0	53.0	36.0	-	-	-	9.5	60	61.2	13	52	59	50/.2		R				
27-31	160.0	162.0	9/30/1982	G	-	-	-	-	-	-	-	-	29.8	160	162	31	53	58	64	73	122	170	17600	0.347	59
27-32	164.0	166.0	9/30/1982	G	ML-CL	0.0	0.0	8.0	92.0	-	-	-	31.5	164	166	32	22	42	39	68	81	113	18040	0.342	39
27-33	170.0	172.0	9/30/1982	G	ML-CL	-	-	-	-	31	23	8	30.4	170	172	33	19	24	32	36	56	78	18700	0.336	26
27-34	175.0	177.0	9/30/1982	G	ML-CL	0.0	0.0	2.5	97.5	-	-	-	29.7	175	177	34	20	31	29	40	60	84	19250	0.331	28
29-34	149.5	150.7	9/24/1982	G	-	-	-	-	-	-	-	-	-	149.5	151.2	34	8	28	60	50/.2	88	123	16445	0.358	44
29-35	158.0	158.0	9/24/1982	G	-	-	-	-	-	-	-	-	-												

Notes: Soil Type:

D - Glaciolacustrine (Susitna Hydroelectric Project - 1982 Supplement to 1980-1981 Geotech Report Volume 1)
G - Glaciolacustrine (Susitna Hydroelectric Project - 1982 Supplement to 1980-1981 Geotech Report Volume 1)
J` - Glaciolacustrine (Susitna Hydroelectric Project - 1982 Supplement to 1980-1981 Geotech Report Volume 1)

Table A1-3: Summary of Non-Refusal SPT Values for Lacustrine Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Boring	*Depth, z*	*Uncorrected N*	*Energy Correction*	*Overburden Pressure*	C_N	*Corrected N*	ϕ [1]
	(feet)	*Blows per foot*	*Em*	σ_z'		*Blows per foot*	º
AH-D-15	35.5	21	29	3905	0.736	22	33
	37	8	11	4070	0.721	8	29
	39	9	13	4290	0.702	9	30
	41	13	18	4510	0.685	12	31
	43	11	15	4730	0.668	10	30
	45	15	21	4950	0.653	14	31
	47	12	17	5170	0.639	11	30
	49	10	14	5390	0.626	9	30
	51	13	18	5610	0.614	11	30
	53	11	15	5830	0.602	9	30
	55	16	22	6050	0.591	13	31
	57	15	21	6270	0.581	12	31
	59	18	25	6490	0.571	14	31
	61	19	27	6710	0.561	15	32
	63	25	35	6930	0.552	19	32
	65	24	33	7150	0.544	18	32
	67	28	39	7370	0.535	21	32
AH-D-16	58	73	102	6380	0.576	59	43
	63	135	188	6930	0.552	104	43
	65	38	53	7150	0.544	29	36
	116	32	45	12760	0.407	18	32
	118	33	46	12980	0.403	19	32
	124	34	47	13640	0.394	19	32
	128	40	56	14080	0.387	22	33
	132	36	50	14520	0.381	19	32
	136	36	50	14960	0.376	19	32
	140	35	49	15400	0.370	18	32
	144	36	50	15840	0.365	18	32
AH-D-17	80	80	112	8800	0.490	55	42
	85	49	68	9350	0.475	32	36
	87	61	85	9570	0.470	40	39
	89	74	103	9790	0.465	48	40
	185	67	93	20350	0.322	30	36
AH-D-18	25	42	59	2750	0.877	51	41
	29	59	82	3190	0.814	67	43
	31	54	75	3410	0.787	59	43
	41	76	106	4510	0.685	73	43
	43	58	81	4730	0.668	54	42
	98	80	112	10780	0.443	49	41
	106	44	61	11660	0.426	26	35
	112	88	123	12320	0.414	51	41
	114	43	60	12540	0.411	25	35
	116	104	145	12760	0.407	59	43
	118	73	102	12980	0.403	41	39
AH-D-19	181	48	67	19910	0.326	22	33
	185	55	77	20350	0.322	25	35
AH-D-20	81	45	63	8910	0.487	31	36
	83	67	93	9130	0.481	45	40
	87	55	77	9570	0.470	36	37
	93	41	57	10230	0.455	26	35

Table A1-3: Summary of Non-Refusal SPT Values for Lacustrine Units Encountered in 1982 Borings Drilled in Relict Channel and Borrow D Areas, Susitna-Watana, Alaska

Boring	*Depth, z*	*Uncorrected N*	*Energy Correction*	*Overburden Pressure*	C_N	*Corrected N*	ϕ[1]
	(feet)	*Blows per foot*	*Em*	σ_z'		*Blows per foot*	*º*
	97	49	68	10670	0.445	30	36
	101	29	40	11110	0.436	18	32
AH-D-21	62	56	78	6820	0.557	43	39
	64	61	85	7040	0.548	47	40
	66	34	47	7260	0.540	26	35
	68	72	100	7480	0.532	53	41
	74	69	96	8140	0.510	49	40
	78	86	120	8580	0.496	60	43
	89	40	56	9790	0.465	26	35
	93	65	91	10230	0.455	41	39
AH-D-23	100	78	109	11000	0.438	48	40
	107	97	135	11770	0.424	57	42
	136	96	134	14960	0.376	50	41
	140	93	130	15400	0.370	48	40
	152	94	131	16720	0.356	47	40
AH-D-26	78	83	116	8580	0.496	57	42
AH-D-27	160	122	170	17600	0.347	59	43
	164	81	113	18040	0.342	39	38
	170	56	78	18700	0.336	26	35
	175	60	84	19250	0.331	28	36
AH-D-29	149.5	88	123	16445	0.358	44	40

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Attachment 2

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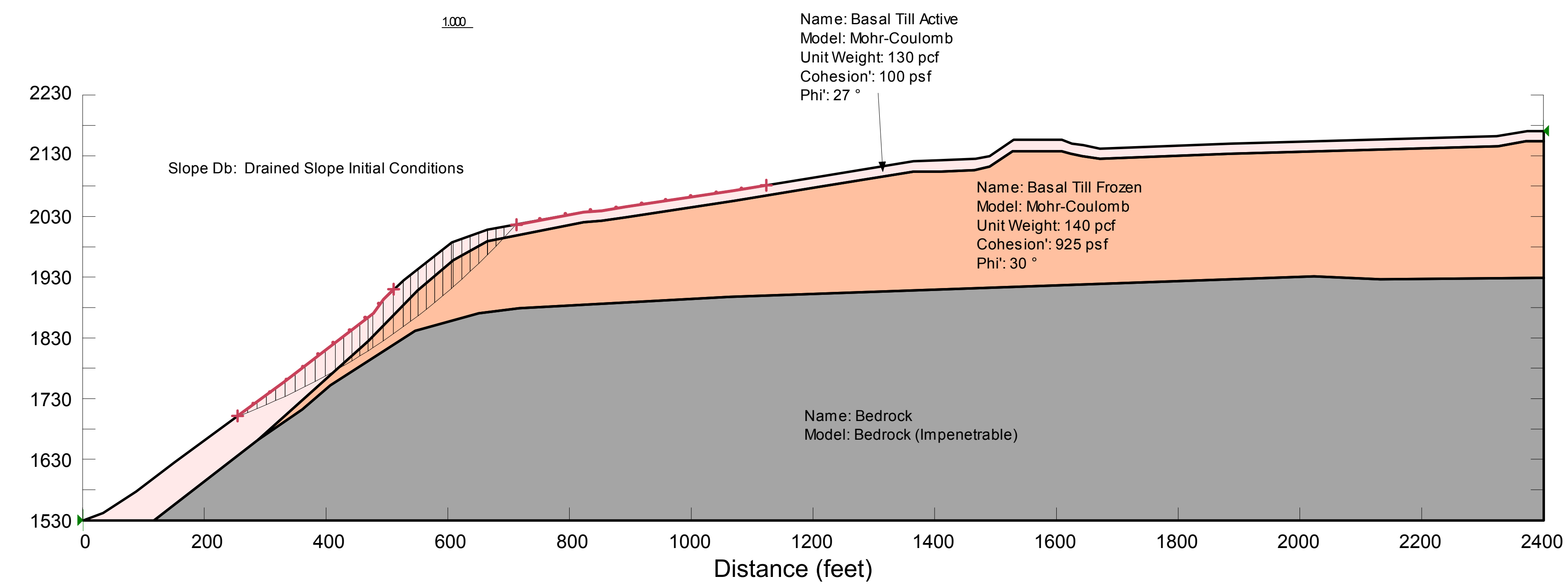
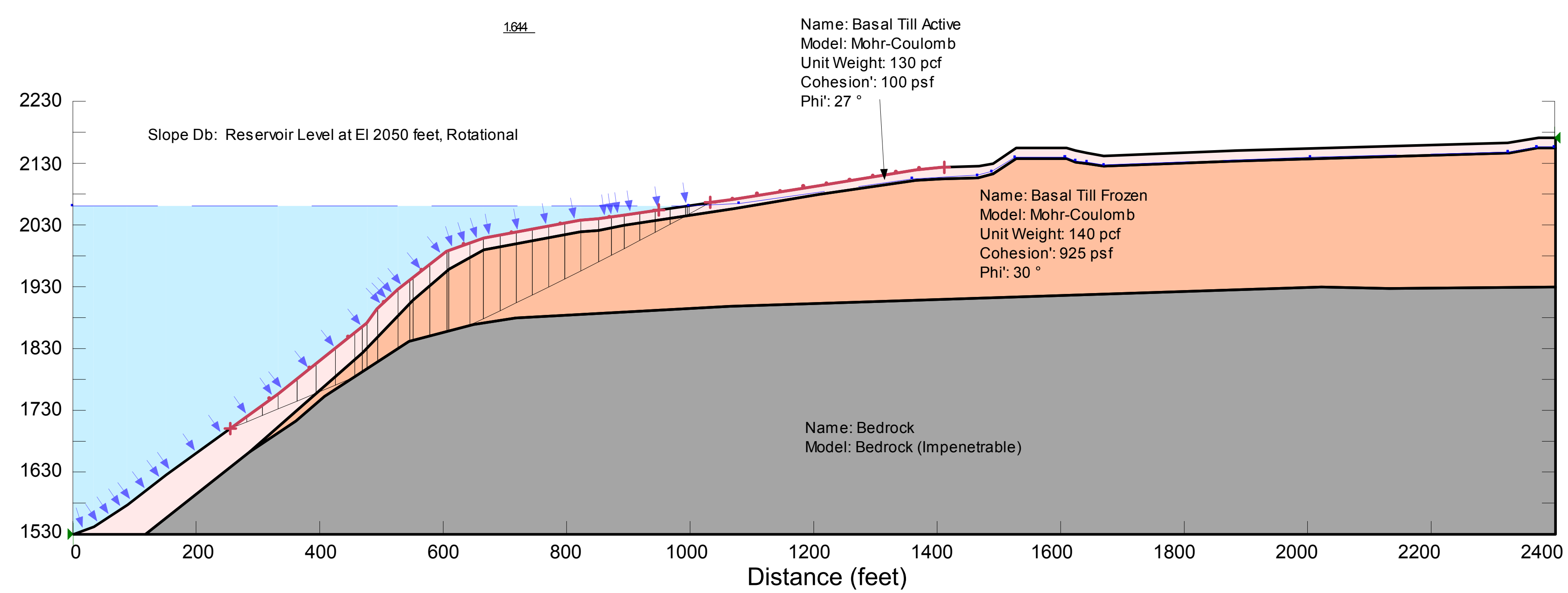


Slope D, Case 1 – Initial drained slope



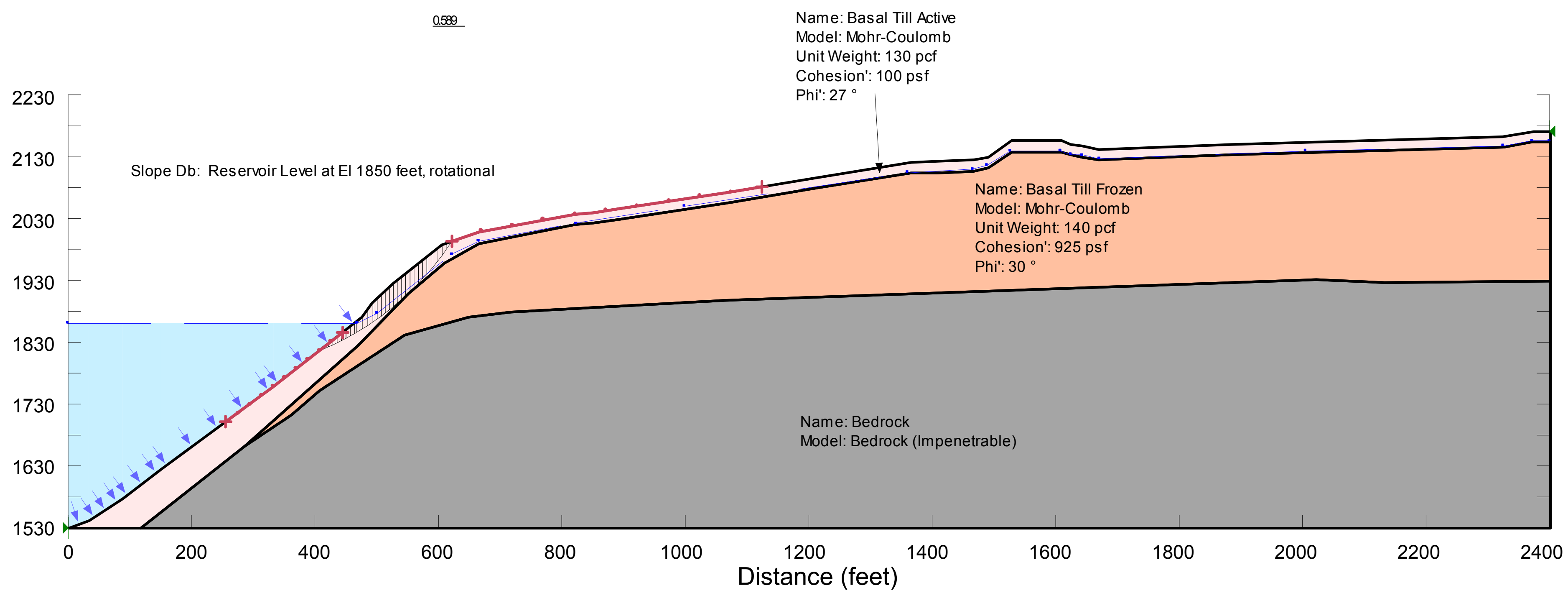
Slope D, Case 2 – Reservoir Normal Mean Operating Level, elevation 2050 feet.

ALASKA ENERGY AUTHORITY

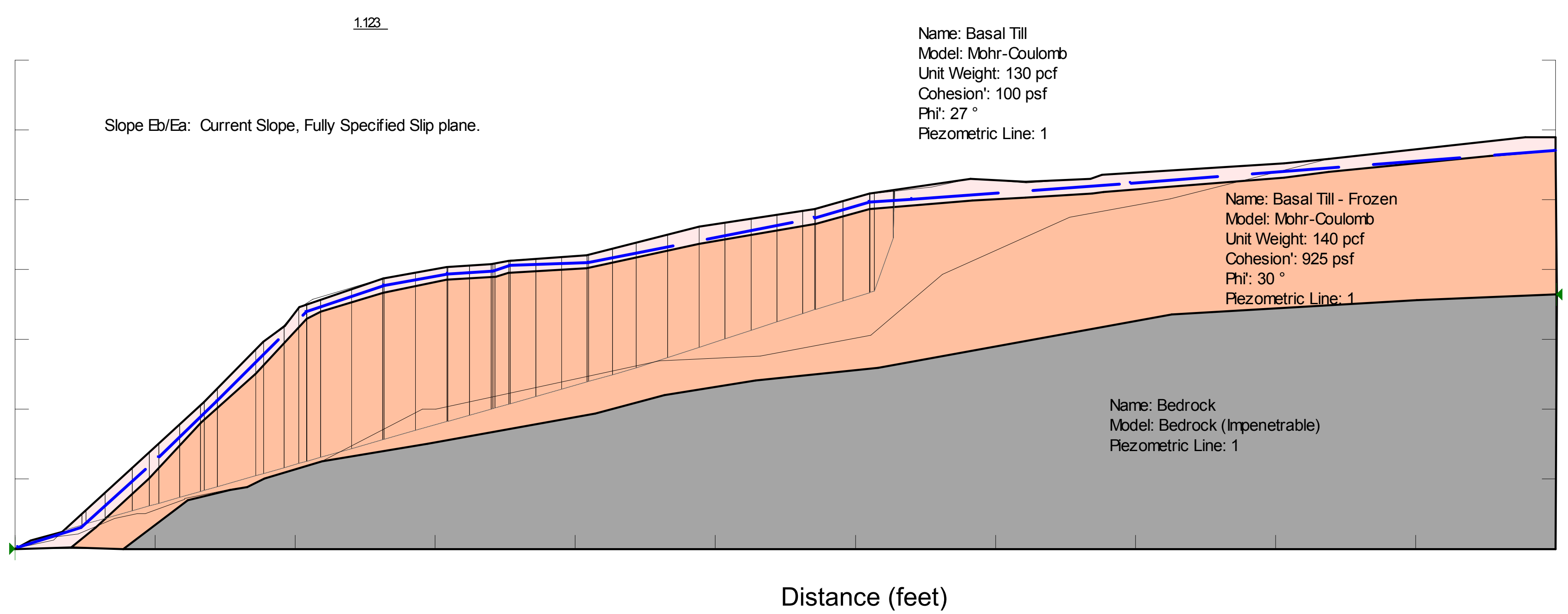
Preliminary Reservoir Slope Stability Assessment

Attachment 2 - SLOPE/W Models and Results

Figure A2-1



Slope D, Case 3 – Reservoir Minimum Operating Level, elevation 1850 feet.



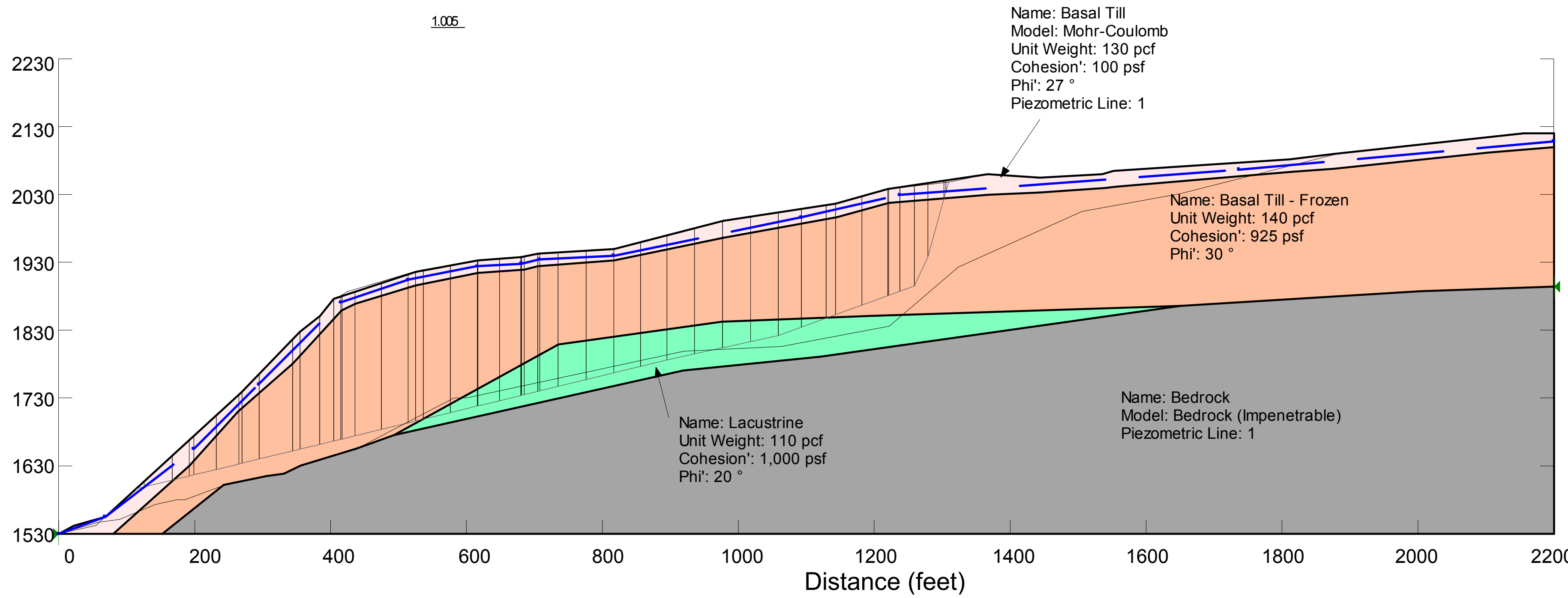
Slope E, Case 1 – Initial slope, fully specified slip plane

ALASKA ENERGY AUTHORITY

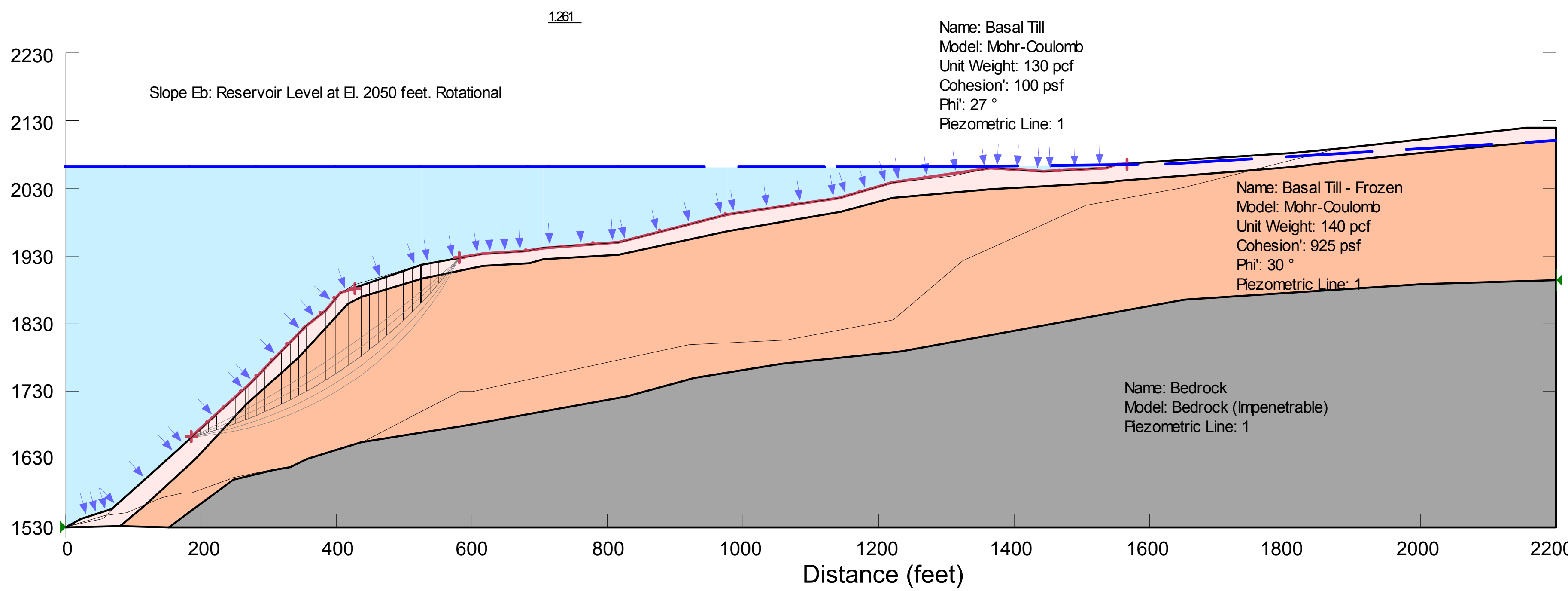
Preliminary Reservoir Slope Stability Assessment

Attachment 2 - SLOPE/W Models and Results

Figure A2-2



Slope E, Case 1a – Initial slope, with lacustrine above bedrock, fully specified slip plane



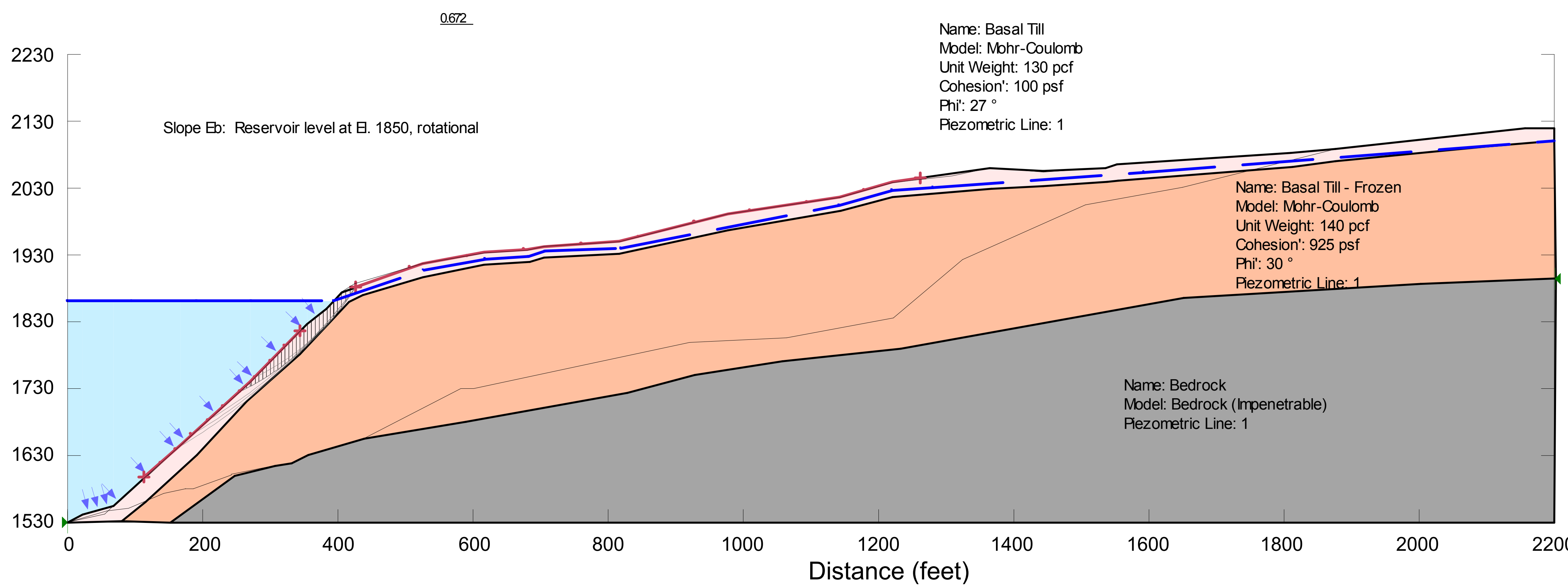
Slope E, Case 2 – Reservoir Normal Mean Operating Level, elevation 2050 feet.

ALASKA ENERGY AUTHORITY

Preliminary Reservoir Slope Stability Assessment

Attachment 2 - SLOPE/W Models and Results

Figure A2-3



Slope E, Case 3 – Reservoir Minimum Operating Level, elevation 1850 feet.

ALASKA ENERGY AUTHORITY

Attachment 3

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Table A3-1: Summary List of Active Slope Movement Along Area of Proposed Watana Reservoir

Map ID	Primary Failure Mode	Secondary Failure Mode	Centroid X Coordinate	Centroid Y Coordinate
A	Bimodal Flow/Earthflow/Debris Flow		1,885,337.845390	3,225,601.428740
B	Solifluction		1,886,493.842430	3,225,688.116510
C	Bimodal Flow/Earthflow/Debris Flow		1,893,301.629640	3,231,326.840570
D	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,903,013.423900	3,229,646.949230
E	Rotational Slide		1,910,691.582780	3,230,658.145970
F	Bimodal Flow/Earthflow/Debris Flow		1,947,350.558380	3,226,821.153880
G	Bimodal Flow/Earthflow/Debris Flow		1,948,787.043110	3,226,714.339130
H	Translational Slide		1,943,716.968190	3,244,922.397770
I	Bimodal Flow/Earthflow/Debris Flow		1,942,757.029480	3,246,061.782470
J	Bimodal Flow/Earthflow/Debris Flow		1,943,506.718020	3,248,056.106130
K	Bimodal Flow/Earthflow/Debris Flow		1,950,185.124290	3,251,229.398770
L	Bimodal Flow/Earthflow/Debris Flow		1,951,560.899050	3,255,115.882790
M	Bimodal Flow/Earthflow/Debris Flow		1,935,860.935450	3,231,471.530790
N	Bimodal Flow/Earthflow/Debris Flow		1,934,514.280780	3,225,381.844760
O	Bimodal Flow/Earthflow/Debris Flow		1,971,772.320100	3,211,146.247980
P	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,978,955.868260	3,217,314.651420
Q	Bimodal Flow/Earthflow/Debris Flow		1,982,935.553980	3,218,201.253390
R	Bimodal Flow/Earthflow/Debris Flow		1,985,336.714490	3,216,782.104790
S	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,994,309.002590	3,216,254.862700
T	Bimodal Flow/Earthflow/Debris Flow		2,015,860.163410	3,207,806.119260
U	Bimodal Flow/Earthflow/Debris Flow		2,023,817.795970	3,207,101.018120
V	Rotational Slide		1,922,282.162510	3,236,973.429780
W	Translational Slide	Rotational Slide	1,922,302.911170	3,238,008.603400
X	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,971,674.381190	3,213,486.041640

Locations shown on Figure 4 of Preliminary Reservoir Slope Stability Assessment

Table A3-2: Summary List of Historic Slope Movement Along Area of Proposed Watana Reservoir

Map ID	Primary Failure Mode	Secondary Failure Mode	Centroid X Coordinate	Centroid Y Coordinate
1	Bimodal Flow/Earthflow/Debris Flow	Solifluction	1,913,860.321860	3,227,510.870760
2	Bimodal Flow/Earthflow/Debris Flow	Solifluction	1,914,986.065690	3,227,849.677310
3	Bimodal Flow/Earthflow/Debris Flow	Solifluction	1,917,697.800420	3,227,984.794550
4	Bimodal Flow/Earthflow/Debris Flow		1,926,313.281640	3,230,080.600590
5	Bimodal Flow/Earthflow/Debris Flow		1,933,825.539500	3,231,938.015890
6	Translational Slide		1,943,313.453900	3,244,134.987790
7	Bimodal Flow/Earthflow/Debris Flow		1,939,239.836600	3,246,463.562190
8	Bimodal Flow/Earthflow/Debris Flow		1,939,261.101510	3,247,774.730170
9	Bimodal Flow/Earthflow/Debris Flow		1,939,795.077190	3,247,088.977740
10	Bimodal Flow/Earthflow/Debris Flow		1,940,459.496120	3,245,474.448210
11	Bimodal Flow/Earthflow/Debris Flow		1,938,261.274170	3,248,532.030440
12	Bimodal Flow/Earthflow/Debris Flow		1,937,112.916660	3,249,389.575780
13	Bimodal Flow/Earthflow/Debris Flow		1,938,519.018120	3,245,502.925370
14	Bimodal Flow/Earthflow/Debris Flow		1,939,703.421500	3,243,685.473280
15	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,939,357.877590	3,242,389.227020
16	Bimodal Flow/Earthflow/Debris Flow		1,942,626.049360	3,246,978.731870
17	Bimodal Flow/Earthflow/Debris Flow		1,944,301.649190	3,249,246.157560
18	Bimodal Flow/Earthflow/Debris Flow		1,945,671.227670	3,249,593.105580
19	Bimodal Flow/Earthflow/Debris Flow		1,946,530.500460	3,250,451.619610
20	Bimodal Flow/Earthflow/Debris Flow		1,949,951.604400	3,253,568.569120
21	Bimodal Flow/Earthflow/Debris Flow		1,945,470.193930	3,248,294.886460
22	Bimodal Flow/Earthflow/Debris Flow		1,941,804.004430	3,244,970.583940
23	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,898,386.415020	3,234,428.185950
24	Bimodal Flow/Earthflow/Debris Flow		1,896,305.301760	3,234,278.233660
25	Bimodal Flow/Earthflow/Debris Flow		1,898,222.101200	3,236,022.683050
26	Bimodal Flow/Earthflow/Debris Flow		1,895,574.435370	3,233,353.314910
27	Bimodal Flow/Earthflow/Debris Flow		1,895,317.545380	3,231,856.054020
28	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,907,469.378290	3,229,500.585470
29	Bimodal Flow/Earthflow/Debris Flow	Solifluction	1,910,638.333300	3,226,256.032260
30	Solifluction	Bimodal Flow/Earthflow/Debris Flow	1,911,426.025200	3,227,847.393190
31	Bimodal Flow/Earthflow/Debris Flow	Solifluction	1,916,364.569560	3,228,128.233610
32	Bimodal Flow/Earthflow/Debris Flow		1,934,029.918980	3,223,563.978980
33	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,933,733.019000	3,222,682.481550
34	Bimodal Flow/Earthflow/Debris Flow		1,934,638.793880	3,224,083.162100
35	Bimodal Flow/Earthflow/Debris Flow		1,934,696.999900	3,225,464.705240
36	Bimodal Flow/Earthflow/Debris Flow		1,938,740.754700	3,223,253.371870
37	Bimodal Flow/Earthflow/Debris Flow		1,945,513.042790	3,226,529.353080
38	Bimodal Flow/Earthflow/Debris Flow		1,937,115.623100	3,230,832.448210

Table A3-2: Summary List of Historic Slope Movement Along Area of Proposed Watana Reservoir

Map ID	Primary Failure Mode	Secondary Failure Mode	Centroid X Coordinate	Centroid Y Coordinate
39	Bimodal Flow/Earthflow/Debris Flow		1,935,053.635930	3,231,414.478220
40	Bimodal Flow/Earthflow/Debris Flow		1,937,872.035170	3,231,859.576580
41	Bimodal Flow/Earthflow/Debris Flow		1,960,333.632400	3,224,385.009800
42	Bimodal Flow/Earthflow/Debris Flow		1,961,742.848890	3,224,315.751320
43	Bimodal Flow/Earthflow/Debris Flow		1,960,513.999210	3,225,570.984080
44	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,912,254.586280	3,230,473.253180
45	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,899,108.407410	3,229,811.017830
46	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,900,037.564940	3,229,482.361290
47	Translational Slide		1,913,670.296450	3,230,790.286460
48	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,918,920.311200	3,233,555.452840
49	Bimodal Flow/Earthflow/Debris Flow		1,921,733.685270	3,242,850.205370
50	Bimodal Flow/Earthflow/Debris Flow		1,920,538.855880	3,239,859.809830
51	Bimodal Flow/Earthflow/Debris Flow		1,920,652.767750	3,237,494.693140
52	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,925,893.713480	3,233,797.462430
53	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,927,314.987970	3,233,934.161940
54	Bimodal Flow/Earthflow/Debris Flow	Translational Slide	1,928,355.910330	3,233,847.731900
55	Bimodal Flow/Earthflow/Debris Flow		1,938,036.577670	3,241,290.898710
56	Bimodal Flow/Earthflow/Debris Flow		1,936,346.896550	3,240,751.498820
57	Bimodal Flow/Earthflow/Debris Flow		1,934,595.889370	3,237,980.363980
58	Translational Slide		1,944,443.629600	3,245,363.600480
59	Bimodal Flow/Earthflow/Debris Flow		1,945,164.820170	3,245,764.795040
60	Translational Slide		1,947,392.355670	3,249,174.203140
61	Bimodal Flow/Earthflow/Debris Flow		1,950,173.983910	3,250,957.119930
62	Bimodal Flow/Earthflow/Debris Flow		1,923,992.062340	3,230,295.045600
63	Translational Slide	Bimodal Flow/Earthflow/Debris Flow	1,971,837.704880	3,213,911.595990
64	Bimodal Flow/Earthflow/Debris Flow		1,976,146.107270	3,213,856.541020
65	Bimodal Flow/Earthflow/Debris Flow	Bimodal Flow/Earthflow/Debris Flow	1,981,510.772110	3,217,723.694230
66	Bimodal Flow/Earthflow/Debris Flow		1,988,164.814480	3,215,951.650330
67	Bimodal Flow/Earthflow/Debris Flow		2,037,273.336720	3,189,271.578000
68	Bimodal Flow/Earthflow/Debris Flow		2,014,561.693350	3,209,623.350620
69	Bimodal Flow/Earthflow/Debris Flow		1,889,889.802290	3,229,906.567430
70	Bimodal Flow/Earthflow/Debris Flow		1,892,136.875240	3,227,201.555310
71	Bimodal Flow/Earthflow/Debris Flow		1,895,483.593550	3,226,830.067820

Locations shown on Figure 4 of Preliminary Reservoir Slope Stability Assessment