Downtown Juneau Landslide and Avalanche Hazard Assessment



PRESENTED TO
City and Borough of Juneau

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EXECUTIVE SUMMARY

Tetra Tech Canada Inc. (Tetra Tech) was retained by the City and Borough of Juneau (CBJ) to complete a hazard assessment for the occurrence of landslides and avalanches in the Downtown Juneau area, including terrain on the slopes of Mt. Juneau and Mt. Roberts. It is understood that this hazard assessment and the associated mapping will be used to update the existing hazard maps that were based on low-resolution maps created in the 1970s and adopted by CBJ in 1987 for Downtown Juneau. Tetra Tech completed the landslide portion of the hazard assessment and retained Dynamic Avalanche Consulting Ltd. (DAC) to complete the snow avalanche portion of the assessment.

A field reconnaissance of landslide and avalanche terrain was completed during September 8 to 15, 2019, which included a helicopter fly-over of the Study Area, walk-over inspections of avalanche/landslide terrain and vegetation, and collection of field data.

The purpose of this report is to provide the key results of the landslide and avalanche hazard assessment, including the surficial geology mapping update, historical air photo record analysis to identify changes in slope features and mass movement activity, identification of landslide and avalanche types, categorization and refinement of hazard designation map polygons, and preparation of geohazard designation mapping in support of the future development of appropriate zoning, building regulations, and mitigation options.

The completed mapping is presented in a series of figures, which are included in the “Figures” section of the report. Also included is a series of technical memos prepared to respond to and support CBJ’s public review and outreach program. The technical memos provide additional explanation on certain elements and areas of the assessment. Of note, Technical Memo #4 “Guide to Avalanche and Landslide Hazard Designations” may serve as a useful reference for readers, as they review hazard designations.

Landslide Hazard

Surficial geology and landslide types, including debris flows, were identified, and mapped, as well as related initiation and runout zones. Landslide activity was mapped via historical air photo record review.

Fieldwork, initial mapping, and the review of historical air photo records, satellite images, and LiDAR data were used to designate potential landslide hazards on a three-part hazard designation system as requested by CBJ, including: *Low, Moderate,* and *Severe* hazard designations. However, fieldwork and mapping revealed that a fourth designation of *“High”* might be warranted. To explore this possibility, a semi-quantitative analysis of the mapping was completed, and it was concluded that a four-part landslide hazard designation system was in fact required and informative. The landslide hazard designation mapping was updated accordingly.

The main landslide types in the Study Area are debris slides, rockfalls, and debris flows. The first two initiate at higher elevations and may channelize to form debris flows at lower elevations. The debris flows form fans at the base of the mountain slopes. These, and a potential deep-seated bedrock slide apparently developing at high elevation in the southern part of the Study Area, form the *Severe* landslide hazard designation category. Hazards designated as *High* include steep slopes where rockfalls occur but cause less damage than in locations where the hazards are designated as *Severe*.

Snow Avalanche Hazard

Avalanche hazard designation mapping was based on the results of the following tasks: analysis of snow climate data; review of previous reports, historical avalanche occurrence records and magnitude-frequency analysis; review of historical air photos, satellite imagery, LiDAR data, and topographic contours; field investigation of terrain and

vegetation; discussion of historical activity with Juneau-based avalanche experts; and dynamic and statistical avalanche modelling.

Avalanche hazard mapping identified 52 unique avalanche paths, each of which includes delineation of *Severe, Moderate*, and *Low* hazard areas. The paths were identified in three areas: Mt. Juneau (25 paths), Gastineau Avenue (11 paths), and Thane Road (16 paths). Individual avalanche paths within the Study Area were mapped to delineate an estimated 300-year avalanche path boundary for destructive avalanche flow.

Continued use of the three-avalanche hazard designation system is recommended, including *Low*, *Moderate*, and *Severe* hazard designations. These designations are based on the expected return period and impact pressure of avalanches, with threshold return periods at 30 and 300 years and threshold impact pressures at 20 lb/ft^2 (1 kPa) and 600 lb/ft^2 (30 kPa).

Four modifications to the current CBJ designation system (CBJ 2001) were recommended to clarify and make the system consistent with systems used in other parts of the world. These modifications are summarized in greater detail in Section 2.2.2, but in summary include: (1) *High* Hazard/*Severe* Hazard/High Severity Zone designation is changed to "*Severe*"; (2) The *Severe* designation is modified to include both return period and impact pressure criteria by use of an "AND/OR" statement; (3) A definition is provided for the *Low* hazard designation; and (4) *Low* hazard designation is expanded to consider low impact pressure events (less than 20 lb/ft^2 or 1 kPa), which is an important consideration for powder avalanche hazards.

Recommendations

More detailed assessment and investigation of the apparently developing deep-seated bedrock slide conditions located near the top of Mt. Roberts is recommended to determine if there is active movement, and to identify the potential mechanisms and movement direction of the slide. A debris flow feature originally mapped by Swanston (1975) upslope of the southeast end of East Street should be further investigated in case a change in landslide hazard designation is warranted at this location.

A forestry road-deactivation format for slope review and the preparation of recommendations for proposed mitigations could be considered to mitigate or reduce the potential for damage resulting from slope instabilities that are attributable to abandoned or active infrastructure on the slope, especially linear infrastructure that tends to alter surface water drainage.

Periodic LiDAR and air photo flights, supplemented with digital elevation models and orthorectified imagery, would also help CBJ monitor upslope conditions. Detailed records should be kept of known landslide activity, especially landslide activity that impacts developed areas.

The Avalanche Path Mapping should be used to develop a database for improved record-keeping of avalanche events within the Study Area. This database will improve the understanding of the magnitude-frequency relationship, which are important inputs to hazard designation mapping and the design of avalanche defences. Recommended fields to record include the avalanche path name, date, time, estimated avalanche destructive size, and runout distance related to a fixed reference point (e.g., a road or power transmission line) for each avalanche path (AAA 2016).

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ACRONYMS & ABBREVIATIONS

Acronyms/Abbreviations	Definition
AAA	American Avalanche Association
AELP	Alaska Electric Light & Power
AJGMC	Alaska Juneau Gold Mining Company
Alaska DOT&PF	Alaska Department of Transportation and Public Facilities
amsl	above mean sea level
BCTCS	Terrain Classification System for British Columbia, Canada
CAA	Canadian Avalanche Association
CBJ	City and Borough of Juneau
DAC	Dynamic Avalanche Consulting Ltd.
GNSS	Global navigation satellite system, such as GPS or GLONASS
HS	Height of snow
LiDAR	Light Detection and Ranging
QSI	Quantum Spatial, Inc.
RIC	Resources Inventory Committee
SLF	Swiss Institute for Snow and Avalanche Research
Tetra Tech	Tetra Tech Canada Inc.; Tetra Tech Inc.
UAS	University of Alaska Southeast
USA	United States of America
USDA	U.S. Department of Agriculture

GLOSSARY OF TERMS

Term	Definition
Activity	For landslides, activity is the visual evidence at the time of the historical record, such as lack of vegetation or the presence of recently-exposed soil or rock, that indicates movements or changes on the slope. Includes the appearance or reappearance of, or changes in, slope movement features and/or gully erosion features, and indicates the occurrence of mass movement. (See also *Mass movement*.) For avalanches, activity is the visual evidence of current and historical avalanche paths in the form of trim lines and even-aged stands that can often be dated to specific avalanche events. Activity is also seen in the effects of avalanches on individual trees, e.g., snapped stems, flagging, and sometimes trees with pistol-butted or sweeping stems. For both landslides and avalanches, an assessment of activity includes the review of historical air photos, satellite images, LiDAR images, and/or field observations.
Anthropogenic	Human-made or modified geological material whose original properties have been drastically changed, often by removal of material from an original site followed by deposition elsewhere; locally includes rock fragments from mining and backfill used in land reclamation.
Avalanche	Refers to a snow avalanche (hereafter called an “avalanche”), unless otherwise specified. A snow avalanche is a volume of snow moved by gravity at perceptible speed. Snow avalanches may contain rock, broken trees, soil, ice, or other material in addition to snow (after CAA 2016).
Avalanche Hazard Designation - *Low*	For avalanche hazards: Return period greater than 300 years; OR Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.
Avalanche Hazard Designation - *Moderate*	For avalanche hazards: Return period between 30 and 300 years; AND Impact pressure less than 600 lbs/ft^2 (30 kPa).
Avalanche Hazard Designation - *Severe*	For avalanche hazards: Return period less than 30 years; AND/OR Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).
Bedrock	Bedrock outcrops and rock covered by a thin mantle (up to 10 cm (4 in.) thick) of unconsolidated or organic materials (Howes and Kenk 1997). In the Study Area, bedrock consists of meta-sedimentary and meta-volcanic rocks: generally well-foliated, dark grey and green, fine-grained phyllite, semi-schist and schist. Metamorphic grade increases toward the northeast (i.e., more significant metamorphic change). (See also *Metamorphic grade*.)
Blanket	A deposit greater than 1 m (39 in.) thick; minor irregularities of the underlying unit (generally bedrock) are masked but the topographic form is still evident. Thickness is estimated based on air photo interpretation and is revised with field data where available. (See also *Veneer*.)
Colluvium, Colluvial deposit	Poorly- to non-sorted mixture of rock fragments up to boulder size with silt, sand, gravel, and often organic debris, deposited by gravity-induced mass movement of upslope materials, including rockfall, rockslide, debris slide, debris flow, creep, and slumping. This is the dominant material in the Study Area. (See also *Colluvial veneer* and *Mass movement*.)

Term	Definition
Colluvial veneer	A deposit of colluvium of less than 1 m (39 in.) thick. Colluvial veneer is shown separately in the mapping, because the thickness of the colluvium has an effect on its stability, and on the corresponding Landslide Hazard Designation for the areas where it is present in the Study Area. (See also *Colluvium, Colluvial deposit*.)
Cone	A conical feature that dips down from a pointed apex to a broader, curving base at a lower elevation; bedrock topography is masked. A cone is distinguished from a fan by slope gradient (steeper than 15° or 26%). Colluvial cones are steeper than fluvial fans. (See also *Fan*.)
Consequence	The effect on human well-being, property, and/or the environment, that is, the change, loss, or damage caused to the elements of value by a landslide, debris flow, or avalanche (adapted from Wise et al. 2004). (See also *Hazard* and *Risk*.)
Debris flood	A very rapid, surging flow of water heavily charged with debris, sometimes called a *flash flood* (Waythomas and Jarrett 1993). *Debris floods* can transport large quantities of sediment at relatively high solids concentrations in the form of “hypoconcentrated flows.” *Debris floods* typically produce relatively thin, wide sheets of material, whereas *debris flows* produce thicker, more hummocky and lobate deposits. The destructiveness of *debris floods* is similar to that of water floods. Objects impacted by *debris floods* are buried or surrounded by debris but are often undamaged. *Debris floods* can continue moving in channels with considerably flatter slopes than those required for *debris flows* and are, therefore, observed on larger streams (adapted from Hungr et al. 2001). (See also *Debris flow*.)
Debris flow	A sudden and destructive landslide where loose material on a slope, with more than 50% of particles larger than sand size, is mobilized by saturation and flows very rapidly to extremely rapidly down a steep channel or canyon, becoming slower when slope angles lessen. The flow contains a combination of all of the following: soil, surficial materials, bedrock, and plant material. A debris flow behaves much like a viscous fluid when moving, and can continue for days or even weeks, as long as a sufficient source of water is present to keep the material mobile. (See also *Debris flood*.)
Debris slide	A shallow slide consisting of a mass of soil, vegetation, and surficial material; initial displacement is along one or several surfaces of rupture. Composed of comparatively dry and largely unconsolidated earthy material and results in an irregular, hummocky deposit. May initiate downstream debris flows.
Deep-seated bedrock slide	A large landslide or creeping mass of bedrock with a slide plane located at depth along which portions of bedrock are moving and deforming as a coherent unit along the slide plane. More information is available in Hungr et al. (2014).
Dense flow	The high-density core at the bottom of a mixed-motion avalanche flow which is typically 3 ft. to 6 ft. thick but can be substantially thicker in channelized terrain.

Term	Definition
Diamicton	A non-sorted to poorly-sorted sediment with a wide range of particle sizes, usually with the larger particles suspended within a finer-grained matrix, and sometimes incorporating sorted or stratified layers. Diamictons can be deposited in a variety of geologic settings and can contain materials from diverse sources. Though often used as a synonym for “till” or soils of glacial origin, not all diamictons are tills (adapted from Menzies 2009).
Elements of value, or elements at risk	Items or factors to be considered in risk analysis, including human life and well-being, public and private property (such as buildings or land), transportation or utility corridors, domestic water supply, and/or parts of the environment such as wildlife habitat (adapted from Wise et al. 2004). (See also *Consequence*, *Hazard*, *Likelihood*, and *Return Period*.)
Fan	A fan-shaped feature that dips down from a pointed apex to a broader, curving base at a lower elevation; bedrock topography is masked. A fan is distinguished from a cone by slope gradient (less than 15° or 26%). (See also *Cone*.)
Flooding	The inundation by water of any area not normally covered with water, owing to a rapid rise in the water level of a stream or other water body.
Fluvial deposit	Sediment deposited by rivers and small streams in channels, or as point bar or overbank deposits. Synonymous with alluvial deposits, which is an older term. Generally moderately or well sorted, with bedded cobbles, gravel, sand, and occasional boulders; silt, clay, and organic matter are less common. A distinction between glaciofluvial and fluvial materials has not been made in the Study Area.
Geohazard	A hazard relating to the geology, topography, landforms, climate, and water flow in an area. Landslides are a specific type of geohazard that involve movement of material downslope. (See also *Mass movement*).
Geomorphological/Geomorphic processes (Geomorphology)	The description and interpretation of landforms that are used to understand the geologic structure, history, and processes that define each unit of a map.
Glaciofluvial deposit	Sediment deposited by meltwater streams flowing from glaciers. Sometimes called fluvioglacial deposits. These deposits are similar to fluvial deposits and are often coarser-grained than typical fluvial deposits. The degree of sorting typically varies according to the distance from the melting ice front. (See also *Fluvial deposit*.)
Glaciomarine deposit	Sediments of glacial origin laid down in a marine environment in close proximity to glacier ice (Howes and Kenk 1997). Dense till-like stone diamicton; rich in mollusks and Foraminifera deposited prior to and during the last glaciation.
Hazard	A source of potential harm, or a situation with a potential for causing harm, in terms of human injury, and/or damage to property, the environment, or other things of value (adapted from Wise et al. 2004). (See also *Consequence*, *Likelihood,* and *Return Period*.)
Hazard Designation (Hazard Designation Category)	The rating or level of the hazard assigned to an area, in accordance with the observed or estimated likelihood of a landslide event or avalanche event in that area.

<table>
<tr><th>Term</th><th>Definition</th></tr>
<tr><td>Hazard Designation System</td><td>A method of organizing and understanding the relative hazard due to landslide events in an area, including a rating (i.e., the Landslide Hazard Designation or the Avalanche Hazard Designation), a symbol or colour to represent that rating, and a list of attributes that describe the rating.</td></tr>
<tr><td>Initiation zone</td><td>The upper part of a landslide feature where the landslide begins.</td></tr>
<tr><td>Landslide</td><td>Gravity-induced mass movement of upslope materials, including rockfall, rockslide, debris slide, debris flow, and creep. In general, landslide types include falls, topples, slides, spreads, flows, and slope deformations (Varnes 1978, Turner and Schuster 1996, Highland and Bobrowsky 2008, and Hungr et al. 2014). (See also Colluvium, Colluvial deposit, and Mass movement.)</td></tr>
<tr><td>Landslide Hazard</td><td>Landslide events that have the potential to cause physical injury, loss of life or damage, and/or loss to property/infrastructure (adapted from Bobrowsky and Couture 2014). Hazards can be singular in their origin, timing, and effects (e.g., isolated rock fall) or combined (e.g., debris slide accumulation in gully contributing to a larger debris flow at a lower elevation).</td></tr>
<tr><td>Landslide Hazard Designation - Low</td><td>A slope that is given a landslide hazard designation of Low usually has:
Gentle to moderate slopes (0° to 26°)
No signs of historical landslide activity on the air photos
No written record of property damage or loss of life
Surficial geology and texture for the Classes I, II, and III as shown in Table 1.2
Estimated event probability is “Unlikely to Very Unlikely,” with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future
(See Hazard Designation (Hazard Designation Category), Hazard Designation System, Landslide Hazard, Landslide Hazard Designation - Moderate, Landslide Hazard Designation - High, and Landslide Hazard Designation - Severe. See also Table 1.4 in the main text and Figures 1.6a to 1.6j. Green areas on the figures correspond to Low landslide hazard.)</td></tr>
<tr><td>Landslide Hazard Designation - Moderate</td><td>A slope that is given a landslide hazard designation of Moderate usually has:
Moderate to Moderately steep slopes (27° to 35°)
May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on air photos)
Can include low-lying areas within the runout zones of slides from nearby slopes
No apparent written record of property damage or loss of life
Surficial geology and texture for Class IV as shown in Table 1.2
Estimated event probability is “Possible,” with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events. Therefore, landslide events could happen in the future
(See Hazard Designation (Hazard Designation Category), Hazard Designation System, Landslide Hazard, Landslide Hazard Designation - Low, Landslide Hazard Designation - High, and Landslide Hazard Designation - Severe. See also Table 1.4 in the main text and Figures 1.6a to 1.6j. Yellow areas on the figures correspond to Moderate landslide hazard.)</td></tr>
</table>

Term	Definition
Landslide Hazard Designation - *High*	A slope that is given a landslide hazard designation of *High* usually has: ▪ Steep slopes (>35°) ▪ Areas where rock fall activity impacts individual trees but does not knock them over or destroy them ▪ May have written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 ▪ At least two of the following criteria are met: – Thin colluvium (Cv) present – A maximum polygon slope of 70° to 80° – A mean polygon slope of 40° to 50° ▪ Estimated event probability is “Likely,” with a return period of 5 to 30 years. This is the return period estimated for Class IV terrain where slopes are known to be susceptible to landslides, and where there are signs of recent and/or historical landslide events. Therefore, landslide events are likely to keep happening in the future (See *Hazard Designation (Hazard Designation Category)*, *Hazard Designation System*, *Landslide Hazard*, *Landslide Hazard Designation - Low, Landslide Hazard Designation - Moderate*, and *Landslide Hazard Designation - Severe*. See also Table 1.4 in the main text and Figures 1.6a to 1.6j. Orange areas on the figures correspond to *High* landslide hazard.)
Landslide Hazard Designation - *Severe*	A slope that is given a landslide hazard designation of *Severe* usually has: ▪ Steep to vertical slopes (>35°) ▪ Signs of recent activity either in aerial photographs or from field inspection (rock fall tracks, debris slide activity, debris flow paths etc.) ▪ May have written record of property damage or loss of life ▪ Signs of repeated historical activity ▪ Surficial geology and texture for Class V as shown in Table 1.2 ▪ Estimated event probability is “Very Likely to Almost Certain,” with a return period of 1 to 20 years. This is the return period estimated for Class V terrain, where the slopes are highly susceptible to landslides, and where there are signs of recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are very likely to almost certain to keep happening in the future (See *Hazard Designation (Hazard Designation Category)*, *Hazard Designation System*, *Landslide Hazard*, *Landslide Hazard Designation - Low, Landslide Hazard Designation - Moderate*, and *Landslide Hazard Designation - High*. See also Table 1.4 in the main text and Figures 1.6a to 1.6j. Red areas on the figures correspond to *Severe* landslide hazard.)
LiDAR	LiDAR, which stands for Light Detection and Ranging, is a technology that emits laser light and measures the return time and wavelength of the laser reflected from the terrain. In this context, it is used to create a high-resolution digital elevation model of the terrain, which is used to refine landslide and avalanche hazard mapping.
Likelihood	A qualitative or semi-quantitative estimate of the probability that a specified hazard (e.g., landslide, debris flow, or avalanche) will occur, referred to as a probability rating, and described with terms such as “very low” to “very high” (adapted from Wise et al. 2004). Numerical values may be applicable if there is sufficient supporting data. (See also *Consequence*, *Hazard*, and *Return period*.)
Mass movement	The movement of material downslope usually associated with landslide events.

Term	Definition
Metamorphic grade	A term describing the relative pressure and temperature conditions that a metamorphic rock formed at. Low-grade metamorphism occurs at lower temperature and pressure conditions while high-grade metamorphism happens at higher temperature and pressure conditions. Each grade of metamorphism has characteristic mineral assemblages.
Metamorphism	The process by which changes are brought about in rocks within the Earth's crust by the agencies of heat, pressure, and chemically active fluids. These changes include the texture, composition, or mineralogy of a rock.
Metasedimentary rock	Sedimentary rock that shows evidence of having been subjected to metamorphism, i.e., which underwent physical or chemical changes or both to achieve equilibrium with conditions other than those under which it was originally formed (the processes of weathering and diagenesis are excluded).
Metavolcanic rock	Volcanic rock that shows evidence of having been subjected to metamorphism, i.e., which underwent physical or chemical changes or both to achieve equilibrium with conditions other than those under which it was originally formed (the processes of weathering and diagenesis are excluded).
Morainal material (Till)	Poorly-sorted and unstratified sediment (diamicton) deposited directly by ice, lodgement, meltout, or post-meltout gravity flow; generally matrix-supported and compact. Clasts consist of subangular to angular gravel, cobbles, and boulders, with a clay to fine gravel matrix. Till is synonymous with morainal material.
Polygon, Terrain polygon, Terrain unit	A distinct many-sided map unit, enclosed by a boundary line, with its own label describing the conditions within that area. The label consists of a specific terrain code that includes a description of surficial materials, surficial expression, and/or geomorphological process(es) that distinguish it from the adjacent map units or areas. The map units are also assigned a landslide hazard designation in accordance with their descriptions and associated stability characteristics.
Powder flow	The lower density layer of a mixed-motion avalanche flow that appears above the dense core, and which can be tens or even hundreds of feet thick.
Return period	The anticipated repeat occurrence of a natural hazard event based on the analysis of event data or theoretical modelling, usually cited in terms of annual, 10, 30, 100, and 300-year intervals. Probability or likelihood is the inverse of the return period. A return period does not mean that a specified event will only happen once during a specified return period. In fact, an event, e.g., a 1-in-30-year event, could happen this year, and it could happen again next year, i.e., at any time during a given 30-year period. "Return period" is also known as "recurrence interval" or "event period."
Ridge	A narrow, elongated, and commonly steep-sided feature that rises above the surrounding landscape; bedrock topography is usually masked (unless it is a bedrock ridge).
Risk	The qualitative evaluation of a potential loss, defined as a measure of the likelihood of an adverse event and the consequence of that adverse event (adapted from Wise et al. 2004). Where semi-quantitative data are available, risk may be estimated as the combination of the probability or frequency of occurrence of a defined hazard and the magnitude of the consequences.

Term	Definition
Rock avalanche	Extremely rapid, massive, flow-like motion of fragmented rock originating from a large rockslide or rockfall. Large rockslides can disintegrate rapidly during motion down mountain slopes and travel as extremely rapid flows of fragmented rock. Large rock avalanches can achieve a degree of mobility that far exceeds that expected from a frictional flow of dry, angular, broken rock (adapted from Hungr et al. 2014). Peak velocities can be as high as 65 mph to 220 mph (100 km/h to 360 km/h), with exceptional velocities of up to 620 mph (1,000 km/h) recorded (Evans et al. 1989). These velocities far exceed the typical 11 mph (18 km/h) velocity of “extremely rapid” landslides (Hungr et al. 2014).
Rockfall	A rapid release and downslope movement of rock fragments recently detached from a bedrock face, which fall freely and then cascade down a steep slope.
Rockslide	A type of rock failure in which part of the plane of failure passes through intact rock and where material collapses *en masse*, not in individual blocks (Whittow 1984). The following types of slides in rock are defined in the modified Varnes classification of landslide types (Hungr et al. 2014): ▪ Rock rotational slide (“rock slump”); ▪ Rock planar slide (“block slide”); ▪ Rock wedge slide; ▪ Rock compound slide; and ▪ Rock irregular slide (“rock collapse”).
Runout zone	The lower section of a landslide or avalanche path where the debris is deposited.
Slab avalanche	A snow avalanche that releases as a segment of cohesive snow that breaks away from the mountainside.
Soil creep	The imperceptibly slow downward movement of soil on slopes caused by gravity, facilitated by occasional saturation or freeze/thaw cycles.
Start zone	Where large avalanches start. While there is always a start zone at the top of a path, there may be many start zones, not all at the top, for a single path.
Surficial expression (Surface expression)	The form (assemblage of slopes) and pattern of forms expressed by a surficial material at the land surface. This three-dimensional shape of the material is equivalent to “landform” used in a non-genetic sense (e.g., ridges, plain). Surface expression symbols also describe how unconsolidated surficial materials relate to the underlying substrate (e.g., veneer) (Howes and Kenk 1997).
Surficial material, Surficial geology	The type(s) of soil or rock that appear at ground surface and can be represented on a map.
Terrace	A level or gently inclined surface flanked by a steep slope or scarp; bedrock topography is masked.

Term	Definition
Terrain code	A structured method of representing surficial material types, surficial expressions of those material types, and geomorphological processes to efficiently show rock or soil units on a map. The maps for the Study Area show a sample terrain code to assist readers in understanding the terrain codes presented on the map. Descriptions for the surficial materials, surficial expressions, and geomorphological processes are shown on each map. (See also *Surficial material*, *Surficial expression*, and *Geomorphological processes (Geomorphology)*. All of the surficial materials and geomorphological processes shown on the maps and several of the surficial expressions (*Blanket*, *Cone*, *Fan*, *Ridge*, *Terrace*, and *Veneer*) are also defined in the Glossary.)
Topple, toppling	Forward rotation and overturning of rock columns or plates (one or many), separated by steeply dipping joints. The rock is relatively massive, and rotation occurs on well-defined basal discontinuities. Movement may begin slowly, but the last stage of failure can be extremely rapid (Hungr et al. 2014).
Track	The middle part of an avalanche path between the start zone and runout zone. It is where large avalanches reach their maximum speed.
Veneer	A deposit less than 1 m (39 in.) thick; minor irregularities of the underlying unit (generally bedrock) are masked but the topographic form is obvious. Thickness is estimated based on air photo interpretation and is revised with field data where available (See also *Blanket*.)
Vulnerability	For the purpose of risk management calculations, the fraction of loss of an element at risk (e.g., fraction of replacement cost), or the probability of death of a person, impacted by a hazard of a specified magnitude (adapted from CAA 2016). For the purpose of identifying landslide or avalanche hazards in Juneau, CBJ (2012) uses this concept to describe zones or areas that could be affected by landslides or avalanches.

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the City and Borough of Juneau and its agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the City and Borough of Juneau, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the City and Borough of Juneau (CBJ) to complete a hazard assessment for the occurrence of landslides and snow avalanches in the Downtown Juneau area. It is understood that this hazard assessment and the associated mapping will be used to update CBJ's existing hazard maps that were adopted in 1987 for Downtown Juneau, and which were based on low-resolution maps created in the 1970s. The area assessed is referred to as the "Study Area," as shown in Figure 1.1 in the "Figures" Section at the end of the report.

Tetra Tech (including Tetra Tech Alaska, LLC) is a consulting firm of engineers, geoscientists, and architects with a strong presence in the Northwest since 1943. Tetra Tech completed the landslide portion of the hazard assessment and retained Dynamic Avalanche Consulting Ltd. (DAC) to complete the snow avalanche portion of the assessment. DAC is an industry-leading avalanche consulting engineering firm that specializes in the assessment and mitigation of snow avalanche hazards. Tetra Tech and DAC have each prepared relevant sections of the technical engineering report to describe the landslide and avalanche investigation techniques, analysis methods, procedures, assumptions, and findings with detailed hazard designation mapping.

This work builds upon previous studies conducted in the Juneau area between 1967 and 2011, including work by Hart (1967, 1968), LaChapelle (1968), Frutiger (1972), Miller (1972, 1975), Swanston (1972), Mears et al. (1991, 1992), CBJ (2004, 2009, 2012), and the Swiss Institute for Snow and Avalanche Research (SLF 2011).

The purpose of this report is to provide the key results of the landslide and avalanche hazard assessment, including:

- Surficial geology mapping update;
- Historical air photo record analysis;
- Identify changes in slope features and mass movement activity;
- Identify landslide and avalanche types;
- Prepare hazard designation mapping in support of the future development of appropriate zoning, building regulations, and mitigation options;
- Prepare landslide hazard designation mapping that shows *Low*, *Moderate*, *High*, and *Severe* hazard designation areas.
- Prepare avalanche path mapping that delineates individual 300-year avalanche path boundaries for destructive flow and, where possible, uses historical avalanche path names; and
- Prepare avalanche hazard designation mapping that shows *Low*, *Moderate*, and *Severe* hazard designation areas.

Tetra Tech has provided supplemental explanations in Technical Memos #1 to #7, including Technical Memo #4 "Guide to Avalanche and Landslide Hazard Designations."

This report incorporates and is subject to Tetra Tech's Limitations on Use of this Document which are included in Appendix A.

1.0 PART 1 LANDSLIDE HAZARD ASSESSMENT

1.1 Project Description – Landslides

The CBJ has requested detailed high-resolution landslide hazard mapping that shows the initiation zones, main bodies/paths (where applicable), and runout zones; and delineates *Low*, *Moderate*, and *Severe* hazard designations.

The current work scope for the landslide hazard assessment study does not include risk zoning (consideration of elements of risk in landslide hazard areas), zoning regulations, or engineering interventions (mitigation). It also does not consider how the existing buildings could affect landslide behaviour. However, a comment made during the 2021 Juneau public and CBJ meetings that the current study should address how structures factor into landslide hazards was addressed in Technical Memo #3 (see Question/Comment #13) attached to this Report (Appendix C, Tetra Tech 2022c). The premise of that comment was that upslope structures would protect the structures downslope. However, this is not always true. Most of the upslope structures in the Downtown Juneau area are not designed and built to withstand the force of landslides or avalanches and, upon the destructive impact of mass movement, are sometimes incorporated into the debris, adding more mass to damage or demolish the downslope structures. A classic example of this kind of event is the January 2, 1920 landslide that occurred between Decker Way and Bulger Way, destroying 16 buildings from Gastineau Avenue to Front Street (now South Franklin Street). That landslide resulted in numerous buildings sliding downslope with the debris and, while overrunning other structures, obliterating them. Similarly, the 1962 avalanche in the Behrends path produced severe or moderate damage to multiple houses on both sides of Berhrends Avenue and on Glacier Avenue, some of which were located directly downslope of other damaged or destroyed residences.

The new landslide hazard maps are intended to update the existing hazard maps that were adopted in 1987 for Downtown Juneau, and which were based on low-resolution maps created in the 1970s. The new hazard maps are intended for use by the CBJ to develop appropriate zoning, building regulations, and mitigation options. The Study Area includes Downtown Juneau as shown in Figure 1.1. Additional information about the scope and limitations is provided in Technical Memos #1 and #4.

1.2 Methodology – Landslides

1.2.1 Overview

Tetra Tech has completed detailed surficial geology mapping, including historical air photo and LiDAR data interpretation. Results of the mapping were verified in the field by a Tetra Tech geotechnical engineer. Field observations were used to refine the surficial geology mapping of the Study Area for subsequent landslide hazard designation mapping.

1.2.2 Review of Available Information

Available information for the Study Area was reviewed, including air photos, satellite images, 2002 and 2013 LiDAR bare earth hillshade model imagery, 2012 and 2013 LiDAR elevation surface data, geological mapping, previous hazard assessment reports, and incident reports provided by CBJ. A complete list of information used is listed in the References section at the end of this report.

The Study Area is located as shown in Figure 1.1.

1.2.3 Site Reconnaissance Visit

The Study Area reconnaissance was completed by two field engineers, Alan Jones, P.Eng., P.E., of DAC, and Shane Greene, P.Eng., of Tetra Tech, from September 8 to 15, 2019. The reconnaissance included the following tasks:

- Helicopter fly-over of the Study Area to provide a wider perspective of suspected areas of slope instability, target specific areas for ground truthing, and to provide access to otherwise inaccessible or difficult-to-access areas.
- Walkover inspection of a large portion of the Study Area for field mapping of landslide areas and ground-truthing of geomorphic features/hazards (e.g., landslides), key terrain features, and vegetation damage (slope instability-related) identified from air photo and LiDAR data analysis. Maps used to assist in site reconnaissance were compiled from 2013 photos, 2013 LiDAR bare earth hillshade model imagery, as well as existing geological and geohazard maps by Mears (1992), Miller (1975), Swanston (1972), and CBJ (2009, 2012).
- Measurements, photographs, and Global Navigation Satellite System (GNSS such as GPS/GLONASS) data collection of landslide initiation and runout zones to help define hazard types and mechanisms.

1.2.4 Mapping

1.2.4.1 Surficial Geology Mapping Update

Surficial geology was mapped at a scale of 1:2,000 to 1:4,000 using the Terrain Classification System for British Columbia, Canada (BCTCS) (Howes and Kenk 1997). Howes and Kenk (1997) outline how to map surficial geology according to this system.

The BCTCS is the accepted standard for terrain and landslide hazard mapping in adjacent British Columbia. Although it is a Canadian regulation, a modified version of the standard (with permafrost-related hazards incorporated) has been used previously for mapping in northwest Alaska (EBA 2011a) and in Canada's Northwest Territories (EBA 2011b, Nehtruh-EBA 2019). Given Juneau's location and the similarities in terrain to coastal British Columbia, the non-permafrost version of the BCTCS was chosen as the most appropriate starting point for the mapping as it incorporates many types of landslides as well as slope angles, which are important features in the mountainous terrain of the Study Area. The BCTCS mapping system is also easily adapted to account for variations in terrain, hazard types, and mapping requirements. Further explanation of the landslide hazard designation system adopted for this study is provided in Section 1.2.4.2.4 below.

The mapping for this project extends up the mountain slopes and covers the complete Study Area, improving upon Miller (1975). The Study Area was refined to end at the top of each slope (i.e., the ridgelines).

Table 1.1: Air Photos and Images Used in the Study

Year	Type	Imperial Scale	Scale/ Resolution	Hard Copy (contact print)	Digital Copy	Study Area Coverage
1948	B/W photos		1:40,000	Y	N	Nearly complete
1962	B/W photos	1 in.=1,800 ft.	1:21,600	Y	N	Nearly complete
1977	B/W and color photos	1 in.=500 ft.	~1:6,000	Y	N	Lower slopes
1988	Color photos	1 in.=400 ft.	1:4,800	Y	N	Parts of lower slopes

Table 1.1: Air Photos and Images Used in the Study

Year	Type	Imperial Scale	Scale/ Resolution	Hard Copy (contact print)	Digital Copy	Study Area Coverage
1997	Color photos	1 in.=1,000 ft.	1:12,000	Y	N	Complete
2002	B/W LiDAR bare earth hillshade model ; Elevation surface	3 ft.		N	Y	Complete
June 2006	Color satellite image	6 in.		N	Y	Highest slopes missing
August 2006	Color satellite image		30 cm	N	Y	Complete
2012	LiDAR elevation surface	3 ft.		N	Y	Complete
2013	Color satellite image	6 in.		N	Y	Highest slopes missing
2013	B/W LiDAR bare earth hillshade model; elevation surface	3 ft.		N	Y	Highest slopes missing

Mapping was completed in PurVIEW, an add-on to ArcGIS that allows the mapper to view three-dimensional (3D) air photo images on the computer screen in spatially-accurate locations. Mapping can then be completed for various air photo years with a high level of confidence in the location of the various features. Digital air photos were acquired from CBJ, Quantum Spatial, Inc. (QSI), and the U.S. Department of Agriculture (USDA). The air photos were georeferenced and aerially triangulated for viewing in PurVIEW. Hardcopy air photos were first scanned at high resolution for this purpose, and then georeferenced. Satellite and LiDAR images of the Study Area were supplied by CBJ. The air photos, LiDAR, and satellite images used in the Study Area are shown in Table 1.1. Coverage across the Study Area for each set of images is shown in Figure 1.2a to 1.2e.

The LiDAR bare earth hillshade model images were used to refine the locations of such major terrain features as gullies and debris flow fans. Due to the high resolution of the LiDAR data, it was possible to map a large number of gullies. The reason gully erosion, as a hazardous geomorphic process, was given such attention in this landslide hazard assessment study is the role of gully erosion in mass movement on the slopes with some of the gullies being conduits for conveying debris flows, debris slides, and wet avalanches. For clarity, the gullies are presented on a separate series of maps at a scale of 1:11,000 (Figures 1.5a, 1.5b, and 1.5c). These maps used a mosaic of high resolution 2013 and 2002 LiDAR bare earth hillshade model imagery as a base map. It should be noted that the large number of gullies mapped for 2013, as compared to the gullies mapped for other years, is solely due to the high resolution of the 2013 LiDAR bare earth hillshade imagery, which lacks tree cover, and not due to unusual gully erosion activity in 2013.

Topographic contours were generated from the 2013 LiDAR elevation surface data, using the 2012 LiDAR elevation surface data to generate additional contours outside the 2013 coverage area (100 ft. contours on Figures 1.4a to 1.4c, and 25 ft. contours on Figures 1.6a to 1.6j). The 2012 and 2013 LiDAR elevation surface data were provided by CBJ.

Miller (1975) was referenced during the mapping process to confirm that no previously identified landslide features were missed.

1.2.4.2 Landslide Hazard Mapping

1.2.4.2.1 Identification of Landslide Types

Landslide types were identified while completing the surficial geology mapping in PurVIEW. These were based on the mapper's and the field investigator's knowledge and followed the BCTCS system of classification (see the Glossary of Terms at the beginning of this report). One exception was a deep-seated bedrock slide identified in the field, for which a new slide classification was added.

1.2.4.2.2 Historical Air Photo Record Analysis

Surficial geology was mapped using the 1948 air photos to provide a baseline for the maps that extends as far back in time as the air photo coverage of the Study Area allows. The 1948 air photos are of poor quality given the camera capabilities of that time, so the base historical mapping and the surficial geology mapping were checked against the 1962 air photos in a number of areas. The 1948 air photos also have some parallax issues, which make viewing some of the photos in 3D difficult. However, it was still possible to complete the historical mapping with 1948 as the base year.

Once the 1948 base mapping was complete, air photos from the more recent years, including 1962, were checked for mass movement activity. At the scale of the air photos, lack of vegetation was the only proxy that could be mapped to determine slide activity in any given year. If rockfall movement, for example, passed through a forest without knocking down any trees, then it would not be detectable on the air photos. The heavy vegetation cover in the middle to lower parts of many of the slopes likely masks the smaller rockfall and slide evidence. Considering the large number of small debris flows and heavy vegetation cover observed during site reconnaissance, the mass movement activity levels suggested by the historical air photo analysis should be considered the minimum likely activity levels.

The unvegetated areas for the remaining air photo years were mapped and assigned a color according to year so that they can be easily identified on the maps (both polygonal and linear features). Areas showing activity in two or more air photo years were identified and given a hazard designation of *Severe* on the hazard designation maps due to their higher activity levels, as discussed further in Section 1.2.4.2.4.

Coverage of the Study Area is not complete for all air photo years or satellite images (Table 1.1). As a result, it may appear that in some areas there was no activity in certain years (e.g., higher elevation areas), when, in fact, there was no air photo coverage in these areas for those time periods. Figures 1.2a to 1.2e show the air photo and satellite image coverage of the Study Area. The lack of air photo coverage during specific time periods should be kept in mind when viewing the historical air photo interpretation mapping.

The 1988 air photos were not particularly useful as they had strong parallax issues when viewed in PurVIEW and covered very little of the Study Area. There was also no obvious evidence of change in these limited-extent lower-slope areas between 1977 and 1988. The 1988 air photos were therefore removed from the historical air photo record review, rather than having a line type represented on the legend for which there are no corresponding lines on the maps.

Snow cover in some of the air photos may have obscured possible mass movement activity, most notably rockfall activity at high elevations. It is therefore possible that rockfall activity has been underestimated at high elevations.

Data from the 2019 fieldwork was added to the historical mapping. The higher activity areas were added to the 2019 layer as well.

1.2.4.2.3 Historical Studies and Incident Reports

The mapping of mass movement features based on the historical air photo record analysis was supplemented with data from previous hazard assessment reports, known rockfall data, and incident reports, as provided by CBJ. Previous hazard assessment reports consisted of those by CBJ (2009, 2012), Mears et al. (1992), Swanston (1972), and DMJM (1972a, 1972b). Findings from these reports are summarized in Section 1.3.2.

1.2.4.2.4 Landslide Hazard Designation System

Three levels of hazard designation were initially included in the landslide hazard designation system (*Low*, *Moderate*, and *Severe*). The Resources Inventory Committee (RIC 1996) defines five slope stability classes (Table 1.2), but Classes I, II, and III are considered generally stable and fit well into a hazard designation of *Low* for the purposes of this study. Classes IV and V typically correspond to the hazard designations of *Moderate* and *Severe*, respectively. For this study, the terms Hazard Designation and Hazard Designation Category are used, rather than the term Hazard Class used by RIC (1996) as shown in Table 1.2. This change in terms was made to improve the correspondence with terminology previously used by CBJ (2009, 2012).

Table 1.2: BCTCS Hazard Designation Categories (adapted from RIC 1996)

A. Slope Class[1]

Class	Slope Gradient (%)	Slope Gradient (Degrees)
1	0-5	0-3
2	6-27	4-15
3	28-49	16-26
4	50-70	27-35
5	>70	>35

B. Soil Drainage Class

<table>
<tr><td>r</td><td>Rapidly Drained</td><td>i</td><td>Imperfectly Drained</td></tr>
<tr><td>w</td><td>Well Drained</td><td>p</td><td>Poorly Drained</td></tr>
<tr><td>m</td><td>Moderately Well Drained</td><td>v</td><td>Very Poorly Drained</td></tr>
<tr><td colspan="4">Where two drainage classes are shown: if the symbols are separated by a comma, e.g., “w,i", then no intermediate classes are present; if the symbols are separated by a dash, e.g., “w-i", then all intermediate classes are present.</td></tr>
</table>

C. Criteria for Slope Stability Interpretations

<table>
<tr><th>Potential Slope Stability and Surface Erosion Classes</th><th>Dominant Slope Class[1]</th><th>Material and Landforms[2]</th><th>Dominant Texture[3]</th><th>Active Processes[4]</th><th>Soil Drainage</th><th>Slope Morphology</th></tr>
<tr><td rowspan="2">I</td><td>1 and 2</td><td>Cf; F</td><td>sand, gravel</td><td>None</td><td rowspan="9">Poorly drained and wet soils are relatively susceptible; units with slopes within 3° or 4° of an upper class boundary may be assigned to the next highest class.</td><td rowspan="9">Slopes with irregular or benched topography controlled by bedrock are relatively stable; units with slopes close to a lower class boundary may be assigned to the next lowest class.</td></tr>
<tr><td>1&2 Mixed</td><td>Mv, Mb; Cv; Cf; R</td><td>silt, sand, gravel</td><td>None</td></tr>
<tr><td rowspan="2">II</td><td>2</td><td>Mv, Mb, WG</td><td>silt, sand</td><td>None</td></tr>
<tr><td>2 and 3</td><td>Cf; R</td><td>sand, gravel</td><td>None</td></tr>
<tr><td rowspan="2">III</td><td>3</td><td>Mv, Mb; WG Cv</td><td>silt, sand, gravel</td><td>None</td></tr>
<tr><td>4</td><td>Cj, Ca, Ck, R</td><td>sand, gravel</td><td>None</td></tr>
<tr><td rowspan="2">IV</td><td>4 and 5</td><td>Mv, Mb, C</td><td rowspan="2">All</td><td rowspan="2">gullying, rockfall</td></tr>
<tr><td>4 and 5</td><td>Rk, Rs</td></tr>
<tr><td>V</td><td>Any Gradient</td><td>M, C, Rs</td><td>All</td><td>debris flow, debris slide, rockfall</td></tr>
</table>

Notes:

1. Dominant slope class in Part C of this table refers to the slope class determined in Part A of the table as being the primary slope class in the map unit.
2. See the Legend in Figures 1.3a to 1.3c for description of terrain codes used in the Study Area. Anthropogenic areas are classified individually based on various factors including suspected underlying surficial geology.
3. See the Legend in Figures 1.3a to 1.3c to compare to typical active processes in the Study Area.
4. Adapted for Juneau mapping from RIC (1996)

The main attributes initially used to characterize and identify each level of hazard in this fashion are summarized in Table 1.3. The assessment of these attributes was based on topography, field observations, slope class, and other relevant features, as shown in Part C of Table 1.2. Historical air photo analysis also contributes to the final hazard designation selected for a map unit, so the classification system has been refined to include this extra information.

Table 1.3: Preliminary Landslide Hazard Designation System

Hazard Designation[2]	Symbol	Hazard Attribute Description
Low	L	▪ Gentle to moderate slopes (0° to 26°) ▪ No signs of historical landslide activity on the air photos ▪ No written record of property damage or loss of life ▪ Surficial geology and texture for the Classes I, II, and III as shown in Table 1.2 ▪ Estimated event probability is "Unlikely to Very Unlikely," with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future[2]
Moderate	M	▪ Moderate to Moderately steep slopes (27° to 35°) ▪ May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on air photos) ▪ Can include low-lying areas within the runout zones of slides from nearby slopes ▪ No apparent written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 ▪ Estimated event probability is "Possible," with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events. Therefore, landslide events could happen in the future[2]
Severe	S	▪ Moderately steep to vertical slopes (>35°) ▪ Signs of recent activity either in aerial photographs or from field inspection (rockfall tracks, debris slide activity, debris flow paths etc.), and/or ▪ Areas where rock fall activity impacts individual trees but does not knock them over or remove them[3] ▪ May have written record of property damage or loss of life ▪ May have signs of repeated historical activity ▪ Surficial geology and texture for Class V as shown in Table 1.2 ▪ Estimated event probability is "Likely to Almost Certain," with a return period of 1 to 30 years." Class IV or Class V terrain indicates slopes that are susceptible or highly susceptible to landslides. There are signs of recent and/or historical landslide events; and/or recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are likely to very likely to almost certain to keep happening in the future[2]

Notes:

1. Landslide hazard designations (*Low*/*Moderate*/*Severe*) correspond to green/yellow/red (Figure B.5 in Appendix B).
2. Estimated event probability based on observed and recorded slope movement activity level. Note that this is not an indication of consequence (potential for damage), nor is it a magnitude/frequency study, which can determine return periods with more accuracy.
3. This type of rockfall can be highly active but has a small enough impact not to be readily visible on the air photos or satellite imagery.

Following the initial hazard designation mapping, it was determined that the landslide hazard designation system should be further refined to better distinguish the hazard attributes in areas initially designated as *Moderate* or *Severe*. The historical air photo record analysis described in Section 1.2.4.2.3 and the fieldwork completed for the project were therefore used to further refine the hazard designation categories, as discussed in Appendix B. This refinement resulted in an additional hazard designation category, to allow the hazard designation mapping to be more specific. The revised Hazard Designation classification is provided in Table 1.4. Additional discussion of landslide hazard designations is provided in Technical Memo No. 4 (Appendix C, Tetra Tech 2022d).

Table 1.4: Refined Landslide Hazard Designation System

Hazard Designation[1]	Symbol	Hazard Attribute Description
Low	L	▪ Gentle to moderate slopes (0° to 26°) ▪ No signs of historical landslide activity on the air photos ▪ No written record of property damage or loss of life ▪ Surficial geology and texture for Classes I, II, and III as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is “Unlikely to Very Unlikely,” with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future[2]
Moderate	M	▪ Moderate to Moderately steep slopes (27° to 35°) ▪ May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on the air photos) ▪ Can include low-lying areas within the runout zones of slides from nearby slopes ▪ No apparent written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is “Possible,” with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events. Therefore, landslide events could happen in the future [2]
High	H	▪ Steep slopes (>35°) ▪ Areas where rockfall activity impacts individual trees but does not knock them over or destroy them[3] ▪ May have written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 (Tetra Tech 2021a) ▪ At least two of the following criteria are met: – Thin layer of colluvium (Cv) present – A maximum polygon slope of 70° to 80° – A mean polygon slope of 40° to 50° ▪ Estimated event probability is “Likely,” with a return period of 5 to 30 years. This is the return period estimated for Class IV terrain where slopes are known to be susceptible to landslides, and where there are signs of recent and/or historical landslide events. Therefore, landslide events are likely to keep happening in the future [2]

Table 1.4: Refined Landslide Hazard Designation System

Hazard Designation[1]	Symbol	Hazard Attribute Description
Severe	S	▪ Steep to vertical slopes (>35°) ▪ Signs of recent activity either in aerial photographs or from field inspection (rockfall tracks, debris slide activity, debris flow paths etc.) ▪ May have written record of property damage or loss of life ▪ Signs of repeated historical activity ▪ Surficial geology and texture for Class V as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is "Very Likely to Almost Certain," with a return period of 1 to 20 years. This is the return period estimated for Class V terrain, where the slopes are highly susceptible to landslides, and where there are signs of recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are very likely to almost certain to keep happening in the future [2]

Notes:

1. Landslide hazard designations (*Low*/*Moderate*/*High*/*Severe*) correspond to green/yellow/orange/red on Figures 1.6a through 1.6j, and Figure B.6 in Appendix B.
2. Estimated event probability based on observed and recorded slope movement activity level. Note that this is not an indication of consequence (potential for damage), nor is it a magnitude/frequency study, which can determine return periods with more accuracy.
3. This type of rockfall can be highly active but has a small enough impact not to be readily visible on the air photos or satellite imagery.

1.2.4.2.5 Landslide Hazard Designation Mapping

For the purposes of this assessment, the definition of landslide hazard was modified from Bobrowsky and Couture (2014) and is broadly defined as, "landslide events (e.g., rockfall, debris slide, debris flow) that have the potential to cause physical injury, loss of life or damage, and/or loss to property/infrastructure."

Using this landslide hazard definition, the hazard maps were developed as outlined in the previous sections.

The hazard designations assigned do not account for current or future positioning of infrastructure or people, as this is considered risk mapping, which is beyond the scope of this study. Similarly, analysis of magnitude/frequency, runout, and risk assessment are not part of this study. Preliminary runout identification has been undertaken through mapping the extents of historical landslides. However, runout modeling or theoretical scenarios have not been undertaken as they are beyond the scope of the study. We note that in developed areas, debris that would identify an area as a runout zone on the air photos has been removed, which makes the mapping of these zones difficult. We have mapped runout zones that are visible on the air photos but have not extrapolated them into built-up areas unless other data was available (e.g., the presence of a defined colluvial fan or news stories about past events). See Technical Memo #4 for additional discussion on landslide hazard designation mapping (Appendix C, Tetra Tech 2022d). Runout modelling is required for more accurate results in these areas.

1.3 Background Data Review – Landslides

1.3.1 Geology

1.3.1.1 Surficial Geology

Surficial geology was mapped along the shoreline of Gastineau Channel by Miller (1972, 1975). Although the upper slopes of Mt. Juneau and Gastineau Peak were not mapped, the Juneau townsite area and lower slopes were included in the mapping.

Miller (1975) shows that in the townsite area, fill was the main material between Glacier Avenue, Front Street, South Franklin Street, and the shoreline. Fill was also found on the floor of Evergreen Bowl (now Cope Park). Miller's mapping of fill at Cope Park appears to be confirmed by a history of Cope Park, in which mine fill was used by the U.S. Forest Service in 1934 to fill in Wagner's Pond (Weed 2015). Mine dump waste was identified on the slopes of Mt. Roberts along and below the former Alaska Juneau Gold Mining Company (AJGMC) tramway/railway grade and tunnel portals, and the mill site; and also formed two terraces along the shoreline of Gastineau Channel south of the mining infrastructure.

Fluvial fan material (sand and gravel) was present on the nearly flat-lying area extending from the mouth of Gold Creek valley to Glacier Avenue. A few debris-flow deposits flanked the creek near Evergreen Bowl and floodplain deposits were found in upper Gold Creek. Modern deltaic deposits of silt and sand were found at the mouth of the creek adjacent to the fill units.

Glaciofluvial deltaic material (silt, sand, gravel) was found at higher elevations along the base of the steeper mountain slopes from 2nd Street to the southern end of Glacier Highway.

Raised beach deposits with a variety of grain sizes were found to overlie finer-grained fossiliferous glaciomarine sediments between 2nd and Front Streets and just above Franklin Street where it exits the downtown core. They were also found in the Behrends and Troy Avenue areas. The lower fossiliferous material was also found along the shoreline from Norway Point to the northwest edge of the Study Area and at various locations on the slope side of Thane Road. Raised beach deposits consisting of sand to boulder-sized material underlain by sand were found in the gently-sloping area where the upper portions of 5th and 6th Streets are located, in the Starr Hill subdivision (Miller 1975).

The remainder of the surficial deposits consisted of colluvium on the lower mountain slopes. The upper slopes were not mapped by Miller (1975). Some deposits were shown as stabilized landslides, such as landslides in Lemon and Salmon Creeks and along Nugget Creek (all north of the study area, but generally representative of it). These deposits reflect catastrophic events of the fairly recent past (Miller 1972) while others were shown (in 1975) as being active. Narrow slide zones were generally considered to comprise blocky talus (rock fall boulders) while other areas ranged in particle size from silt to boulders. "Rockslide avalanche" deposits containing boulders up to 30 ft. in diameter were found on the slopes in the eastern part of Gold Creek adjacent to the fluvial floodplain and on both of the slopes flanking the creek. A rubble deposit was found on the north-facing slope to the east of the "rockslide avalanche" area, south of the floodplain, described as Holocene in age, generally less than 20 ft. thick, and consisting of angular to round blocks and fragments of slate, greenstone, and granite (Miller 1975).

1.3.1.2 Bedrock Geology

Exposed bedrock was found throughout the Study Area and was generally most prominent at elevations above 750 ft. above mean sea level (amsl). Within the main downtown area of Juneau, prominent bedrock outcrops were mapped by Miller (1975), including:

- Below Main Street, mostly between 3rd Street and Dixon Street;
- Near the intersection of Irwin Street and Cope Park Road;
- Along the north and south bank of Gold Creek near the Evergreen Bowl and along the Cope Park Road; and
- On the slopes of Mt. Maria above Basin Road, 6th Street, and on the northwest end of Mt. Roberts above Nelson Street.

Bedrock geology was summarized on the USGS Geological Map of Alaska (Wilson et al. 2015). The Study Area is primarily composed of faulted interbedded metavolcanic and metasedimentary rocks. The main rock types included greenschist to amphibolite facies schist, semi-schist, and phyllite that was green, grey, and dark grey. Metamorphic grade was observed to be increasing toward the northeast. Wilson et al. (2015) noted that the rock generally weathers to platy tabular blocks and sheets. The rock was generally found to be moderately strong to strong. Localized outcrops of very strong rock were noted above Norway Point.

Field observations and background geological information suggested that, within the Study Area, bedrock foliation generally dips to northeast into the mountainside at angles ranging between 30° and 75°. In addition, two main joint sets were observed: one dipping northwest at angles between 55° and 80° and another dipping southwest at angles between 65° and 80°.

1.3.2 Previous Studies and Reports of Landslide Hazards

The All-Hazards Mitigation Plan (CBJ 2009, 2012) was referenced to understand historical landslide activity in the Study Area. The extent of vulnerable zones was referenced from the report. The term "vulnerability" is used in CBJ (2012) with respect to the people and property that are likely to be affected by possible landslide activity on or near the slopes. Swanston (1972), DMJM (1972a, 1972b), and Mears et al. (1992) were also referenced for technical details on observed landslides. Recent observations of slope activity provided by CBJ (2020b, 2020c), as well as local news reports, as described below were also taken into account for the final mapping.

Mount Juneau (Gold Creek to Mile 2.5 Near Salmon Creek Area)

Swanston's study of landslides on Mount Juneau was divided into two main sections: from Mile 2.5 to Norway Point, and from Norway Point to Gold Creek. Mile 2.5 is located approximately 150 ft. southeast of the current access to the Salmon Creek Dam and Reservoir Trail on Egan Drive, just outside the current Study Area. Distances reported by Swanston are assumed to have been measured from Gold Creek, along Glacier Avenue, Glacier Highway, and Channel Vista Drive, since Egan Drive was still under construction in 1972.

According to Swanston (1972), the most northerly pre-settlement landslide (occurring before Juneau was established in 1881) in this section was located between about Mile 2.0 and Mile 2.5 (along the present-day Channel Vista Drive and Egan Drive at the northwest end of Swanston's study area), where there was evidence of repeated landsliding and active talus creep. Reconciling the mileposts to the description of the area, that location appears likely to be the northwest end of the White Subdivision at about Mile 1.65, where Miller (1975) mapped a large unstable talus slide with a landslide of undetermined type downslope, and Mears et al. (1992) reported debris flow activity on the entire alluvial fan upslope (No. 1B on Swanston's Map 7). Miller (1975) also mapped a generally stabilized talus slide about 550 yards further north, centered roughly at Mile 1.96 (the driveway of 2280 Channel Vista Drive) with the base of the feature about 200 yards upslope.

On December 4, 2020, a debris slide was observed within the White Subdivision at the northwest end of Wickersham Avenue, reported by CBJ as originating high on the slope above Wickersham Avenue, and depositing mud and debris to about 8 ft. deep (Photo 21). Some of the debris continued downslope to Glacier Highway, resulting in a large volume of boulders and finer debris along the drainage swale immediately southeast of the building at 2020 Glacier Highway, and considerable debris blocking the concrete sump (Photo 22), directly downslope of the Photo 21 location (CBJ 2020c). Debris was also noted at 1941 Glacier Highway, the next house to the southeast. This house is located very close to the back of the lot along Wickersham Avenue, resulting in some debris spilling over the crest of the road into the lot and alongside the building, with muddy water apparently reaching the lower part of the balcony and spraying a lower side window (CBJ 2020b). The small shed at the roadside appeared to have had muddy debris about 2 ft. high against it. Some smaller shrubs and trees had some branches and bark stripped off, but the adjacent “No Parking” sign was intact. See also Technical Memo #4 for additional discussion about this slope (Appendix C, Tetra Tech 2022d).

Further southeast, two more large pre-settlement landslides were noted, one near the [former] Johnson Children’s Home where stream-cutting had dissected the deposit, and heightened debris slide and debris flow activity were noted. The channel above the former Johnson Children’s Home (which seems to have been located northwest of No. 2A on Swanston’s Figure 7), was also classified as *High* hazard (equivalent to present-day *Severe* hazard designation), apparently partly due to the presence of rockslide hazard and mainly due to accumulations of debris in the channel (DMJM 1972a), though the lower part of the slope extending to the channel was classified as potential hazard (equivalent to present-day *Moderate* hazard).

A large landslide deposit of pre-settlement age was observed just to the northwest of Norway Point, with an active V-shaped gully considered to be a source of landslide and debris slide materials from upslope and upgradient (Swanston 1972). The gully corresponds with the mapping of a landslide in Miller (1975) and appears to coincide with the gully near the AWARE shelter downslope (approximately No. 2A on Swanston’s Figure 7). Just to the southeast of that site, Swanston noted that the largest landslide in the urban area formed the ridge that comprises Norway Point, estimated the landslide at over 200 years old, and remarked that it must once have extended well into Gastineau Channel. A series of channels associated with periodic rock and debris falls or slides was noted between the lower bluff and the slope below at that location (No. 2B on Swanston’s Figure 7). Miller (1975) mapped this location as an unstable talus slope above a landslide of undetermined type extending into the channel at Norway Point.

On December 2, 2020, Juneau experienced a severe winter storm, with record rainfall of 6.54 in. in 48 hours and winds gusting up to 60 mph. By December 4, 2020, Juneau had observed one avalanche, and experienced numerous small landslides and considerable flooding. Just southeast of the White Subdivision, the AWARE shelter was one of the structures affected by a debris flow, with saturated debris and water running across Glacier Highway and down into the parking lot and the first floor of the building (Photos 19 and 20). Local news reported that employees in the building heard rumbling as the debris came down the mountain, and consequently rushed out of their offices to move their cars before they were inundated with mud (McChesney 2020). This site is understood to have experienced other events previously (email communications: December 4, 2020; T. Camery, V. Roujanski). One such event is understood to have taken place on October 19 and 20, 1998, when the AWARE shelter was flooded with muddy water, due to the landslides resulting from record rainfall (CBJ 2012). See the July 21, 2021 presentation for additional information about this slope (Tetra Tech 2021a).

Between Norway Point and Gold Creek, Swanston (1972) recorded two more very large landslide deposits originating at major breaks in the rock bluff upslope, where repeated sliding was evident, and at least one destructive debris flow was channeled into the urban area along Gold Creek. Three smaller deposits beginning at small gullies above urban areas were also noted.

On the slope between Norway Point and Behrends Avenue, Swanston (1972) observed active creep, small scale sliding, and slumping on treed slopes. Several shallow gullies and a small V-notch channel were noted, with the channel originating at an opening in the bluff above. A landslide deposit was observed along the west side of the Behrends snow avalanche track, below a small gully in the lower bluff, and estimated to be about 60 years old. A channel leading from the gully could carry landslide debris (Swanston 1972). Extensive deposits of talus and landslide debris were also noted at the lower end of the avalanche track, apparently the result of repeated landslide activity, and two major gullies were observed in the middle of the track (Swanston 1972).

Another very large landslide deposit was observed immediately southeast of the Behrends Avenue site, consisting of the debris from at least three landslide events in the form of a large (older) lobe with two smaller lobes superimposed on it. The second lobe was estimated to be over 80 years old. Debris levees present on either side of a channel located mid-deposit indicated probable activity within the preceding 10 years (Swanston 1972). Small debris slides and rockfalls appeared to be common above Coleman Street, Willow Drive, and Evergreen Avenue, where several shallow gullies were also noted. One of the gullies appeared to cut through the bluff upslope and contained a small amount of talus debris. At Evergreen and Pine Street, small debris slides and rockfall appeared to be common (Swanston 1972). At the east end of Evergreen, Swanston (1972) noted four landslide deposits, two of which pre-dated the settlement of Juneau (one very large), which originated in a major gully also associated with a snow avalanche track. This gully is understood by Tetra Tech to be the Bathe Creek gully. The other two deposits originated in minor gullies just to the west. Again, the presence of gullies was associated with the movement of debris and, in 1954, the major gully channelled two pulses of debris within an hour onto Irwin Street at the Gold Creek Calhoun Bridge (locally known as the Cope Park Bridge, and sometimes as the Irwin Street Bridge or the Gold Creek Bridge), resulting in damage to a home and filling the street with mud (Swanston 1972). Landslide activity in this area continues to the present day. For example, a mudslide on October 27, 2017, diverted the flow of water, resulting in concerns about erosion and the bridge being temporarily closed for safety (KINY Radio 2017). CBJ reported that debris entering the flume is invariably due to a side drainage that enters into the flume just upstream of the bridge. Overtopping of the flume at the weir (wooden boards at the upstream end of the flume, at the lower end of the settling basin) has not happened for about 20 years. The settling basin is cleaned out annually, from the flume to as far upstream as the parking lot, and the debris is hauled offsite (personal communications: R. Langel, C. Watts, T.Camery, V. Roujanski, R. Kors-Olthof; April 15, 2022). See also Technical Memo #2 for additional information about this slope (Appendix C, Tetra Tech 2022b).

Mears et al. (1992) indicated that debris flows were an active process at the Behrends Subdivision, where debris flows could contain rocks up to 3 ft. long, and mud and tree fragments and other vegetation had been deposited against trees. Numerous lobe-shaped deposits had been noted upslope in this area, as was also observed by Swanston (1972).

On October 19 and 20, 1998, 6 in. to 10 in. of rain fell in less than 48 hours (NOAA 1999). CBJ (2012) reported associated saturation of the soil and several related slope failures, resulting in several sections of highway being closed, and damage to homes, roads, and state trails. Within the Study Area, slides were reported along Glacier Highway in several locations, including “just north of the high school,” likely the Juneau-Douglas High School, based on an event reported in 2019 (see below).

On October 6, 2019, heavy rainfall resulted in flooding and landslides in several parts of Juneau. Debris was reported on Glacier Avenue between the Juneau-Douglas High School and the Egan Drive access road (Miller and McChesney 2019).

On December 2, 2020, record-breaking rainfall resulted in flooding and landslides in several parts of Juneau, and at least one injury. Behrends Avenue in Juneau's Highland's neighborhood, a slide resulted debris flowing down the street in two directions, extending to Egan Drive (McChesney 2020). Near the northwest end of Behrends, a stream of debris and, later, runoff water flowed downslope behind one of the houses on the upslope side of the road. The stream required ditching to divert it to Glacier Avenue (CBJ 2020b), and the debris was cleaned up from the driveway and the road (McChesney 2020). Debris was also noted at Ross Way and Glacier Avenue (CBJ 2020b). Ross Way is the connector between the northwest end of Behrends Avenue and Glacier Avenue. Additional discussion about this slope is provided in Technical Memos #2 and #4.

Evergreen Bowl (Cope Park)

The slopes into Evergreen Bowl were considered oversteepened, with bedrock dipping into the Bowl, increasing the likelihood of landslide damage. Two historical landslides were reported in Evergreen Bowl. The first initiated near the corner of 7th Street and Goldbelt Avenue (on the southwest side of the Bowl) in 1918 and resulted in a cabin sliding into the Bowl and being destroyed. The second occurred in 1935 and was described as "serious," though no details were available (Swanston 1972).

Swanston (1972) also reported that a potential rockfall hazard was present above Calhoun Street between Dixon Street and 6th Street. Since Dixon forks off upslope of Calhoun heading northwest, and 6th Street is a stub on the slope between Main Street and Calhoun/Dixon, Swanston (1972) appeared to be referring to the slope section between the 6th Street stub and Calhoun/Dixon below. Although not in Evergreen Bowl itself, this slope was roughly 150 yards due south of Evergreen Bowl and appeared to have been located along an extension of the same terrain as the Bowl, above and below Calhoun/Dixon. CBJ has reported regular landslide activity in this area (email communications: July 20, 2021; A. Pierce, T. Camery, Q. Tracy, V. Roujanski, and R. Kors-Olthof). See Technical Memo #5 for more information on this slope (Appendix C; Tetra Tech 2022e).

On October 19 and 20, 1998, 6 in. to 10 in. of rain fell in less than 48 hours (NOAA 1999). CBJ (2012) reported associated saturation of the soil and several related slope failures, resulting in several sections of highway being closed, and damage to homes, roads, and state trails, including slides in Downtown Juneau near Cope Park (Evergreen Bowl). No specific locations were reported.

Mt. Maria (Decker Hill)

Rockfall in the form of a "rock avalanche" on the cliff face of Mt. Maria (Decker Hill) destroyed several houses in 1913 and left debris consisting of angular rocks above Basin Road between 6th and 7th Streets. Angular rock debris was also found above 6th Street from Basin Road to Nelson Street and a talus cone was present behind a house at the corner of 6th and Nelson (Swanston 1972). According to Swanston (1972), the exposed rock cliff above Basin Road and the small cliff above 6th and Nelson and on the back side of Mt. Maria were high rockfall hazard zones (*Severe* in the current designation system). See further discussion of these slopes in Technical Memo #3, #6 and #7 (Appendix C; Tetra Tech 2022c, 2022f, 2022g). According to CBJ (2020c), rockfall had also been reported at 712 Basin Road in about 2009 or 2010. The observation of rockfall debris below the road at this location indicates that rockfall affecting residences downslope (southwest) of Basin Road also extended further northwest along Basin Road from the intersection of 7th Street and Harris Street.

On December 2, 2020, a "mudslide" was also reported on Basin Road (McChesney 2020). The location of the slide was not reported, but the description suggests a different type of landslide event than the rockfall previously reported along Basin Road.

Mt. Roberts

Swanston (1972) reported similar conditions on the slopes of Mt. Roberts as on Mt. Juneau. The Mt. Roberts slopes extending from the corner of 3rd and Harris streets to Thane Road experienced 11 combination slides (slides with debris slide and debris flow components) prior to 1972, three of which pre-dated the establishment of Juneau (Swanston 1972). The ages of these events are unknown. The remaining eight slides on these slopes were smaller but quite destructive (Swanston 1972).

The debris flow deposits of the three large older slides were 20 ft. to 50 ft. thick and about 200 ft. wide (Swanston 1972). The slides initiated in the upper portions of the flow paths via rock or soil failure (rockfall or debris slide) (Swanston 1972). Slide material travelled through gullies, forming deposits on the lower slopes (Swanston 1972). Evidence of other pre-settlement slides included deposits containing rocks, logs, and soil in areas between Gastineau Avenue and South Franklin Street (Swanston 1972).

Of the eight historic slides, three formed via rock/soil failure on steep slopes (>70°) that became channeled in gullies and three formed by reactivation of debris within the gullies (Swanston 1972). Two slides formed due to surcharging of water on open slopes, one of which was human-caused, and the other was due to heavy rain (Swanston 1972).

Smaller mass movements of debris were observed to be ongoing, resulting in debris building up behind rocks, logs, and other debris within 21 gullies on the Mt. Roberts slope above the city (Swanston 1972). As a result, the slopes above South Franklin Street and Gastineau Avenue were considered to be very hazardous (Swanston 1972). Swanston also tabulated a summary of numerous landslides occurring between 1913 and 1954, the most destructive of which were highlighted by CBJ (2009, 2012). Several significant landslide events within the Study Area are listed below.

Mears et al. (1992) noted that while debris flows could occur in the channels on the slopes of eastern Juneau (i.e., Mount Roberts), debris slides were considered to be the greater hazard in that part of Juneau. Numerous major debris slides that terminated in Gastineau Channel were observed to have occurred prior to the settlement of Juneau. Mears et al. (1992) observed that these large landslides had occurred when the forest cover was in an undisturbed, natural state. Thus, although destructive and frequent debris slide activity also occurred earlier in the 20th century when tree cover was less continuous than it was in 1992, Mears et al. concluded that landslides could continue to occur in Juneau, even on reforested slopes.

CBJ (2012) reported on all the major slides that resulted in fatalities and/or major damage along the slope of Mt. Roberts, as described below:

- Debris slides on January 2, 1920, between Gastineau Avenue and South Franklin Street (Gastineau Heights), killed four people and injured eight. Buildings were damage by impacts from the debris slides and/or by impacts from upslope buildings that were pushed downslope. Swanston (1972) further reported $50,000 damage; boarding house, three homes, and twelve cabins destroyed; debris broke through into Goldstein's store; and the overflow of the Alaska Juneau (A.J.) Flume. One discrepancy arose between accounts of the landslide: Swanston (1972) reported three fatalities. Swanston also reported warm weather, snowmelt, and 1.79 in. of rain in 24 hours. Mears et al. (1992) took note of the debris slide interactions with the structures. See Technical Memos #3, #5, and #7 for further information about this landslide (Appendix C).
- A Gastineau Avenue landslide destroyed one home on November 15, 1929. (No direct mention of this slide was made in Swanston (1972) or Mears et al. (1992)).
- A debris slide on October 16, 1936, between Gastineau Avenue and South Franklin Street, destroyed several buildings and buried one resident. Mears et al. (1992) noted the destruction of buildings via crushing and relocation. Swanston (1972) noted that this slide injured one woman, and damaged two houses and the Alaskan Hotel. The debris slide descended the Mt. Roberts slope, crossed Gastineau Avenue, and damaged/entered

the back side of the Alaskan Hotel (Sanborn 1914). Notably, the 1914 survey of Juneau shows the Alaskan Hotel to be located on the uphill side of Front Street. Front Street in 1936 appears to have been essentially the same as it was in 1914 (Sanborn 1914). Therefore, southeast of the intersection with present-day Front Street, the present-day South Franklin Street used to be part of Front Street. Rainfall was reported as 1.43 in. in three hours.

- On November 22, 1936, heavy rainfall again triggered a debris slide that caused 15 deaths in a residential area. Swanston (1972) reported that there had been nine people injured. Rainfall was reported as 3.89 in. in 48 hours. The slide debris covered South Franklin Street to a depth of about 10 ft. Mears et al. (1992) noted that the slide had exerted large thrust pressures against the structures while the debris was moving, and significant depositional pressures after the movement had stopped. Swanston (1972) recorded that the slide had occurred in Gastineau Heights above the Juneau Cold Storage Plant, resulting from a slope failure below the flume where a tension crack had been noticed. A contemporary news story reported that “The first slide was soon followed by a second slide, which was worse. The second slide cut a swath 100 ft. wide and ranged from 10 ft. to 40 ft. deep. The slides tore down the mountainside through a district in the vicinity of Gastineau Avenue and Ewing Street. They stopped just short of the Juneau Cold Storage Company’s warehouse on the bay side of Front Street” (Fairbanks Daily News-Miner 1936). Historical photos indicate that the slide actually ran up against the building, running up an estimated 3 ft. further up the wall of the building, with a splash zone extending even further up (ASL 2021). As noted above, the applicable portion of Front Street is the present-day South Franklin Street. An apartment house, a boarding house, and two homes were destroyed according to Swanston (1972), although the newspaper reported that the first slide had “engulfed two apartment houses, a lodging house, several small frame dwellings, and the Peterson store” as well as disrupting lights and power lines. The Peterson store was noted to be a two-storey concrete building, in the ruins of which its proprietors had died. In all, more than a dozen structures were reported to have been destroyed by the slides. See Technical Memos #3, #5, and #7 for further information about this landslide (Appendix C).
- On October 19 and 20, 1998, 6 in. to 10 in. of rain fell in less than 48 hours (NOAA 1999), saturating the soil and causing several slope failures, including slides on Thane Road. Several sections of highway were closed and homes, roads, and state trails were damaged.

Slides occurring after CBJ (2012) and relating to some of those events included the following:

- On October 6, 2019, heavy rainfall resulted in flooding and landslides in several parts of Juneau, including a landslide that covered a portion of Thane Road. A precise location for the Thane Road slide was not provided, but travel was reported as being restricted to one lane of local traffic between Miles 1 and 5 (Miller and McChesney 2019). Mile 1 is roughly the location of Snowslide Creek.
- An avalanche was reported at Snowslide Creek as a result of the winter storm of December 2, 2020 (Photo 23, CBJ 2020b). Debris flows from the channels in this path would be expected to have a similar flow direction as wet avalanches, due to the earthworks constructed on the terrain above the road.

Other Landslide Types Within the Juneau Region

The following events were noted outside the Study Area, but they are potentially relevant to the terrain within the Study Area.

Additional erosion and sedimentation, and potentially debris floods, can also be produced when a landslide deposit creates a dam across a stream, partly or completely blocking the water flow, causing the water to build up into a new pond or lake. The water can often erode a channel through the debris dam, sometimes catastrophically (Highland and Bobrowsky 2008). For example, a large landslide blocked the Inklin River (a tributary of the Taku River, about 85 mi. east-northeast of Juneau), in 1979 for about one month, creating a lake of about 27 acres in area, and later exposing about a half-mile length of debris along the river to erosion (Septer 2007). A large landslide also deposited some 20 million cubic feet of debris on much of the Taku River valley on December 24, 2020. Much of the debris appeared to have been added to the previously-existing cone, covering the vegetation there. Water was already visible along the toe of the cone, near where part of the braided stream had flowed before, although it appeared that the water was no longer in well-defined streams at that location. The debris over the remainder of the stream valley was thick enough to cover at least two of the largest stream braids but a stream was present along the toe. The full implications of the slide will remain unknown until Spring 2021, but observations thus far suggest that complete blockage of the water would be unlikely (Miller 2020).

Landslides into an impounded water body resulting from a landslide dam or a water reservoir, or into a natural lake, can also cause problems. For example, a large rockfall that occurred at Cowee Creek about 28 mi. north-northwest of Juneau on December 30, 2016 was investigated and reported by Rick Edwards of the U.S. Forest Service's Pacific Northwest Research Station. The rockfall descended into a lake at the foot of the slope, displacing 600,000 cubic yards of water. This forced a 30 ft. high displacement wave down the valley, cutting a 300 ft. wide swath and destroying some 3,000 trees as it went. The wave was recorded to be almost 6 ft. high some 8 mi. downstream (Miller 2018, Edwards 2018). Within the Study Area, such events might be more relevant as a follow-on event to a landslide dam event. Just outside the Study Area, for example, at the Salmon Creek water reservoir, such events could be directly relevant.

1.4 Landslide Mapping Results

1.4.1 Landslide Hazard Assessment

Three series of thematic draft maps were created using the surficial geology and historical air photo mapping completed for the project:

- A surficial geology map series, which also shows geomorphological processes such as debris flow, debris slide, rockfall, rock slide, soil creep, and slumping (Figures 1.3a, 1.3b, and 1.3c);
- A map series showing slope movement activity and feature changes from 1948 to 2019 based on historical air photo record analysis and fieldwork (Figures 1.4a, 1.4b, and 1.4c);
- A map series showing gullies and related changes from 1948 to 2019 based on historical air photo record analysis and fieldwork (Figures 1.5a, 1.5b, and 1.5c); and
- A landslide hazard designation map based on the refined landslide hazard designation system with *Low*, *Moderate*, *High*, and *Severe* hazard designations as described in Section 1.2.4.2.4 (Figures 1.6a through 1.6j), showing:
  - Initiation zones; and
  - Runout zones (derived from mapping of the historical landslides – see Section 1.2.4.2.5 of the report).

These maps are provided in the "Figures" section of the report. A guide to landslide and avalanche hazard designations and some additional explanations for frequently asked questions are provided in Technical Memo #4 (Appendix C; Tetra Tech 2022d).

1.4.1.1 Updated Surficial Geology

Mapping was completed at 1:2,000 to 1:4,000 scale by zooming into the photos without loss of resolution using PurVIEW. Mapping is presented at different scales in the figures for varying purposes. The scales are shown on each figure. The surficial geology map (Figures 1.3a, 1.3b, and 1.3c) provides more detailed mapping (presented at 1:11,000 scale) and more slope coverage, improving upon Miller's earlier 1:48,000 scale mapping Miller (1972, 1975).

1.4.1.2 Landslide Types

Landslide types in the Study Area include debris slides, debris flows, rockfalls, and a deep-seated bedrock slide. All hazard types are defined in the Glossary of Terms at the front of the report. For the deep-seated bedrock slide, although it was suspected that the failure surface would be located within bedrock, it is noted that insufficient evidence is available to determine the potential failure mechanism of this slide (e.g., rotational, translational), since failure has not yet occurred, nor is subsurface information available at this site. It is referred to as a "deep-seated" bedrock slide to distinguish it from the other mass movement types that were mapped.

A typical debris slide is shown in Photos 1 to 5. Debris slide deposits are generally irregular and hummocky. Within the Study Area, most debris slides were observed to be relatively shallow and located along over-steepened gully walls or lightly-vegetated upper slopes. Debris slides are most prominent in areas of existing slope colluvium or older debris flow deposits.

Debris flows are also common within the Study Area. They generally involve mobilization of saturated slope colluvium or materials that have accumulated behind fallen trees or other gully obstructions (Photos 6 to 18).

Rockfalls are ubiquitous across all slopes, so much so that its presence is noted on the surficial geology maps as a geomorphological process, but not on Figure 1.4 as discrete rockfall paths, as it is not possible to separate out individual rockfall paths (especially since much rockfall is not visible on the air photos as it does not always damage vegetation). Rockfall deposits often form relatively random piles of various-sized rock fragments whose frequency decreases with increasing distance from the bedrock outcrop (Photos 19 to 23).

In contrast, only one deep-seated bedrock slide was identified. It is located at the southern end of the study area above Snowslide Creek (Figures 1.3c and 1.6f; Photos 24 to 26). Detailed assessment of the deep-seated bedrock slide was not part of the scope of work. However, it is recommended that additional work be undertaken to better evaluate its mechanism, activity, and direction of movement. See also Sections 1.5.1 and 1.5.3.

Debris floods, as described in the Glossary at the front of this report, could occur if debris slides enter Gold Creek upstream of the downtown area. Four-foot diameter boulders were observed after a Gold Creek flood event (p. 89 of CBJ 2012). It is not clear whether that flood consisted of a water flood event or a debris flood event, nor was a date reported by the CBJ for the flood. The CBJ also noted that Gold Creek had been "a source of flooding prior to the construction of a flood control channel by the Corps of Engineers. However, since the completion of the project in 1958, the channel carries flood flows adequately and there have been no serious flood problems in the area" (p. 97 of CBJ 2012). Gold Creek presently flows through Downtown Juneau within a concrete flood-control channel that restricts the lateral movement of the creek and reduces the likelihood of flooding from water or debris floods in the downtown area (see Figure 10B, Technical Memo #4, Appendix C). See Section 1.5 for conclusions, limitations, and recommendations.

The only flood-related hazards directly addressed in this report are those that are also specifically related to landslide hazards, for example, debris flows, and where they are noted as a geomorphological process on floodplain and fluvial fan deposits (Figure 1.3).

1.5 Summary Conclusions, Limitations, Recommendations

This section of the report presents conclusions, limitations, and recommendations of the landslide hazard assessment completed in the Study Area. Historical air photo record analysis, previous study reports review, fieldwork, semi-quantitative analysis, and landslide hazard designation mapping were completed to better understand current and future landslide hazard potential.

1.5.1 Conclusions

- Surficial geology of the Study Area was updated, and landslide types were identified and mapped, including their initiation and runout zones. Landslide activity was mapped via historical air photo record review.
- Initial mapping and the historical air photo record review were used to designate potential landslide hazards on a tripartite hazard designation system as requested by CBJ, consisting of *Low, Moderate,* and *Severe* designations. However, fieldwork and mapping revealed that a fourth designation of *"High"* might be warranted. To determine this, a semi-quantitative analysis of the mapping was completed, and it was concluded that a four-part landslide hazard designation system is required to adequately represent the landslide potential in the Study Area. The landslide mapping was updated accordingly.
- Figures 1.4a, 1.4b, 1.4c, 1.5a, 1.5b, and 1.5c show areas of new landslide hazard-related activity observed on each year of imagery interpreted. Only newly active landslide or erosion features were mapped, e.g., an area of freshly-removed or newly-growing vegetation caused by debris flow activity or a new erosion feature identified on a slope. These features were accurately delineated and are shown in their exact locations. Thus, the arrow symbols shown on these figures represent actual scars or accumulations of mass movement material that were identified during the air photo analysis. The arrows may not extend all the way to the lower edge of the *Severe* hazard designation mapping shown on Figures 1.6a through 1.6j, because they are essentially a snapshot of the activity in each specific year. The activity of an individual year is not the same as the cumulative activity over many years, which is covered by the Hazard Designation mapping in Figures 1.6a through 1.6j. However, these snapshots are useful for identifying areas of greater activity and, thus, areas of higher hazard. The snapshots do not represent the actual hazard and Figures 1.4a, 1.4b, 1.4c, 1.5a, 1.5b, and 1.5c should not be used as such. Figures 1.6a through 1.6j represent the hazard potential, and therefore provide the appropriate hazard designations.
- The main landslide types in the Study Area are debris slides, rockfalls, and debris flows. The former two initiate at higher elevations and may channelize to form debris flows at lower elevations. The debris flows form fans at the foot of the mountain slopes where the debris is deposited. These landslide types, as well as landslide areas that exhibit recurring activity, form the *Severe* landslide hazard designation category. Hazards designated as *High* include steep slopes where rockfalls occur but cause less damage than in locations where the hazards are designated as *Severe*.
- The hazard of the potential deep-seated bedrock slide area is also mapped as *Severe* (Figure 1.6e). It is anticipated that if the bedrock fails here, it could produce a slide large enough to reach and enter the water. This potential should be confirmed and elucidated by further study, including geotechnical investigation and modelling. See Section 1.5.3 for further information.
- The hazard designation for landslide hazards on the fluvial fan in Downtown Juneau has been mapped as *Low*. However, debris floods can be produced when large amounts of landslide debris suddenly enter Gold Creek from higher-hazard terrain located upstream of the downtown area. Given that over 60 years have passed since the completion of the flood-control channel in 1958, it may be desirable to update the hydrotechnical evaluation of Gold Creek, including the potential for debris-flood-related hazards, and a review of the monitoring and maintenance program for the flood-control channel. See Section 1.5.3 for recommendations.

1.5.2 Limitations

- The accuracy of the hazard designation mapping is greatly dependent on the information provided by CBJ. To date, CBJ has provided a large amount of very useful information for this study which is gratefully acknowledged. However, if additional landslide hazard incident reports become available, these would help to improve the accuracy of the mapping.

- The landslide hazard designation maps include the property boundary data provided by CBJ. The accuracy of this information has not been verified by Tetra Tech, and it may need to be updated should property boundary information change.

- The boundary lines between *Low* and *Moderate*, or *Moderate* and *High*, or *High* and *Severe* hazard designations should not be considered as hard lines between designations, but rather as indications of transition zones between designations. Furthermore, the transition zone between two hazard designations might not always lie conveniently between separate properties, potentially resulting in a single property having more than one hazard designation.

- There is another important reason to consider the transition between hazard designations as a zone rather than a hard line. Geologic conditions are known to be variable, and the amount of information available from mapping using remote sensing data plus limited field-checking means that there are bound to be some areas with conditions different than those anticipated from the air photo interpretation and mapping work done to date.

- The landslide hazard boundaries and designations presented in this report do not account for current or future locations of infrastructure or people. The spatial and temporal exposure of elements at risk and their vulnerability to the hazard serve as inputs to vulnerability and risk mapping (CBJ 2012 p.7), which are not part of the scope of the current study.

- Although debris floods form part of a continuum that ranges from landslides to floods, they were not specifically considered for this report, which deals with landslides in the stricter sense. Other flood-related hazards are not directly addressed in this report, except as specifically noted herein.

1.5.3 Recommendations for Future Work

- More detailed assessment and investigation of the apparently developing deep-seated bedrock slide located near the top of Mt. Roberts (Photos 24 through 26) is recommended to determine if there is active movement, and to identify the potential mechanisms and movement direction of the slide. A bedrock geologist or geotechnical engineer experienced with deep-seated landslides should investigate the area further on foot, recording strike, dip, and other relevant features and should be asked to suggest what additional work is required to allow modelling of a potential failure in this area.

- Slope terrain modified by human activities, including roads, trails, cuts and fills, and other potential modifications affecting surface water runoff and slope loading, can have an effect on slope stability. See Technical Memo #7 for more information (Appendix C; Tetra Tech 2022g). A forestry road-deactivation format for slope review and the preparation of recommendations for proposed mitigations could be considered for future work. The intent of the work would be to mitigate or reduce the potential for damage resulting from slope instabilities that are attributable to abandoned or active infrastructure on the slope, especially linear infrastructure that tends to alter surface water drainage. It might not be possible to prevent all infrastructure-related slope instabilities but could reduce the likelihood that the infrastructure triggers slope instabilities or that it makes the effects of natural slope instabilities worse. A debris flow feature originally mapped by Swanston (1975) upslope of the southeast end of East Street should be further investigated in case a change in landslide hazard designation is warranted. This slope is presently mapped as having a *High* hazard, but the debris flow feature seems to have become active again in about 2011 (Google Street View 2022), and exposed soil still seemed to be present in 2013 (imagery from CBJ), There is also a cutline or trail upslope, so it is possible that the slope movement activity is related to a natural surface water drainage route being obstructed by the trail and water running consequently running where it should not. If this is not the case, and/or if the problem cannot be rectified, this landslide hazard may need to be redesignated as *Severe*. See Technical Memo #3 for more information (Appendix C, Tetra Tech 2022c).

- Detailed records should be kept of known landslide activity, especially landslide activity that impacts developed areas. Information collected should include the date of the event; weather associated with the event; exact location(s) affected; boundaries of affected area; thickness, type(s), and volume(s) of debris cleaned up; photos of the site (including affected upslope areas); and, if/as applicable, costs of cleanup, costs of damage to property, injury, or loss of life. Supplemental information could include observations of upslope instabilities that could later be correlated with downslope impacts, e.g., slide debris accumulating in a gully that, months or years later, might be flushed down the gully in a major storm and impact developed areas. Workers on slopes, helicopter pilots, hikers, mountain bikers, and others who happen to observe upslope instabilities would ideally have an open invitation to report their observations to the CBJ. Photos and GPS coordinates for observations would help in documenting locations and conditions, as well as assisting possible follow-up efforts for investigators to locate event sites, and track slope and gully activity.
- Periodic LiDAR and air photo flights, supplemented with digital elevation models and orthorectified imagery, would also help CBJ monitor upslope conditions.
- The potential for debris floods has been identified as a possible hazard on the Gold Creek floodplain and the fluvial fan upon which the downtown area is built. Potential hazards from floods and debris floods should be further considered in an updated hydrotechnical engineering study, with the assistance of a geoscientist experienced in slope stability to further address potential upstream debris inputs to the creek channel. A hydrotechnical study would also provide an opportunity to review the monitoring and maintenance program for the existing flood-control channel.

2.0 PART 2 SNOW AVALANCHE HAZARD ASSESSMENT

2.1 Project Description – Snow Avalanches

The Juneau area has a well-documented history of avalanche hazards affecting urban areas, including effects to residential and commercial structures, roads, and other public and private infrastructure. The CBJ requested completion of avalanche hazard mapping that shows the avalanche initiation zones, track and runout zones, and delineates the Study Area into *Low, Moderate,* and *Severe* hazard designations.

The scope of work for avalanche hazards was completed by DAC, which included mapping of avalanche hazards, field investigation, and technical analyses combined to prepare the avalanche hazard designation mapping. The following sections present the results of the snow avalanche hazard assessment.

2.2 Methodology – Snow Avalanches

2.2.1 Avalanche Magnitude and Frequency

The magnitude and frequency of avalanches depends on snow supply (frequency/amount of snowfall and wind redistribution) and terrain (slope incline, aspect, size, and shape). Seasonal snowpack structure can also affect magnitude. For example, a deeply buried weakness in the snowpack can result in large avalanches.

Avalanche frequency estimates are generally described in terms of an avalanche return period that ranges from 1-year (high frequency) to 100-years (very low frequency) (Table 2.1). Annual probability of the avalanche is the reciprocal of the return period (the annual probability of a 100-year return period is 0.01). Avalanches with return periods greater than 300-years are not typically considered in hazard mapping and are not considered in this report.

Table 2.1: Definitions of Avalanche Frequency

Average Return Period	Typical Average Return Period Range (Years)	Frequency Descriptor	Comments
Annual	<1 to 3	High	Active in most winters
10	3 to 20	Moderate	Active in major storm events or widespread avalanche cycles
30	20 to 50	Low	Long return period avalanches
100	50 to 300	Very Low	Very long return period avalanches

Avalanche magnitude is often related to frequency. In general, large destructive avalanches occur less frequently within an avalanche path, while smaller ones occur more frequently. Likewise, frequency is related to a specific location within the avalanche path. Avalanche frequency decreases with distance travelled from the starting zone down the avalanche path.

Magnitude estimates are described in terms of the Avalanche Size – Destructive Force classification included in American Avalanche Association (AAA 2016), which is based on the destructive potential of an avalanche (Table 2.2). Scaling parameters of typical mass, path length, and impact pressure are also included.

Table 2.2: Avalanche Size – Destructive Force (Adapted from AAA 2016)

Size	Description (Destructive Potential)	Typical mass (t)	Typical Path Length, m (ft)	Typical Impact Pressure, kPa (lbs/ft^2)
D1	Relatively harmless to people	<10	10 (30)	1 (20)
D2	Could bury, injure, or kill a person	10^2	100 (300)	10 (200)
D3	Could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees	10^3	1,000 (3,000)	100 (2,000)
D4	Could destroy a railway car, large truck, several buildings, or substantial amount of forest	10^4	2,000 (6,000)	500 (10,000)
D5	Could gouge the landscape. Largest snow avalanche known	10^5	3,000 (10,000)	1,000 (20,000)

Avalanche magnitude and frequency is assessed using a combination of various sources of data and evidence, including: field investigation to collect evidence such as vegetation damage and accumulated woody or soil/rock debris, dendrochronology, statistical analysis of historical records, and dynamic avalanche modelling.

When long-term, consistently well-documented historic avalanche occurrence records are available for an avalanche path, the information can be used to develop a statistical magnitude-frequency relationship. This information is combined with other information (field evidence, dendrochronology, and modelling) to assess magnitude and frequency in avalanche paths. Within the study area, 4 of the 52 identified paths included a thorough, long-term history of avalanche observations from which it was possible to establish a statistical magnitude-frequency relationship: J015 White Subdivision, J010 Behrends Avenue, T011 Snowslide Creek, and T014 Middle. Within these paths, there was insufficient observational data available to discern changes in avalanche magnitude-frequency over time, although these changes could be expected in some paths due to changing climate and/or forest cover.

The remaining 48 avalanche paths identified in the study area had insufficient long-term observational data of avalanche occurrences to be able to develop a reliable statistical magnitude-frequency relationship. For these paths, the hazard assessment considered all historical avalanche events that were available, but a higher level of reliability of data was provided by other methods and observations (as noted above), most importantly, field observations.

2.2.2 Avalanche Hazard Designation System

Several systems of avalanche hazard designation are published in guidelines or standards (e.g., CAA 2016, SLF 1984). However, there are no national guidelines or standards for the United States of America (USA). In the USA, hazard designation is typically mandated independently by jurisdiction, often a town or county. Historically, because many of these recommendations have been developed in consultation with Art Mears, P.E., they tend to be fairly consistent throughout the various US jurisdictions.

Most avalanche hazard designation systems are based upon the combination of magnitude (e.g., impact pressure) and frequency (Jamieson 2018) and use either three or four hazard designation categories or definitions.

CBJ (2012) describes three avalanche hazard designations, which were developed based on the Mears et al. (1992) recommendations and are enacted in CBJ ordinances (2001). The recommended designations were: *Low*, *Moderate*, and *High*/*Severe*. These designations were previously called Unaffected, Special Engineering, and High in Mears et al. (1992), but the *Low*, *Moderate*, and *Severe* terminology has been accepted by CBJ as the preferred terminology. This three-designation system is somewhat simpler and less conservative compared to some other systems (e.g., CAA 2016) but is considered suitable for land-use management purposes within the CBJ Study Area. Four modifications to the CBJ (2001) designation system are recommended, as outlined below.

1. The *High* Hazard/*Severe* Hazard/High Severity Zone designation should be called "*Severe*", which is consistent with the Landslide Hazard Designation System (Table 1.3) and the terms chosen by CBJ.

2. For the *Severe* hazard designation, the description should be modified to state that this hazard designation is to be applied to the locations where either the return period is less than 30 years, AND/OR the impact pressure is greater than 600 lbs/ft^2. This definition means that the *Severe* hazard designation would be applied based on whichever of these criteria extends the hazard designation to the furthest location downslope. This result is more conservative than what was stated in CBJ (2001 and 2012) and is consistent with what was stated (and presumably intended) in Mears et al. (1992) and with other jurisdictions (e.g., CAA, 2016).

3. CBJ (2001) does not provide a definition for the *Low* hazard designation, but by default (i.e., by virtue of not being designated part of the *Moderate* or *Severe* hazard designations), a *Low* hazard designation should be defined as an area where the return period is greater than 300 years.

4. Further, it is recommended that the *Low* hazard designation include areas where the impact pressures are less than 20 lbs/ft^2 (1 kPa), with a return period greater than 30 years. This designation is consistent with the CAA (2016) guidelines and is also similar to the original zoning proposed by Frutiger (1972). This term allows for the entry of non-destructive (i.e., <20 psf or 1 kPa) powder avalanche hazards into *Low* hazard areas, which is a common occurrence in the Juneau area and should be considered acceptable.

The hazard designations are defined in Table 2.3.

Table 2.3: Avalanche Hazard Designation System

Hazard Designation	Symbol	Hazard Attribute Description
Low	L	▪ Return period greater than 300 years; OR ▪ Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.
Moderate	M	▪ Return period between 30 and 300 years; AND ▪ Impact pressure less than 600 lbs/ft^2 (30 kPa).
Severe	S	▪ Return period less than 30 years; AND/OR ▪ Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

Note that there are some avalanche paths where both of the conditions are met under the *Severe* designation, for example, areas within Snowslide Creek with avalanche return period less than 30 years and impact pressure greater than 600 lbs/ft^2 (30 kPa). The *Severe* definition is intended to be inclusive of these two conditions, such that if either condition is met, then that area is considered to be within the *Severe* designation. Thus, use of the term “AND/OR” (see Table 2.3) is recommended for adoption to the avalanche hazard designation system, which differs from the definition previously adopted by CBJ (e.g., Mears 1992).

Although the *Low*, *Moderate*, and *Severe* hazard designations are not explicitly called White, Blue, and Red hazard zones in this report, as they are in Frutiger (1972), SLF (1984), Mears et al. (1992), and CAA (2016), the hazard attribute descriptions are considered equivalent and the areas are colored in the avalanche hazard designation maps accordingly.

2.2.3 Field Investigation

From September 8 to 15, 2019, Alan Jones, P.Eng., P.E., of DAC conducted a field investigation of the Study Area to collect avalanche hazard mapping field data. The field investigation was completed concurrent to the landslide field investigation described in Section 1.2.3 and relevant information between the two disciplines was shared.

The intent of the fieldwork was to identify key terrain features that affect avalanche runout, observe areas of previous avalanche occurrences, and perform a vegetation survey to gather evidence of historical avalanche magnitude and frequency, including lateral and terminal boundaries of avalanche impacts.

The field investigation was completed by field traverses throughout the project area, as well as helicopter reconnaissance to observe the project area from the air and obtain oblique photographs of the terrain. During the extensive ground-based field observation program, 573 individual locations were recorded with observations of avalanche activity, vegetation, and terrain.

Examples of evidence observed in the field of vegetation damage and patterns, include the following:

- **Flagging:** Upslope-facing tree branches have been removed by avalanches, while the downslope branches remain intact due to being protected by the stem (tree trunk), which can indicate dense and/or powder flow impact and direction (e.g., Photo 32).
- **Snapped stems with regrowth:** Indicates where avalanche impact is forceful enough to break a tree stem and the age of regrowth is used to estimate avalanche frequency (e.g., Photos 32 and 33). Tree stems snapped in the mid to upper part may indicate forceful powder flow impacts.

- **Scarring:** Avalanche impacts can gouge the upslope side of the tree, leaving a visible scar (e.g., Photo 36). Damage can also be caused by rockfall or debris flows, so sometimes it is difficult to determine the event which caused the damage.
- **Pistol butt:** An avalanche may push a tree over at an angle without completely uprooting or destroying it. If the tree survives, regrowth will occur, and it will correct itself to vertical growth. The result is a curve in the base of the tree. This occurrence can also be associated with slope movement such as a landslide or ground creep, so sometimes it is difficult to determine the event which caused the damage (e.g., Photo 33).
- **Sweeping tree:** Similar to a pistol butt; however, the tree retains a gradual bend at the base due to repeated and frequent avalanche impacts that push over, but do not break, the tree (e.g., Photo 34).
- **Trim lines:** These are distinct lateral and/or terminal vegetation age class boundaries in an avalanche path that indicate the boundary of historic avalanche damage. A path may have multiple trimlines of differing vegetation age classes, indicating a series of avalanche events of different magnitude and frequency (e.g., Photo 35). Historical air photo interpretation is used to evaluate trim lines in addition to changes observed in the field.
- **Debris:** Trees and rocks displaced by avalanches may accumulate at the end of the runout, indicating historical runout distances. This is more commonly associated with debris flows in stream channels, but extensive evidence of this nature, clearly distinct from debris flows, was observed in the larger Behrends Avenue and White paths (e.g., Photo 37). Conversely, debris transport in the Thane avalanche paths was primarily related to debris flow events.
- **Dendrochronology:** Analyzing the number and spacing of tree rings to date trees to date avalanche events (Burrows and Burrows 1976). Avalanche impacts resulting in tree damage can be observed in the spacing of tree rings, known as reaction wood. Observations of tree rings were made by taking core samples using an increment borer as well as by sectioning small trees with a bush saw. The University of Alaska Southeast is completing detailed studies using these methods in some of the project area, including the Behrends Avenue path. Results from this study have not been published to date, and were not considered in this study other than general information obtained during in-person and teleconference meetings with UAS personnel.

2.2.4 Historical Air Photo, Imagery, and LiDAR Data

Available images were used to observe changes to the terrain and vegetation over time, as they relate to snow avalanche hazards. Avalanche mapping was completed and is presented on the 2013 CBJ LiDAR imagery base with background imagery by ESRI (2020) provided where incomplete LiDAR coverage was present. The mapping includes 25 ft. topographic contours (generated from 2012 and 2013 LiDAR), and land parcels provided by CBJ. Mapping is presented on State Plane Alaska Zone 1 5001 using the NAD 83 Datum.

The topographic data was presented as 5-foot interval contours for completion of the mapping, which is sufficiently detailed to identify small micro-terrain features on the landscape. The LiDAR data was also processed to produce a slope map with 5-degree slope class intervals. This information was used to supplement the identification of avalanche starting zones (>25° to 30° terrain) and runout zones (<10° to 15° terrain) where avalanches typically slow and come to a stop. The LiDAR imagery overlain on the bare earth imagery was also used to observe small terrain features that were difficult to observe with forest cover, notably small gully features that could channel and/or deflect avalanche flow.

An orthorectified 1962 air photo series was also used extensively for the avalanche hazard mapping. This series was dated July 16, 1962, which was taken the summer following the historic March 22, 1962, destructive avalanche event in the Behrends Avenue avalanche path. This provided baseline information for mapping of this historic event and avalanche patterns in the forest cover prior to 1962.

The 1948 air photo series was also used to observe vegetation patterns up to and prior to 1948. This photo series was particularly useful for observing older vegetation damage caused by avalanche in the White, Behrends, and Thane areas prior to some of the more recent development.

Other supplied images were also reviewed as part of this study, including:

- 1902 oblique air photo of Mt. Juneau and town;
- 1926 stereo pair of Mt. Junea (US Navy);
- 1964 oblique air photo of Mt. Juneau and town;
- 1984 stereo pair aerial Mt. Junea and town;
- 1985 image of Behrends avalanche path by Dan Bishop; and
- Multiple images provided by Richard Carstensen, and available on the site: http://juneaunature.discoverysoutheast.org/, including recent images from 2021, 2022, and additional interpretive information of avalanche activity in the Behrends avalanche path.

The assessment included evaluation of the avalanche hazard observed during the 2019 field investigation and Google Earth imagery as recent as September 2022, but also included consideration of changes to the forest cover that could be observed in the historical images (e.g., 2013, 1962, 1948), additional Google Earth imagery (including various summer and winter images up to 2020), and changes inferred from evidence observed in the field. A change in, or loss of, forest cover in starting zones due to fire, disease, landslides, or climate change may result in a change in avalanche hazard, including the formation of new avalanche paths. If a change in forest cover occurs, avalanche hazard designation mapping may need to be re-assessed due to the potential change in avalanche hazard.

2.2.5 Avalanche Motion and Runout Models

Modelling of avalanche motion and runout distances was completed for all 52 avalanche paths identified in the Study Area. A higher level of intensity of avalanche modelling was completed at some paths (e.g., Behrends, Greenhouse, Bartlett 1, 2, and 3, White) where there was a larger degree of complexity and/or uncertainty due to the terrain, forest cover, historical records, and observations made during the field investigation. Also, paths that had more historical avalanche information available (see Section 2.3.3, including Behrends and White paths) warranted additional more detailed analyses than paths with limited data, as multiple observed events within a path can be used to better calibrate the model at points with known (or interpreted) avalanche return periods.

Avalanche runout distances were estimated using both statistical and dynamic avalanche models of avalanche motion and runout. Some models are better suited for particular avalanche paths or regions. In many cases, due to the continuously steep terrain to the highway and presence of a dense forest cover, the statistical models were of limited utility. By using several methods in each path, the uncertainty associated with these models due to statistical variation and input parameter assumptions can be reduced.

2.2.5.1 Dynamic Avalanche Models

Three dynamic avalanche simulation models were used: PCM (Perla et al. 1980), PLK (Perla et al. 1984), and RAMMS (Christen et al. 2008). These models are based on different physical models of avalanche motion and require different types of input parameters. PCM and PLK are one-dimensional (1D) models that output velocity of a mass along the centerline of the path. RAMMS is a two-dimensional (2D) model which outputs depth-averaged velocity across and along the path and provides a modern visual output that can be presented in map form.

The dynamic models were calibrated using the indirect calibration method, which means input parameters are guided by publications or default values for the models, and then adjusted for the region or specific path characteristics (e.g., Jamieson 2018). This is the case with the RAMMS model, which includes default values based on European data – these default values were then adjusted based on site-specific information (e.g., field evidence, historical imagery review, historical avalanche occurrences, local snow climate, and previous reports (e.g., SLF 2011)).

Table D.1 in Appendix D provides a summary of the range of model inputs used during the assessment, grouped by model and by the scale of the paths (i.e., large, medium, small). Within these ranges, there was variation in the model inputs and, ultimately, runout positions were determined by these inputs combined with other site-specific information, particularly field evidence, historical observations, review of imagery, and expert judgment. Thus, a range of model inputs are provided rather than specific model parameters associated with individual avalanche paths.

For the PCM model, the basal sliding friction value (μ) was varied between 0.2 and 0.4, increasing from the start zone to runout zone as frictional resistance increases with decreased slope, lower elevation and forest cover. For paths with large powder avalanche potential (e.g., Snowslide Creek, Behrends), simulations were also conducted with lower friction inputs (e.g., 0.155) to simulate the low frictional resistance of powder avalanches. The mass-to-drag ratio, M/D (turbulent friction) was typically initially estimated as 25% of the vertical path height or 80% of the sum of slope length, and varied between 200 and 860, as needed for model calibration.

For the PLK model, the basal sliding friction value (μ) used an initial value of between 0.25 and 0.35 but was varied during calibration. The turbulent friction (M/D) inputs were similar to the PCM model described above, but this model uses the log (M/D) value, which results in a range of 2.3 to 2.9 for the Study Area paths. The random term, R, was varied between 0.2 and 0.3, with the lower value corresponding to a lower velocity sliding mass in the smaller paths, and the higher value corresponding to a larger scale, turbulent, fast-moving avalanche mass.

The RAMMS model includes a larger number of inputs, including avalanche release depth and area, friction volume, friction return period, and friction elevations. The release depth was grouped into three general classes: 6.6 ft. (2.0 m) for the larger scale paths with higher elevation start zones, 4.9 ft. (1.5 m) for the medium scale paths, and 3.3 ft. (1.0 m) for the small scale paths. This input variable represents the average depth of release; the maximum and minimum depths of an actual avalanche would vary significantly within a release area. These values were determined using the snow climate analysis, a review of literature (e.g. SLF 2011, Jamieson 2018), and expert judgment. Release areas were interpreted based on a potential maximum (300-year) avalanche slab in each path. Figures D.1 and D.2 show map presentations of the RAMMS release areas and depths, and Table D.1 describes the range of release areas assumed, grouped by path scale.

The Friction Volume was varied between Small, Medium, and Large, and the Friction Return Period was assumed to be 300 years. These two values provide the default RAMMS friction parameters used in the modelling.

Figures D.3 and D.4 provide an example of the RAMMS model results presented on the project map, plotting the maximum velocity of avalanches in meters per second (m/s) with the avalanche path outlines shown. In general, areas with orange and red tones correspond to faster moving avalanche flows in the starting zone, track and upper runout zones, with speeds in the 25 m/s to 50 m/s range. The green and blue tones in the mid to lower runout zones shows the slower moving avalanche flows with speeds in the range of approximately 5 m/s to 15 m/s.

The reader is referred to the original papers (listed above and in the References section at the end of this report) for more details about the individual avalanche models; Jamieson (2018) also provides summary descriptions of each model and their input parameters.

2.2.5.2 Statistical Avalanche Models

The Alpha-Beta (McClung et al. 1989) and Runout Ratio (McClung et al. 1989; McClung and Mears 1991) statistical models were applied to provide estimates of extreme (i.e., 100 to 300-year) avalanche runout positions. Both models use the reference β-point where the slope's incline first decreases to 10°, moving downslope. In many areas in the Study Area, the terrain does not reach a 10° incline until either the valley bottom near the highway, or in the Gastineau Channel.

The Coastal Alaska regression parameters were applied for both the Alpha-Beta and Runout Ratio models, as described in McClung et al. (1989) and McClung and Mears (1991). Non-exceedance probabilities of 0.5 and 0.85 were applied to consider the uncertainty in the models for long-term runout positions.

Statistical models are not well suited to estimating runout in smaller, below-treeline avalanche paths, of which there were many identified in the Study Area (e.g., paths G000 to G009, J016 to J026). Thus, in some cases, where statistical models would produce unrealistically long runout distances that were not supported by other evidence, they were not given weight in the hazard designation mapping and additional reliance was placed on other methods of analysis.

2.2.6 Interviews and Discussions with Local Avalanche Experts

At various times during completion of this project between 2019 and 2022, discussions were had with local avalanche experts in order to obtain important local knowledge of avalanche path characteristics, historical events and snow, weather, and avalanche characteristics. Experts that were interviewed and/or provided data during completion of this project included (in alphabetical order):

- Kaanan Bausler
- Richard Carstensen, Discovery Southeast
- Pat Dryer, Alaska Department of Transportation and Public Facilities (AKDOT&PF)
- Bill Glude, Alaska Avalanche Specialists
- David Hamre, David Hamre & Associates, LLC
- Eran Hood, Professor of Environmental Science, University of Alaska Southeast
- Michael Janes, Avalanche Forecaster, Alaska Electric Light & Power (AELP)
- Tom Mattice, Emergency Programs Manager at CBJ
- Erich Peitzsch, PhD, U.S. Geological Survey, Northern Rocky Mountain Science Center
- Dr. Gabriel Wolken, Manager, Climate and Cryosphere Hazards Program, Alaska Division of Geological & Geophysical Surveys

The authors would like to thank these individuals for their time and data/information contributions to this project, and for important discussions on the Juneau avalanche hazard history. Also, we would like to thank the Juneau public for questions and discussions received during the public consultations, and review comments by anonymous reviewers for CBJ, which required the authors to critically consider the work presented, improve the report content between report drafts, and clarify concerns that were raised. Both the expert and public contributions to this project greatly improved the results of this work.

2.3 Background Data Review – Snow Avalanches

2.3.1 Previous Studies of Avalanche Hazards

A review was completed of previous studies and documents related to avalanche occurrence, mitigation, and hazard designation mapping for the CBJ dating back to 1949. Initial avalanche hazard mitigation options were proposed by Hart (1967), with the recommendation of house removal in the *High* hazard areas along Behrends Avenue.

LaChapelle (1968) made similar recommendations for the Behrends and White Subdivisions, and recommended completion of a survey of geophysical hazards. Various deflection structures were discussed in the Hart (1967) and LaChapelle (1968) reports as potential avalanche hazard mitigation options, but it was acknowledged that there was a large degree of uncertainty regarding the effectiveness of these structures. Deflection structures are typically earth fill structures that are constructed in the avalanche runout zone to deflect or constrain much of the flow of avalanches (Jamieson, 2018).

The first avalanche hazard designation mapping completed in the Juneau area was by Frutiger (1972) who designated hazard zones as White Zone (no hazard), Blue Zone (potential hazard), and Red Zone (high hazard). This hazard zone mapping was based on similar methods that were used in Switzerland at that time.

Davidson et al. (1979) completed provisional snow avalanche potential mapping of the Juneau area (B-2 Quadrangle) that included the entire Study Area. Areas were delineated into High to Moderate Potential (1- to 5-year return periods) and Moderate to Low Potential (areas where avalanches may occur every 5 to 100 years). Within the Study Area, most areas immediately upslope of the highways (Egan Drive and Thane Road) were identified as High to Moderate Potential. The scale of mapping presented in that report was of limited use for the current study.

The Frutiger (1972) mapping was re-evaluated by Art Mears, Doug Fesler, and Jill Fredston (Mears et al. 1992) with changes to the hazard zone definitions to include High Severity Areas (Red Zone), Special Engineering Areas (Blue Zone), and Unaffected Areas (White Zones). Mears et al. (1992) updated the hazard zone boundaries based on long-term historical records and field investigations. The hazard mapping in these two reports was limited to the Behrends Avenue and White Subdivision avalanche paths.

The CBJ All Hazards Mitigation Plan (CBJ 2012) provided a summary of the avalanche hazard mapping completed up to 2012, along with avalanche occurrence records and avalanche path descriptions. Hazard mapping along Thane Road was included in this report, and an Avalanche Hazard Areas map was presented on the city lot plan based on various mapping data sources, which delineated High Hazard – Zone A and Moderate Hazard – Zone B areas (further definition of these zones was not available on the map).

The most recent avalanche report for the CBJ was prepared by SLF (2011). The purpose of this report was to provide mitigation recommendations to reduce the avalanche hazard to the Behrends Avenue and White Subdivision areas. The various mitigation options recommended in this report included evacuation plans, avalanche forecasting, mitigation structures in the White Subdivision area, and a government buyout of endangered homes. As has been recommended since LaChapelle in 1968, SLF emphasized that new buildings should be forbidden in *Severe* hazard zones, and appropriate mitigation should be designed into any new building in the special engineering zones. Although detailed avalanche hazard designation mapping was not the mandate in this report, a comparison was made between the previous mapping and the results of their modern avalanche dynamics models (RAMMS and AVAL-1D). A summary of this comparison is discussed in Section 8 of the SLF report, with the most significant adjustments suggested for the Behrends Avenue path (SLF 2011).

This summary of previous avalanche studies presented above is intentionally brief. For a more comprehensive summary of the historical avalanche reports, refer to SLF (2011).

2.3.2 Concurrent Studies

Dr. Eran Hood of University of Alaska Southeast (UAS) and Dr. Gabriel Wolken of the Alaska Division of Geological & Geophysical Surveys are leading a study of the history of avalanches in the Juneau areas (CASC 2018). According to the UAS project information, their goal is to collect samples of wood from trees that had been exposed to avalanches, which will be used to understand avalanche history in the Juneau area. After an avalanche, impacted trees continue to grow and heal, resulting in dark rings that can be dated to create a time frame of past avalanche events. Their work aims to understand how climate change might impact the frequency and intensity of avalanches in the future. Their project includes sites on Mt. Juneau and particularly the Behrends avalanche path, which should prove beneficial to the project in better understanding older avalanche events that may have occurred in the area.

Currently, the research team is continuing dendrochronological analyses of more than 500 samples and have not yet published results (Dr. Eran Hood, pers. comm. February 2022). As of April 2022, Tetra Tech – DAC are not aware of any published articles summarizing the project results, and UAS expects to start publishing results later in 2022 during the final year of the project. Accordingly, this report only considers information provided by UAS during in-person and teleconference meetings.

Dr. Gabriel Wolken's work includes completing high resolution LiDAR surveys of Mt. Juneau and Mt. Roberts to assess the distribution and depth of snow, as part of a collaborative research project with the UAS, as described above. A sample of snow depth data was provided for Mt. Juneau, which is discussed in the snow climate analysis is Section 2.3.4. Published results from their research was not available at the time of completion of this report.

2.3.3 Historical Avalanche Summary

Previous studies provided summaries of historical avalanche occurrence events in the Study Area. A table of historical events for the Behrends Avenue and White Subdivision paths was provided in CBJ (2012), which was originally presented in Mears et al. (1992). The same authors submitted a report to the Alaska Department of Transportation (Mears et al. 1991) which outlined avalanche occurrence along Thane Road. Additional data was available by correspondence with Juneau-based experts (e.g., Michael Janes, AELP; Pat Dryer, Alaska DOTP&F; Tom Mattice, CBJ; Bill Glude), and observations of imagery and video, from which it was possible to update with additional information up to 2022 in the Behrends and Snowslide Creek avalanche paths, plus some historical observations in other paths (e.g., Bathe Creek, Chop Gully). However, for the most part the remainder of the avalanche paths in the Study Area had limited avalanche observation data available, which limits a summary of events beyond what was provided in CBJ (2012).

The Behrends Avenue and White avalanche paths have the most recorded historical avalanche events in the Study Area. The history of the Behrends Avenue path extends back to 1890 where an avalanche event was described as reaching tidewater in the area presently occupied by the Aurora Basin Small Boat Harbor (Mears et al.1992). Since that time, two more events were reported to have reached tidewater from the Behrends path. The main deposit of the avalanche event in 1926 was reported to have stopped 300 ft. above Glacier Highway (measured vertically), with one finger of debris blocking the road and reaching tidewater. The best documented event was the March 22, 1962, avalanche when damage resulted to many residential structures, vehicles, and city infrastructure (CBJ 2012). Only the powder component of this event reached tidewater while the dense flow component stopped above Behrends Avenue. SLF (2011) Section 6.2 provides a detailed description of this event. As described in these previous studies, avalanches have repeatedly blocked roads and damaged structures either with dense flow or powder avalanches, and numerous other large avalanche events have stopped above, but close to, the Behrends Avenue subdivision.

Additional data and observations were provided by Richard Carstensen (pers. comm. March 2022; http://juneaunature.discoverysoutheast.org/) and others regarding avalanche deposition in Behrends path during events in 1985, 2017, 2021, and 2022. Observations of these four events were included in our analyses of the Behrends path but had limited effect on the interpreted magnitude-frequency relationship or runout position of extreme avalanches due to the many other events in the dataset (total of 27 observed avalanches during 1890-2010, which results in an average return period of 18 years to Behrends Avenue). Of these more recent events, the 1985 avalanche was the longest running and largest event, which impacted and damaged one residential structure on Troy Avenue, and stopped short of several others, reaching within approximately 135 ft. of Behrends Avenue (see photos in Technical Memo #4 in Appendix C).

The recorded history for the White Subdivision path extends back to 1962 when an avalanche was reported to have stopped just upslope of Glacier Highway. LaChapelle (1968) also mentioned that an avalanche reached the Glacier Highway in the 1930's; however, due to the lack of other observations between 1930's and 1962, that observation was excluded from the frequency analysis. Since 1962, four avalanches were reported to have damaged structures (one event in 1981, two events in 1985, and one event in 1990). An additional four events are reported to have stopped just above the subdivision. An event in 1991 was reported to have reached Wickersham Avenue. The SLF (2011) estimates a return period to the Tow residence (1940 Sutherland Drive) is approximately 5 years; our analysis closely agrees showing a 7-year return period to this elevation (100 ft). They also suggest a return period of 10 years to the Glacier Highway in the White path. Our estimate shows a return period to Glacier Highway closer to approximately 30 years, as there has only been a single event recorded to reach the highway (1930's), and the 1962 event extended "nearly to the edge of the highway in the vicinity of the present-day grey condominium". Without additional recorded events to Glacier Highway this is interpreted to be close to a 30-year return period, not 10 years as suggested in SLF (2011).

Avalanche occurrence data for the Thane Road paths was summarized by Mears et al. (1991), which described avalanches in Snowslide Creek (T011) and Middle Path (T014) reaching tidewater. Snowslide Creek reached tidewater on six occasions during 1910 to 1991 (1910, 1923, 1924, 1928, 1985, 1989), suggesting an approximate return period of 10 years to tidewater during that observation period. However, it is expected that there are many additional events missing from the record of the high-frequency Snowslide Creek path. The 1989 event impacted and destroyed conductor spans and "deposited debris on water 2/3 the distance across Gastineau Channel" (Mears et al. 1991).

Since 1989, at least 10 avalanche observations were available for the Snowslide Creek path, including events in 2007, 2009, 2013, 2017, 2020, 2021, and 2022. Our frequency analysis of Snowslide Creek for the period of 1910-2022 confirms an annual frequency of avalanches to Thane Road, which agrees with the CBJ (2012) assessment of 1.2 years and is consistent with local observations of the high-frequency nature of this path. Some events, e.g., the March 4, 2021 controlled avalanche that was recorded with a video (https://www.youtube.com/watch?v=7c5qND3tALQ; https://weather.com/storms/winter/video/alaska-avalanche-caught-on-camera) clearly reached tidewater, with dense flow reaching the channel and powder flow travelling far out onto the channel by hundreds of feet.

Middle Path (T014) reportedly reached tidewater once during this same observation period in 1953, implying an approximate 50-year return period for this path. However, given the large size of this path, steep terrain to Thane Road and vegetative evidence, the return period for this path to tidewater is interpreted to be significantly lower (i.e., more frequent) than reported, and the hazard boundary was mapped accordingly. An artillery-control event on January 25, 1989, blocked the road 20 ft. deep by 500 ft. long, hit four AELP structures and destroyed one and two conductor spans (AELP observation data). This highlights the infrequent, but potentially destructive nature of the Middle Path, which is partially mapped in this study (the Study Area boundary was located partway through the path by CBJ).

One event was recorded in 1974 in the T009 Garbage dump path that blocked the road 15 ft. deep by 75 ft. wide, impacted a DOT&PF bulldozer and another vehicle, and destroyed trees. The lack of subsequent observations in this path implies a relatively long return period of T009 reaching the road, interpreted to be greater than 30 years.

There were no other historical records available of avalanches reaching tidewater other than the paths described above. However, potential for future events to reach tidewater in other paths is possible for long return period events (e.g., 100 to 300 years), as indicated by the Avalanche Hazard Designation Map shown in Figure 2.3a (Avalanche Hazard Designation Mapping Overview). Additional paths identified with potential to reach tidewater include: J015 White, J011 Greenhouse, T007, West AJ, T008, T009 Garbage Dump, T012, T013.

2.3.4 Snow Climate Analysis

Juneau is affected by a maritime snow climate which is characterized by relatively mild temperatures and relatively heavy precipitation (McClung and Schaerer 2006). Juneau is situated in the inside waters of the eastern coast of the Gulf of Alaska, and is exposed to Pacific storm systems which bring the bulk of the precipitation. While this maritime influence predominates, Coleman (1986) notes that Juneau is also periodically influenced by relatively cold and dry polar/arctic air masses (continental snow climate) as well as transitional weather when the large-scale weather patterns are shifting (transitional snow climate). Continental snow climate influence promotes the development of persistent weak layers in the snowpack, which can result in deep slab avalanche release.

Weather station data in the Juneau area dates to 1890 and several of the previous avalanche studies include a climate analysis. Mears et al. (1992) estimated that the snowfall at the starting zone elevation was double the amount at sea level and that, when wind loading was factored in, accumulation in the starting zones could be four to five times greater than at sea level. SLF (2011) agreed with this estimate of 240 in. to 300 in. of potential snow accumulation in the starting zones, potentially resulting in average slab avalanche release depths of 60 in. to 84 in., with extreme events reaching maximum depths of 84 in. to 156 in. Mears et al. (1992) also stated that the area is subject to extreme temperature fluctuations which play a significant role in the development of weak snow layers that act as failure planes. Mears et al. (1992) stated that the Behrends Avenue path and the White path are subject to intense loading from strong north to northeast outflow winds, common during periods of arctic air mass influence.

Long-term snow supply estimates were obtained using data from four nearby snow monitoring sites: Juneau Airport, Juneau Downtown, Eaglecrest Base, and Eaglecrest Top of Ptarmigan.

A snow climate analysis was used to derive statistical estimates for the height of snow (HS). Annual maximum values from each station were fit to a Gumbel extreme value distribution to obtain the theoretical maximum HS for given return periods (Table 2.4). The estimated HS was then used to generate regression equations that allowed the estimation of HS at starting zone and runout elevations at a given return period (Figure 2.3.4-1). These values were in good agreement with previous studies (Mears et al 1992; SLF 2011).

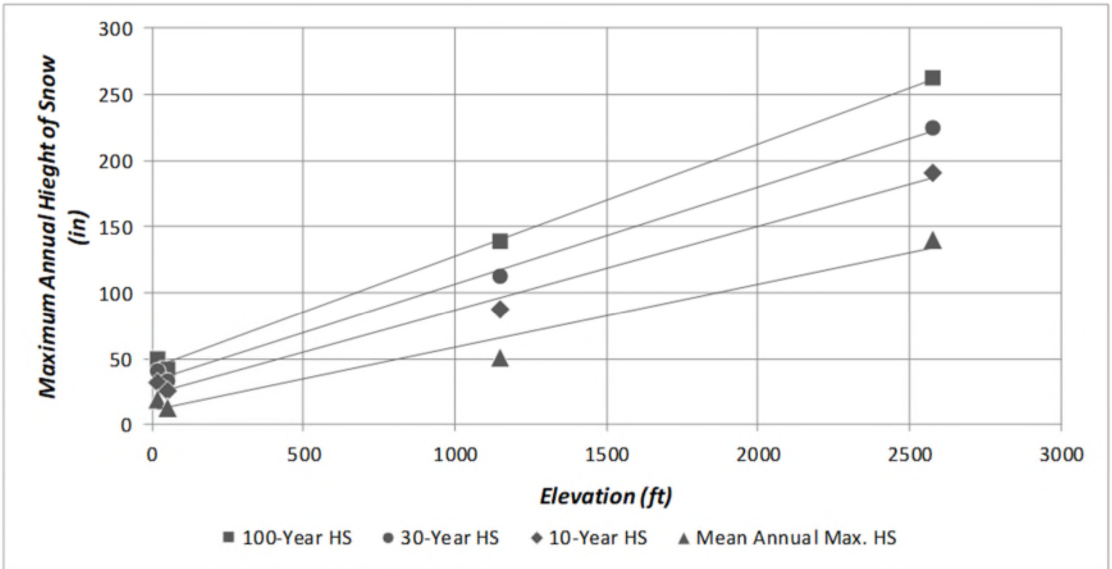
Mt. Roberts Tramway at 1,736 ft. elevation within the Study Area also provided snow data but only has a record of six years as of April 2022, which is insufficient for a robust statistical analysis. Reportedly (Michael Janes, AELP, pers. comm.) this data extends back to 2010, but at the time of this report was not made available to the authors. Generally, this data appeared to be representative of snow depth values when compared to the neighboring stations (Juneau Airport, Juneau Downtown, Eaglecrest Base, and Eaglecrest Top of Ptarmigan), and plotted well within a regression relating maximum snow depth to elevation. Additional data reviewed from 2020 to 2022 showed significantly deeper snow depths at the Mt. Roberts Tramway than the previous three years' data, with a maximum snow depth of 165.9 in. in the winter of 2020-21. This plotted close to a 30-year statistical maximum snow depth value for 1736 ft. elevation within the Gumbel extreme value distribution and consistent with data from the analyzed stations. Thus, this data was excluded from the current analysis, but should be considered for use in future years as additional data becomes available.

The snow climate information presented in this section was considered in combination with terrain and elevation of individual start zones and previous studies such as SLF (2011) to determine the average avalanche slab release depth for use in the RAMMS model. Values were varied between 3.3 ft. (1 m) for smaller, low elevation paths (e.g., Gastineau Avenue avalanche paths) up to 6.6 ft. (2 m) for the larger, higher elevation paths (e.g., Behrends, Snowslide Creek). The maximum slab depth could vary considerably within a start zone depending on the shape of the terrain and exposure to wind transported snow (conceivably as high as the SLF (2011) values described above), but the values of 3.3 ft. to 6.6 ft. (1 m to 2 m) are suitably representative of the average slab depth that could be observed across the full extent of a start zone in a Maritime snow climate (CAA 2017).

A LiDAR survey of snow depth in March 2021, north of Juneau in paths J000 to J026 showed highly variable snow depths consistent with extreme snow heights reported in starting zones of 6 to 8 meters (CBJ, 2012) and deeper in some gullies where avalanche deposits had accumulated such as J010 Behrends Avenue and J003 Gnarly. Depths varied to as little as zero snow cover below 1,230 ft elevation and in scoured areas at ridgetop with large areas between 1 m and 2 m in depth consistent with snowpack estimates (SLF 2011). This supports the use of average avalanche release depths of between 1 m and 2 m with the expectation that the height of the crown at the site of some slab fractures will be greater in some, more loaded areas and much less in others.

Table 2.4: Summary of Weather Station Analyses for Annual Maximum HS (in.)

Station Name	Juneau Airport	Juneau Downtown	Eaglecrest Base	Eaglecrest Top of Ptarmigan
ID	USW00025309	USC00504094	-	-
Elevation (ft.)	16	49	1148	2579
Years of Record (N)	1937-2022 (77)	1966-2021 (47)	1997-2022 (26)	1985-2018 (33)
Mean Annual Max. HS (in.)	19	13	54	140
Standard Deviation	10	9	29	39
Maximum Observed HS (in.)	41	39	123	216
10-Year HS	31	25	92	191
30-Year HS	40	33	117	225
50-Year HS	44	36	129	241
100-Year HS	49	41	144	262



$HS_{100} = 0.0848(Elev) + 42.733 \quad [R^2 = 0.998]$ $HS_{10} = 0.0632(Elev) + 23.817 \quad [R^2 = 0.992]$

$HS_{30} = 0.0736(Elev) + 32.913 \quad [R^2 = 0.997]$ $HS_{Mean} = 0.0478(Elev) + 10.353 \quad [R^2 = 0.970]$

Figure 2.3.4-1: HS vs. Elevation for Annual, 10-year, 30-year, and 100-year Return Periods. Regression equations are provided below that relate the statistical annual maximum HS as a function of elevation for 10-year, 30-year, and 100-year Return Periods. Updated April 2022.

2.4 Avalanche Mapping Results

2.4.1 Avalanche Path Mapping

Individual avalanche paths were mapped using polygons to show the estimated 300-year boundaries for destructive avalanche flow (i.e., greater than Destructive Size 2, D2) for all avalanche paths within the Study Area. A total of 52 unique avalanche paths were identified, mapped, and presented in the Avalanche Path Mapping.

Avalanche Path mapping is presented in a series of figures included with this report, including:

- Figures 2.1a and 2.1b: Avalanche Path Mapping Overview. Two map sheets at 1:12,500 scale.
- Figures 2.4a through 2.4j: Avalanche Path Mapping Detail. 10 map sheets at 1:5,000 scale.

The Avalanche Path Mapping Overview presents all the paths on two map sheets at a scale such that the entirety of the avalanche paths from start zone to runout zone can be observed.

The Avalanche Path Mapping Detail presents the avalanche paths at a greater level of detail so that individual features can be observed in the start zone, track, and runout zones of each path. Both sets of maps are presented on the 2013 CBJ LiDAR imagery base with background imagery by ESRI (2020) provided where the LiDAR coverage was incomplete. The mapping includes 25 ft. topographic contours (generated from 2012 and 2013 LiDAR), and land parcels provided by CBJ.

The avalanche path naming convention from CBJ (2012) was adopted for this study, and newly labelled paths were assigned names in sequence from previously named paths. Areas with avalanche paths that were previously identified but not mapped in detail and/or labelled include paths on Mt. Juneau (J016 to J026) and above Gastineau Avenue (G000 to G009).

The Study Area can be generalized into two areas, with a boundary along Gold Creek serving as a geographical divide. The northern section includes avalanche paths that start on the southwest- and south-facing terrain below Mt. Juneau, and below the ridge that extends west from Mt. Juneau to the Salmon Creek valley. This section includes 25 avalanche paths identified as J000 to J005A and J010 to J026 ("J" representing Mt. Juneau). Paths J006 through J009 are located upstream of the Study Area in the Gold Creek valley and are thus not included in this project mapping. Previous mapping identified avalanche paths as far north as J015 White, so Paths J016 to J026 are newly-mapped and labelled paths. Some of these had previously been identified in the Frutiger (1972) mapping but were not formally labelled in the mapping presented in CBJ (2012).

The southern section is the Mt. Roberts area and includes 27 avalanche paths identified as G000 to G009 ("G" representing Gastineau) and T000 to T014 ("T" representing Thane). The Gastineau paths had not been mapped in detail or represented on the CBJ (2012) mapping, although their history of producing destructive avalanches has been documented in several reports. The Thane paths were previously identified and mapped (CBJ 2012), but many were previously shown as not having an effect to the road or developed areas. Where field observations, historical records, historical imagery review, and/or modelling indicated these paths were capable of travelling past Thane Road, the boundaries were extended accordingly. At least two paths have a history of reaching tidewater (T011 Snowslide Creek and T014 Middle), and several more were mapped to have potential to reach tidewater (e.g., West A-J, Garbage Dump, T012).

All of the paths between T001 and T014 Middle were mapped as being capable of reaching Thane Road, although the historical records presented in Mears et al. (1991) only indicate avalanches reaching Thane Road at T009 Garbage Dump and to the south.

This polygon mapping provides a complete inventory of avalanche paths capable of producing destructive avalanches within the Study Area and, in addition to being used as an input into Avalanche Hazard Designation Mapping, could be used for future record-keeping when documenting avalanche events (i.e., as an avalanche atlas).

2.4.2 Avalanche Hazard Designation Mapping

Avalanche Hazard Designation Mapping was completed that designates areas as *Low*, *Moderate*, or *Severe* as described in Section 2.2.2. This mapping is presented in a series of figures included with this report, including:

- Figure 2.3a and 2.3b: Avalanche Hazard Designation Mapping Overview. 2 map sheets at 1:12,500 scale.
- Figure 2.4a through 2.4j: Avalanche Hazard Designation Mapping Detail. 10 map sheets at 1:5,000 scale.

Each defined avalanche path has an area of *Severe* hazard, which typically corresponds to the initiation zone and track area where avalanches occur with a higher frequency (return period of less than 30 years), and an area of *Moderate* hazard which has a lower frequency (between 30 and 300 years) and lower impact pressure (less than 600 lbs/ft^2). Areas located outside of the identified *Severe* and *Moderate* hazard designation are defined as *Low* hazard areas, where either low frequency (greater than 300 years) or low impact pressure (less than 20 lbs/ft^2) hazard (or no hazard) exists. *Low* designation areas are also labelled on the maps.

Severe avalanche hazard areas are shown in a red tone, which correspond approximately to the Red Zone designation in other jurisdictions. The *Moderate* avalanche hazard area is shown as a blue tone, again corresponding approximately to the Blue Zone designation in other jurisdictions. The corresponding red (boundary between *Severe* and *Moderate* hazard) and blue lines (boundary between *Moderate* and *Low* hazard) are presented as continuous lines due to the overlapping avalanche path track and runout zones. As is evident on the Avalanche

Hazard Designation Mapping, avalanche hazard (in the north to south direction) is continuous in the Mt. Juneau (north) area, and nearly continuous in the Mt. Roberts (south) area.

Where the break in individual path mapping exists on the north end of Mt. Roberts, between avalanche paths G001, G000, and the Study Area boundary, a Moderate designation was applied, with the lower limit of this designation determined by field observations, LiDAR data analysis, and expert judgment. Thus, an area assigned a *Moderate* hazard designation was extended northwards from G000 to include steep terrain on the flanks of Mt. Maria (Decker Hill) and the steep north-facing terrain on the hillside above Gold Creek, excluding the gently sloping terrain at the top of the hill. This Moderate hazard designation boundary follows approximately along the 375 ft. contour line extending north from G001.

2.4.3 Changes Made for the Current (April 2022) Report Update

During updating of this report from previous draft reports presented to CBJ, large amounts of additional new data were considered and evaluated in updating of the report. New data were considered and evaluated in updating of the report, but in general includes information obtained during the public consultation period in 2021, and new data provided by experts and obtained during interviews. This section provides a brief overview of the significant changes made in this report and the presented avalanche hazard mapping, listed from south to north.

- T011 Snowslide Creek: Additional avalanche events observed during 2007 to 2022 (15 years) were added to the frequency-magnitude analysis. Additional information that was evaluated included avalanche event observations (e.g., information from CBJ and observed on recent Google Earth imagery), and discussions with Mike Janes (AELP) and Pat Dryer (AKDOT&PF). Additional runout analyses were completed using this updated dataset – this only had a minor effect on the results and slightly decreased the runout position of the Severe (red) hazard line in the Gastineau Channel.

- West A-J: Additional imagery years were reviewed, and additional modelling and evaluation were completed. The *Severe* (red) hazard boundary was widened immediately upslope of Thane Road to reflect historical observations.

- T003 Union Oil: The path was incorrectly labelled in previous draft reports (labelled as T004 previously); local expertise correctly identified this path.

- J004 Chop Gully: Local observations indicated Basin Road was buried by avalanche debris up to 10 ft. deep, and other locals reported three similar older events reaching Basin Road, with powder avalanches extending well beyond Basin Road up towards the ridgeline. The *Severe* (red) line was shifted between 50 ft. and 75 ft. upslope of Basin Road based on this information and additional review of modelling results, over an approximately 500 ft. long section of Basin Road. This did not affect the location of the *Moderate* hazard line in Chop Gully, which is also upslope of Basin Road.

- J001 Bathe Creek: This path has a long and complicated history and presented a challenge in terms of avalanche modelling and interpretation of the results, especially given the limited number of historical observations available. Michael Janes of AELP provided additional information and review of events that reached the Flume Trail in 2007 and 2012 (see Technical Memo #4 in Appendix C) that reached past the road and indicated greater spreading potential of deposits once they reached this road. Michael Janes indicated that avalanches in Bathe Creek reach the road every year, and cover the gate, and could deflect subsequent avalanches either side of the gully. These observations were considered by expanding the *Severe* (red) hazard line laterally at the road, and further down slope past the road in two distinct gullies. The *Moderate* (blue) hazard line was also widened to reflect long-term (e.g., 100- to 300-year) potential powder avalanche hazard associated with dense flows, and lateral spreading.

- J010 Behrends Avenue: Additional historical avalanche events were added to the database and frequency-magnitude analysis, including more recent events during 2017, 2021, and 2022, based on discussion with Richard Carstensen and Michael Janes (pers. comm. 2022), as well as review of additional photographic evidence provided. Additional analyses on Behrends path with this data did not result in a change to the long-term (e.g., 30- to 300-year) avalanche hazard lines, and the *Moderate* and *Severe* hazard lines were not changed.

- J011 Greenhouse: It was suggested that the location of the *Severe* and/or *Moderate* hazard lines in the Greenhouse path were overly conservative and not reflective of the historical events in this path. Additional, older photo series were reviewed that showed the Greenhouse path (e.g., 1926, 1964, and 1948), additional analyses were completed, including a thorough evaluation of field observations, photographs, and modelling. Based on this additional review, it was determined that the *Severe* and *Moderate* hazard lines as previously presented appropriately reflect the long-term (100- to 300-year) avalanche hazard potential in the Greenhouse path. Only minor changes to the *Severe* and *Moderate* hazard lines were completed, including extending the *Moderate* hazard line slightly further into the channel by approximately 60 ft. to 70 ft.

- J015 White: Added more recent avalanche observations into the database and frequency-magnitude relationship, and refined the location of historical avalanche events prior to 1991. Updating of this information and further analyses resulted in minor changes of the hazard lines; specifically the *Severe* and *Moderate* hazard lines were extended eastwards towards the channel 25 ft. and 65 ft., respectively. The width of the lines remained unchanged, and thus did not change the interactions with property lines.

2.5 Summary, Conclusions, Limitations, Recommendations

This section of the report presents conclusions, limitations, and recommendations of the avalanche hazard assessment completed in the Study Area.

2.5.1 Conclusions

- Avalanche hazard mapping identified 52 unique avalanche paths, each of which includes delineation of *Severe* and *Moderate* hazard areas. Areas located outside of the *Severe* and *Moderate* hazard areas are, by default, designated as *Low* hazard areas. Geographically, the paths were divided into three areas: Mt. Juneau (25 paths), Gastineau (11 paths), and Thane Road (16 paths).

- The level of assessment completed to determine the avalanche hazard designation lines presented in this report is considered suitable for CBJ to determine whether or not land areas could be affected by snow avalanche hazards, according to the *Low*, *Moderate,* and *Severe* hazard designations.

- Continued use of the three-avalanche hazard designation system is recommended, including *Low*, *Moderate*, and *Severe* hazard designations. These designations are based on the expected return period and impact pressure of avalanches, with threshold return periods at 30 and 300 years and threshold impact pressures at 20 lb/ft^2 (1 kPa) and 600 lb/ft^2 (30 kPa).

- Four modifications to the current CBJ designation system (CBJ, 2001) were recommended to clarify and make the system more consistent with systems used in other parts of the world. These modifications are summarized in Section 2.2.2, but in summary include: (1) *High* Hazard/*Severe* Hazard/High Severity Zone designation is changed to "*Severe*"; (2) the *Severe* designation is modified to include both return period and impact pressure criteria by use of an "AND/OR" statement; (3) a definition is provided for the *Low* hazard designation; and (4) *Low* hazard designation is expanded to consider low impact pressure events (less than 20 lb/ft^2 or 1 kPa), which is important for powder avalanche hazards.

2.5.2 Limitations

- Avalanches are complex natural phenomena and there is considerable uncertainty in the estimates of frequency and magnitude and potential snow avalanche effects described in this report. To the extent possible, uncertainty has been reduced in estimates of magnitude, frequency, runout distance, and impact pressure by combining and appropriately weighting results from the following methods: terrain characteristics observed during the field review; historical observations of avalanches; digital imagery and historical air photos; analysis of topographic data; snow supply and regional climate data; application of statistical and dynamic models of avalanche motion. Information provided by these methods was combined with experience and judgment to complete the work presented in this report.

- The boundary lines between the *Low* and *Moderate* or *Moderate* and *Severe* avalanche hazard designations should not be considered as hard lines between designations, but rather as indications of transition zones between designations. Furthermore, the transition zone between two hazard designations will usually not lie conveniently between separate properties, potentially resulting in a single property having more than one hazard designation.

- The avalanche hazard designation maps include the property boundary data provided by CBJ. The accuracy of this information has not been verified by DAC, and it may need to be updated should property boundary information change.

- The avalanche assessment was not completed to a level considered suitable for determining specific avalanche hazard mitigation needs for an individual property; for example, building design to protect against avalanche hazards or structural avalanche defenses. Assessment of mitigation measures within a specific land parcel should be addressed with additional, site-specific investigation(s) to assess potential impact pressure, avalanche flow dynamics (e.g., type, flow thickness) to inform structure design.

- A change in, or loss of forest cover in starting zones due to fire, disease, landslide, or climate change may result in a change in avalanche hazard, including the formation of new avalanche paths. If a change in forest cover occurs, avalanche hazard designation mapping should be re-assessed.

- The avalanche hazard boundaries and designations presented in this report do not account for current or future locations of infrastructure or people. The spatial and temporal exposure of elements at risk and their vulnerability to the hazard serve as inputs to vulnerability and risk mapping (CBJ 2012 p.7), which are not part of the scope of the current study.

2.5.3 Recommendations for Future Work

- The Avalanche Path Mapping should be used to develop a database for improved record-keeping of avalanche events within the Study Area. This database is important to improve the understanding of the magnitude-frequency relationship, which, in turn, is a critical input to hazard designation mapping and the design of avalanche defences. Recommended fields to record include the avalanche path name, date, time, estimated avalanche destructive size, and runout distance related to a fixed reference point (e.g., a road or power transmission line) for each path (AAA 2016).

CLOSURE

We trust this document meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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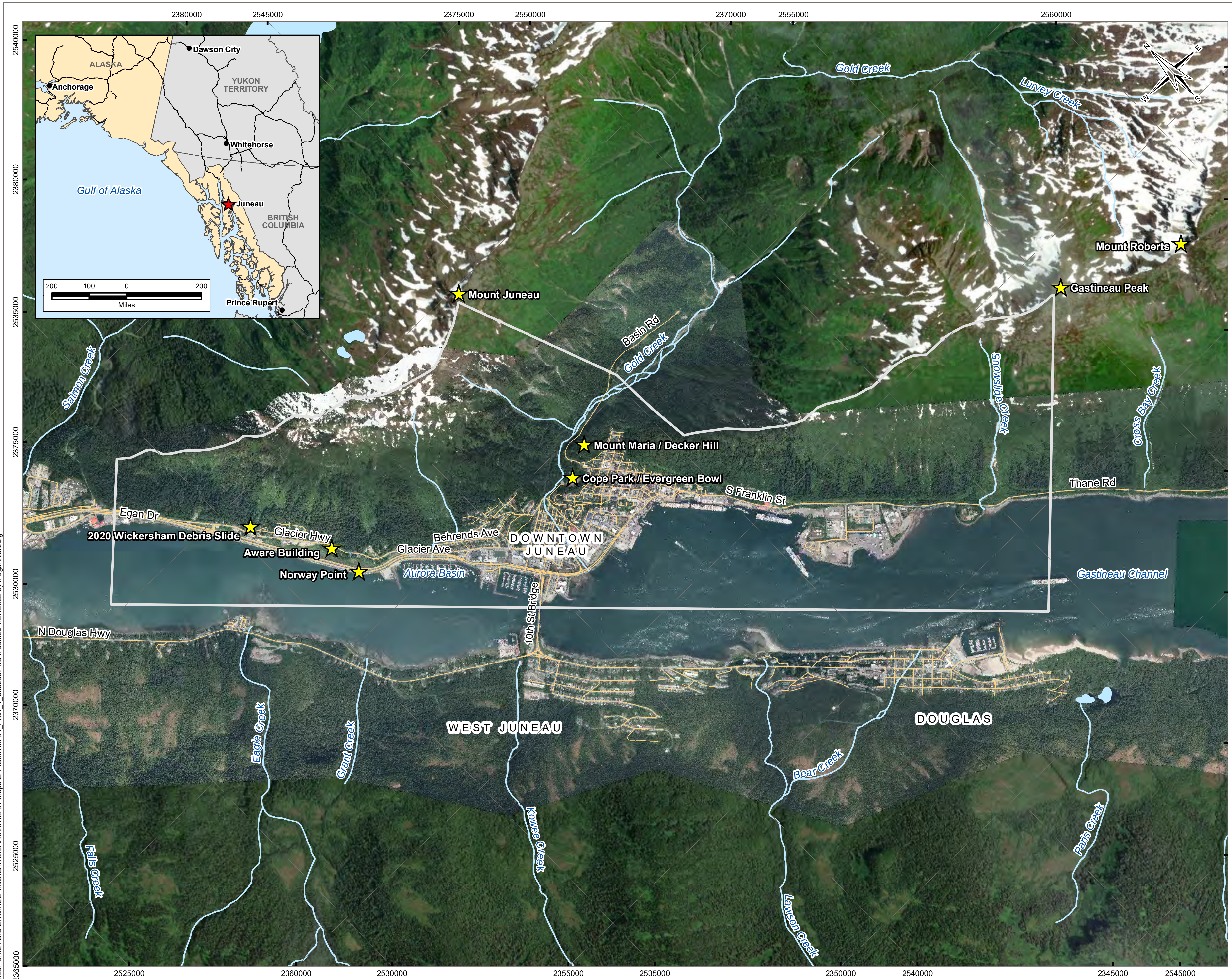
FIGURES



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LEGEND

- Location of Interest
- Study Area
- Road
- Watercourse
- Waterbody

NOTES

Base data source:
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).
Hydrology and roads obtained from Alaska Department of Natural Resources.

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Site Location

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:30,000

1,000 500 0 1,000
Feet

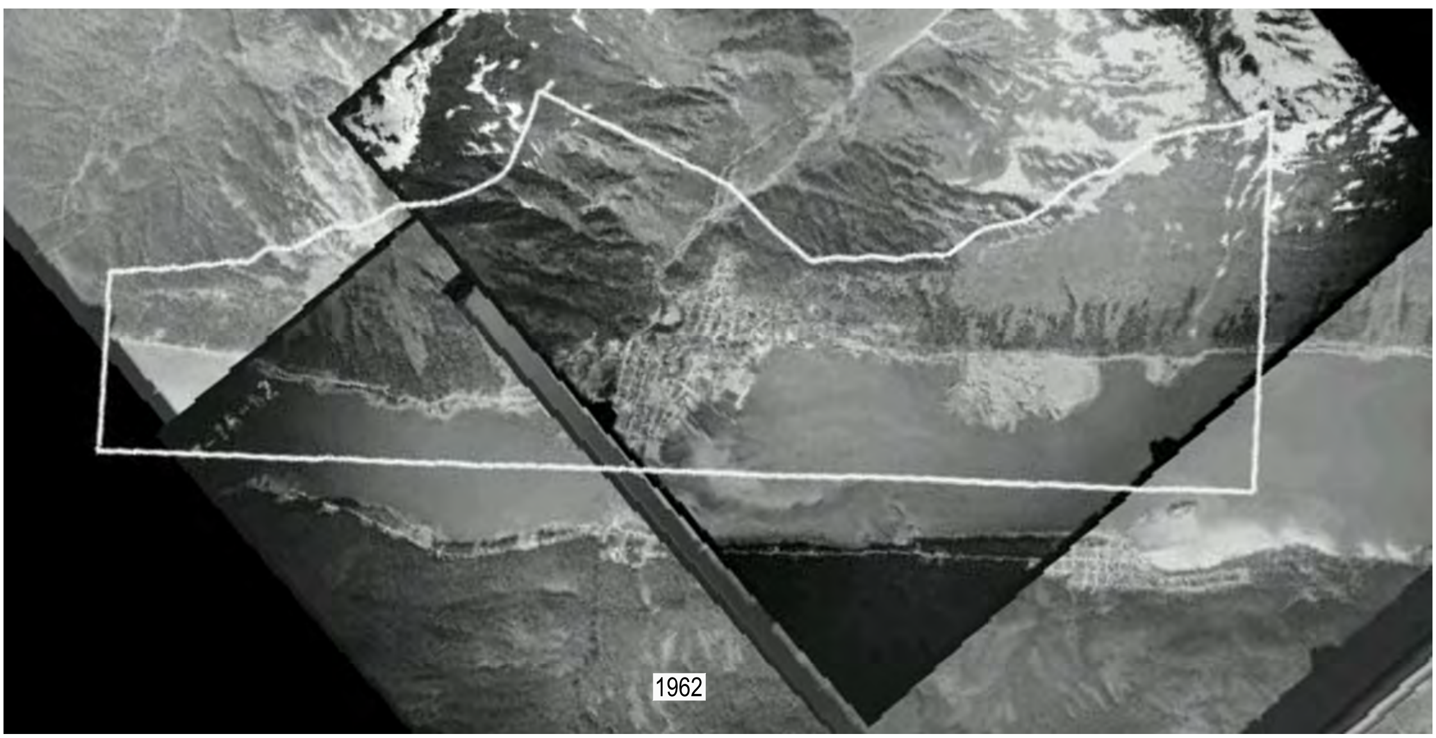
TETRA TECH

FILE NO.
EARC03168-01_FIG1_1_SiteLoc.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.1



ISSUED FOR USE

LEGEND

STUDY AREA

CLIENT

CITY AND BOROUGH OF JUNEAU ALASKA'S CAPITAL CITY

TETRA TECH

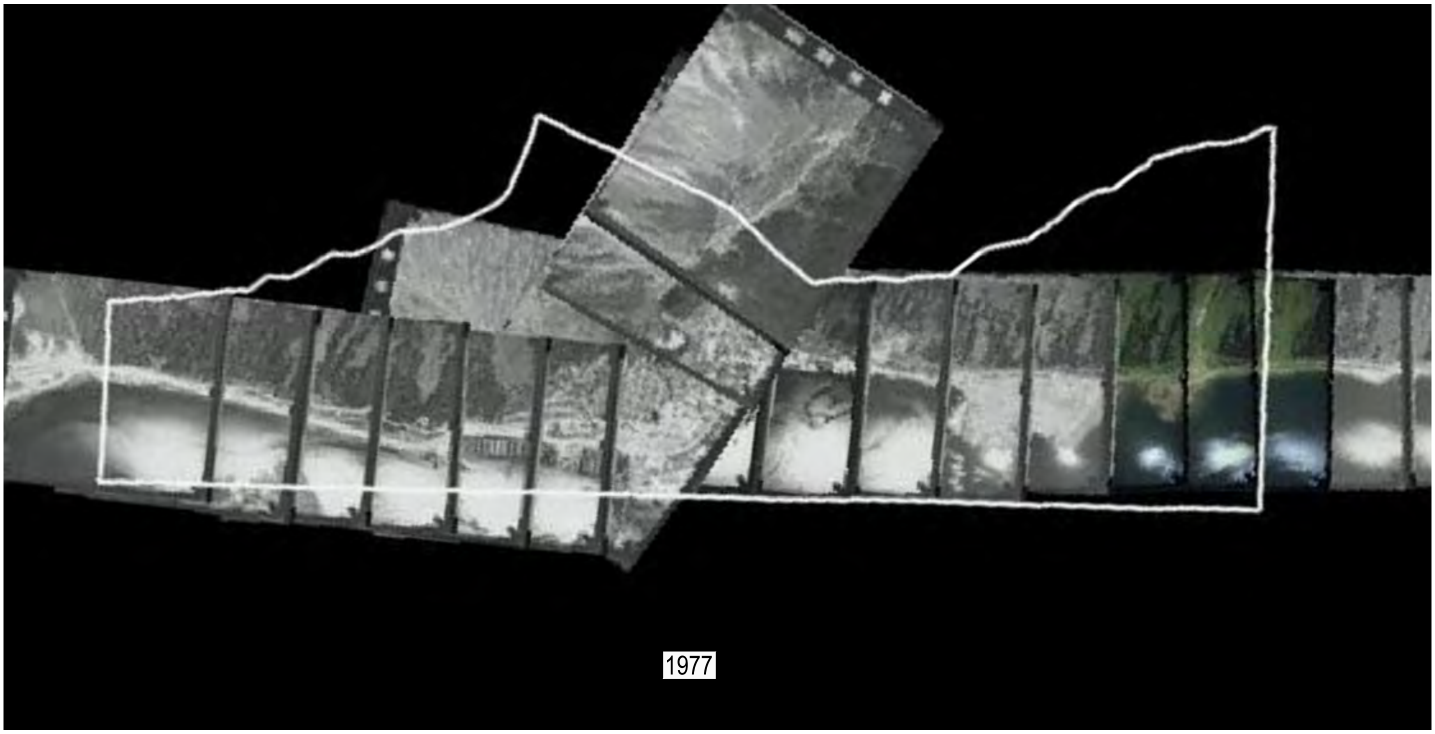
DOWNTOWN JUNEAU LANDSLIDE
AND AVALANCHE ASSESSMENT
JUNEAU, AK

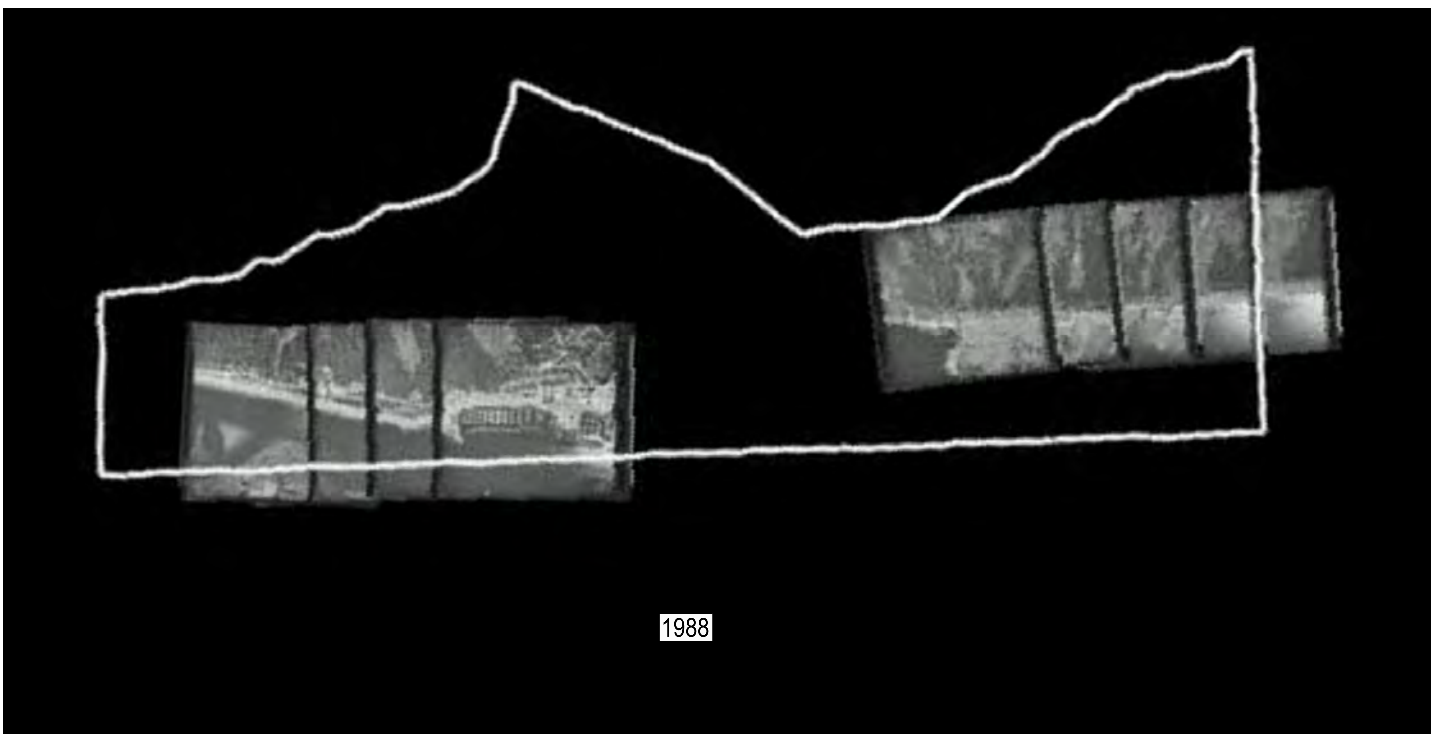
AIRPHOTO COVERAGE 1948 AND 1962

PROJECT NO.	DWN	CKD	REV
ENG.EARC03168-01	EP	VER	0

OFFICE	DATE
EDMONTON	APRIL 2022

Figure 1.2a





ISSUED FOR USE

LEGEND

STUDY AREA

CLIENT

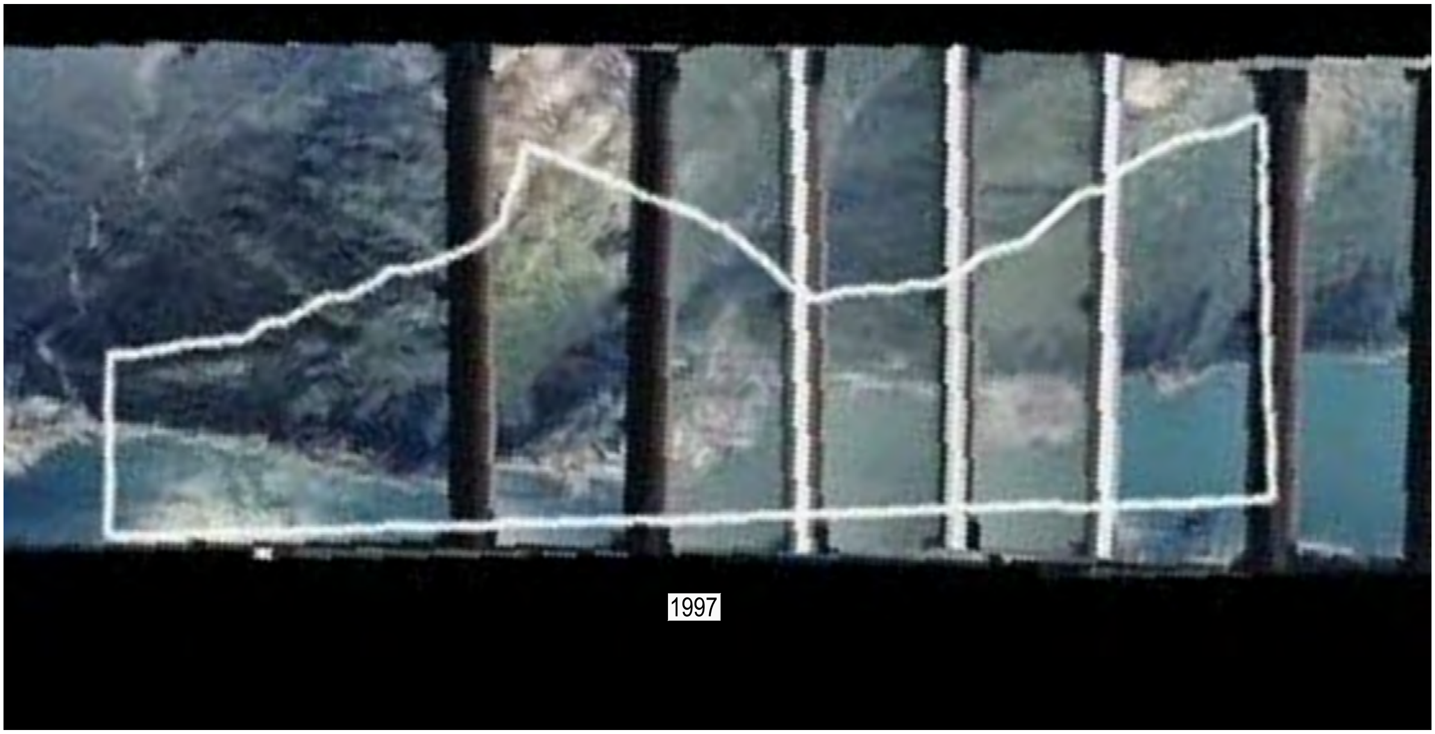
CITY AND BOROUGH OF JUNEAU
ALASKA'S CAPITAL CITY

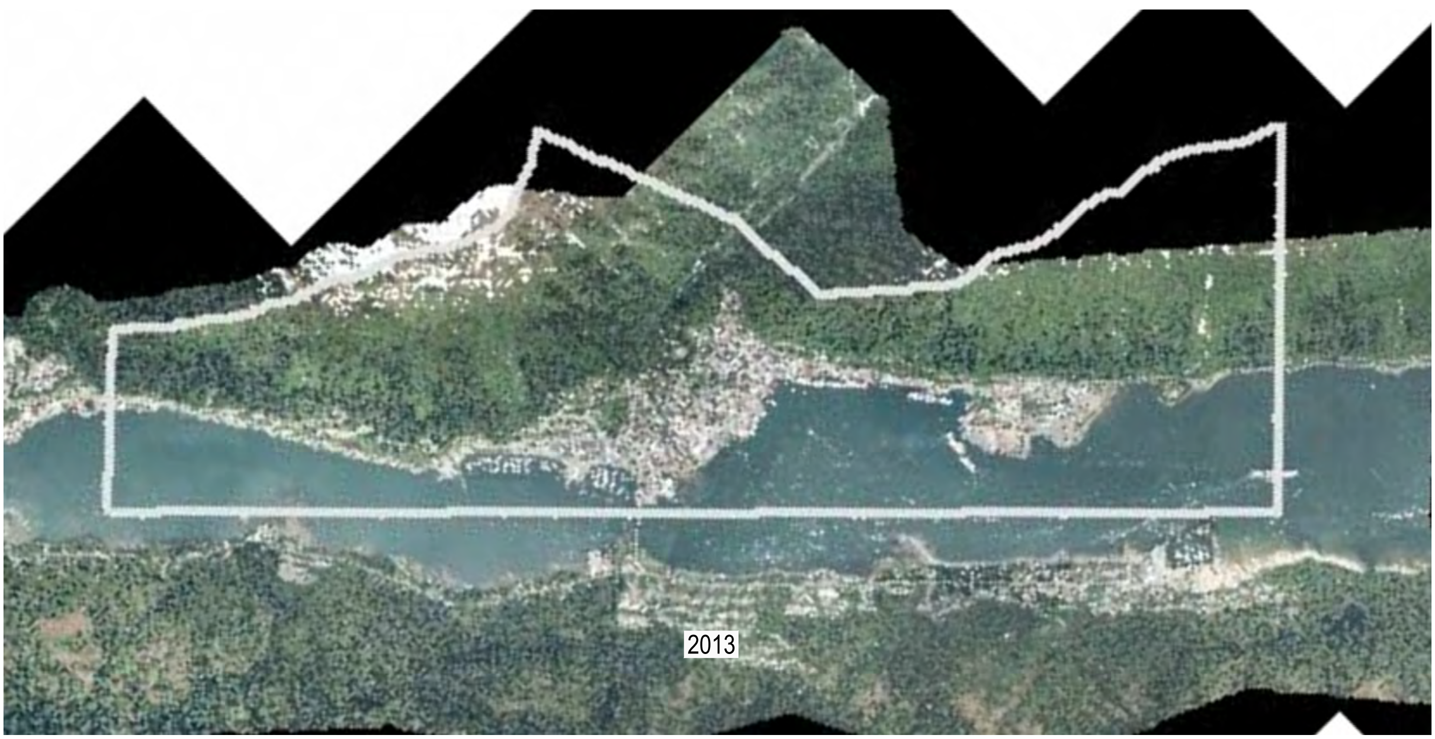
TETRA TECH

DOWNTOWN JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT JUNEAU, AK

AIRPHOTO COVERAGE 1977 AND 1988

PROJECT NO.	DWN	CKD	REV	
ENG.EARC03168-01	EP	VER	0	**Figure 1.2b**
OFFICE	DATE			
EDMONTON	APRIL 2022			





ISSUED FOR USE

LEGEND

STUDY AREA

CLIENT

CITY AND BOROUGH OF JUNEAU
ALASKA'S CAPITAL CITY

TETRA TECH

DOWNTOWN JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT JUNEAU, AK

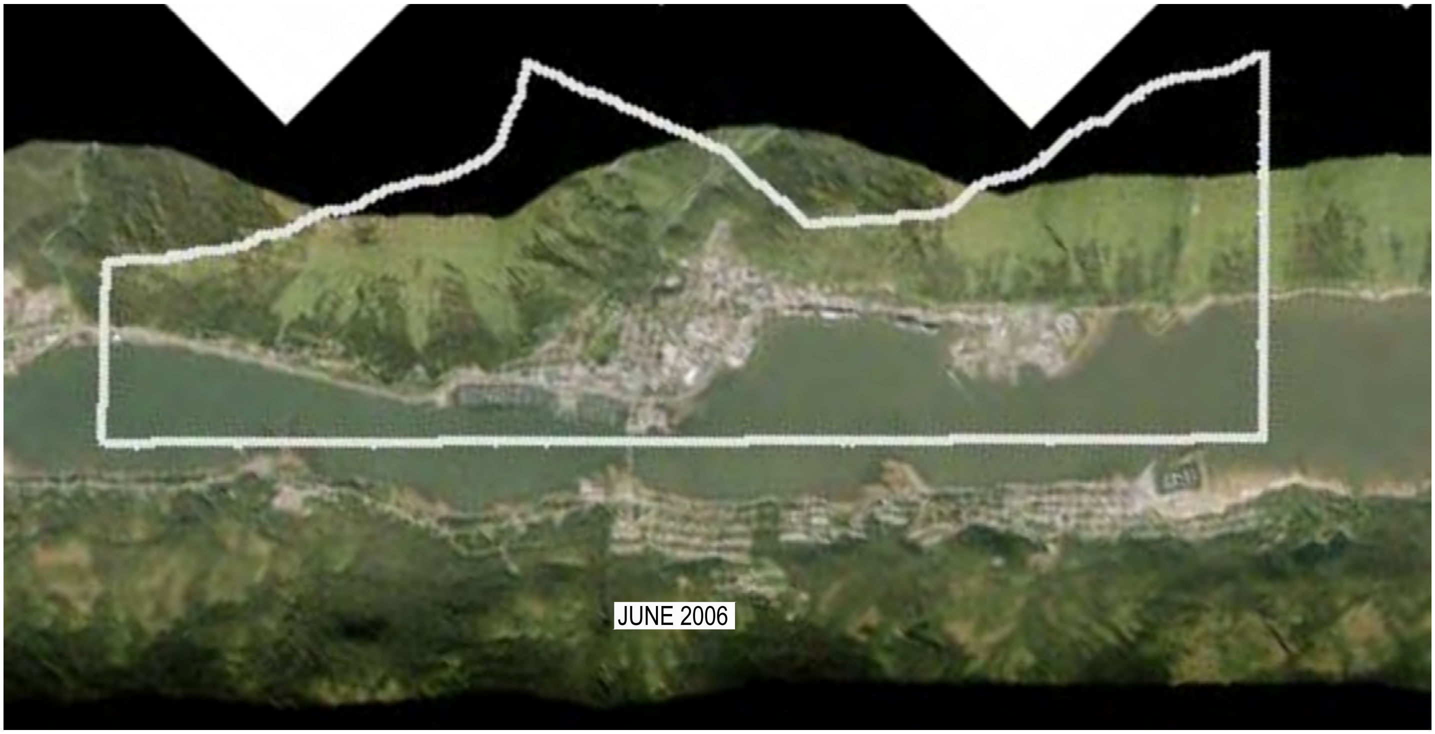
AIRPHOTO COVERAGE 1997 AND 2013

PROJECT NO.	DWN	CKD	REV
ENG.EARC03168-01	EP	VER	0

OFFICE	DATE
EDMONTON	APRIL 2022

Figure 1.2c

Q:\Edmonton\Engineering\E141\Projects\ENG.EARC03168-01 (Juneau)\Figures 1.2a-1.2d\Airphoto_Coverage Figure 1.2a-1.2d.dwg [FIGURE 1.2C] April 27, 2022 - 1:19:24 pm (BY: PALCZEWSKI, ERNEST)



ISSUED FOR USE

LEGEND

STUDY AREA

CLIENT

CITY AND BOROUGH OF JUNEAU ALASKA'S CAPITAL CITY

TETRA TECH

DOWNTOWN JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT JUNEAU, AK

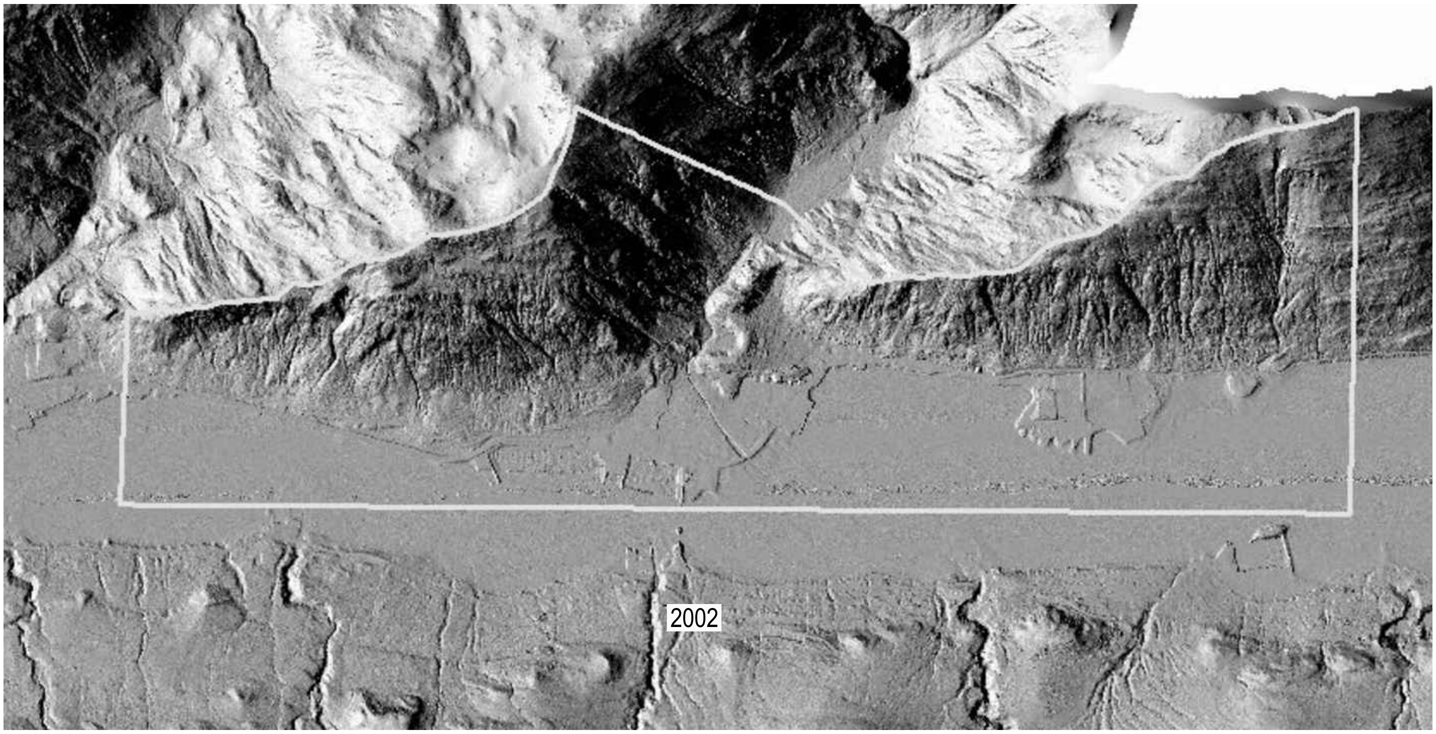
AIRPHOTO COVERAGE JUNE 2006 AND AUGUST 2006

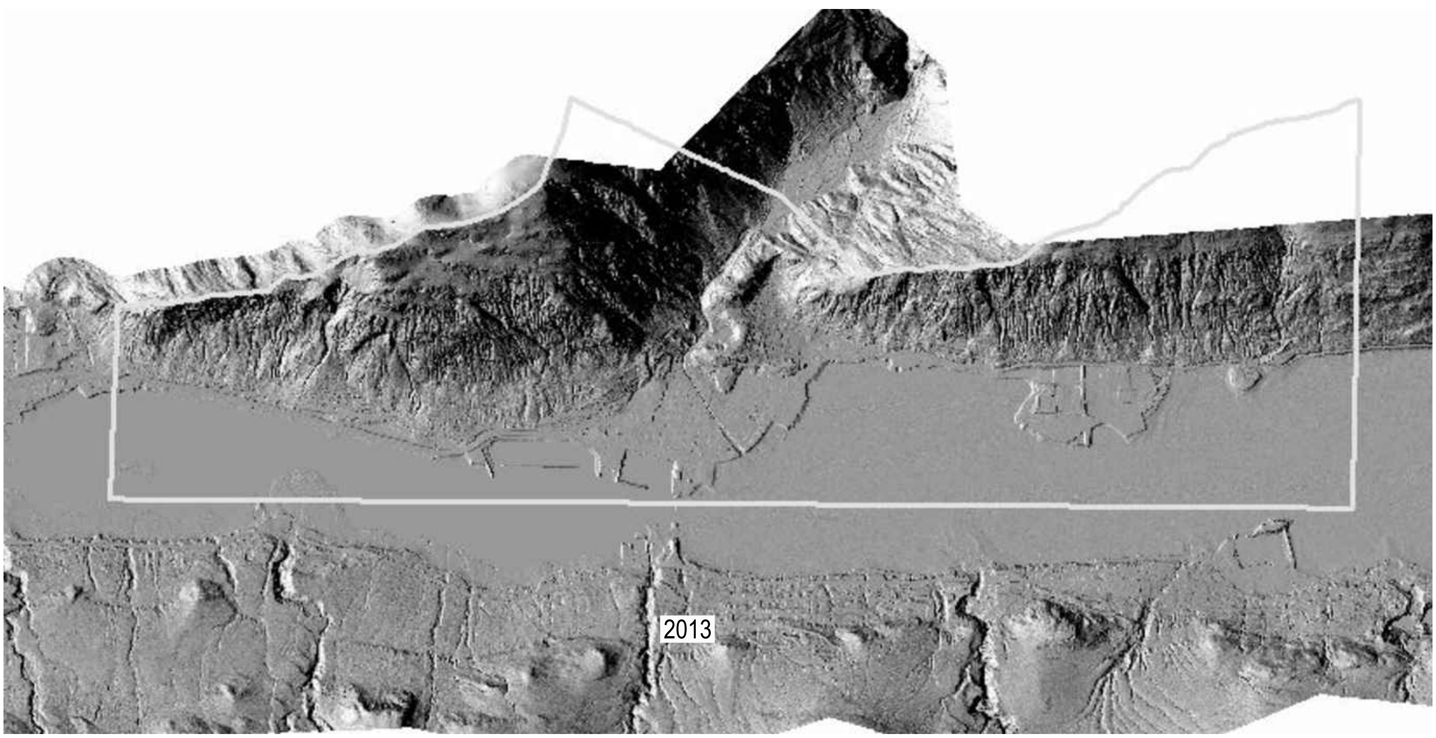
PROJECT NO.	DWN	CKD	REV
ENG.EARC03168-01	EP	VER	0

OFFICE	DATE
EDMONTON	APRIL 2022

Figure 1.2d

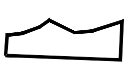
Q:\Edmonton\Engineering\E141\Projects\ENG.EARC03168-01 (Juneau)\Figures 1.2a-1.2d\Airphoto_Coverage Figure 1.2a-1.2d.dwg [FIGURE 1.2E] April 27, 2022 - 1:22:20 pm (BY: PALCZEWSKI, ERNEST)





ISSUED FOR USE

LEGEND


STUDY AREA

CLIENT

CITY AND BOROUGH OF JUNEAU ALASKA'S CAPITAL CITY

TETRA TECH

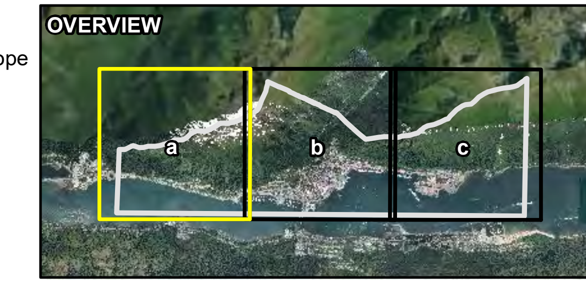
DOWNTOWN JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT JUNEAU, AK

LiDAR COVERAGE 2002 AND 2013

PROJECT NO.	DWN	CKD	REV	
ENG.EARC03168-01	EP	VER	0	**Figure 1.2e**
OFFICE	DATE			
EDMONTON	APRIL 2022			

LEGEND

- Location of Interest
- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope
- Watercourse



TERRAIN CODE

Ft//Cv|rf ← Geoprocess

First unit; Delimiter; Second unit; Division of surficial material and geomorphic process

Upper case letter = Surficial Material
Lower case letter = Surficial Expression

NOTES
Base data source:
Hydrology obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

SURFICIAL MATERIAL

- **C** — **Colluvial Deposit:** poorly to non-sorted mixture of rock fragments up to boulder size with silt, sand, gravel and often organic debris, deposited by gravity-induced mass movement of upslope materials, including rockfall, rock slide, debris slide, debris flow, creep and slumping.
- **Cv** — **Colluvial Veneer:** colluvium is the dominant material in the map area, so colluvial veneer is depicted with a different colour for additional map clarity.
- **F** — **Fluvial Deposit:** sediment deposited by rivers and small streams in channels or as point bar or overbank deposits (synonymous with alluvial). Generally moderately to well sorted, bedded cobbles, gravel and sand with occasional boulders; silt, clay and organic matter are less common. Distinction between glaciofluvial and fluvial materials has not been made.
- **WG** — **Glaciomarine:** dense till-like stone diamicton; rich in mollusks and Foraminifera deposited prior to and during the last glaciation.
- **M** — **Morainal Material (Till):** poorly sorted sediment (diamicton) deposited directly by ice by lodgment, meltout, or post-melt out gravity flow; generally matrix-supported and compact. Clasts consist of subangular to angular gravel, cobbles and boulders, with a clay to fine gravel matrix.
- **R** — **Bedrock:** meta-sedimentary and meta-volcanic rocks: generally well foliated, dark grey and green, fine-grained phyllite, semi-schist and schist. Metamorphic grade increases toward the northeast.
- **A** — **Anthropogenic:** human-made or modified geological material whose original properties have been drastically modified; locally includes rock fragments from mining and uncontrolled fill used in land reclamation.

GEOMORPHOLOGICAL PROCESSES

- **d** **Debris flow:** a sudden and destructive landslide where loose predominantly coarse inorganic and organic material on a slope is mobilized by saturation and flows rapidly down a pre-existing channel, behaving much like a viscous fluid and capable of carrying very large boulders.
- **s** **Debris slide:** a shallow, unconfined (open slope) landslide consisting of a mass of relatively dry, unconsolidated surficial inorganic and organic material, resulting in an irregular, hummocky deposit; involves the detachment and subsequent downslope movement of soil and vegetation.
- **b** **Deep-seated bedrock slide:** large landslide in bedrock with a slide plane located at depth, along which the slide moves as a coherent unit.
- **f** **Flooding:** the inundation by water of any area not normally covered with water, owing to a rapid rise in stream level.
- **r** **Rockfall:** very rapid downslope movement of newly detached pieces of bedrock that fall freely from a cliff or cascade down a steep slope.
- **c** **Soil creep:** the imperceptibly slow downward movement of soil on slopes caused by gravity; facilitated by occasional saturation or freeze/thaw cycles.

SURFICIAL EXPRESSION

- **b** **Blanket:** deposit greater than 1 m thick; minor irregularities of the underlying unit (generally bedrock) are masked but the topographic form is still evident.
- **v** **Veneer:** deposit less than 1 m thick; minor irregularities of the underlying unit (generally bedrock) are masked but the topographic form is obvious.
- **p** **Plain:** slope is generally between 0° and 3°.
- **j** **Gentle slope:** slope is generally between 4° and 15°.
- **a** **Moderate slope:** slope is generally between 16° and 26°.
- **k** **Moderately steep slope:** slope is generally between 27° and 35°.
- **s** **Steep slope:** slope is generally greater than 35°.
- **t** **Terrace:** level or gently inclined surface flanked by a steep slope or scarp; bedrock topography is masked.
- **r** **Ridge:** narrow, elongate and commonly steep-sided feature that rises above surrounding landscape; bedrock topography is masked (unless a bedrock ridge).
- **f** **Fan:** fan-shaped feature that dips from a pointed apex to a broader, curving base at lower elevation; bedrock topography is masked.
- **c** **Cone:** conical feature that dips from a pointed apex to a curving base at lower elevation; bedrock topography is masked. Colluvial cones are much steeper than fluvial fans.

DELIMITERS

- **/** First component more common than second (e.g. Mv/R means morainal material veneer covers 60-75% of polygon area, and exposed bedrock covers the rest).
- **//** First component much more common than second (e.g. Cbv//R means that a combination of colluvium blanket and colluvium veneer cover 80-95% of polygon area, with bedrock covering the rest).
- **.** First component approximately equal in proportion to the second.

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Surficial Geology

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.
EARC03168-01_FIG1_3_Surficial.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

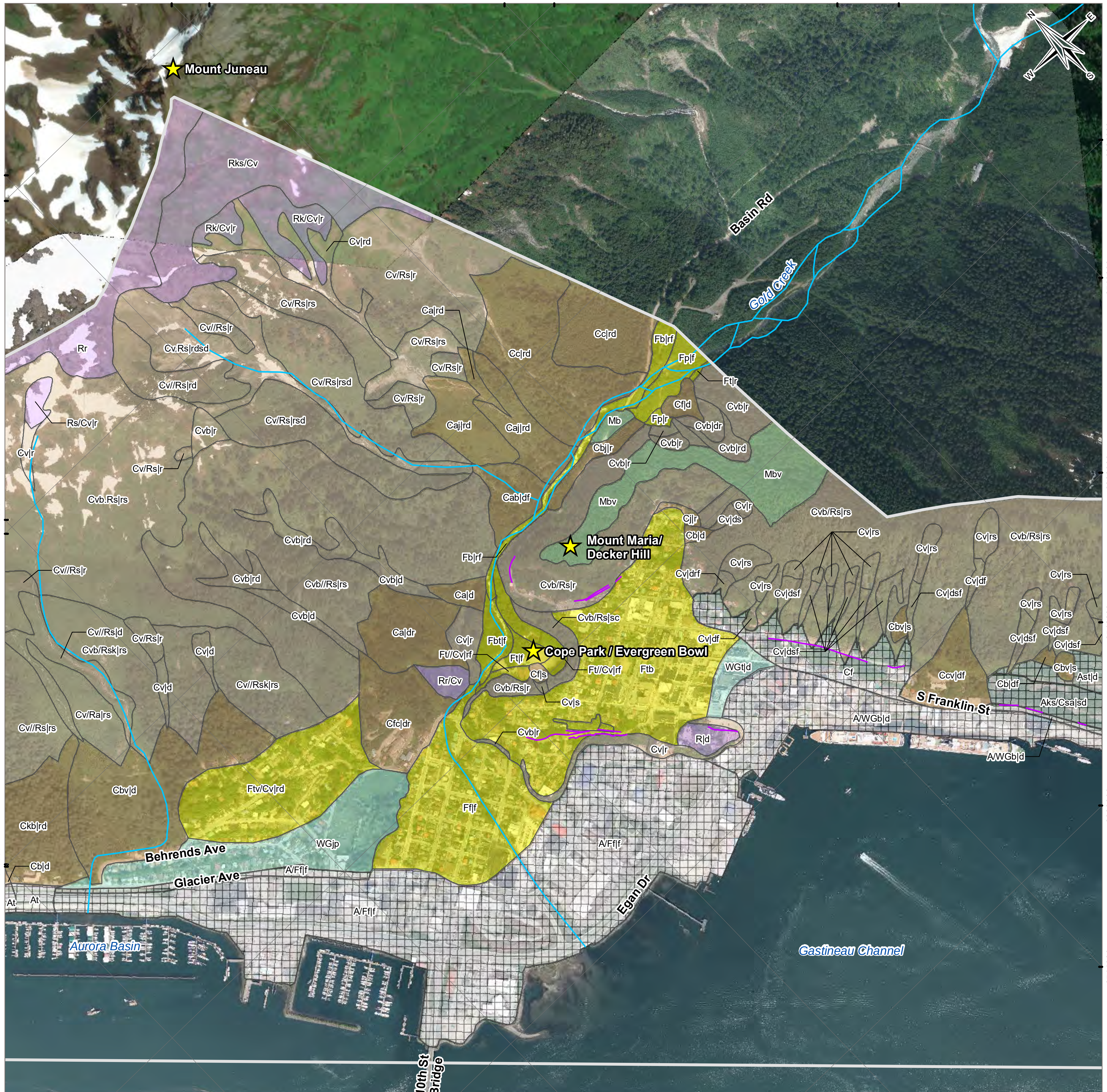
STATUS
ISSUED FOR USE

DATE
April 27, 2022

PROJECT NO.
ENG.EARC03168-01

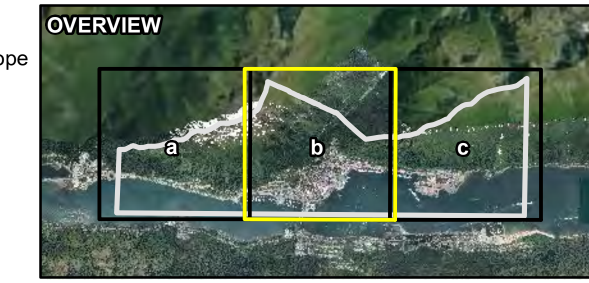
Figure 1.3a

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_3_Surficial.mxd modified 4/27/2022 by megan.verburg



LEGEND

- ★ Location of Interest
- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope
- Watercourse



NOTES

Base data source:
Hydrology obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

TERRAIN CODE

Ft//Cv|rf
- First unit
- Delimiter
- Second unit
- Division of surficial material and geomorphic process
- Geoprocess

Upper case letter = Surficial Material
Lower case letter = Surficial Expression

SURFICIAL MATERIAL

C — **Colluvial Deposit:** poorly to non-sorted mixture of rock fragments up to boulder size with silt, sand, gravel and often organic debris, deposited by gravity-induced mass movement of upslope materials, including rockfall, rock slide, debris slide, debris flow, creep and slumping.

Cv — **Colluvial Veneer:** colluvium is the dominant material in the map area, so colluvial veneer is depicted with a different colour for additional map clarity.

F — **Fluvial Deposit:** sediment deposited by rivers and small streams in channels or as point bar or overbank deposits (synonymous with alluvial). Generally moderately to well sorted, bedded cobbles, gravel and sand with occasional boulders; silt, clay and organic matter are less common. Distinction between glaciofluvial and fluvial materials has not been made.

WG — **Glaciomarine:** dense till-like stone diamicton; rich in mollusks and Foraminifera deposited prior to and during the last glaciation.

M — **Morainal Material (Till):** poorly sorted sediment (diamicton) deposited directly by ice by lodgment, meltout, or post-melt out gravity flow; generally matrix-supported and compact. Clasts consist of subangular to angular gravel, cobbles and boulders, with a clay to fine gravel matrix.

R — **Bedrock:** meta-sedimentary and meta-volcanic rocks: generally well foliated, dark grey and green, fine-grained phyllite, semi-schist and schist. Metamorphic grade increases toward the northeast.

A — **Anthropogenic:** human-made or modified geological material whose original properties have been drastically modified; locally includes rock fragments from mining and uncontrolled fill used in land reclamation.

GEOMORPHOLOGICAL PROCESSES

d **Debris flow:** a sudden and destructive landslide where loose predominantly coarse inorganic and organic material on a slope is mobilized by saturation and flows rapidly down a pre-existing channel, behaving much like a viscous fluid and capable of carrying very large boulders.

s **Debris slide:** a shallow, unconfined (open slope) landslide consisting of a mass of relatively dry, unconsolidated surficial inorganic and organic material, resulting in an irregular, hummocky deposit; involves the detachment and subsequent downslope movement of soil and vegetation.

b **Deep-seated bedrock slide:** large landslide in bedrock with a slide plane located at depth, along which the slide moves as a coherent unit.

f **Flooding:** the inundation by water of any area not normally covered with water, owing to a rapid rise in stream level.

r **Rockfall:** very rapid downslope movement of newly detached pieces of bedrock that fall freely from a cliff or cascade down a steep slope.

c **Soil creep:** the imperceptibly slow downward movement of soil on slopes caused by gravity; facilitated by occasional saturation or freeze/thaw cycles.

SURFICIAL EXPRESSION

b **Blanket:** deposit greater than 1 m thick; minor irregularities of the underlying unit (generally bedrock) are masked but the topographic form is still evident.

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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Surficial Geology

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.
EARC03168-01_FIG1_3_Surficial.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

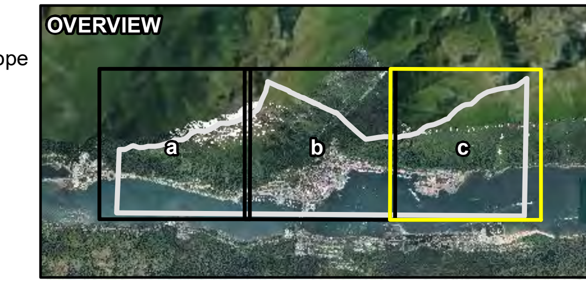
STATUS
ISSUED FOR USE

Figure 1.3b

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_3_Surficial.mxd modified 4/27/2022 by megan.verburg

LEGEND

- ★ Location of Interest
- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope
- Watercourse



NOTES
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TERRAIN CODE

Ft//Cv|rf
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- Delimiter
- Second unit
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Surficial Geology

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.
EARC03168-01_FIG1_3_Surficial.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

STATUS
ISSUED FOR USE

Figure 1.3c

LEGEND

- Location of Interest
- Photo Location and Direction
- Old Cutline
- Study Area

Base Data

- Contour (100 ft)

2020
- Debris flow

2019
- Slide Activity

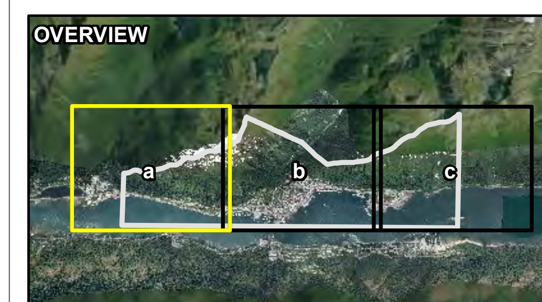
2013
- Slide Activity

2006
- Slide Activity

1997
- Slide Activity
- Debris slide

1962
- Slide Activity
- Debris slide

OVERVIEW



NOTES

Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record Analysis Slope Movement Features (1948-2020)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.
EARC03168-01_FIG1_4_SlopeActivity.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.4a

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_4_SlopeActivity.mxd modified 4/27/2022 by megan.verburg

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_4_SlopeActivity.mxd modified 4/27/2022 by megan.verburg

LEGEND

- Location of Interest
- Photo Location and Direction
- Old Cutline
- Study Area

Base Data

- Contour (100 ft)

2021
- Slide Activity

2020
- Debris slide
- Slide Activity

2019
- Slide Activity
- Debris slide

2013
- Slide Activity
- Debris slide

2006
- Slide Activity
- Debris slide

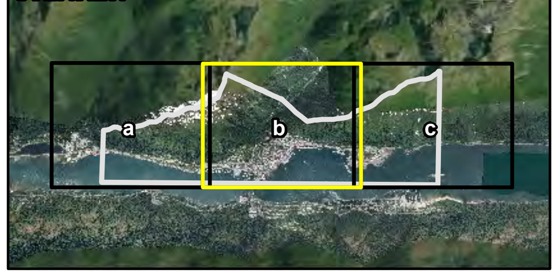
1997
- Slide Activity
- Debris slide

1977
- Slide Activity
- Debris slide

1962
- Slide Activity
- Debris slide

1948
- Debris slide

OVERVIEW



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Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record Analysis Slope Movement Features (1948-2020)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:11,000
500 250 0 500
Feet

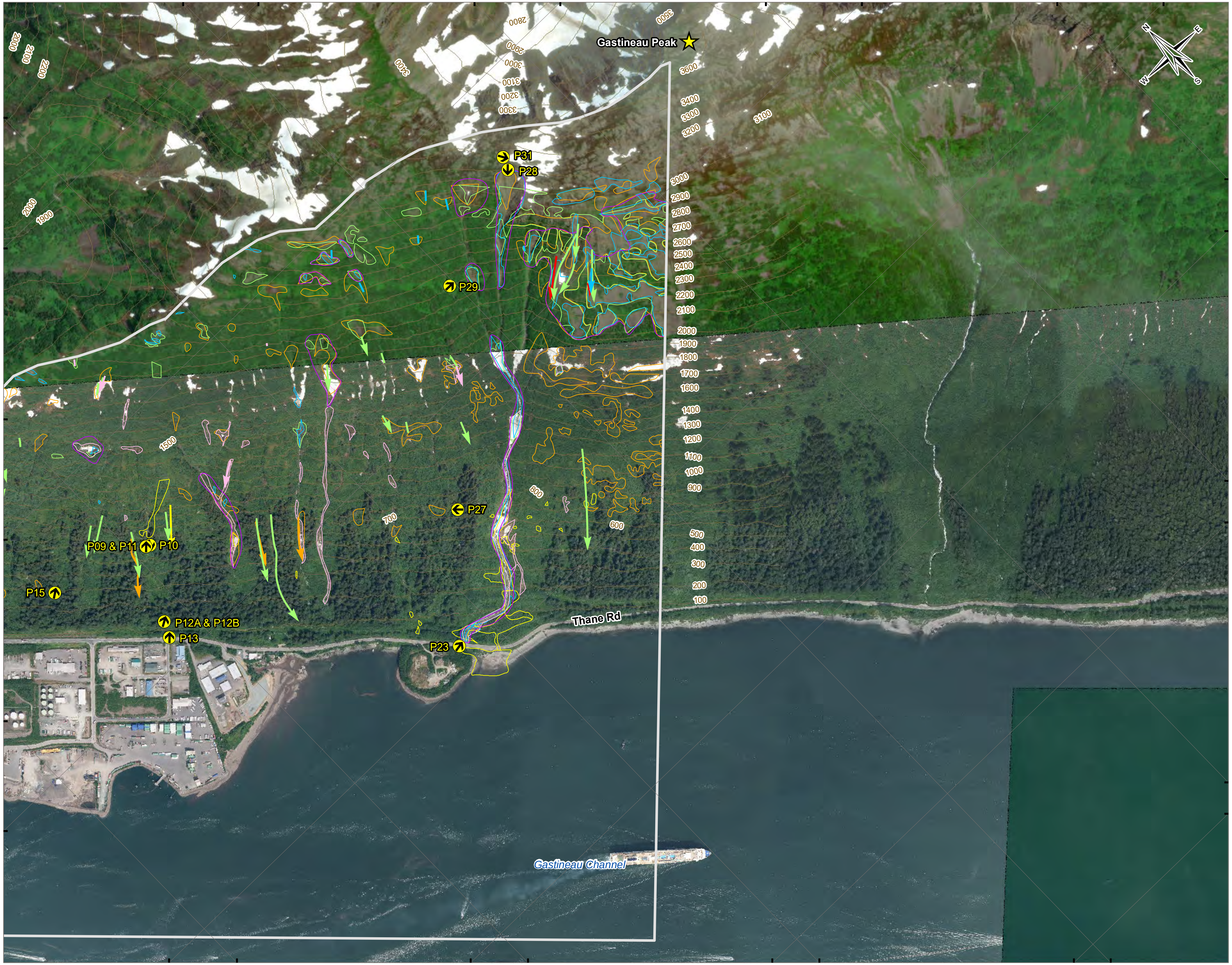
TETRA TECH

FILE NO.
EARC03168-01_FIG1_4_SlopeActivity.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.4b



LEGEND

- Location of Interest
- Photo Location and Direction
- Old Cutline
- Study Area

Base Data

- Contour (100 ft)

2019
- Slide Activity

2013
- Slide Activity
- Debris slide

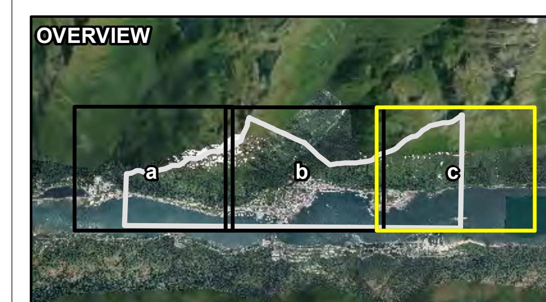
2006
- Slide Activity
- Debris slide

1997
- Slide Activity
- Debris slide

1977
- Slide Activity
- Debris slide

1962
- Slide Activity
- Debris slide

1948
- Debris slide



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STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record Analysis Slope Movement Features (1948-2020)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of JUNEAU

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.
EARC03168-01_FIG1_4_SlopeActivity.mxd

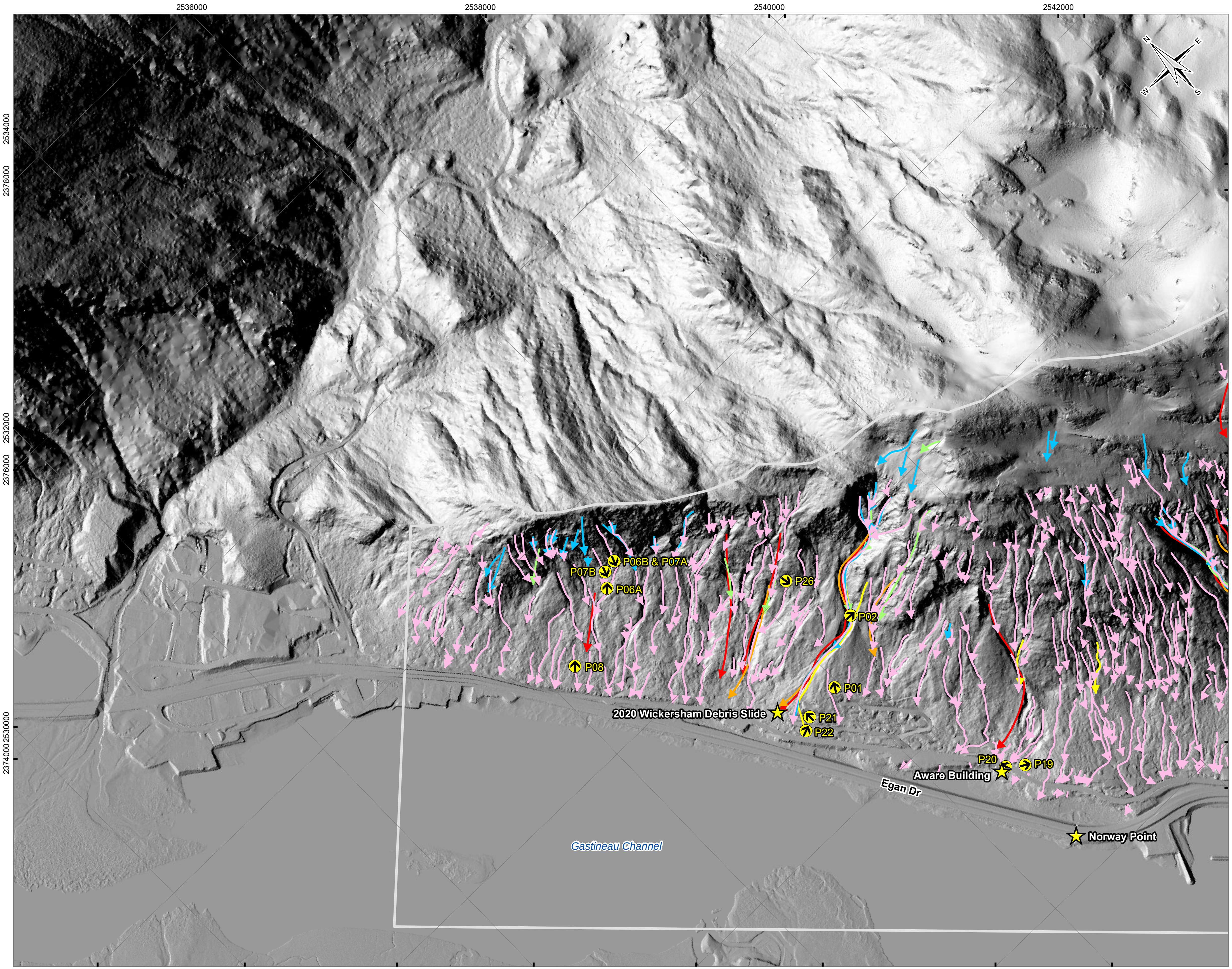
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.4c

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_4_SlopeActivity.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Location of Interest
- Photo Location and Direction
- Study Area

2013
- Gully[1]

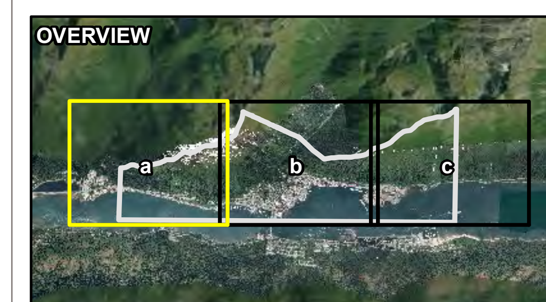
2006
- Gully

1997
- Gully

1977
- Gully

1962
- Gully

1948
- Gully



NOTES

[1] Mapped using 2013 LiDAR bare earth hillshade.
[2] Mapped using 2002 LiDAR bare earth hillshade for areas not covered by 2013 LiDAR bare earth hillshade.
Base data source: Hillshade derived from 2013 LiDAR provided by CBJ.
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STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record and LiDAR Data Analysis Gully Erosion Features (1948-2013)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU ALASKA'S CAPITAL CITY

Scale: 1:11,000

500 250 0 500

Feet

TETRA TECH

FILE NO.
EARC03168-01_FIG1_5_Gullies.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	EP/SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.5a

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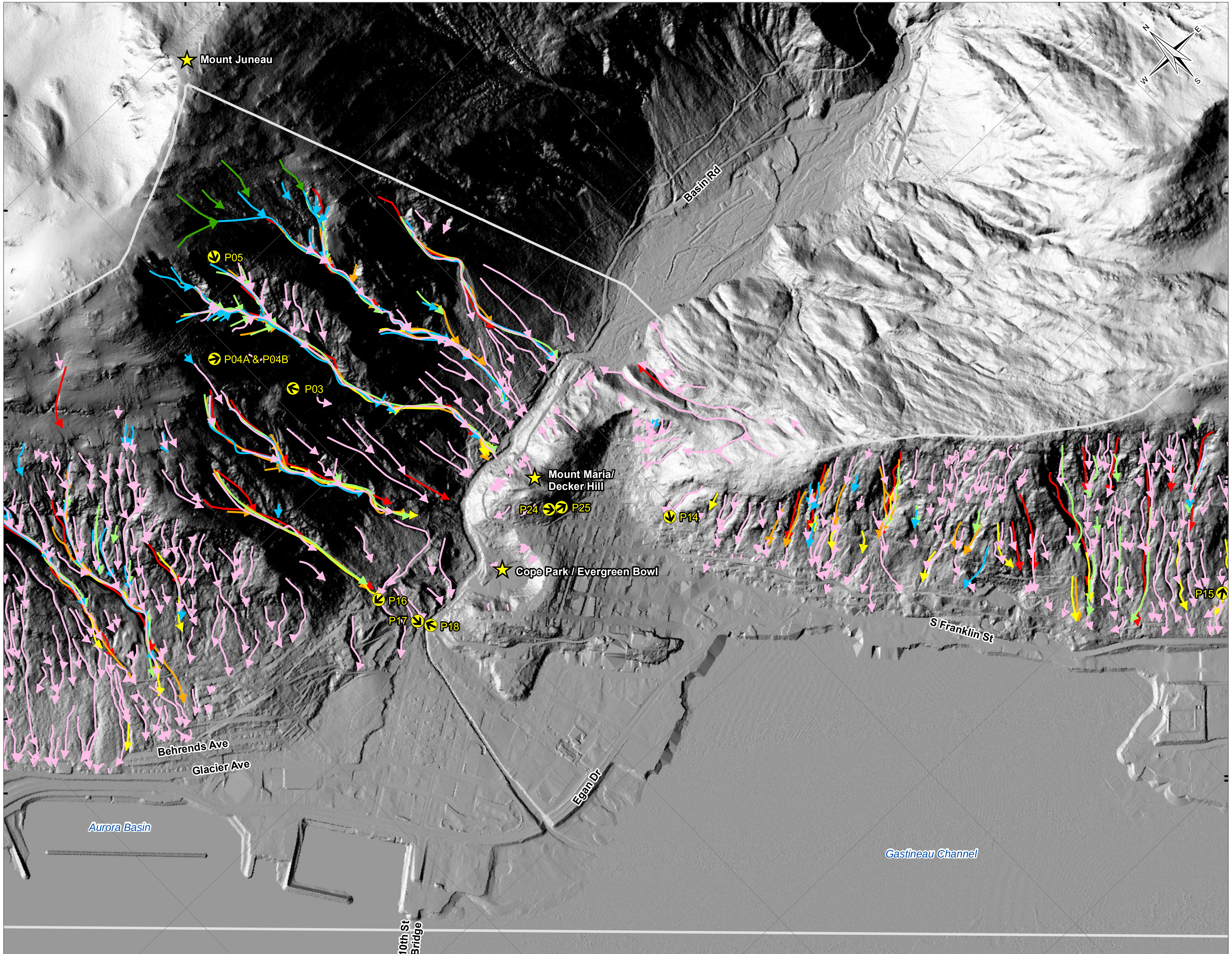


LEGEND

- Location of Interest
- Photo Location and Direction
- Study Area

2013
- Gully[1]

2006
- Gully

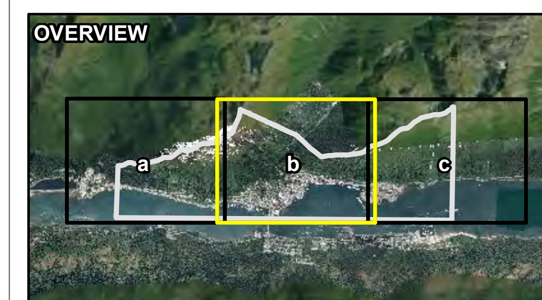
2002
- Gully[2]

1997
- Gully

1977
- Gully

1962
- Gully

1948
- Gully



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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record and LiDAR Data Analysis Gully Erosion Features (1948-2013)

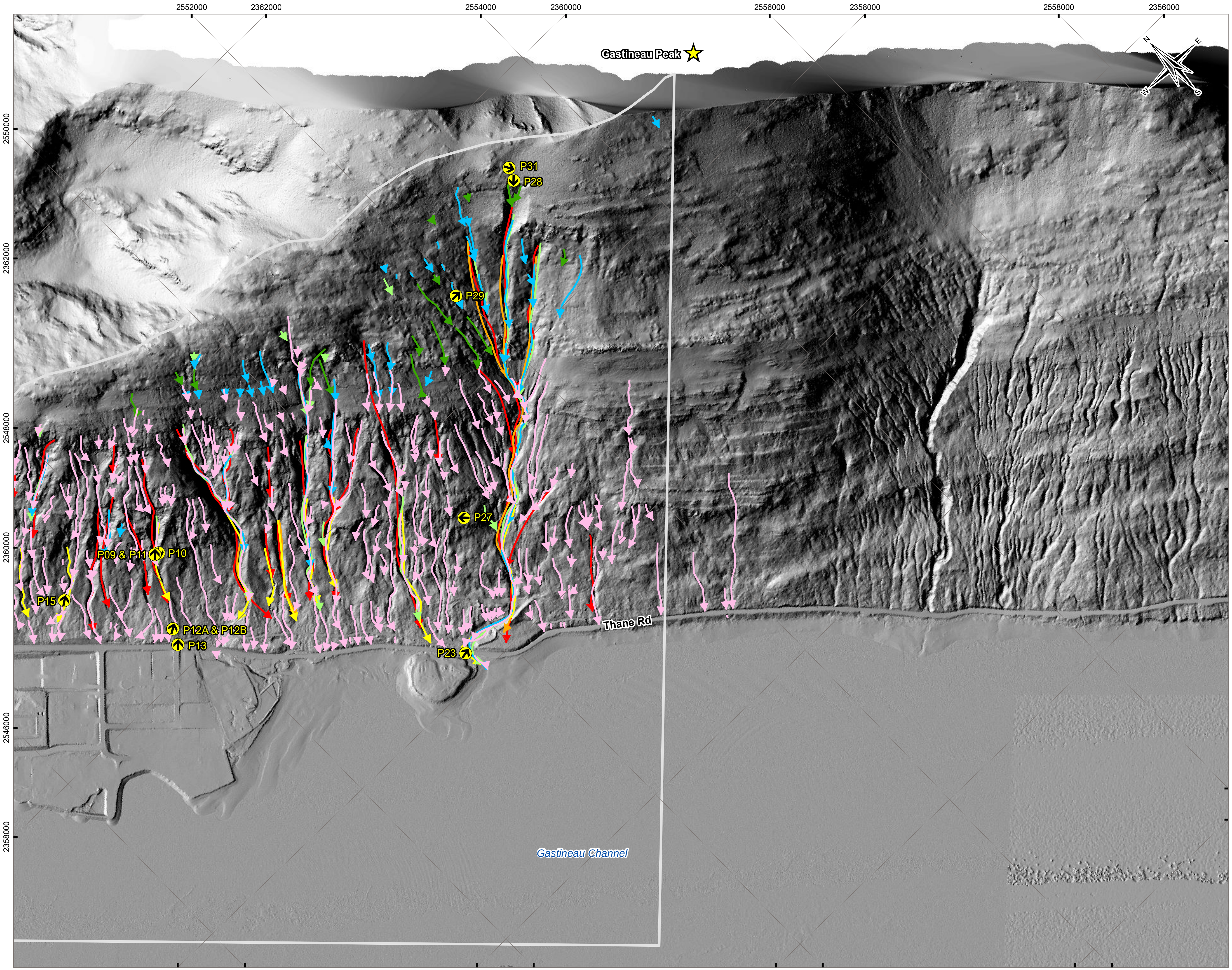
PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:11,000
500 250 0 500
Feet

FILE NO.				
EARC03168-01_FIG1_5_Gullies.mxd				
OFFICE	**DWN**	**CKD**	**APVD**	**REV**
Tt-EDM	MRV	SL	EP/SM/VER	0
DATE	**PROJECT NO.**			
April 27, 2022	ENG.EARC03168-01			

TETRA TECH

Figure 1.5b



LEGEND

- Location of Interest
- Photo Location and Direction
- Study Area

2013
- Gully[1]

2006
- Gully

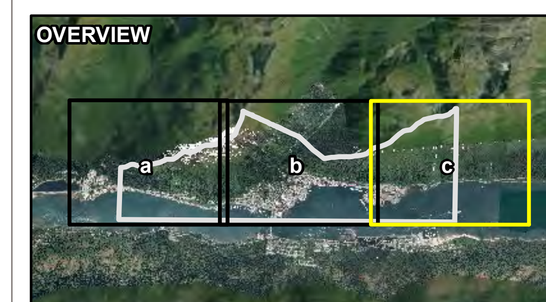
2002
- Gully[2]

1997
- Gully

1977
- Gully

1962
- Gully

1948
- Gully



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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Historical Air Photo Record and LiDAR Data Analysis Gully Erosion Features (1948-2013)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:11,000

500 250 0 500

Feet

TETRA TECH

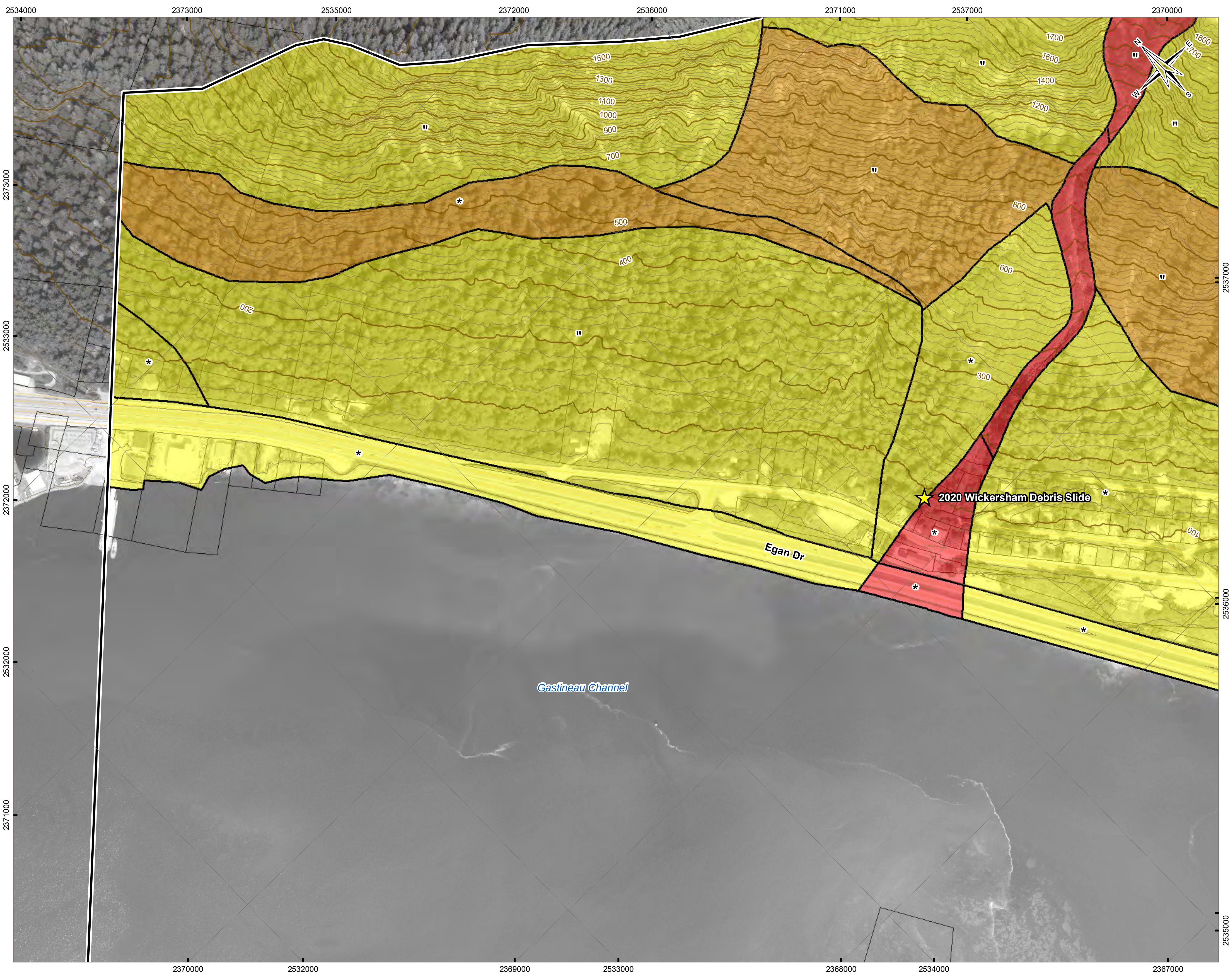
FILE NO.
EARC03168-01_FIG1_5_Gullies.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	EP/SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.5c

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_5_Gullies.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Location of Interest
- Study Area
- Deep-Seated Bedrock Slide

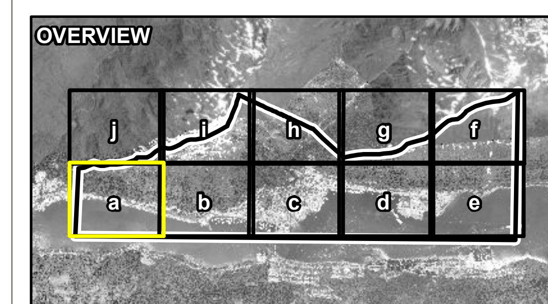
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION State Plane Alaska Zone 1 5001
DATUM NAD83
CLIENT City and Borough of Juneau

Scale: 1:5,000

300 150 0 300
Feet

TETRA TECH

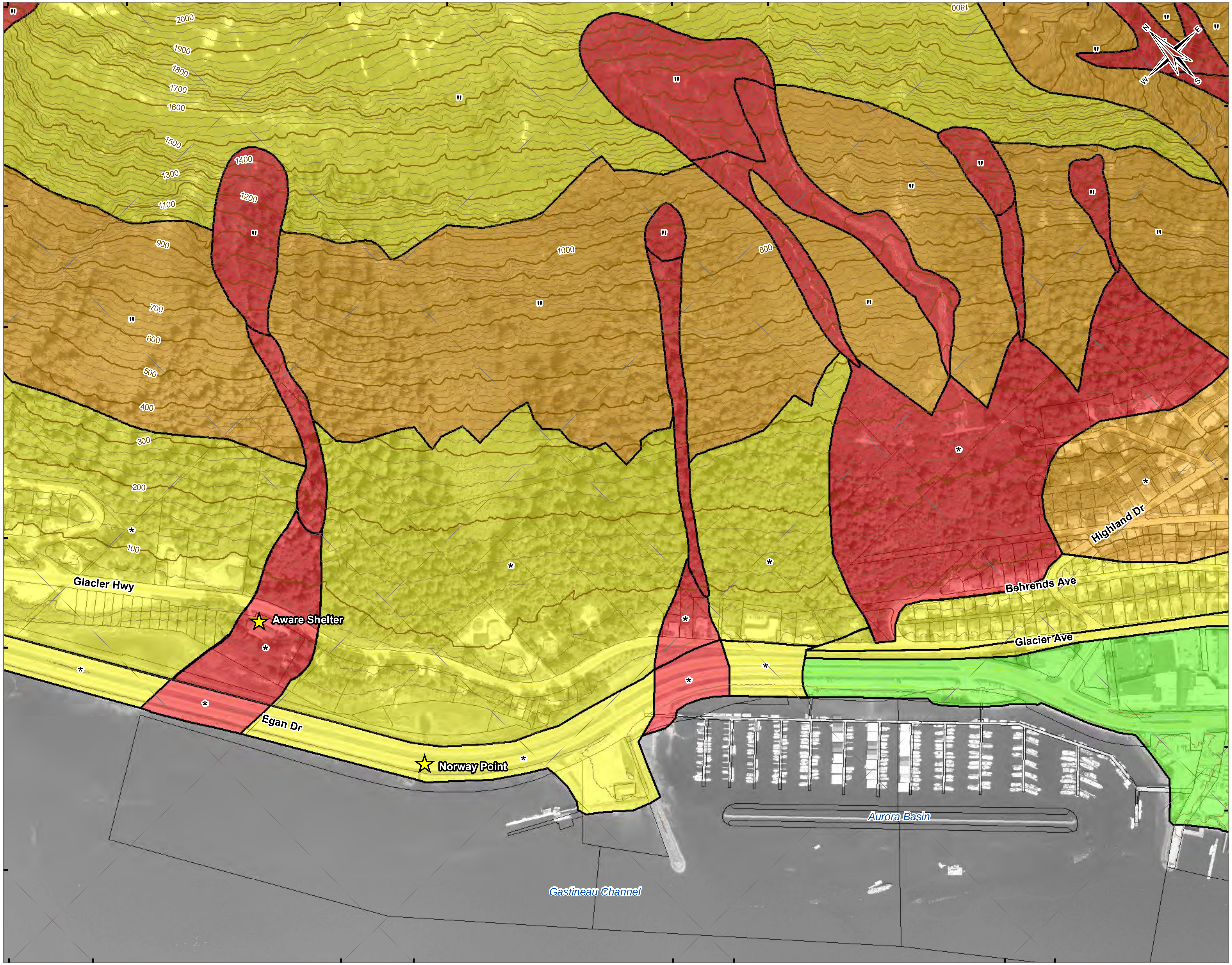
FILE NO. EARC03168-01_FIG1_6_HazardDesignation.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE April 27, 2022
PROJECT NO. ENG.EARC03168-01

Figure 1.6a

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Location of Interest
- Study Area
- Deep-Seated Bedrock Slide

Landslide Hazard

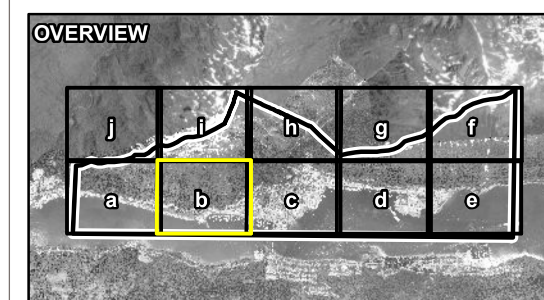
(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- Initiation Zone
- Runout Zone
- Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel

OVERVIEW



NOTES
[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300

Feet

FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE
April 27, 2022

PROJECT NO.
ENG.EARC03168-01

Figure 1.6b

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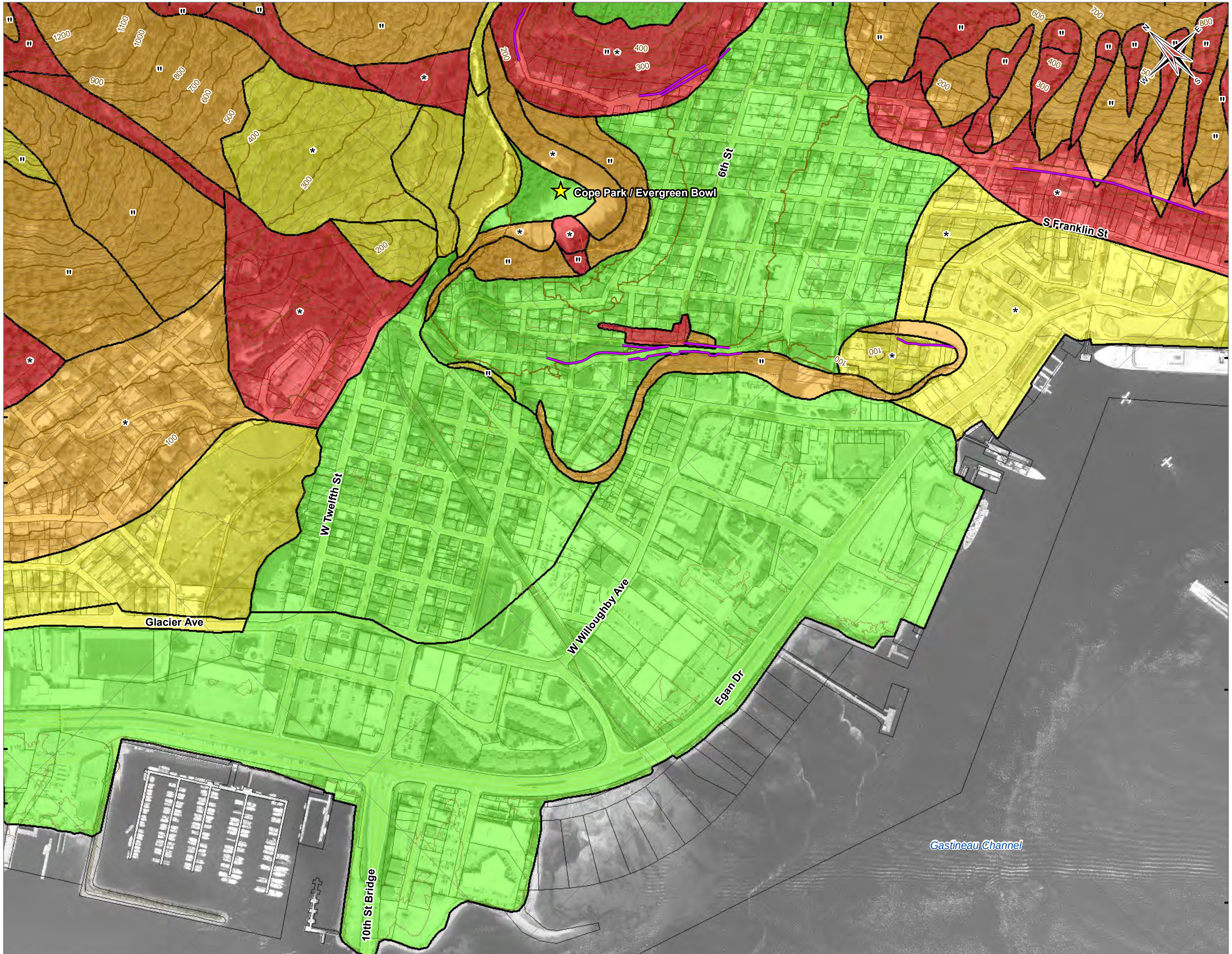


LEGEND

- ★ Location of Interest
- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope[1]

Landslide Hazard

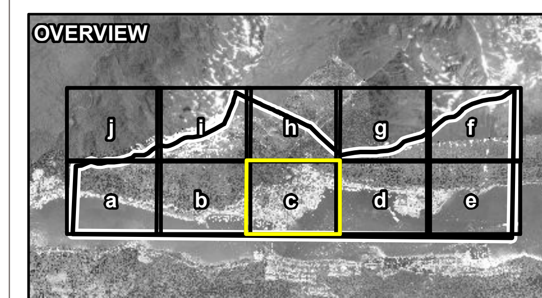
(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel

OVERVIEW



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study

Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000

300 150 0 300
Feet

FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

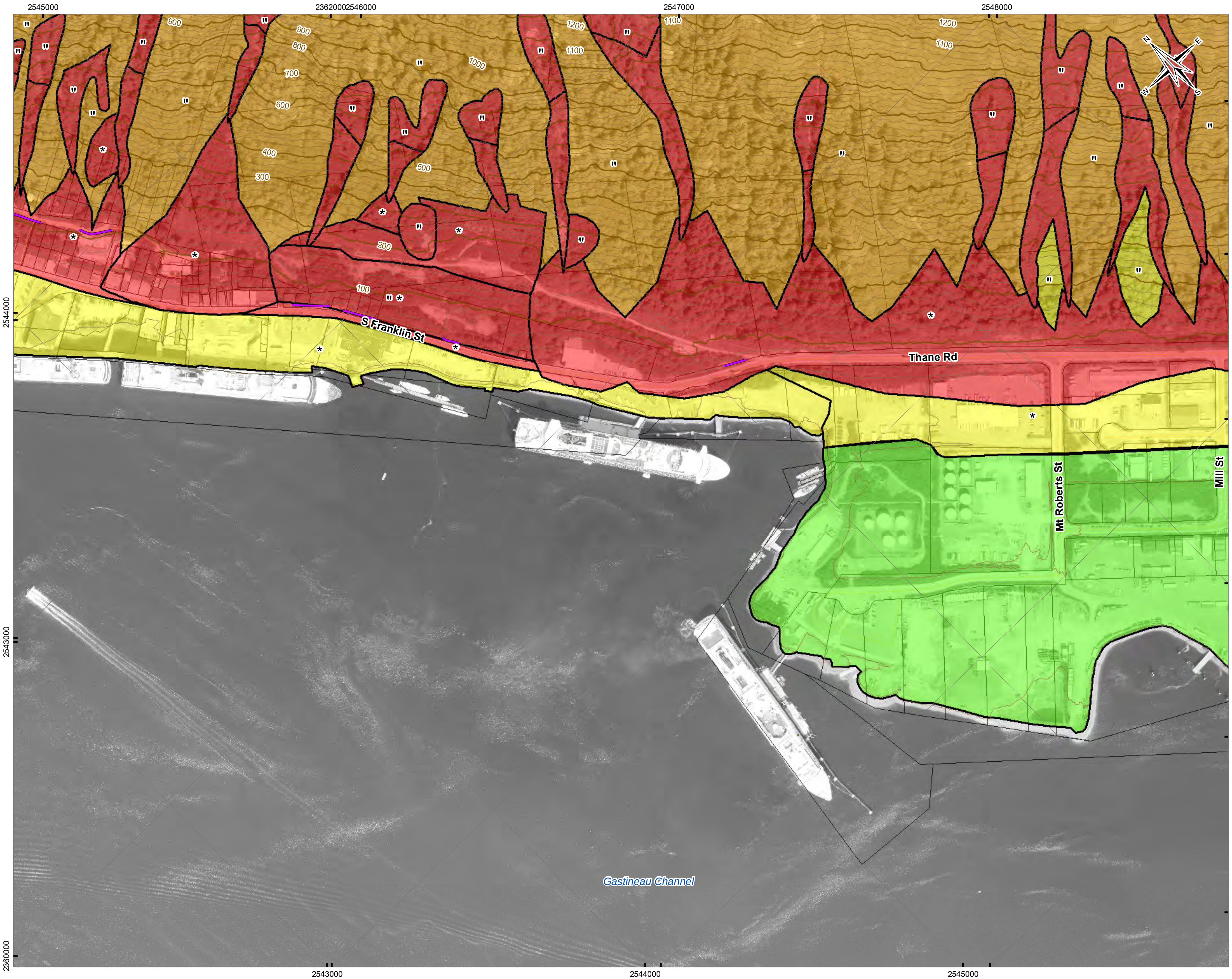
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.6c

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope[1]

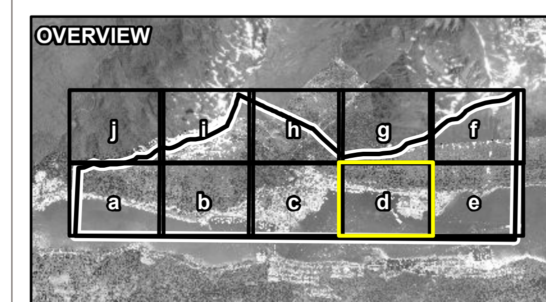
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

TETRA TECH

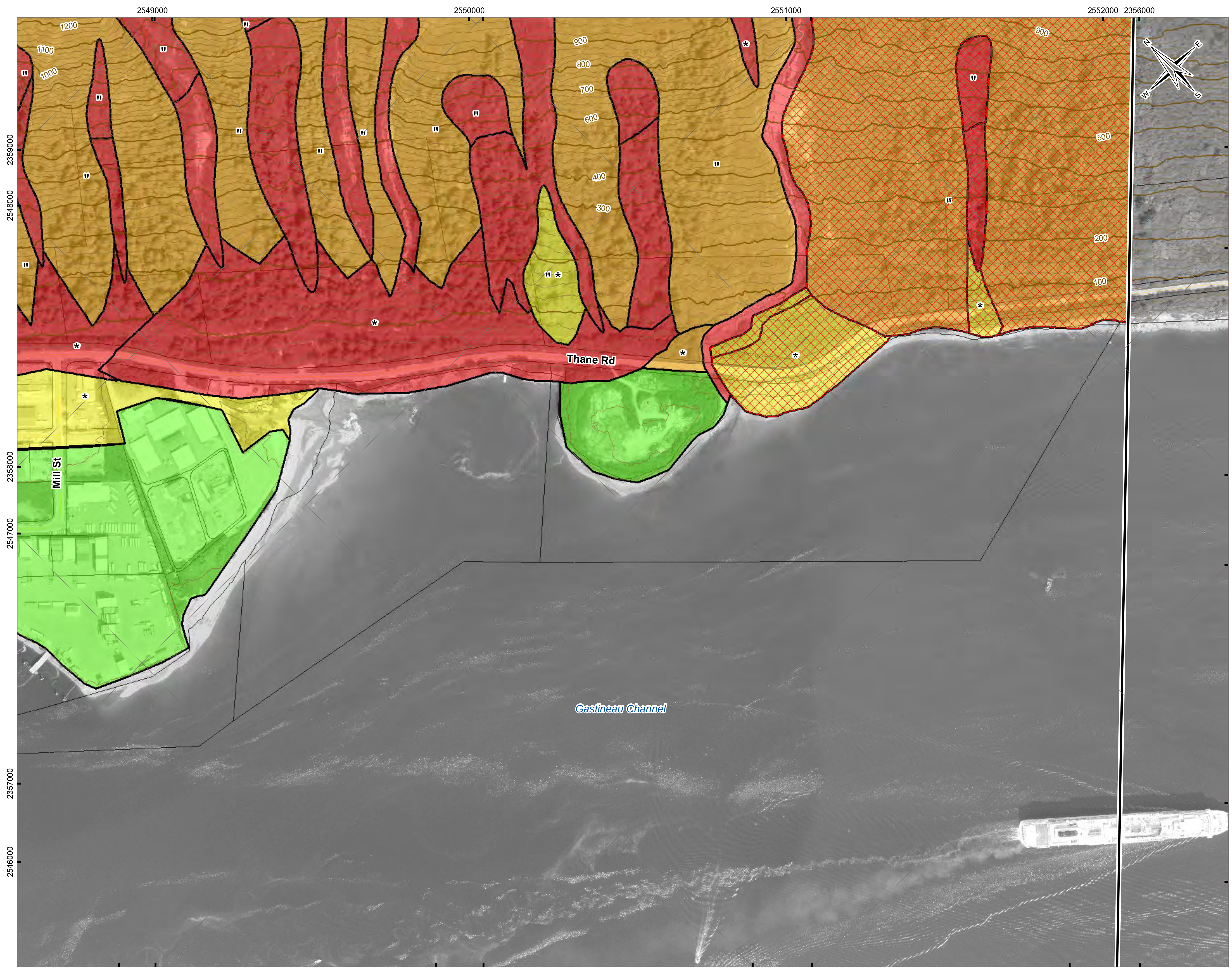
FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE
April 27, 2022

PROJECT NO.
ENG.EARC03168-01

Figure 1.6d



LEGEND

- Study Area
- Deep-Seated Bedrock Slide

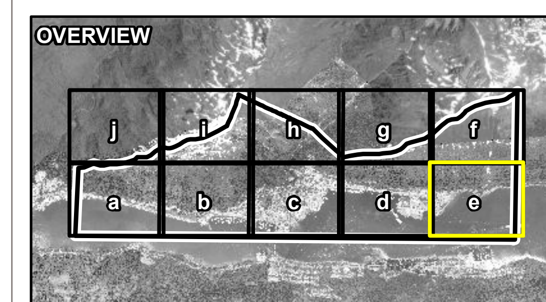
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU ALASKA'S CAPITAL CITY

Scale: 1:5,000

300 150 0 300

Feet

TETRA TECH

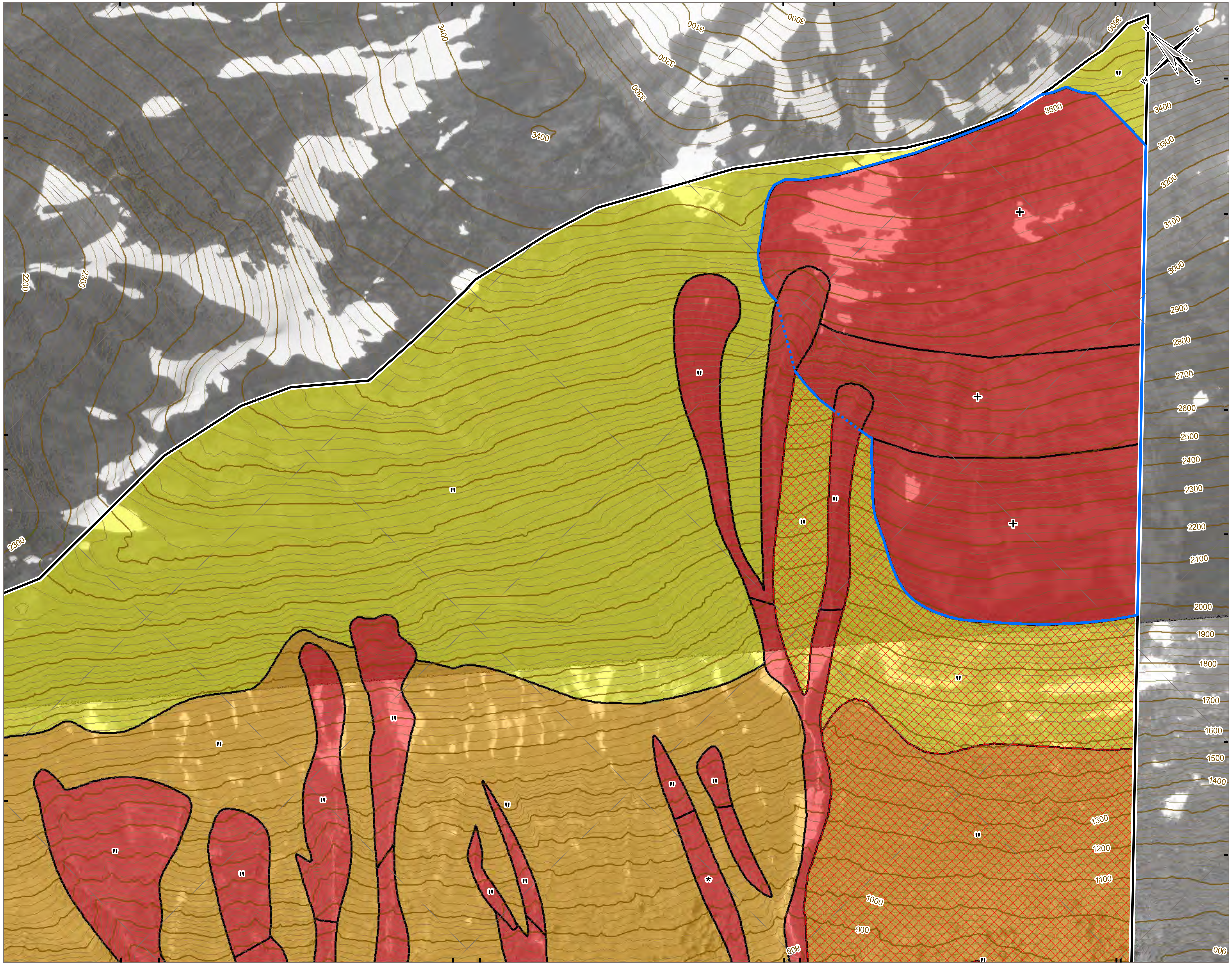
FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.6e

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Study Area
- Deep-Seated Bedrock Slide

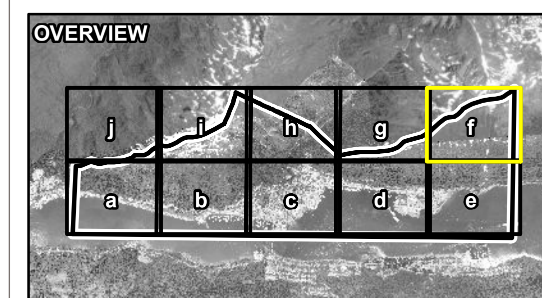
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study

Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300

Feet

FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

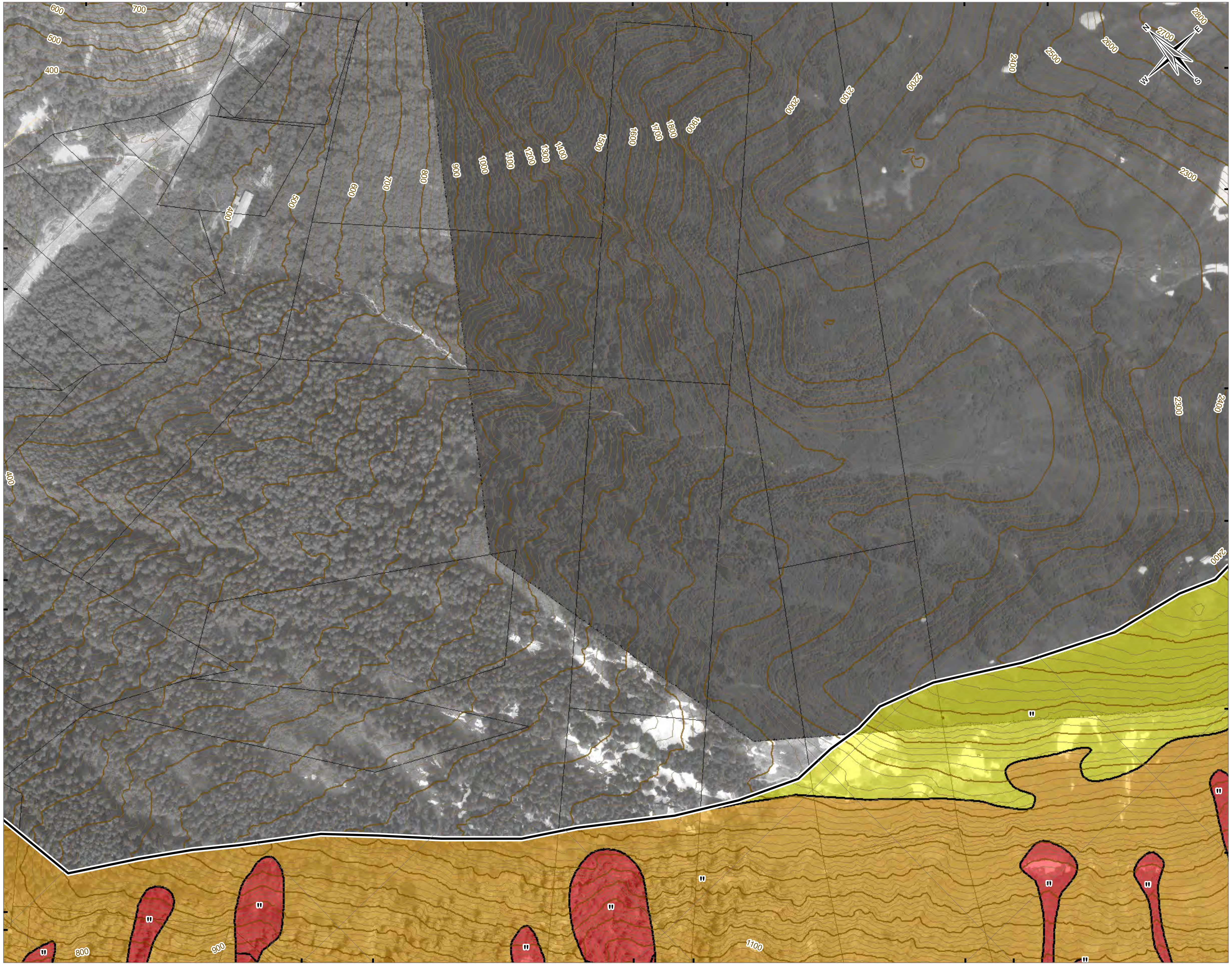
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.6f

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Study Area
- Deep-Seated Bedrock Slide

Landslide Hazard

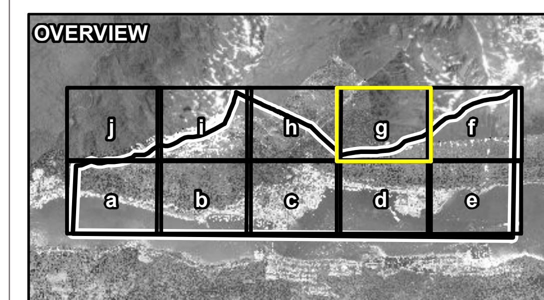
(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- Initiation Zone
- Runout Zone
- Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel

OVERVIEW



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300
Feet

FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

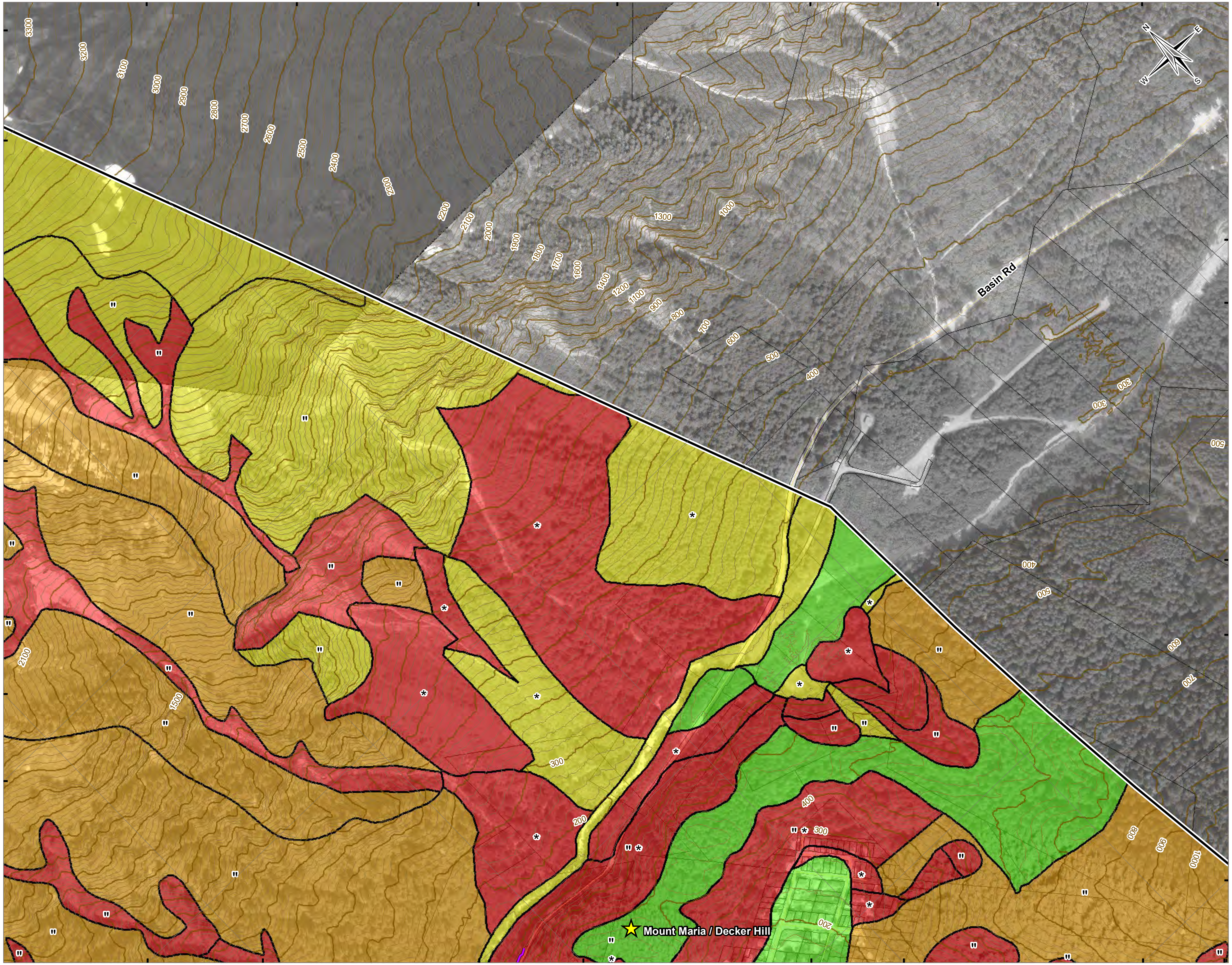
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.6g

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



LEGEND

- Location of Interest
- Study Area
- Deep-Seated Bedrock Slide
- Engineered Slope[1]

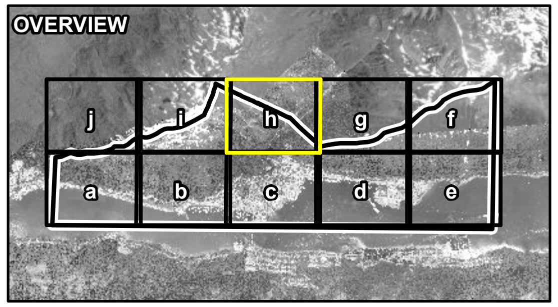
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- Initiation Zone
- Runout Zone
- Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Road
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study

Base data source:

Contours generated from 2013 LiDAR provided by CBJ.

Additional contours generated from 2012 LiDAR provided by CBJ.

Hydrology and roads obtained from Alaska Department of Natural Resources.

Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.

Primary imagery provided by CBJ, 2013.

Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION State Plane Alaska Zone 1 5001
DATUM NAD83
CLIENT City and Borough of Juneau

Scale: 1:5,000

300 150 0 300
Feet

TETRA TECH

FILE NO. EARC03168-01_FIG1_6_HazardDesignation.mxd

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/ VER	0

DATE April 27, 2022
PROJECT NO. ENG.EARC03168-01

Figure 1.6h

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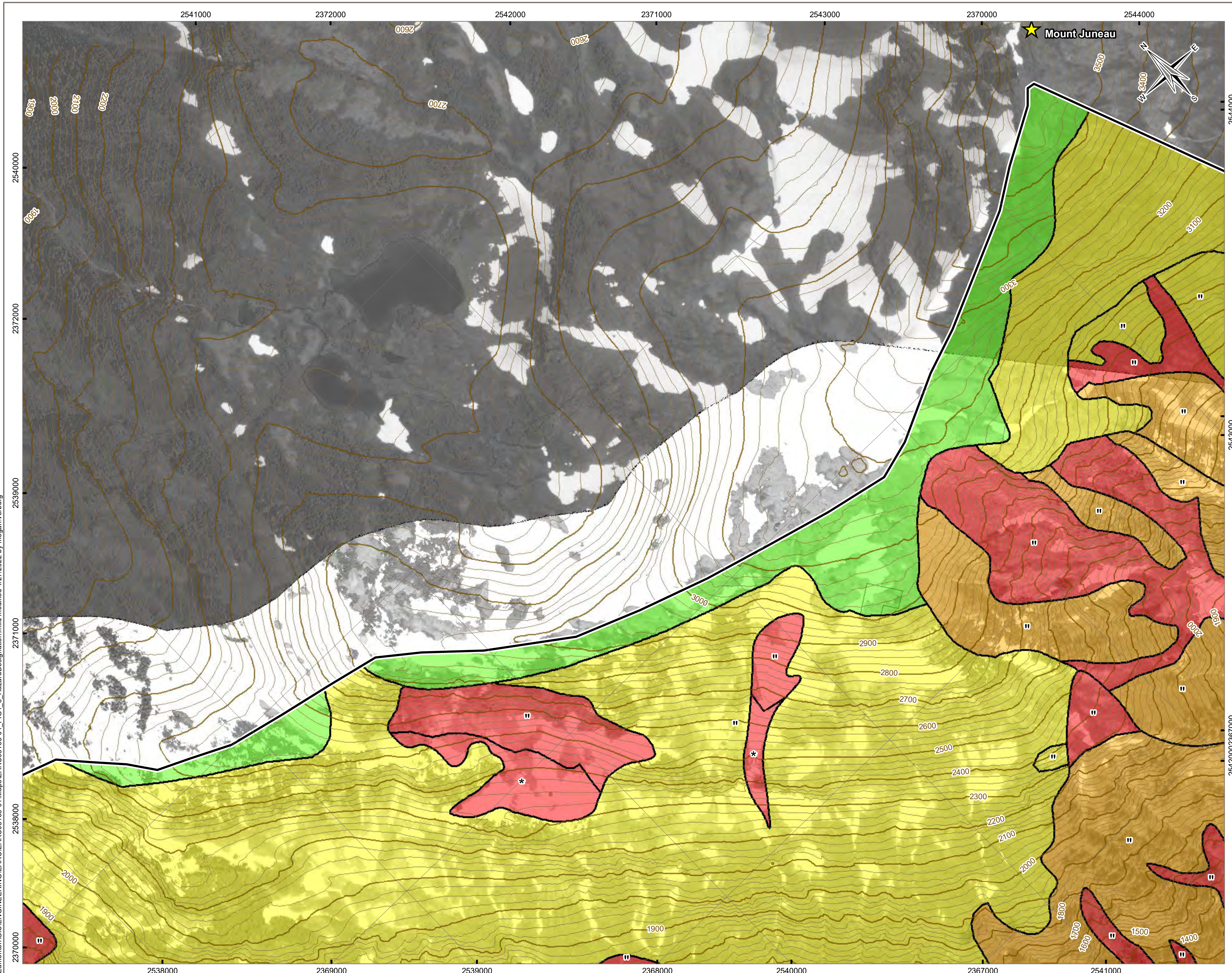

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LEGEND

- Location of Interest
- Study Area
- Deep-Seated Bedrock Slide

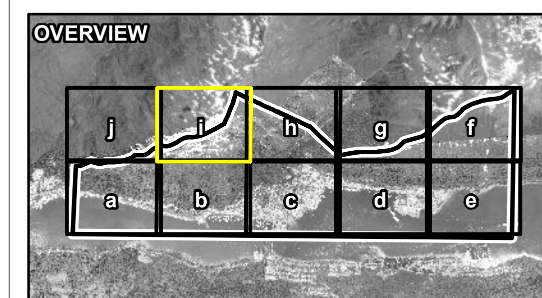
Landslide Hazard

(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000

300 150 0 300

Feet

TETRA TECH

FILE NO.				
EARC03168-01_FIG1_6_HazardDesignation.mxd				
OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0
DATE	PROJECT NO.			
April 27, 2022	ENG.EARC03168-01			

Figure 1.6i

LEGEND

- Study Area
- Deep-Seated Bedrock Slide

Landslide Hazard

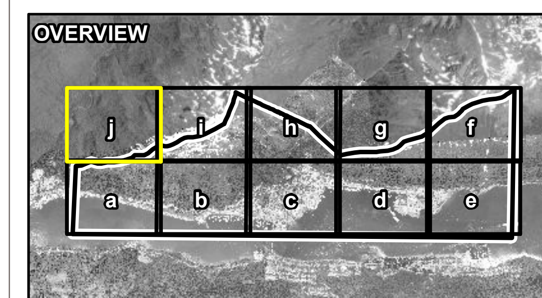
(For Hazard Designation Definitions Refer to Table 1.4 and the Glossary of Terms in the Report)

- Low
- Moderate
- High
- Severe
- Severe if Deep-Seated Bedrock Slide Fails
- " Initiation Zone
- * Runout Zone
- + Potential Initiation Zone for Deep-Seated Bedrock Slide

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

OVERVIEW



NOTES

[1] Engineered slope not evaluated by Tetra Tech for this study
Base data source:
Contours generated from 2013 LiDAR provided by CBJ.
Additional contours generated from 2012 LiDAR provided by CBJ.
Hydrology and roads obtained from Alaska Department of Natural Resources.
Terrain Classification based on Terrain Classification System for British Columbia, Version 2, 1997.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Landslide Hazard Designation Mapping

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
EARC03168-01_FIG1_6_HazardDesignation.mxd

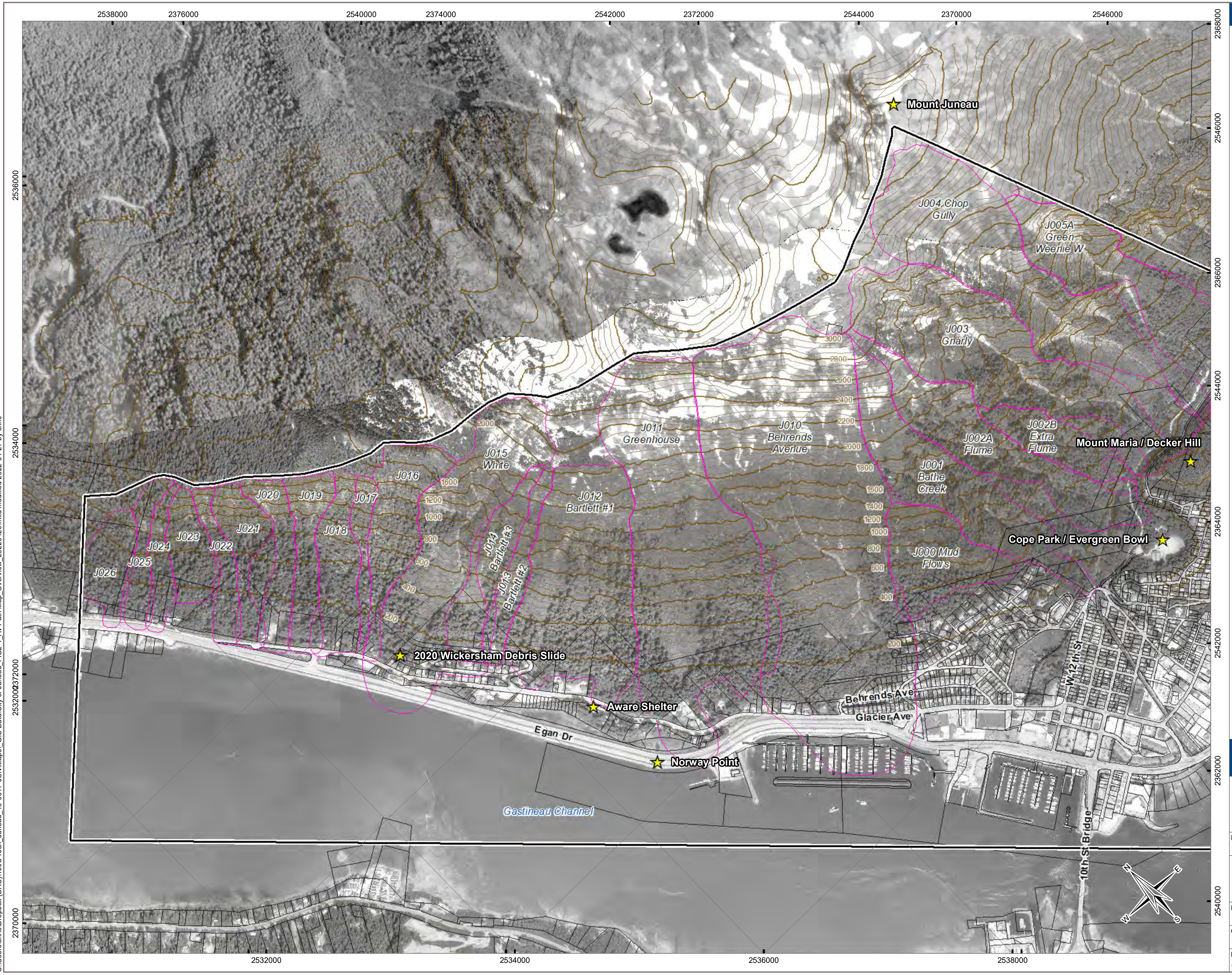
TETRA TECH

OFFICE	DWN	CKD	APVD	REV
Tt-EDM	MRV	SL	SM/VER	0

DATE	PROJECT NO.
April 27, 2022	ENG.EARC03168-01

Figure 1.6j

Q:\Edmonton\GIS\ENGINEERING\EARC\EARC03168-01\Maps\EARC03168-01_FIG1_6_HazardDesignation.mxd modified 4/27/2022 by megan.verburg



C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-1_Av Path Map_Overview_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (200 ft)
- Intermediate Contour (50 ft)
- Land Parcel

NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Overview

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:12,500

800 400 0 800

Feet

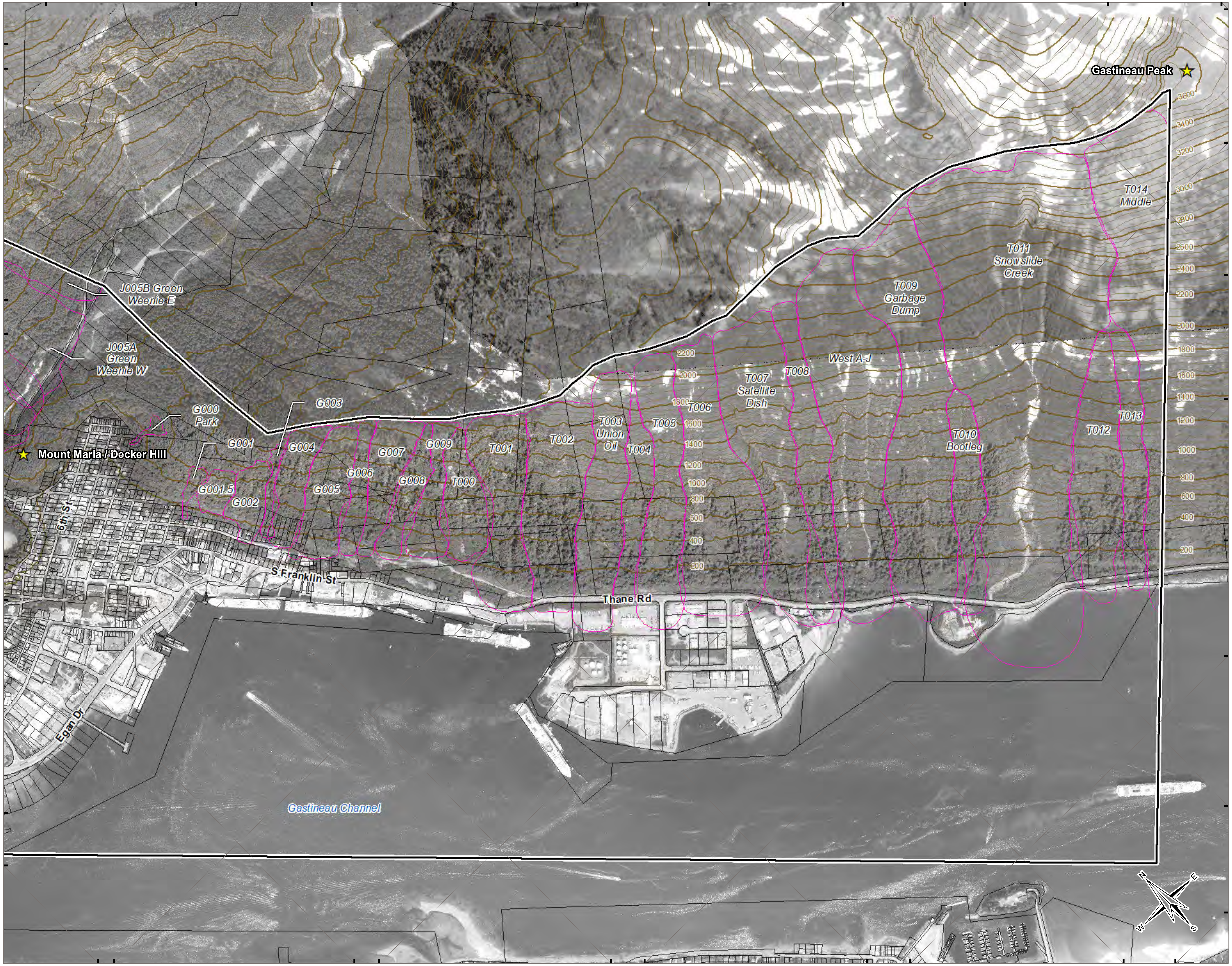
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.1a

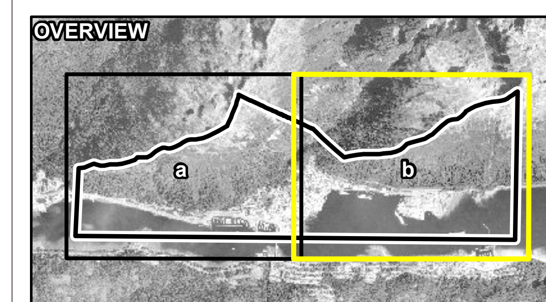


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (200 ft)
- Intermediate Contour (50 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Overview

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:12,500

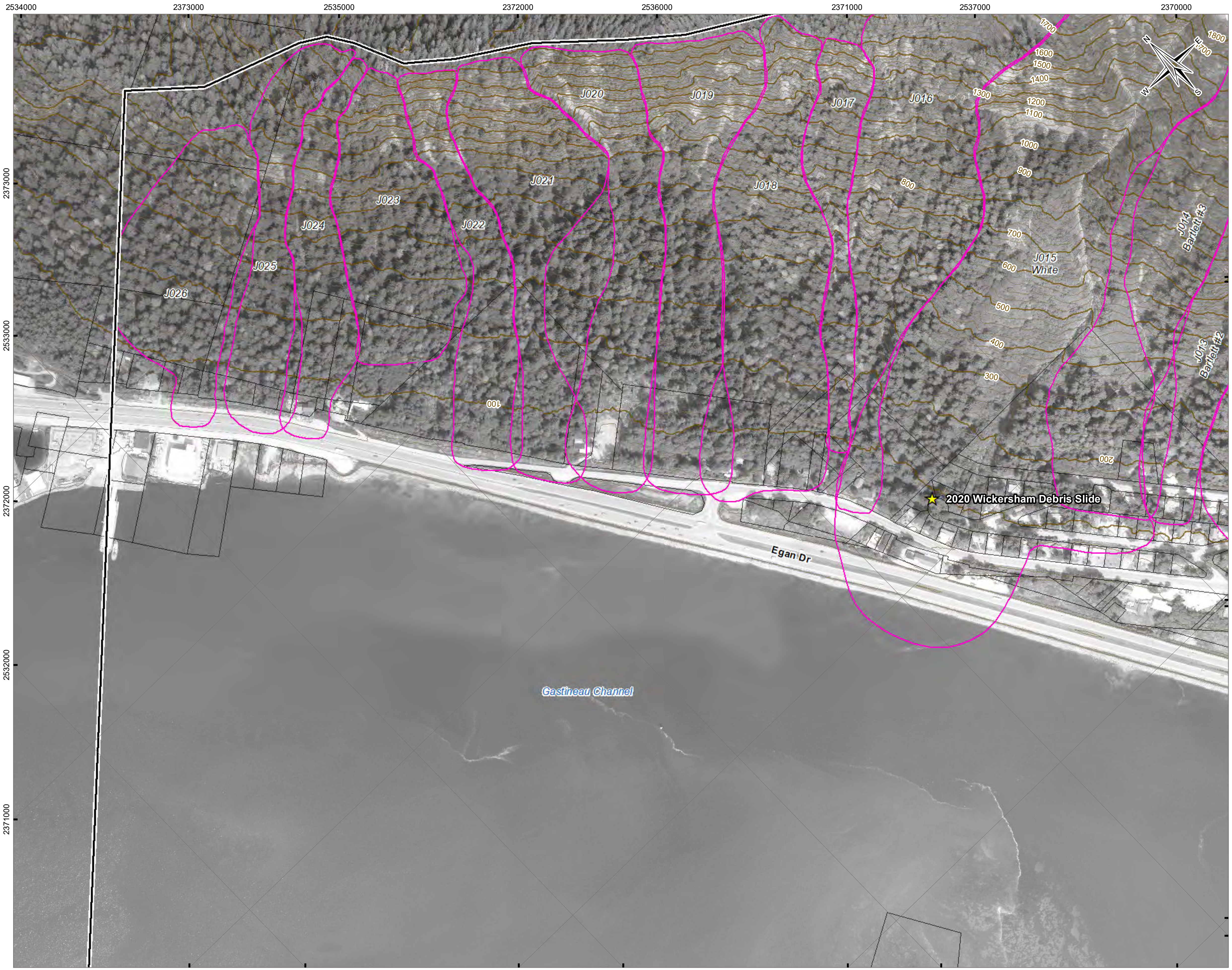
800 400 0 800
Feet

FILE NO.				
19-0017-JUN-002				
OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2
DATE	PROJECT NO.			
April 27, 2022	19-0017-JUN			

DYNAMIC

Figure 2.1b

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-1_Av Path Map_Overview_20220420.mxd modified 2022-04-27 by chris

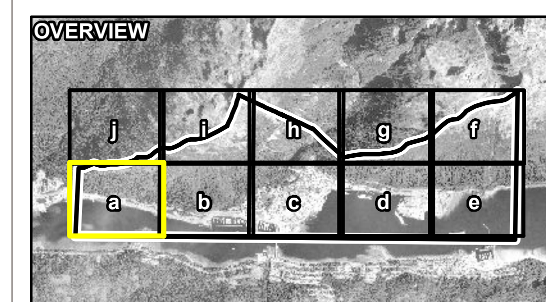


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300
Feet

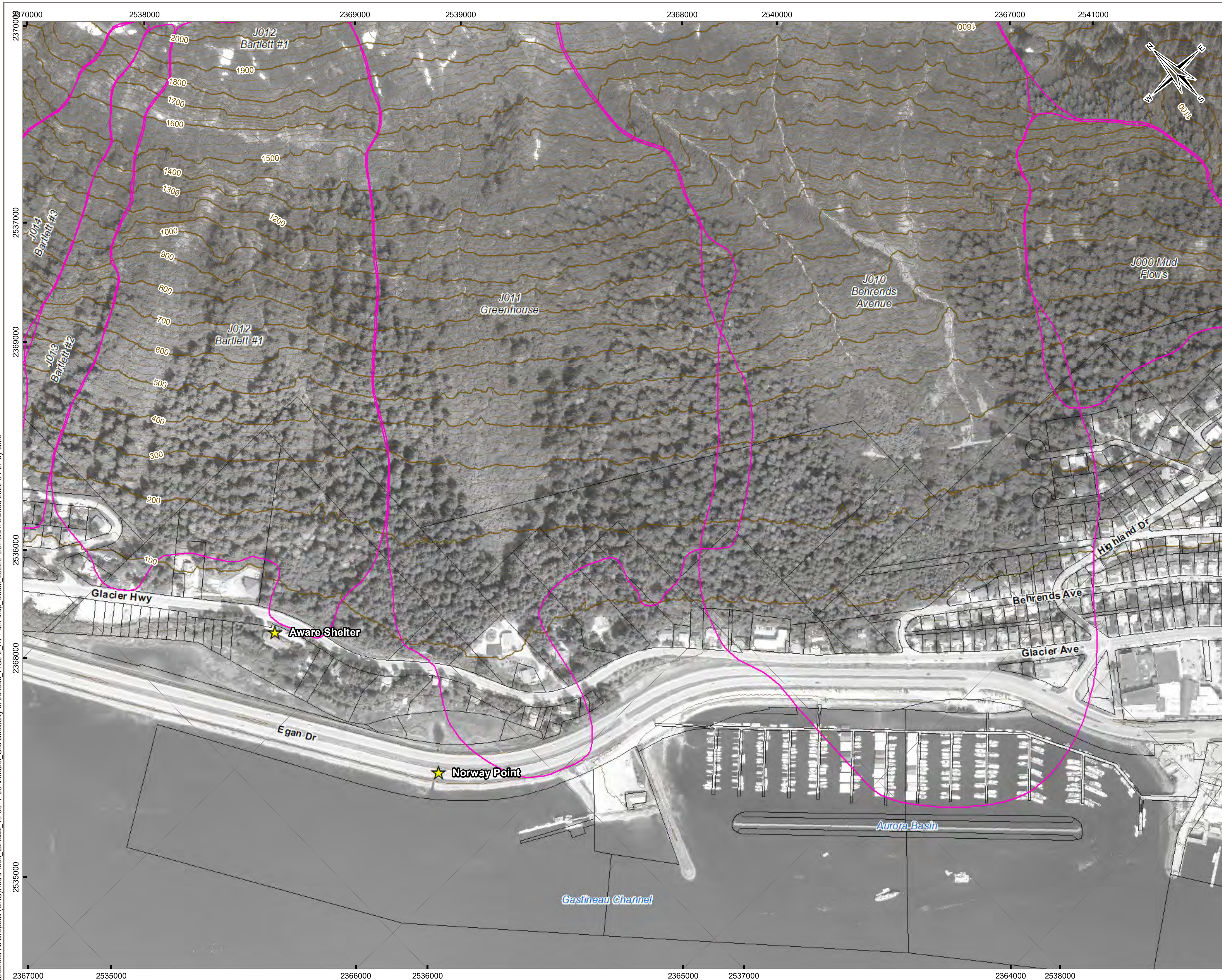
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2a



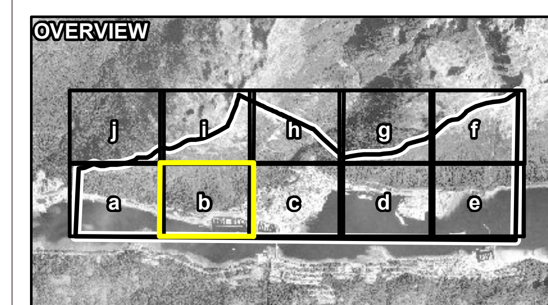
C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
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Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300

Feet

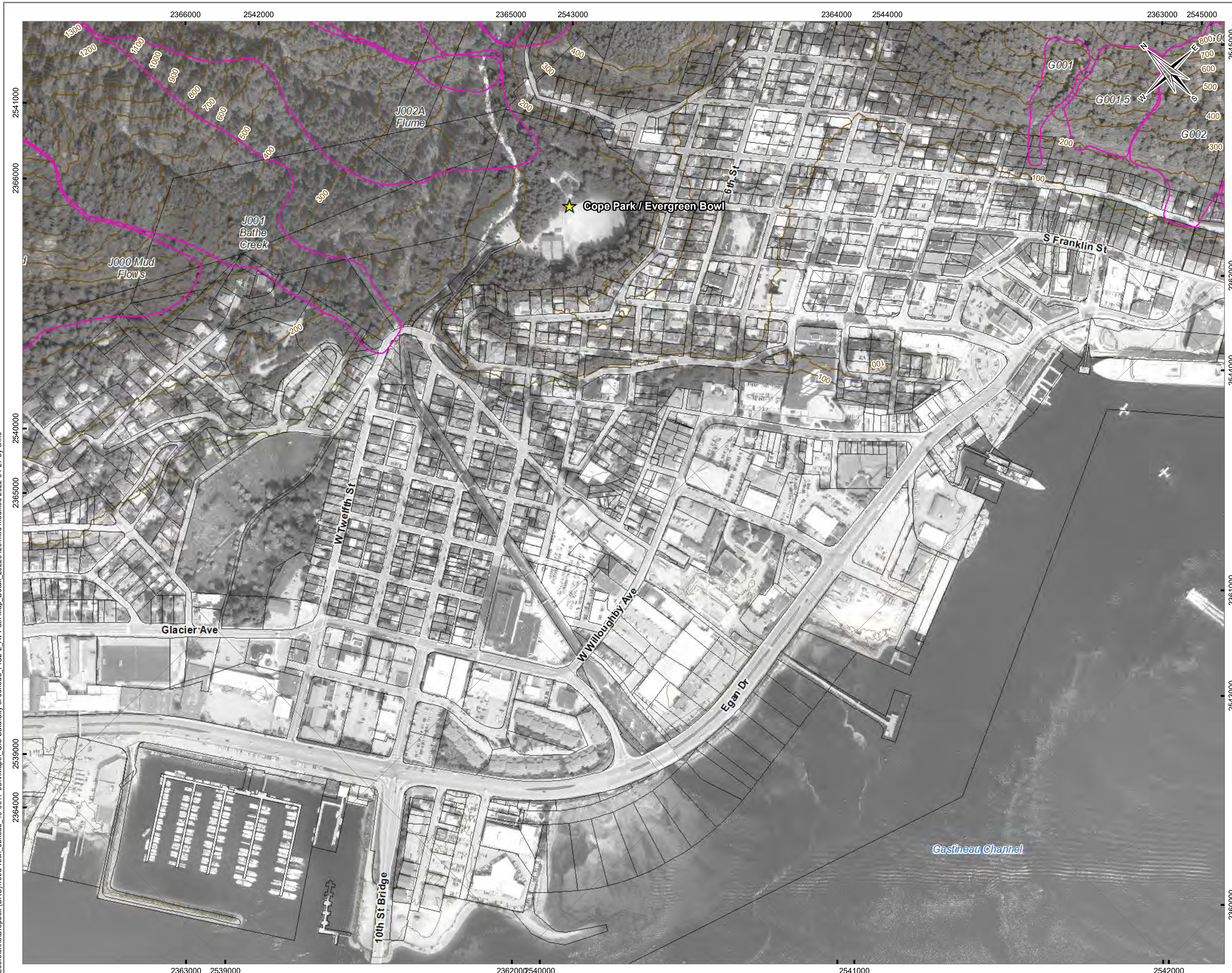
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2b

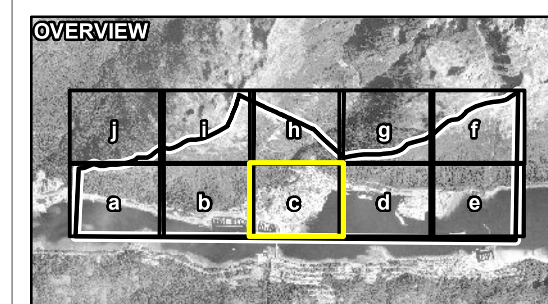


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
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Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

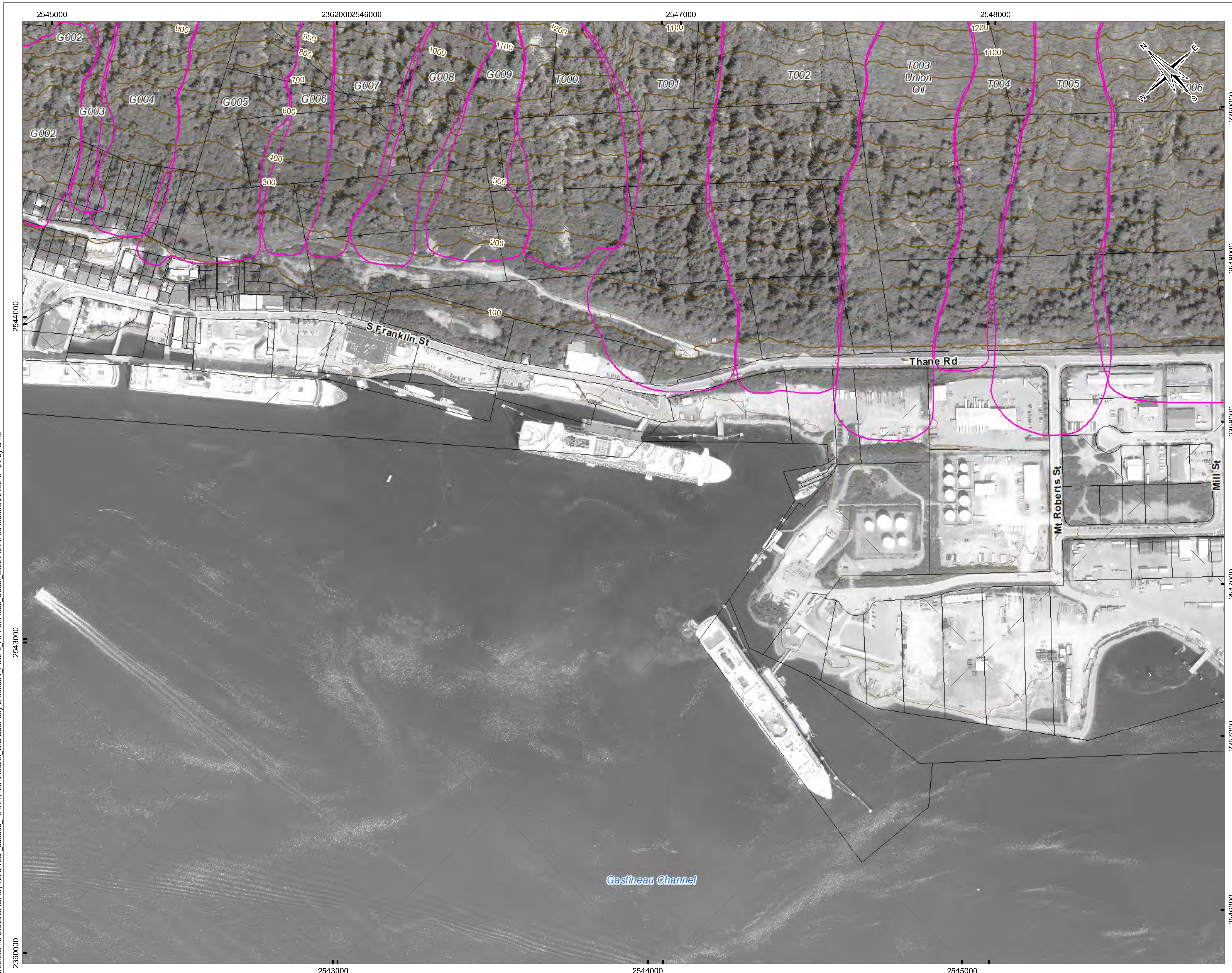
STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION State Plane Alaska Zone 1 5001			DATUM NAD83		CLIENT
Scale: 1:5,000 300 150 0 300 Feet					
FILE NO. 19-0017-JUN-002					
OFFICE DAC-Rev	DWN CA	CKD AJ	APVD AJ	REV 2	Figure 2.2c
DATE April 27, 2022	PROJECT NO. 19-0017-JUN				

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris

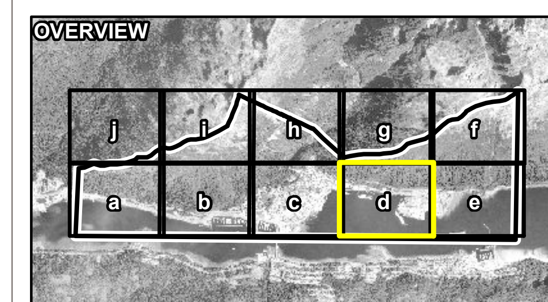


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000
300 150 0 300
Feet

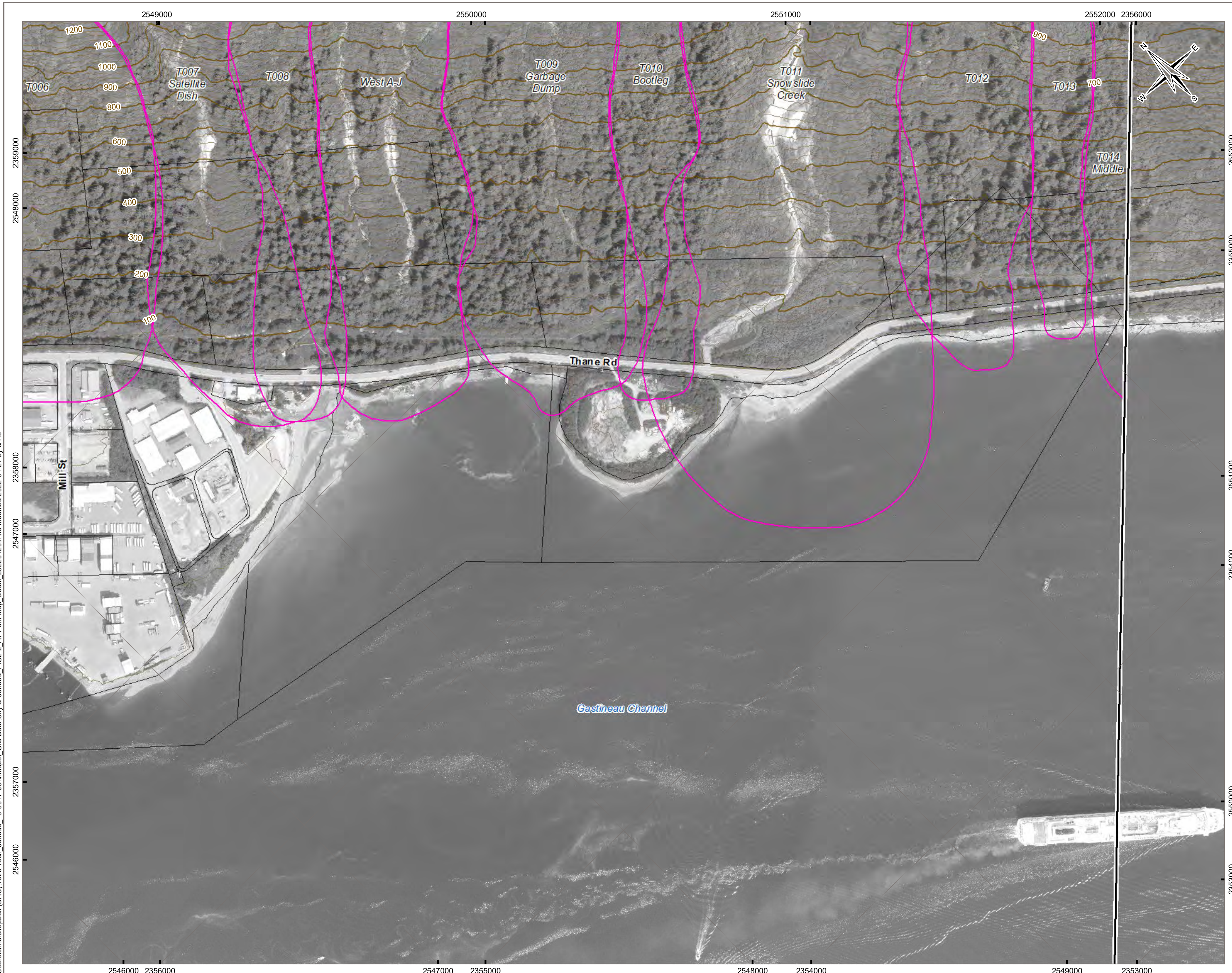
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2d



C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris

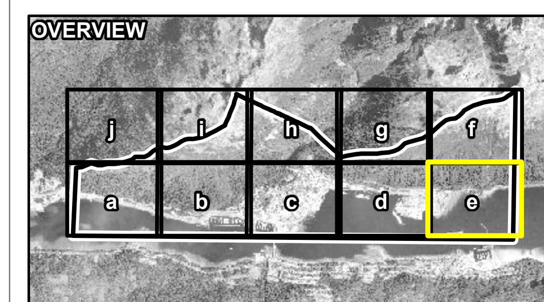
LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

OVERVIEW



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000

300 150 0 300
Feet

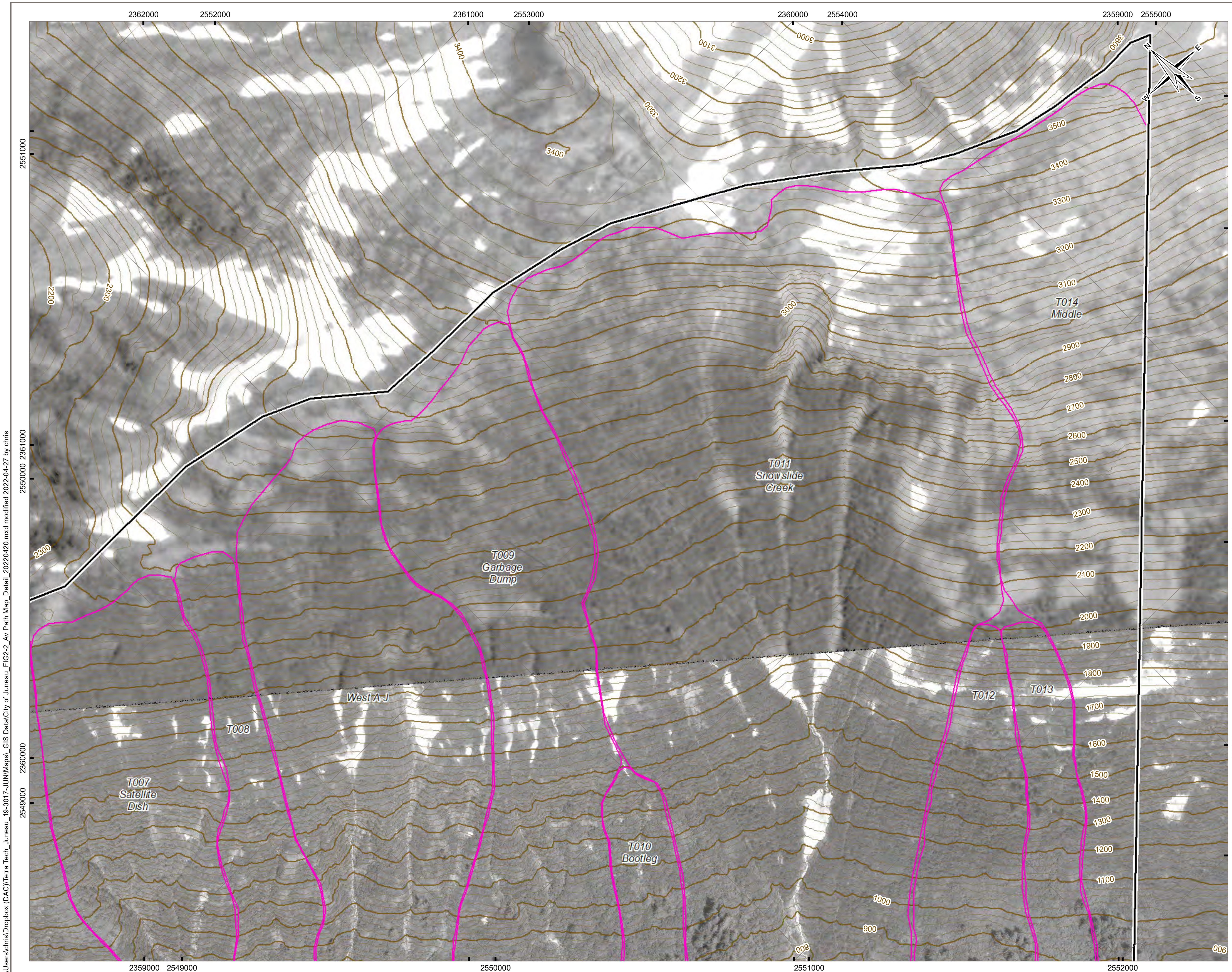
FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

DYNAMIC

Figure 2.2e

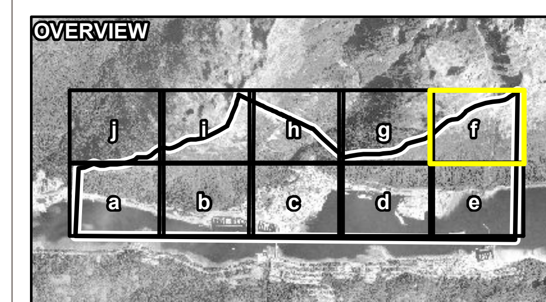


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000

300 150 0 300

Feet

FILE NO.
19-0017-JUN-002

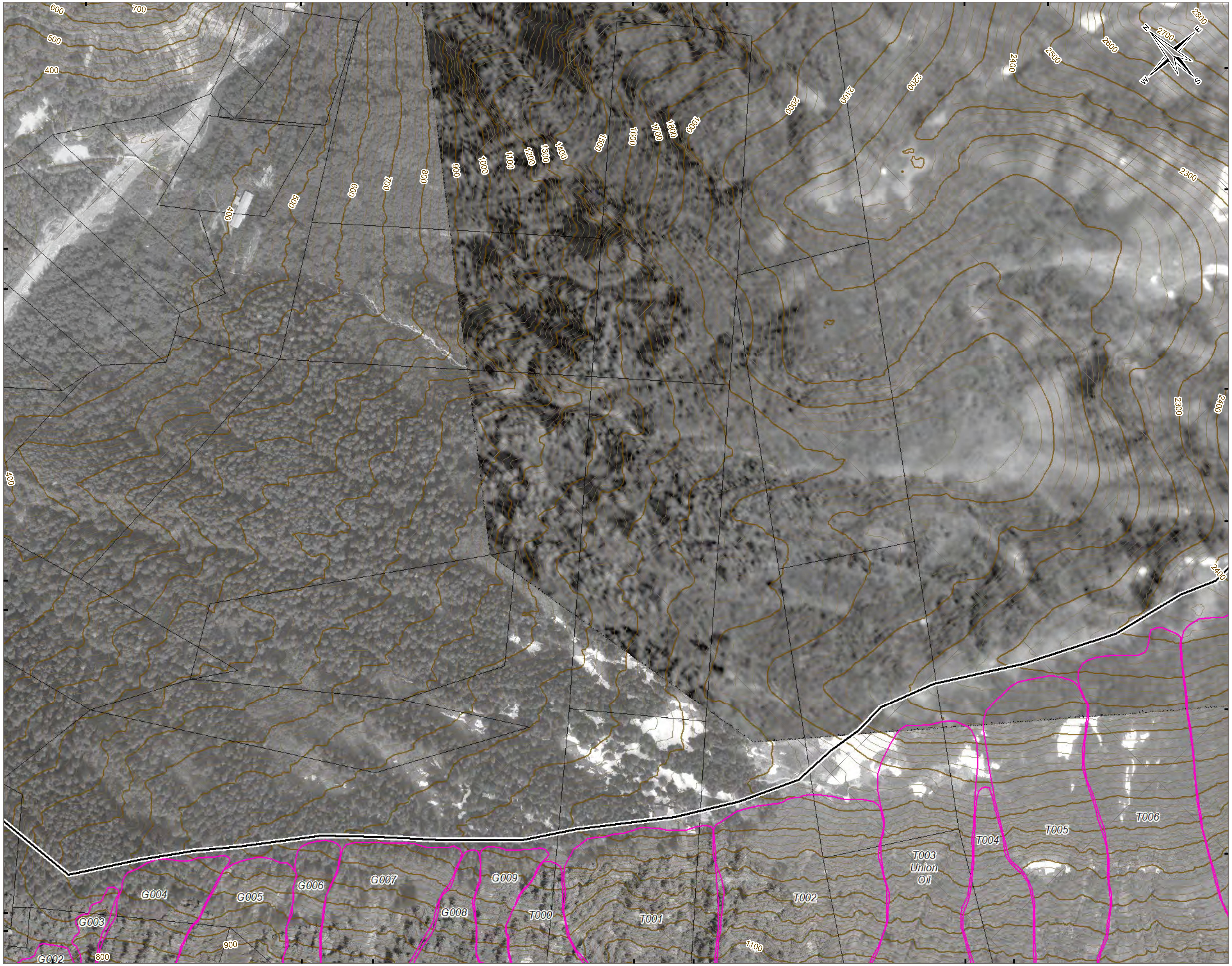
DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

Figure 2.2f

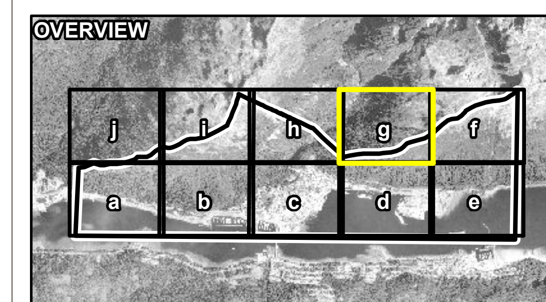


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
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Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	

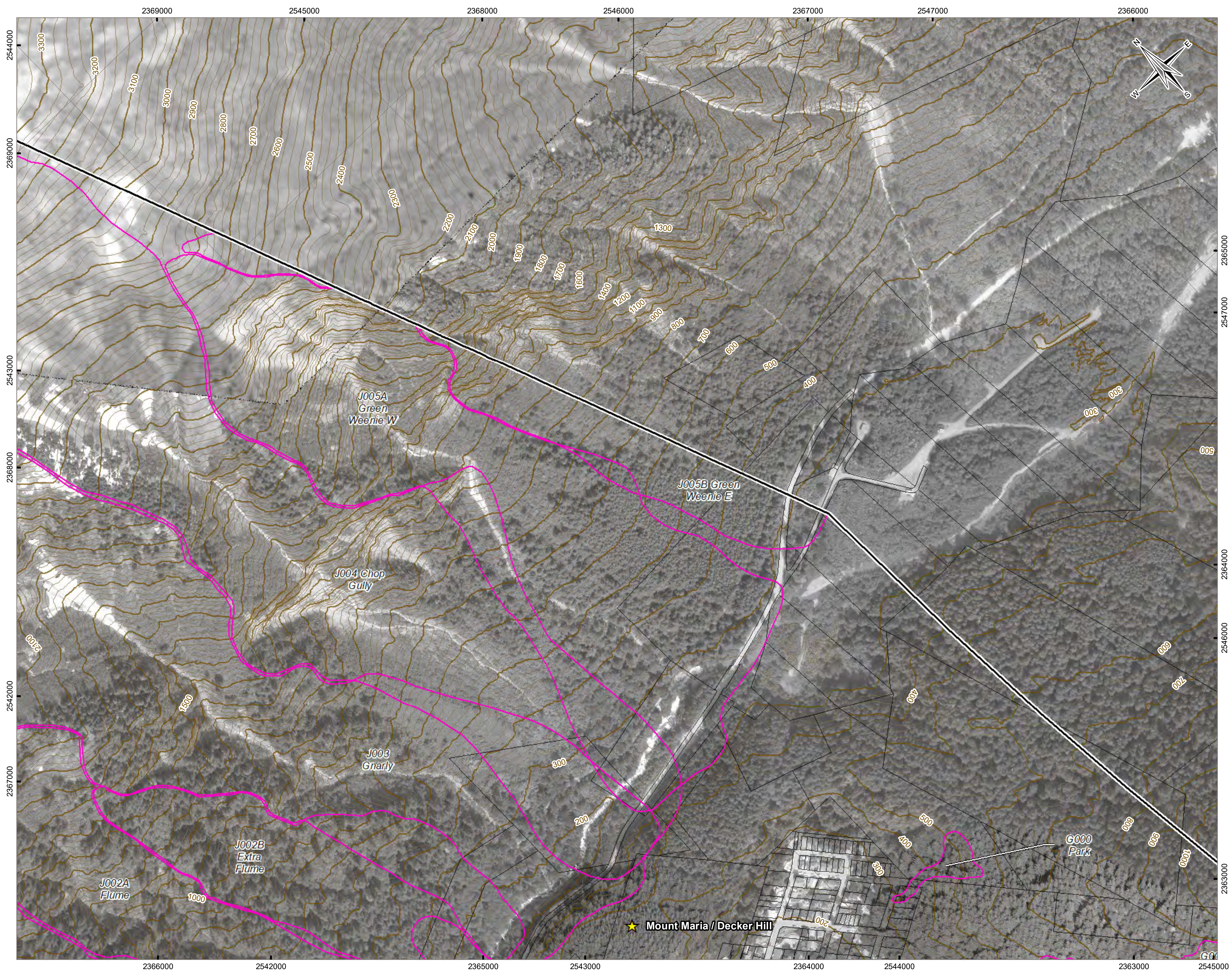
Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2g

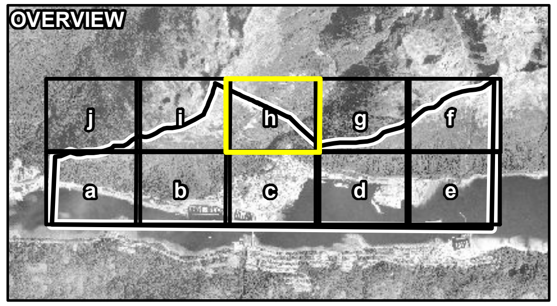


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".

Base data source:

Land parcels provided by CBJ.

Contours generated from 2013 LiDAR provided by CBJ.

Background contours generated from 2012 LiDAR provided by CBJ.

Primary imagery provided by CBJ, 2013.

Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	

Scale: 1:5,000

300 150 0 300

Feet

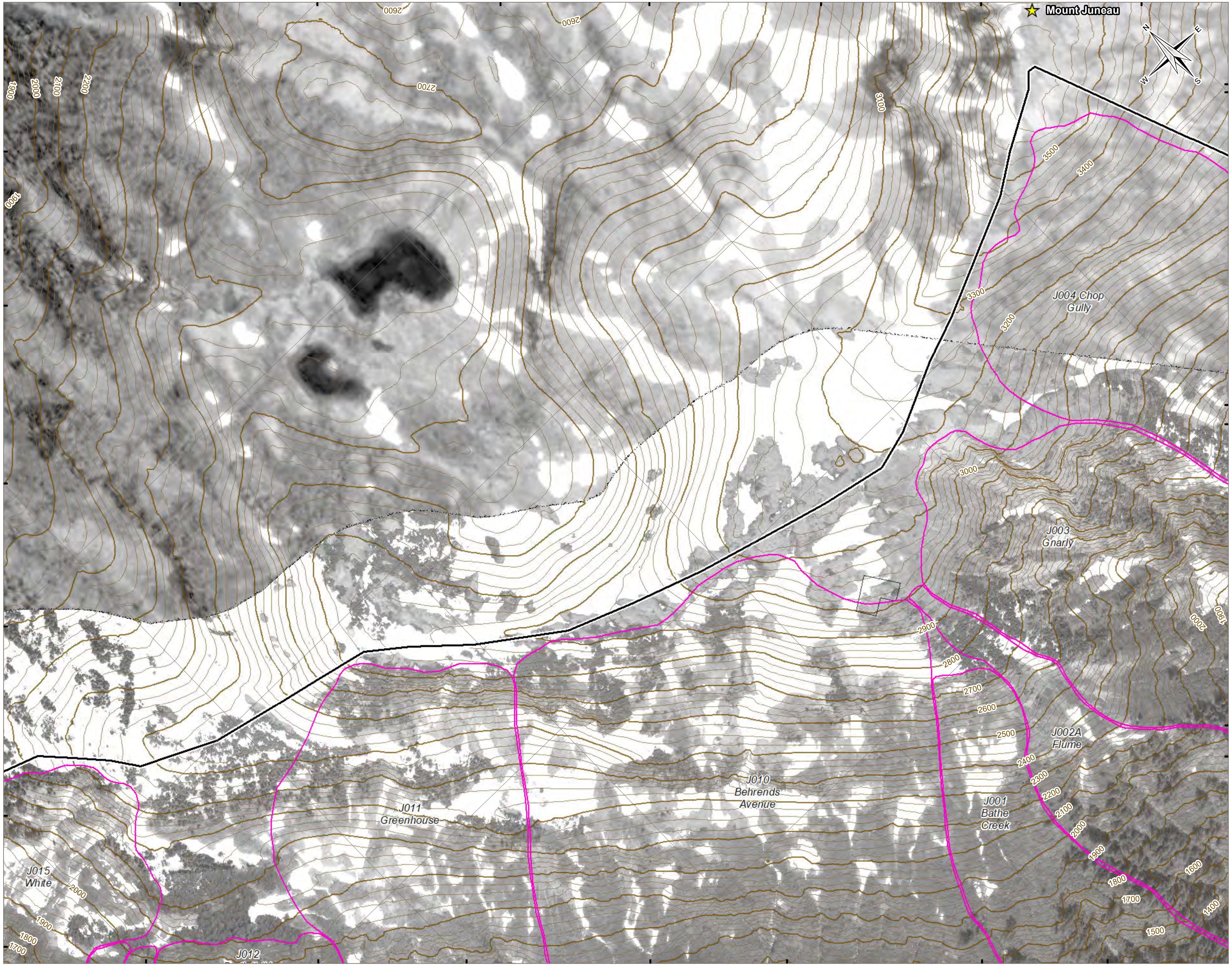
FILE NO. 19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2h

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris



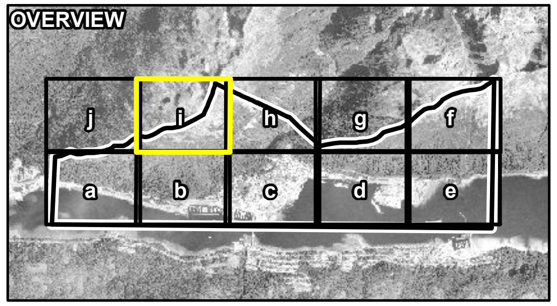
C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES

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Base data source:
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Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000

300 150 0 300
Feet

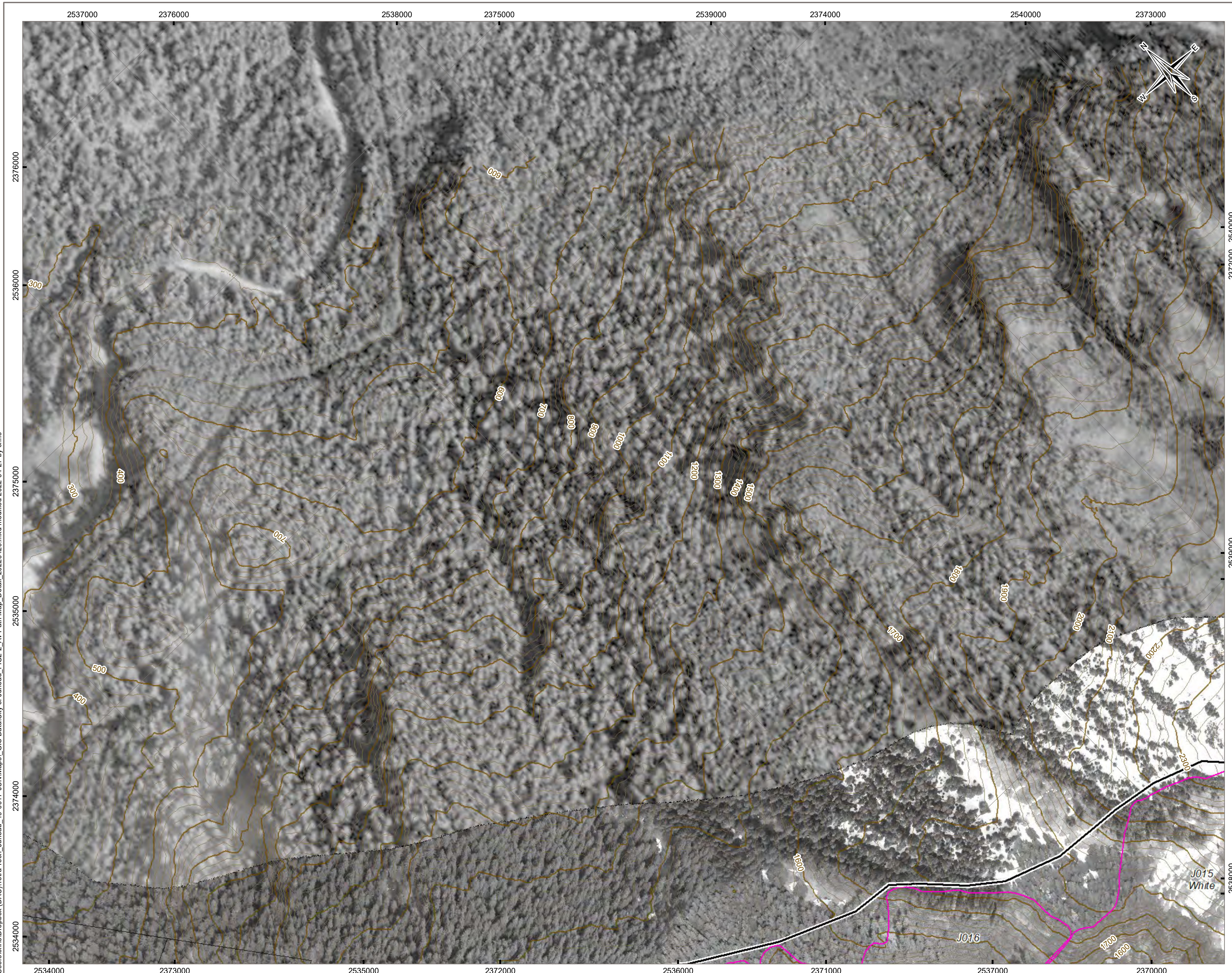
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2i

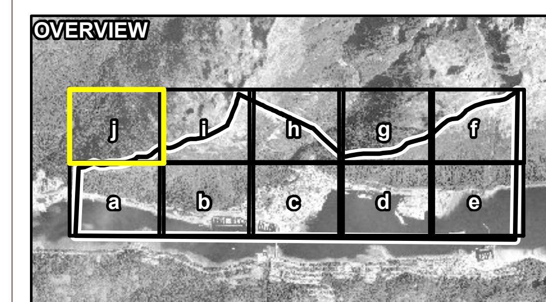


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel



NOTES
Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
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Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Path Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	

Scale: 1:5,000
300 150 0 300
Feet

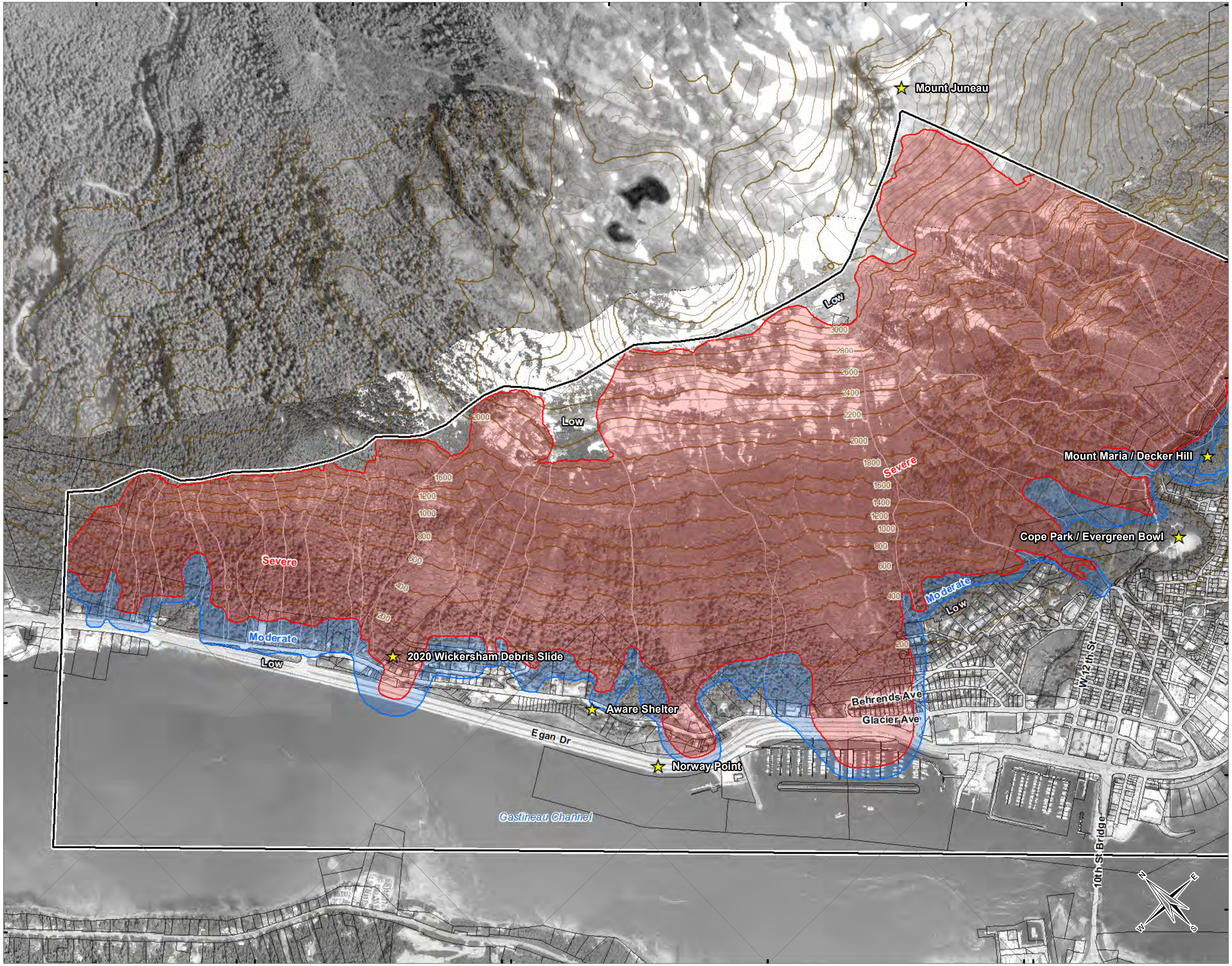
FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.2j

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-2_Av Path Map_Detail_20220420.mxd modified 2022-04-27 by chris



LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (200 ft)
- Intermediate Contour (50 ft)
- Land Parcel

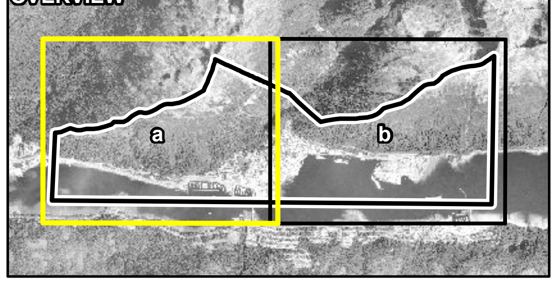
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Overview

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:12,500
800 400 0 800
Feet

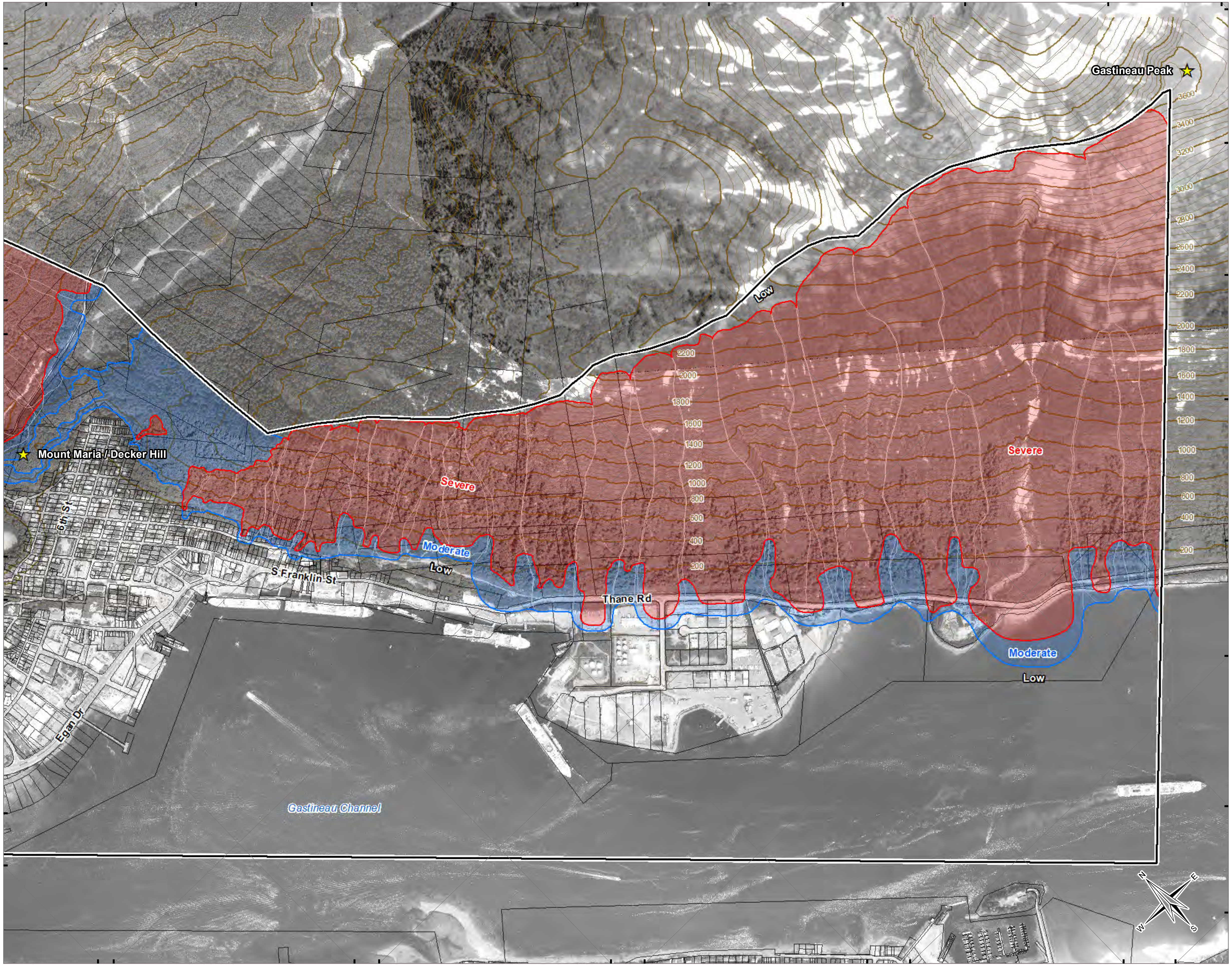
FILE NO. 19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE April 27, 2022
PROJECT NO. 19-0017-JUN

Figure 2.3a

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-3_Av Designation_Overview_20220420.mxd modified 2022-04-27 by chris



C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-3_Av Designation_Overview_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (200 ft)
- Intermediate Contour (50 ft)
- Land Parcel

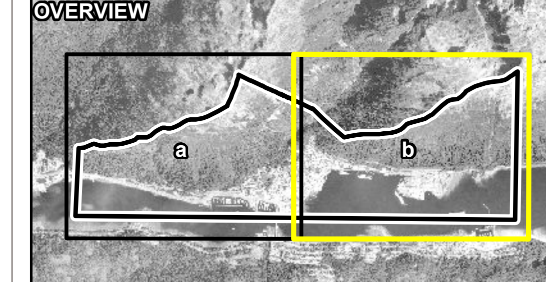
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Overview

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	

Scale: 1:12,500
800 400 0 800
Feet

FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.3b

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

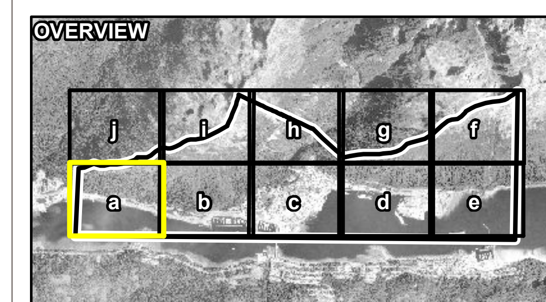
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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Base data source:
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Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

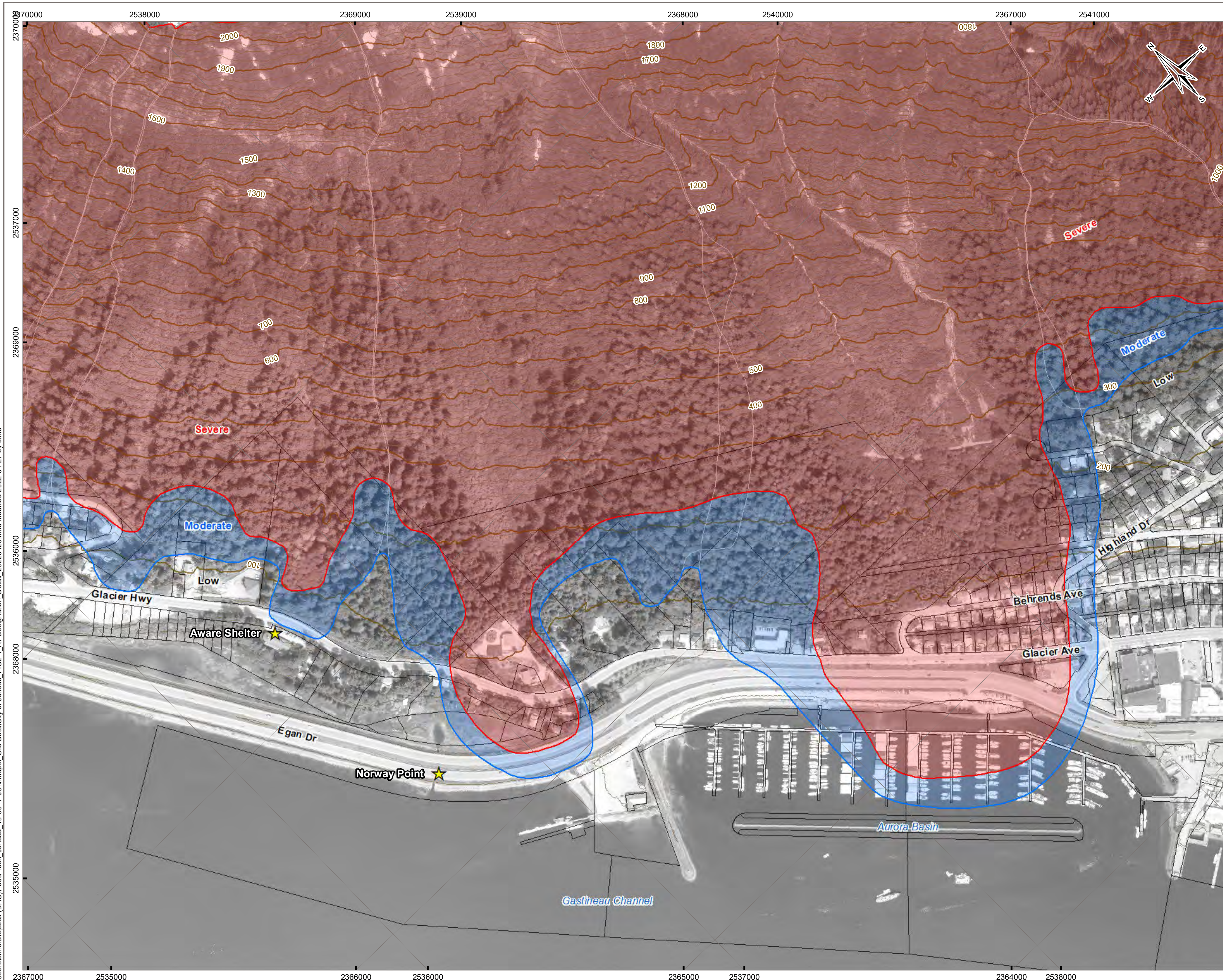
Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.				
19-0017-JUN-002				
OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2
DATE	PROJECT NO.			
April 27, 2022	19-0017-JUN			

Figure 2.4a



LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

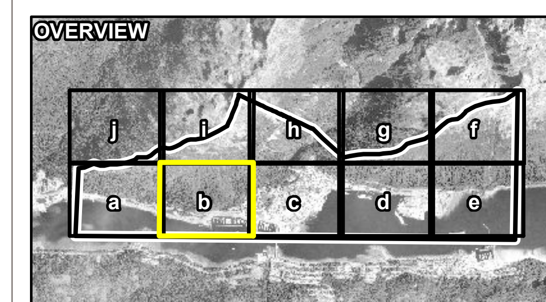
- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).



NOTES
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Base data source:
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Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

Figure 2.4b

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

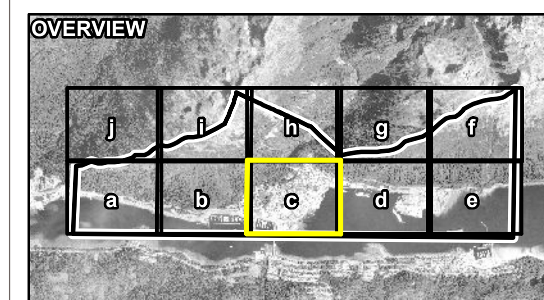
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
Low hazard designation not shown. Low hazard designation includes all areas not designated as "Moderate" or "Severe".
Base data source:
Land parcels provided by CBJ.
Contours generated from 2013 LiDAR provided by CBJ.
Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
Background imagery provided by ESRI; Maxar (2020).

STATUS
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

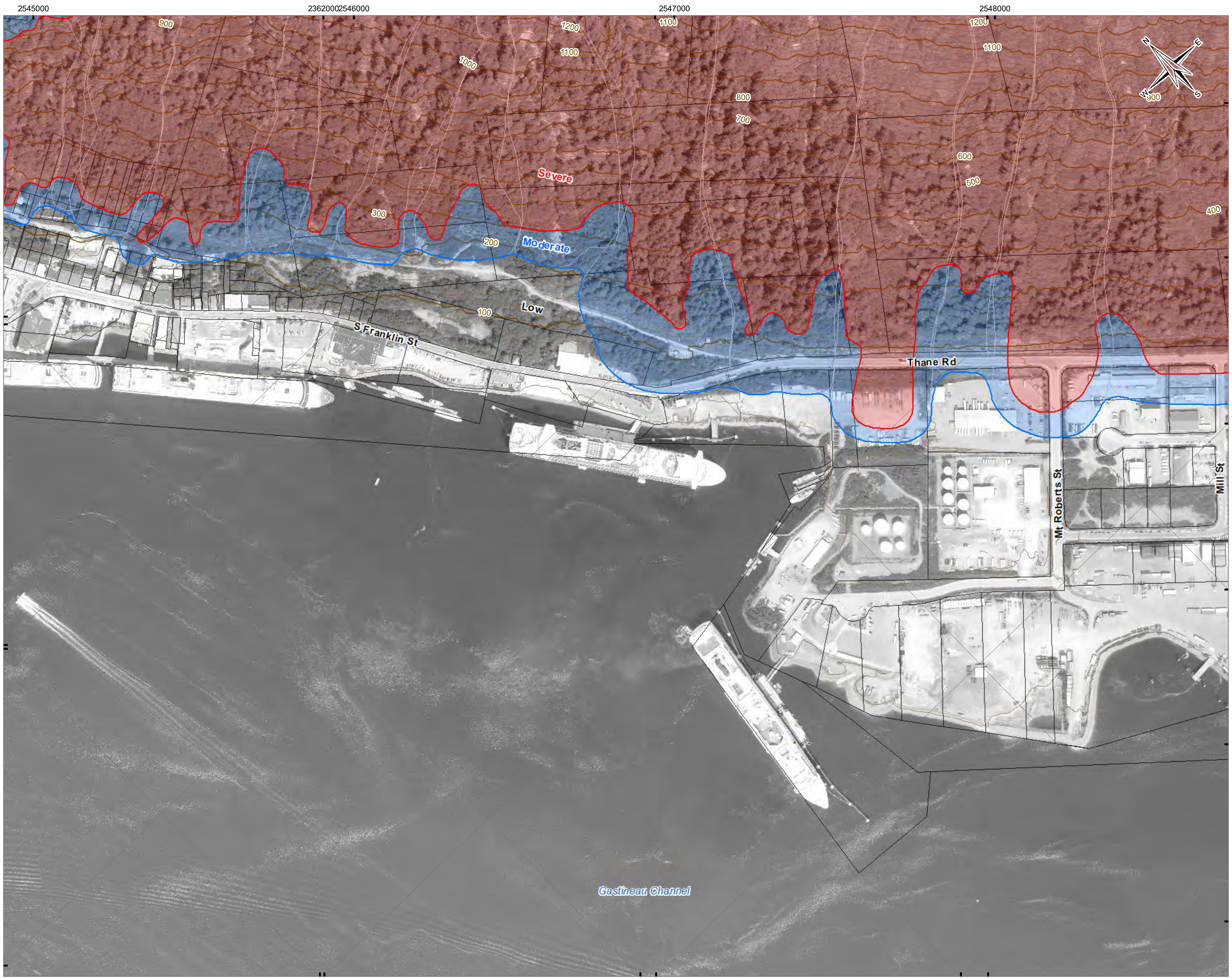
OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

DYNAMIC

Figure 2.4c

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris



C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

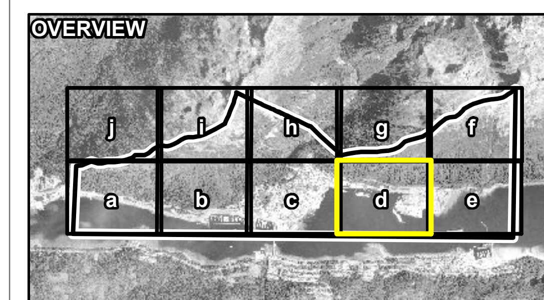
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft² (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft² (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft² (30 kPa).

OVERVIEW



NOTES
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Background contours generated from 2012 LiDAR provided by CBJ.
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STATUS
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

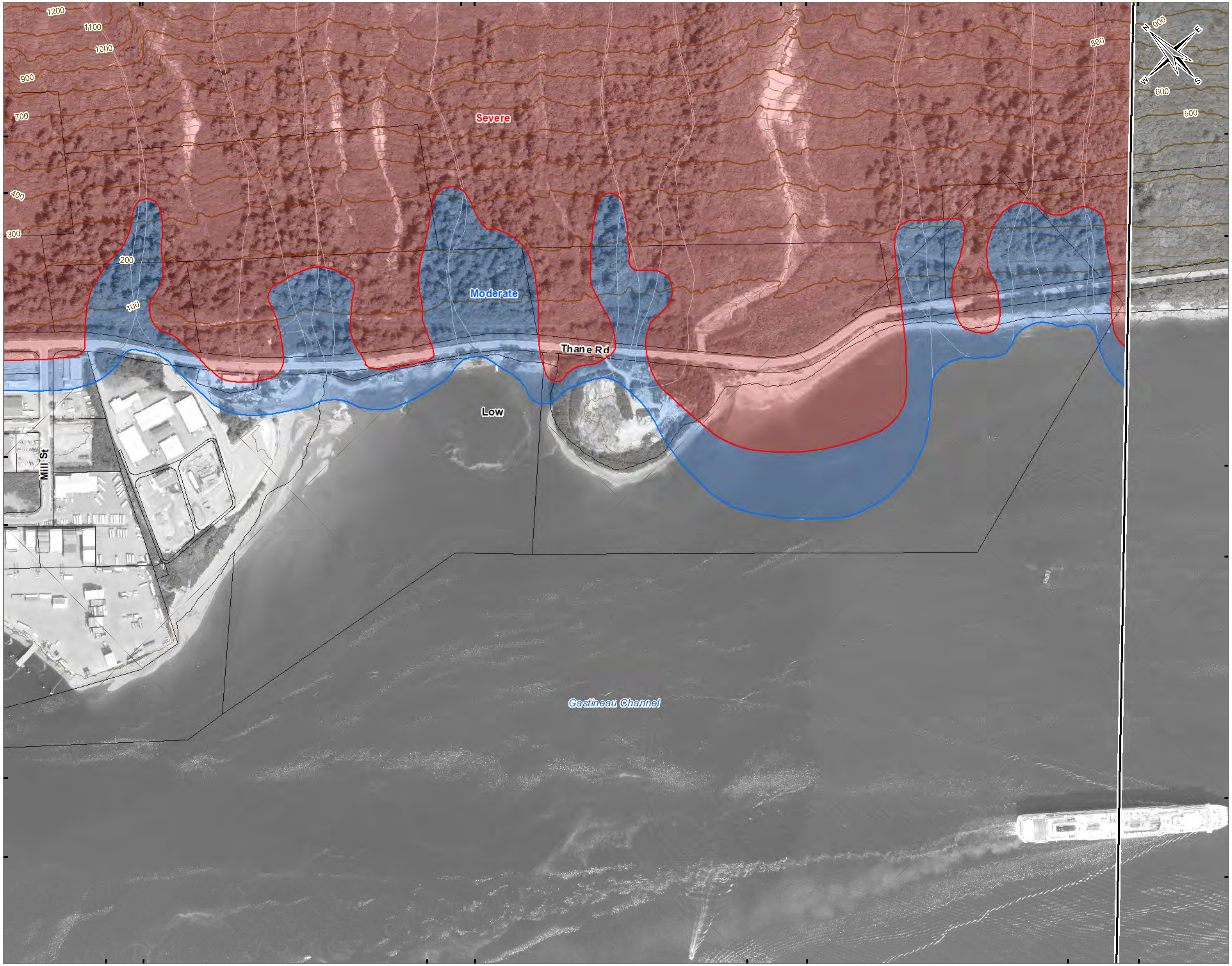
FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE	PROJECT NO.
April 27, 2022	19-0017-JUN

Figure 2.4d



LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

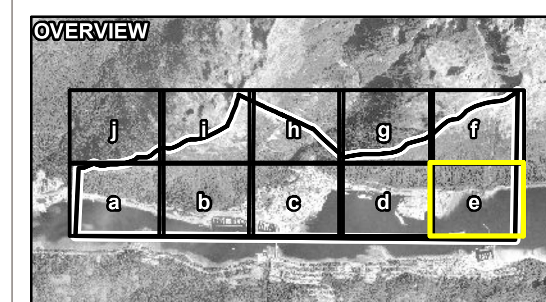
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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Base data source:
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Background contours generated from 2012 LiDAR provided by CBJ.
Primary imagery provided by CBJ, 2013.
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STATUS
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

DYNAMIC

Figure 2.4e

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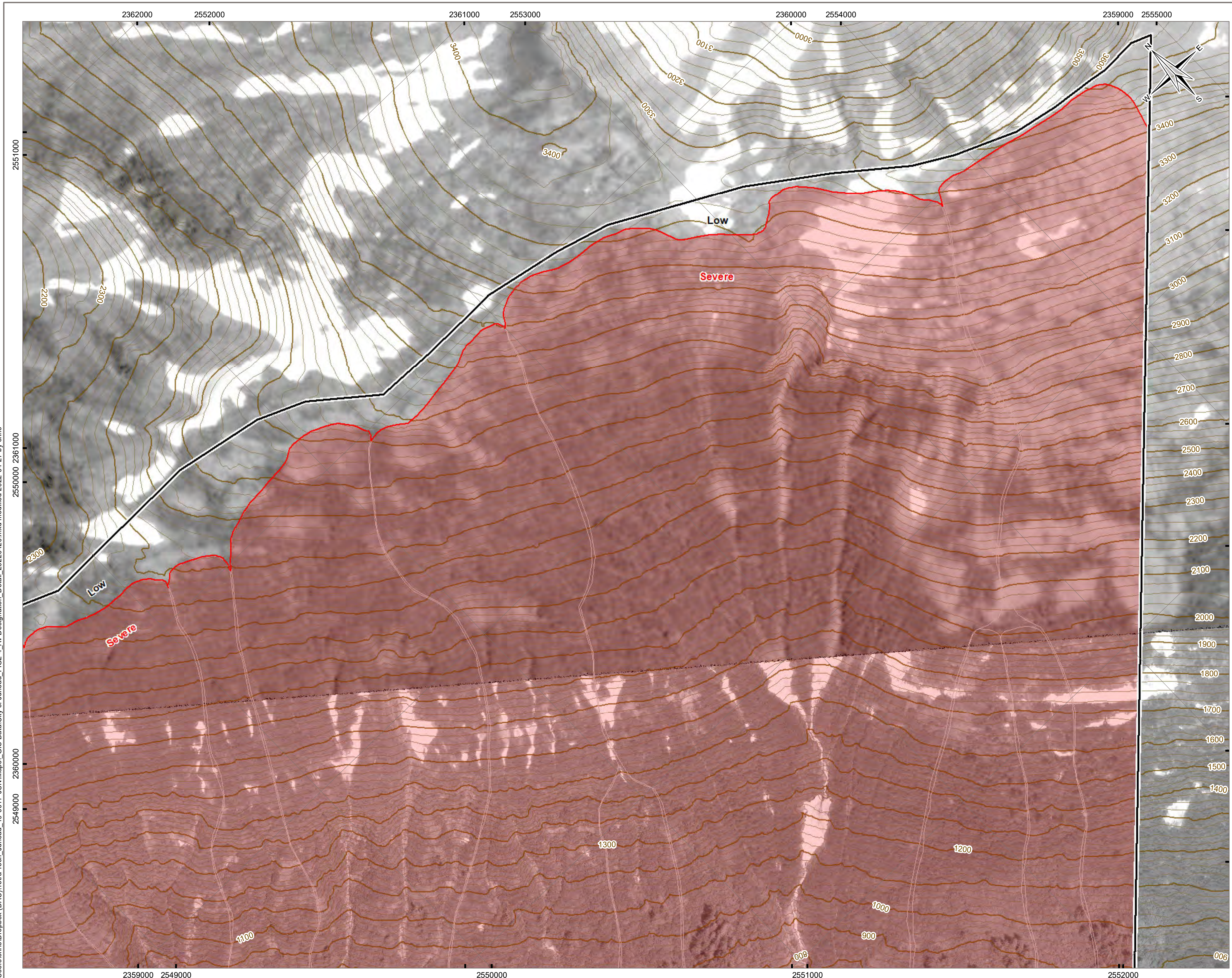


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

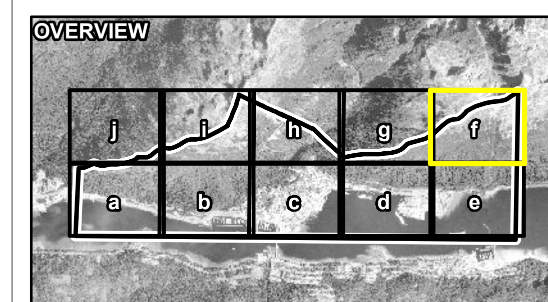
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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Background contours generated from 2012 LiDAR provided by CBJ.
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STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

DYNAMIC

Figure 2.4f

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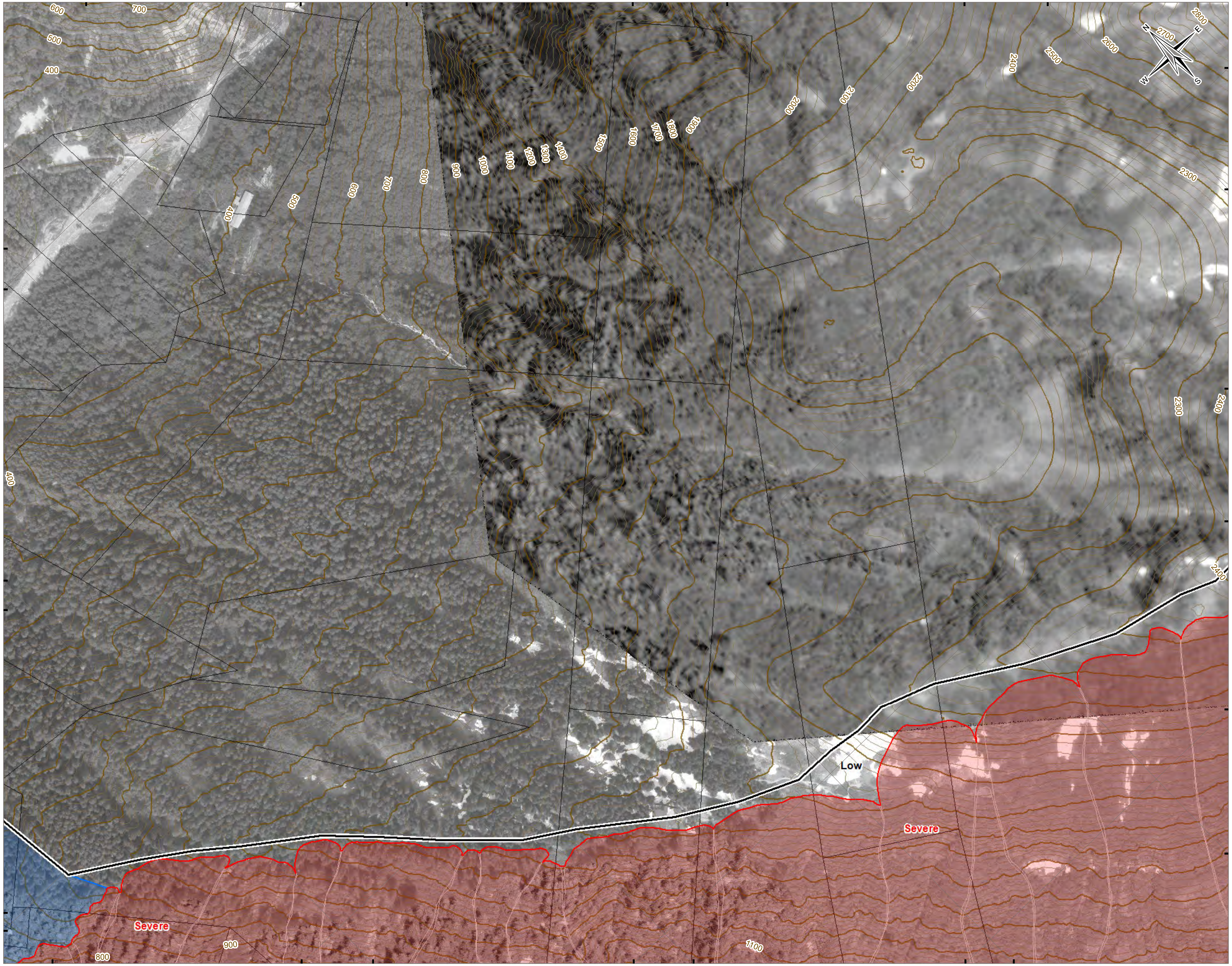


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

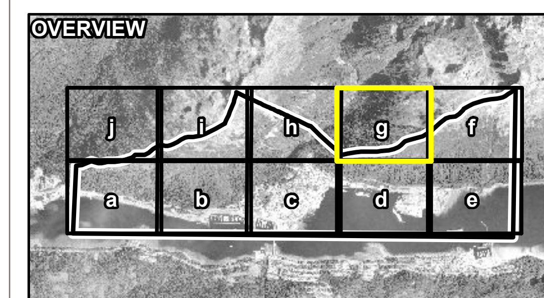
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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Background contours generated from 2012 LiDAR provided by CBJ.
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.				
19-0017-JUN-002				
OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2
DATE	PROJECT NO.			
April 27, 2022	19-0017-JUN			

DYNAMIC

Figure 2.4g

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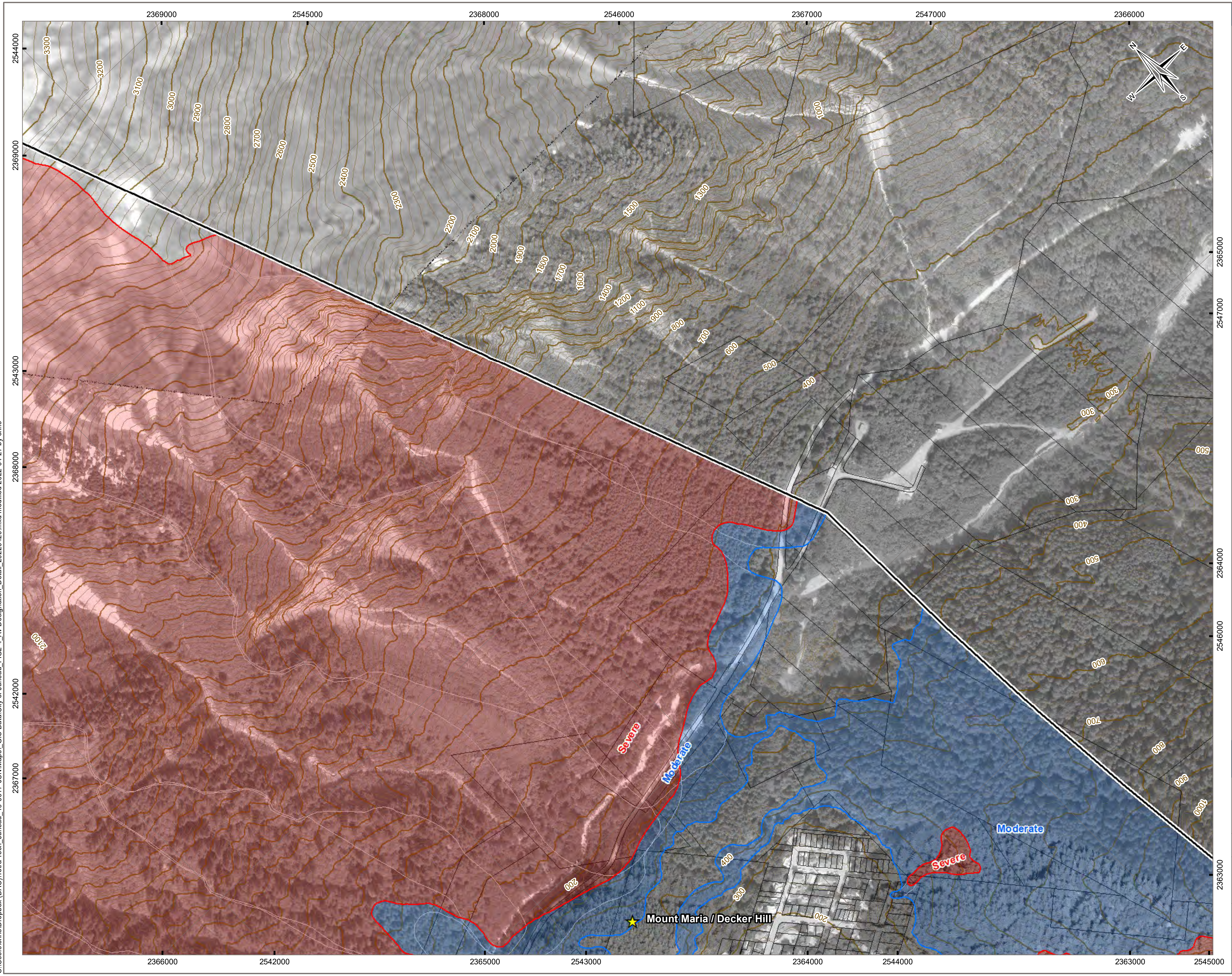


LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

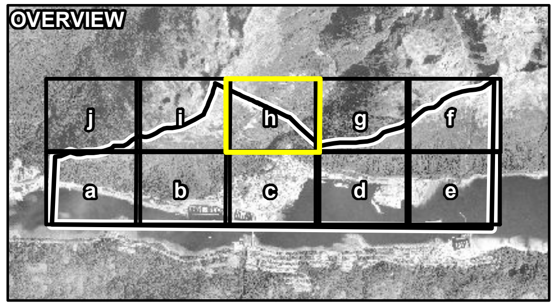
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

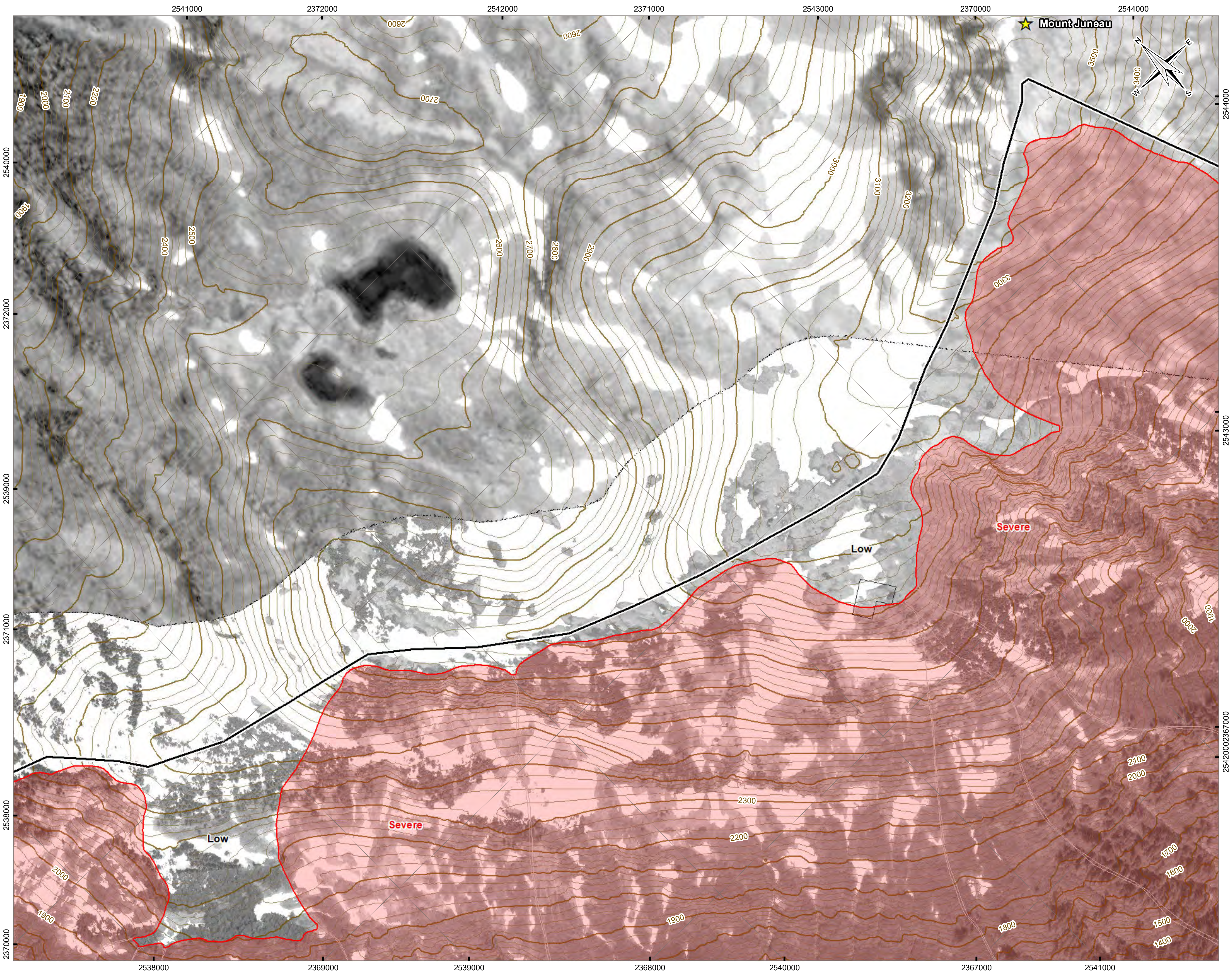
DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

DYNAMIC

Figure 2.4h

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris



LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

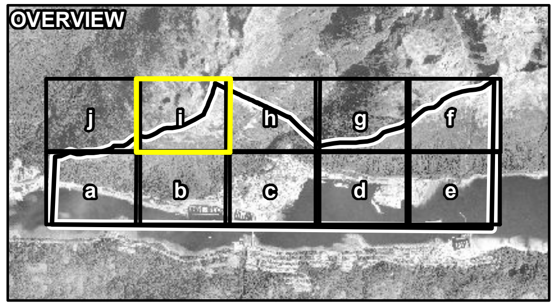
AVALANCHE HAZARD DESIGNATION

Low
Return period greater than 300 years
OR
Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

Moderate
Return period between 30 and 300 years;
AND
Impact pressure less than 600 lbs/ft^2 (30 kPa).

Severe
Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW



NOTES
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JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

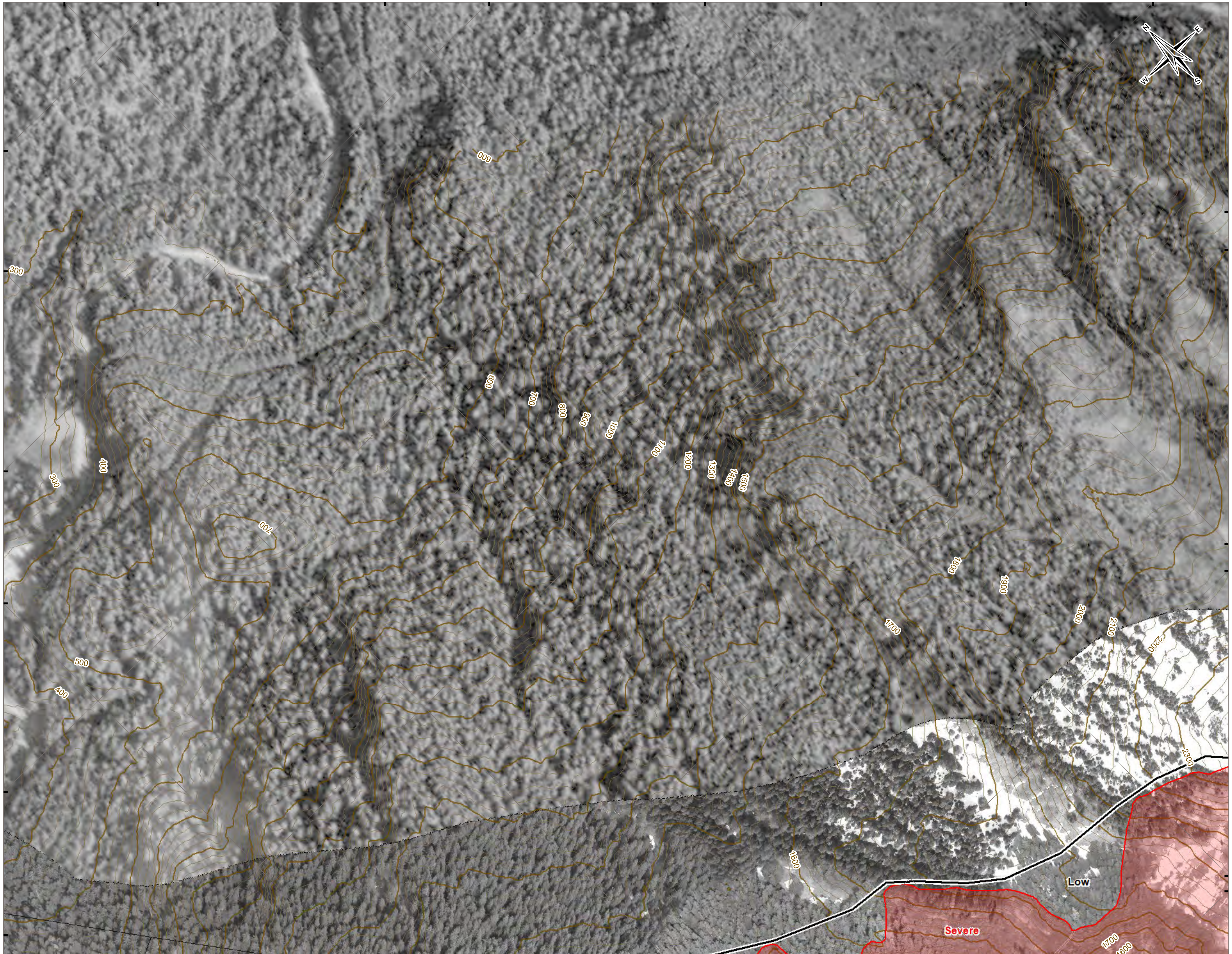
Scale: 1:5,000
300 150 0 300
Feet

FILE NO.				
19-0017-JUN-002				
OFFICE	**DWN**	**CKD**	**APVD**	**REV**
DAC-Rev	CA	AJ	AJ	2
DATE	**PROJECT NO.**			
April 27, 2022	19-0017-JUN			

DYNAMIC

Figure 2.4i

C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris



C:\Users\chris\Dropbox (DAC)\Tetra Tech_Juneau_19-0017-JUN\Maps_GIS Data\City of Juneau_FIG2-4_Av Designation_Detail_20220420.mxd modified 2022-04-27 by chris

LEGEND

- Location of Interest
- Study Area
- Avalanche Path (estimated 300-year boundary)

Base Data

- Index Contour (100 ft)
- Intermediate Contour (25 ft)
- Land Parcel

AVALANCHE HAZARD DESIGNATION

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Return period greater than 300 years
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Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.

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Return period between 30 and 300 years;
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Impact pressure less than 600 lbs/ft^2 (30 kPa).

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Return period less than 30 years;
AND/OR
Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

OVERVIEW

j i h g f
a b c d e

NOTES
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Avalanche Hazard Designation Mapping Detail

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:5,000
300 150 0 300
Feet

FILE NO.
19-0017-JUN-002

DYNAMIC

OFFICE	DWN	CKD	APVD	REV
DAC-Rev	CA	AJ	AJ	2

DATE
April 27, 2022

PROJECT NO.
19-0017-JUN

Figure 2.4j

PHOTOGRAPHS

Photo 1	Looking northeast at part of the White avalanche path showing two minor debris slides in existing slope colluvium. The debris slide pictured in Photo 2 is indicated
Photo 2	Looking east at a small debris slide within the White avalanche path. The bare ground near the top of the photo represents the initiation zone. The red backpack is resting on the deposited material consisting of platy schist cobbles/pebbles, sand, and silt
Photo 3	Looking northwest at an area of debris sliding near the top eastern side of the Gnarly avalanche path. These debris slides mainly affect the overlying vegetation mat but also involve downslope movement of some of the completely weathered bedrock underlying the vegetation cover
Photo 4	A) Looking northeast across slope at the upper portion of a debris slide. B) Looking southeast and downslope at the same area shown in A
Photo 5	Looking south across slope to an area of debris sliding (outlined in dashed white line) near the top of the Gnarly avalanche path
Photo 6	A) Looking northeast and upslope at the gullied path of a debris slide near the northern extent of the study area. B) Looking downslope from the same point as A showing deposited debris
Photo 7	A) Looking southwest and downslope at more deposited slide material and vegetation from the same small slide shown in Photo 6
Photo 8	Looking northeast across slope at an area of minor debris accumulation below the gully pictured in Photos 6 and 7. This debris likely accumulated before the slide event shown in Photos 6 and 7, as it is partially revegetated. Red backpack for scale
Photo 9	Looking northeast and upslope at an example of a relatively minor channel blockage about 680 ft. above the intersection of Mill Street and Thane Road. Path blockage by the tree is trapping a significant amount of debris, as shown in Photos 10 and 11. Bedrock is visible in the lower right corner of the photo
Photo 10	Looking southwest and downslope at an example of debris accumulated behind a tree blocking the debris slide path shown in Photo 9. When the tree rots or debris accumulation overcomes the retaining force of the dead tree, debris will likely release rapidly, forming a debris flow
Photo 11	Looking northeast and upslope at debris accumulated within the gully/debris flow path behind the dead tree shown in Photo 9
Photo 12	A) Looking upslope at an example of debris accumulated just above Thane Road below the blocked gully shown in Photos 9 to 11. B) Looking across slope from the same location as A
Photo 13	Looking northeast across Thane Road. This is an example of a debris flow that has essentially stopped at the upslope edge of Thane Road. Material transited through the same gully pictured in Photos 9 to 12
Photo 14	Looking southwest toward debris flow material accumulation directly above a residence at the end of 3rd Street
Photo 15	Looking northeast and upslope and an example of debris flow material deposited approximately 200 ft. above Thane Road near its intersection with Mt. Roberts Street. Red backpack for scale
Photo 16	Looking west and across slope at debris flow material deposited near the end of Evergreen Avenue. A recent debris flow has partially buried some of the tree trunks
Photo 17	Looking south at debris flow material deposited near the Gold Creek Calhoun bridge. The small grate leading to a drainage culvert indicated and the drainage channel to the grate likely had to be dug out after the event

Photo 18	Looking north at debris flow material deposited beneath the Gold Creek Calhoun bridge
Photo 19	Looking southeast and upslope at debris flow material depositing on Glacier Highway above the AWARE shelter
Photo 20	Looking northwest below Glacier Highway at the parking lot of the AWARE shelter, at debris and water originating from the debris flow on the opposite side of Glacier Highway
Photo 21	Looking northwest at the Wickersham debris slide, located just past the intersection of Sutherland Drive at the cul-de-sac at the northwest end of Wickersham Avenue
Photo 22	Looking upslope (northeast) at 2020 Glacier Highway at the debris running out onto the road from the Wickersham slide. The guard rail is located at the drainage under the road, which appeared to have been largely plugged by debris
Photo 23	Looking upslope (northeast) from Thane Road into the Snowslide Creek (T011) avalanche path
Photo 24	An example of relatively recent rock fall and associated tree damage (estimated to have occurred within the last five years) just above Basin Road
Photo 25	An example of a relatively recent rock fall (estimated to have occurred within the last five years) just above Basin Road
Photo 26	Rock fall in the forested areas immediately north of the White avalanche path
Photo 27	Looking northwest across slope at an example of rock fall and associated tree trunk damage within the Bootleg avalanche path
Photo 28	Looking southwest and downslope over a significant rock fall source area above the head of Snowslide Creek. Ongoing rock fall at high elevations such as this accumulates in the gullies below and over time increases the chance of a debris flow forming within the gully during high rainfall events
Photo 29	Looking east at the top of Snowslide Creek and the headscarp of its rock fall/debris flow path. Deep-seated bedrock creep is evident above and east of it. Evidence of deep-seated movement, i.e., developing bedrock slide, includes multiple graben and horst type structures and deformed bedrock lineaments suggesting creep of the rock mass
Photo 30	Looking west toward the area showing evidence of deep-seated bedrock creep that is, in turn, indicative of developing bedrock slide. A stable area showing straight and continuous bedrock lineaments is visible in the foreground, while deformed and discontinuous bedrock lineaments in the potentially unstable area are visible in the middle ground
Photo 31	Looking southeast toward the area showing evidence of deep-seated bedrock creep that, in turn, is indicative of developing bedrock slide. Potentially ploughed bedrock is visible on the left and the graben and horst structures are visible in the middle of the photo
Photo 32	A snapped stem approximately 2 m to 3 m high provides evidence of historical avalanche activity, J002B Extra Flume path. The tree was snapped at that height by an avalanche and then regrew starting at that point. Trees also show flagging (uphill branches are missing while downhill branches are present) which provides additional evidence of recent historical activity, including at least two significant, damaging events in the tree's lifespan

Photo 33	This photo depicts a variety of evidence supporting historical avalanche activity. The bend at the base of the stem (sometimes called pistol butt) is evidence of either historical avalanche activity, or slope movement. Either way, the tree was displaced in its early years, and then corrected by again growing vertically. Second, a snapped stem is visible on the left side of the tree in the foreground a few meters up. Flagging is obvious, with large branches on the downslope side and no branches facing upslope. There are also two distinct age classes in this area, including the conifers in the photo center and foreground, and the deciduous trees on the left, which grow faster and are a younger age class. In combination, this is evidence of up to three different avalanche events. Magnitude-frequency estimates can be derived with this high-quality vegetation evidence
Photo 34	This photo demonstrates a sweeping tree in the J021 avalanche path, which is similar to pistol butt; however, the tree retains a gradual bend at the base due to repeated and frequent impacts
Photo 35	This photo depicts trim lines along the Behrends Avenue path. 1. The area of frequent avalanche activity is obvious by the lack of trees; only small bushes can grow here. 2. More vegetation exists here, but it is not coniferous old growth forest. This region indicates a large destructive avalanche that could not have occurred more recently than the age of these trees. 3. The old growth trim line along the avalanche path indicates the boundary of damage severe enough to remove trees in the past ~100+ years. However, sometimes avalanches can flow through these mature forests without damaging them, further complicating the evidence
Photo 36	Impacts visible on trees in the J000 Mud Flows path. Rock on the surface indicates that this damage is likely attributable to rockfall rather than avalanches, but shows a similar process
Photo 37	Extensive avalanche impacts and debris observed in northern part of Behrends Avenue path, upslope of 1800 Glacier Avenue. At least two distinct events can be observed, including the event that caused the trees to bend and re-grow straight (pistol-butt) and the event that damaged trees and deposited woody debris
Photo 38	Tree section showing growth rings. Alternating dark (winter) and light (summer) rings combine to indicate a year of growth, which can be used to age the tree. Sometimes reaction wood can be observed which can indicate significant avalanche events in the tree's life

Photo 1: Looking northeast at part of the White avalanche path showing two minor debris slides in existing slope colluvium. The debris slide pictured in Photo 2 is indicated (Date of Photo: September 15, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 2: Looking east at a small debris slide within the White avalanche path. The bare ground near the top of the photo represents the initiation zone. The red backpack is resting on the deposited material consisting of platy schist cobbles/pebbles, sand, and silt (Date of Photo: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 3: Looking northwest at an area of debris sliding near the top eastern side of the Gnarly avalanche path. These debris slides mainly affect the overlying vegetation mat but also involve downslope movement of some of the completely weathered bedrock underlying the vegetation cover (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

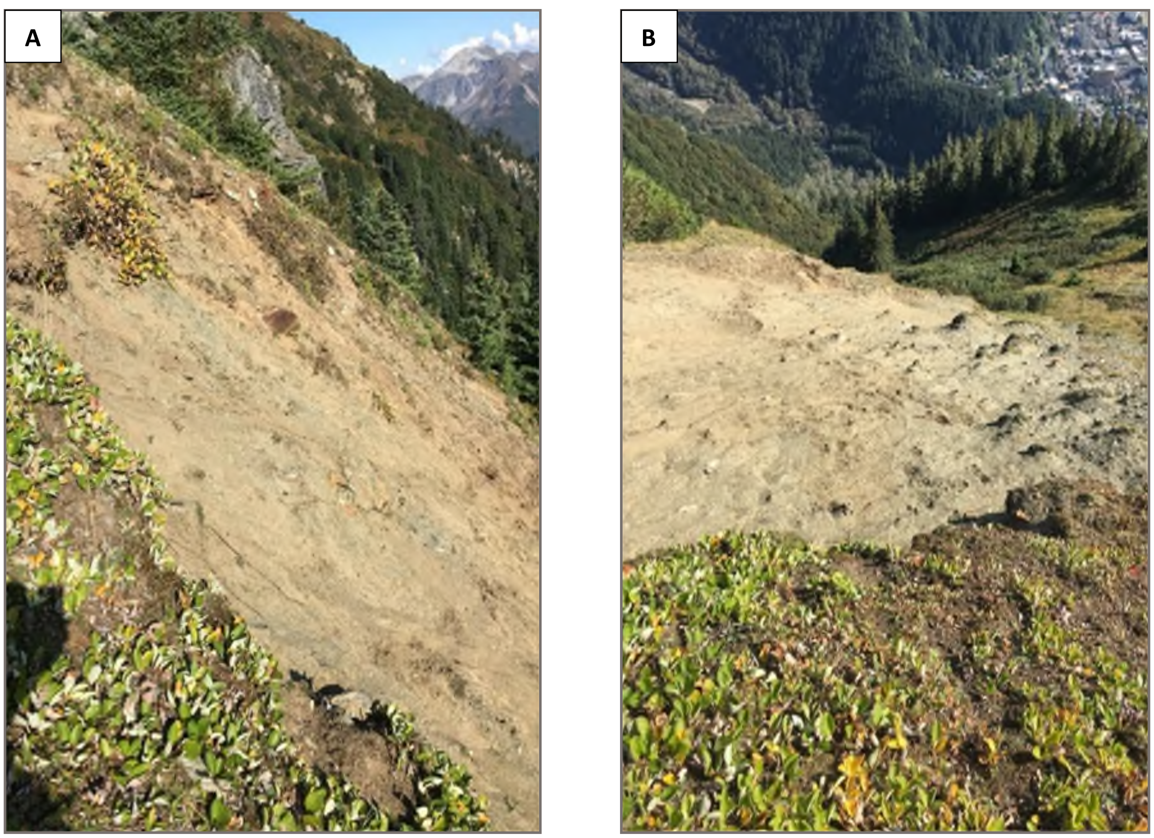

Photo 4: A) Looking northeast across slope at the upper portion of a debris slide. B) Looking southeast and downslope at the same area shown in A (Date of Photo: September 10, 2019; The photo location is shown on Figures 1.4 and 1.5).

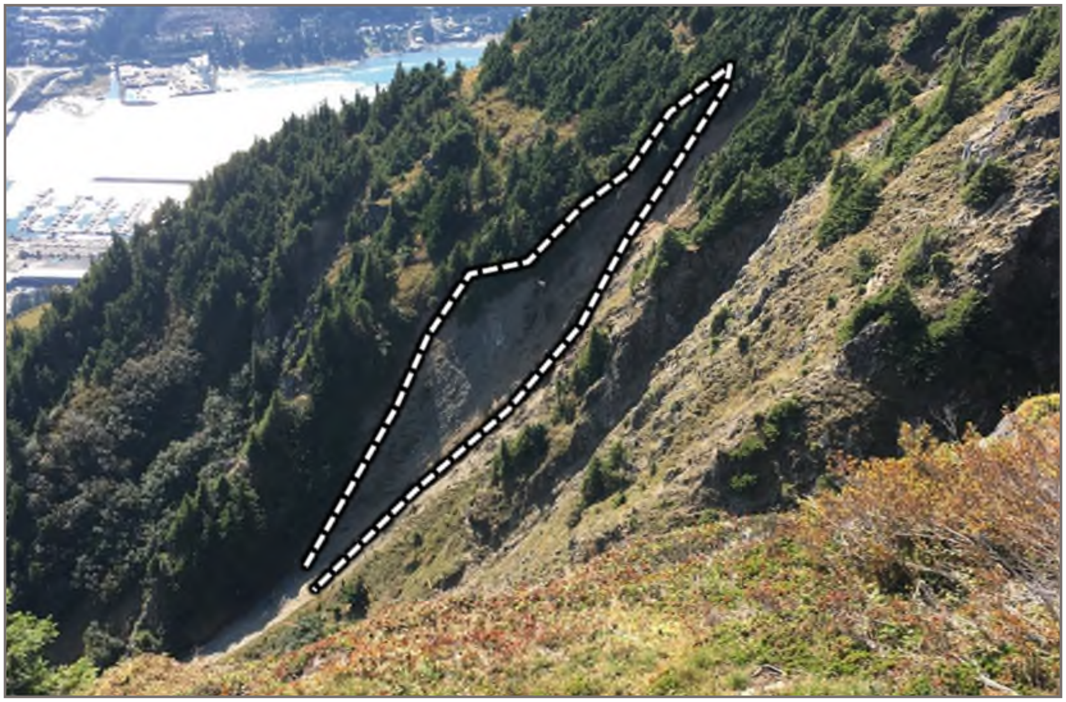

Photo 5: Looking south across slope to an area of debris sliding (outlined in dashed white line) near the top of the Gnarly avalanche path (Date of Photo: September 10, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 6: A) Looking northeast and upslope at the gullied path of a debris slide near the northern extent of the study area. B) Looking downslope from the same point as A showing deposited debris (Date of Photos: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 7: A) Looking southwest and downslope at more deposited slide material and vegetation from the same small slide shown in Photo 6 (Date of Photos: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 8: Looking northeast across slope at an area of minor debris accumulation below the gully pictured in Photos 6 and 7. This debris likely accumulated before the slide event shown in Photos 6 and 7 , as it is partially revegetated. Red backpack for scale. (Date of Photo: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 9: Looking northeast and upslope at an example of a relatively minor channel blockage about 680 ft. above the intersection of Mill Street and Thane Road. Path blockage by the tree is trapping a significant amount of debris, as shown in Photos 10 and 11. Bedrock is visible in the lower right corner of the photo (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 10: Looking southwest and downslope at an example of debris accumulated behind a tree blocking the debris slide path shown in Photo 9. When the tree rots or debris accumulation overcomes the retaining force of the dead tree, debris will likely release rapidly, forming a debris flow (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 11: Looking northeast and upslope at debris accumulated within the gully/debris flow path behind the dead tree shown in Photo 9 (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 12: A) Looking upslope at an example of debris accumulated just above Thane Road below the blocked gully shown in Photos 9 to 11. B) Looking across slope from the same location as A (Date of Photos: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 13: Looking northeast across Thane Road. This is an example of a debris flow that has essentially stopped at the upslope edge of Thane Road. Material transited through the same gully pictured in Photos 9 to 12. (Date of Photo: September 9, 2019; The photo location is shown on Figure 2). , 2019; The photo location is shown on Figures 1.4 and 1.5).

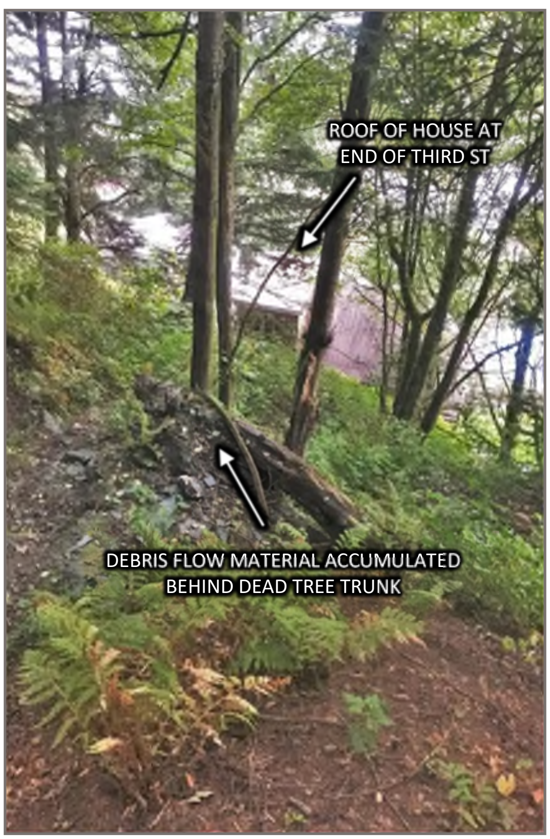

Photo 14: Looking southwest toward debris flow material accumulation directly above a residence at the end of 3rd Street (Date of Photo: September 12, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 15: Looking northeast and upslope and an example of debris flow material deposited approximately 200 ft. above Thane Road near its intersection with Mt. Roberts Street. Red backpack for scale. (Date of Photo: September 12, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 16: Looking west and across slope at debris flow material deposited near the end of Evergreen Avenue. A recent debris flow has partially buried some of the tree trunks. (Date of Photo: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 17: Looking south at debris flow material deposited near the Gold Creek Calhoun bridge. The small grate leading to a drainage culvert indicated and the drainage channel to the grate likely had to be dug out after the event. (Date of Photo: September 10, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 18: Looking north at debris flow material deposited beneath the Gold Creek Calhoun bridge (Date of Photo: September 10, 2019; The location is shown on Figures 1.4 and 1.5).

Photo 19: Looking southeast and upslope at debris flow material depositing on Glacier Highway above the AWARE shelter (Photo Credit: CBJ Dec 4, 2020; The photo location is shown on Figures 1.4 and 1.5).

Photo 20: Looking northwest below Glacier Highway at the parking lot of the AWARE shelter, at debris and water originating from the debris flow on the opposite side of Glacier Highway (Photo Credit: CBJ Dec 4, 2020; The photo location is shown on Figures 1.4 and 1.5).

Photo 21: Looking northwest at the Wickersham debris slide, located just past the intersection of Sutherland Drive at the cul-de-sac at the northwest end of Wickersham Avenue (Photo Credit: CBJ Dec 4, 2020; The photo location is shown on Figures 1.4 and 1.5).

Photo 22: Looking upslope (northeast) at 2020 Glacier Highway at the debris running out onto the road from the Wickersham slide. The guard rail is located at the drainage under the road, which appeared to have been largely plugged by debris (Photo Credit: CBJ Dec 4, 2020; The photo location is shown on Figures 1.4 and 1.5).

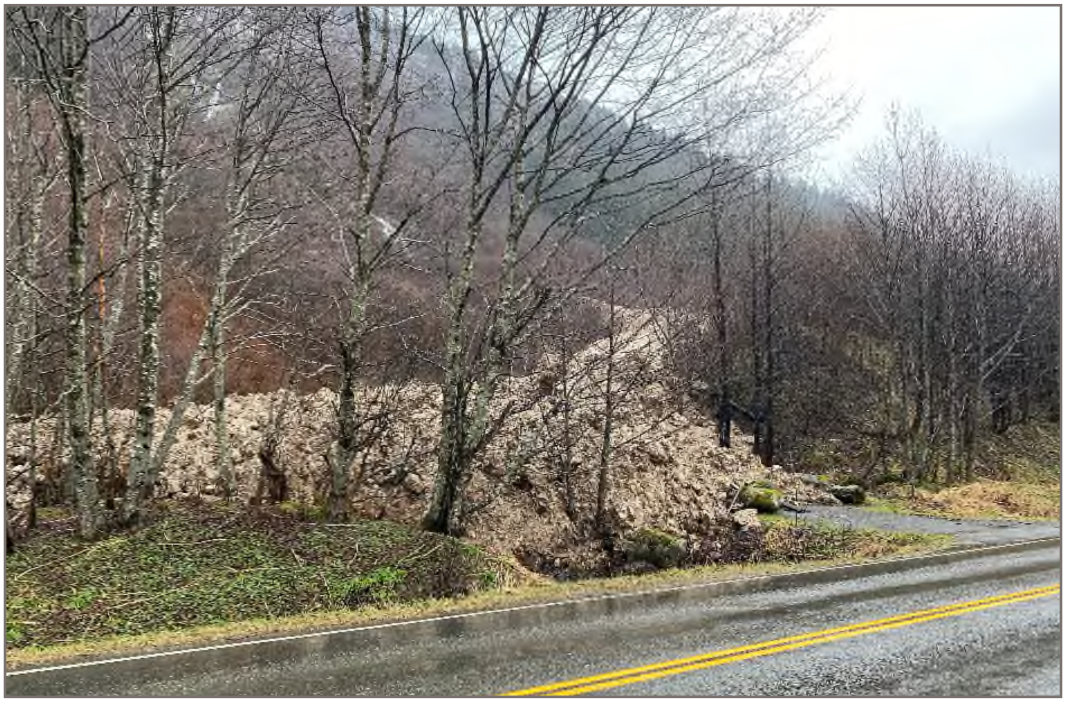

Photo 23: Looking upslope (northeast) from Thane Road into the Snowslide Creek (T011) avalanche path (Photo Credit: CBJ Dec 4, 2020. The photo location is shown on Figures 1.4 and 1.5). Wet avalanche flow was diverted by the earthfill diversion berm toward the northern boundary of the Severe (red) hazard zone.

Photo 24: An example of relatively recent rock fall and associated tree damage (estimated to have occurred within the last five years) just above Basin Road (Date of Photo: September 10, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 25: An example of a relatively recent rock fall (estimated to have occurred within the last five years) just above Basin Road (Date of Photo: September 10, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 26: Rock fall in the forested areas immediately north of the White avalanche path (Date of Photo: September 11, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 27: Looking northwest across slope at an example of rock fall and associated tree trunk damage within the Bootleg avalanche path (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 28: Looking southwest and downslope over a significant rock fall source area above the head of Snowslide Creek. Ongoing rock fall at high elevations such as this accumulates in the gullies below and over time increases the chance of a debris flow forming within the gully during high rainfall events (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

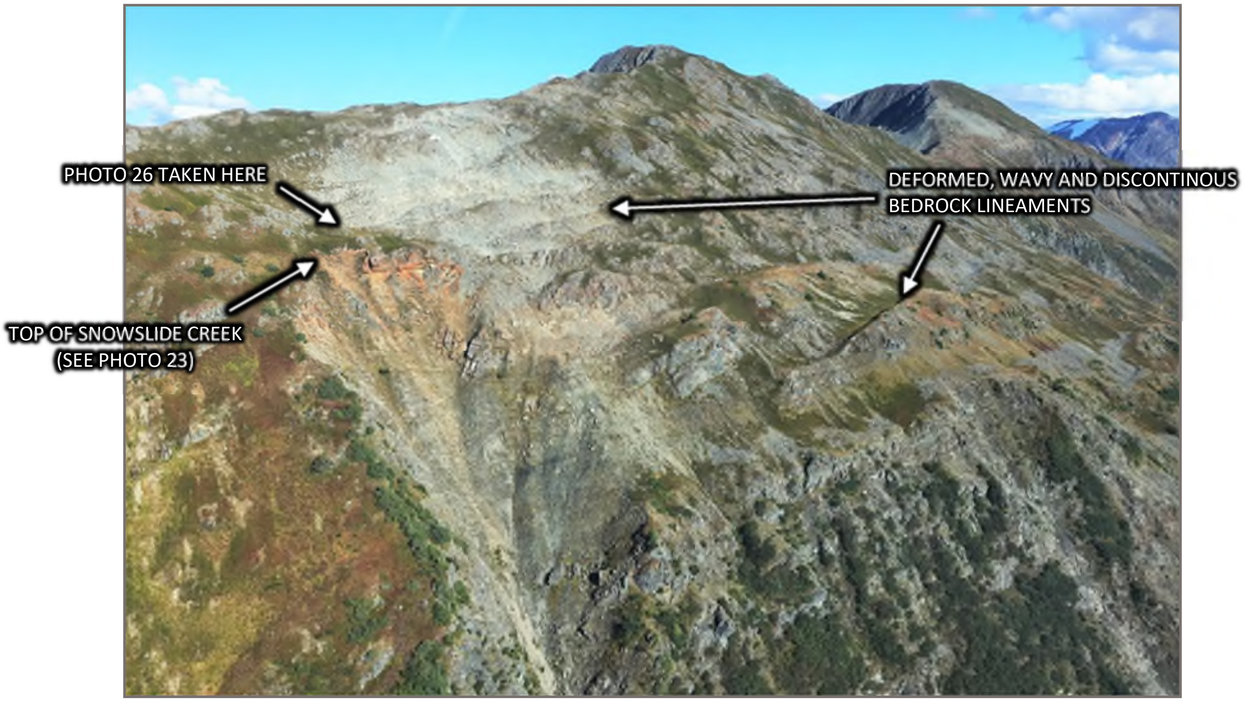

Photo 29: Looking east at the top of Snowslide Creek and the headscarp of its rock fall/debris flow path. Deep-seated bedrock creep is evident above and east of it. Evidence of deep-seated movement, i.e., developing bedrock slide, includes multiple **graben** and **horst** type structures and deformed bedrock lineaments suggesting creep of the rock mass (Date of Photo: September 15, 2019; The photo location is shown on Figures 1.4 and 1.5).

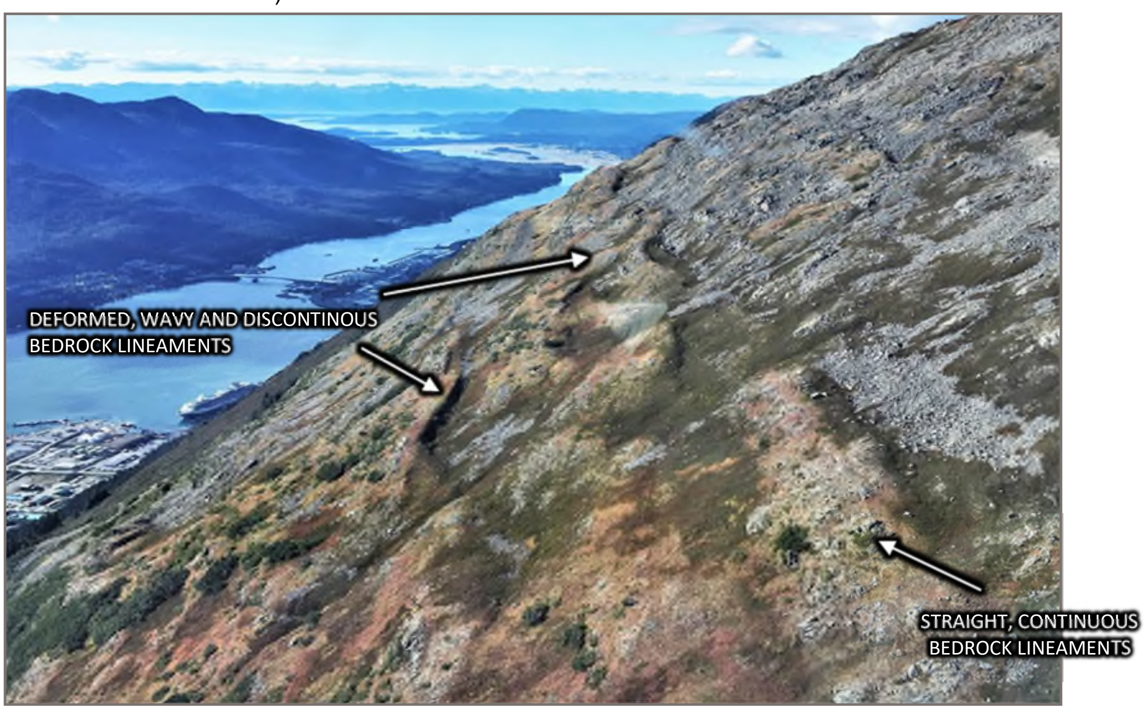

Photo 30: Looking west toward the area showing evidence of deep-seated bedrock creep that is, in turn, indicative of developing bedrock slide. A stable area showing straight and continuous bedrock lineaments is visible in the foreground, while deformed and discontinuous bedrock lineaments in the potentially unstable area are visible in the middle ground (Date of Photo: September 15, 2019; The photo shoot location is not shown on Figures 1.4 and 1.5 because it is outside the extent of the map (approximately 1,500 ft. southeast of the southeastern boundary of the Study Area)).

Photo 31: Looking southeast toward the area showing evidence of deep-seated bedrock creep that, in turn, is indicative of developing bedrock slide. Potentially ploughed bedrock is visible on the left and the graben and horst structures are visible in the middle of the photo (Date of Photo: September 9, 2019; The photo location is shown on Figures 1.4 and 1.5).

Photo 32: A snapped stem approximately 2-3 m high provides evidence of historical avalanche activity, J002B Extra Flume path. The tree was snapped at that height by an avalanche and then regrew starting at that point. Trees also show flagging (uphill branches are missing while downhill branches are present) which provides additional evidence of recent historical activity, including at least 2 significant, damaging events in the tree's lifespan.

Photo 33: This photo depicts a variety of evidence supporting historical avalanche activity. The bend at the base of the stem (sometimes called pistol butt) is evidence of either historical avalanche activity, or slope movement. Either way, the tree was displaced in its early years, and then corrected by again growing vertically. Second, a snapped stem is visible on the left side of the tree in the foreground a few meters up. Flagging is obvious, with large branches on the downslope side and no branches facing upslope. There are also two distinct age classes in this area, including the conifers in the photo center and foreground, and the deciduous trees on the left, which grow faster and are a younger age class. In combination, this is evidence of up to three different avalanche events. Magnitude-frequency estimates can be derived with this high-quality vegetation evidence.

Photo 34: This photo demonstrates a sweeping tree in the J021 avalanche path, which is similar to pistol butt, however the tree retains a gradual bend at the base due to repeated and frequent impacts.

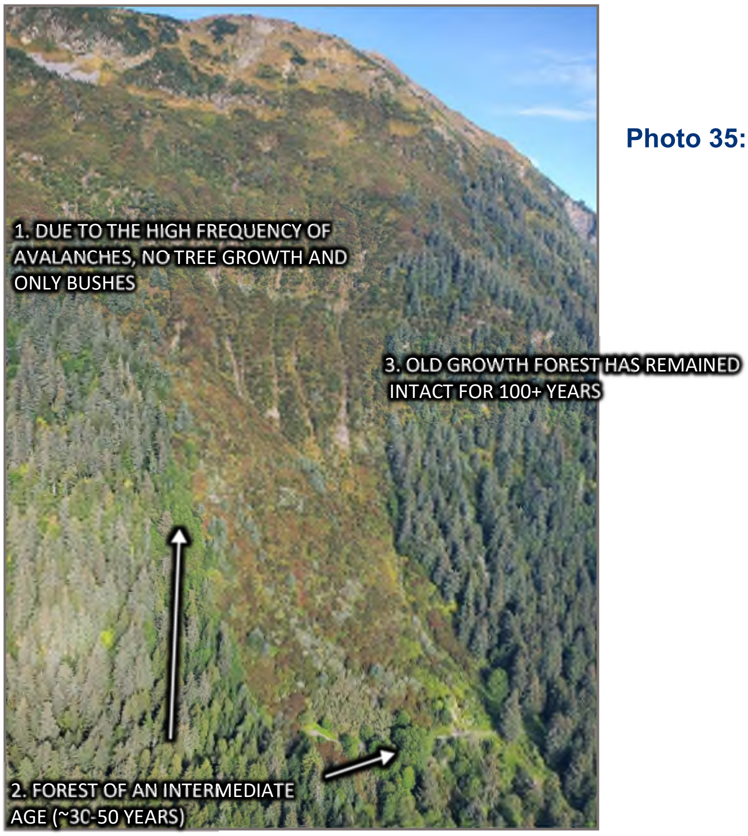

Photo 35: This photo depicts trim lines along the Behrends Avenue path. 1. The area of frequent avalanche activity is obvious by the lack of trees; only small bushes can grow here. 2. More vegetation exists here, but it is not coniferous old growth forest. This region indicates a large destructive avalanche that could not have occurred more recently than the age of these trees. 3. The old growth trim line along the avalanche path indicates the boundary of damage severe enough to remove trees in the past ~100+ years. However, sometimes avalanches can flow through these mature forests without damaging them, further complicating the evidence.

Photo 36: Impacts visible on trees in the J000 Mud Flows path. Rock on the surface indicates that this damage is likely attributable to rockfall rather than avalanches, but shows a similar process.

Photo 37: Extensive avalanche impacts and debris observed in northern part of Behrends Avenue path, upslope of 1800 Glacier Avenue. At least two distinct events can be observed, including the event that caused the trees to bend and re-grow straight (pistol-butt) and the event that damaged trees and deposited woody debris.

Photo 38: Tree section showing growth rings. Alternating dark (winter) and light (summer) rings combine to indicate a year of growth, which can be used to age the tree. Sometimes reaction wood can be observed which can indicate significant avalanche events in the tree's life.

APPENDIX A

TETRA TECH'S LIMITATIONS ON USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

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Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by persons other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

APPENDIX B

LANDSLIDE HAZARD DESIGNATION MAPPING

Discussion on Landslide Hazard Designation Mapping

After the initial hazard zone characterization, it was noted that some of the rockfall areas were mapped as having a moderate hazard, especially in areas where rockfall activity damaged, but did not remove, trees. A *Severe* designation would be inappropriate, as rockfall activity that removes vegetation is a considerably more severe hazard than rockfall activity that does not remove vegetation.

The BCTCS mapping system allows adaptations to be made to accommodate local site complexities, if/as warranted. To determine if a *High* hazard designation was warranted, several semi-quantitative analyses were undertaken. ArcGIS polygon data was summarized, and Excel spreadsheets were created from the data. Histograms were produced to compare the various data types. As the individual map entities (polygons) were mapped based on historical air photo interpretation and field evidence, it was determined that a polygon-by-polygon comparison would be most insightful, rather than raster-based comparisons using ArcGIS.

First, the updated surficial geology was compared to the hazard designation and, as expected, polygons mapped as mainly colluvial strongly dominated the *Severe* hazard designation category. However, colluvial deposits were also the main constituent of the *Moderate* category (Figure B.1). To further elucidate the relationship between colluvium and hazard designation, thin colluvium (colluvial veneer) was distinguished from thick colluvium (all other colluvial deposits) using GIS analysis. Figure B.2 shows that almost three times as many colluvial veneer polygons were related to *Severe* hazards as were related to *Moderate* hazards. Conversely, polygons containing thicker colluvium had a *Severe* designation almost twice as often as a *Moderate* one. Colluvial veneer, therefore, appeared to be more strongly correlated with a hazard designation of *Severe* than thicker colluvial deposits were.

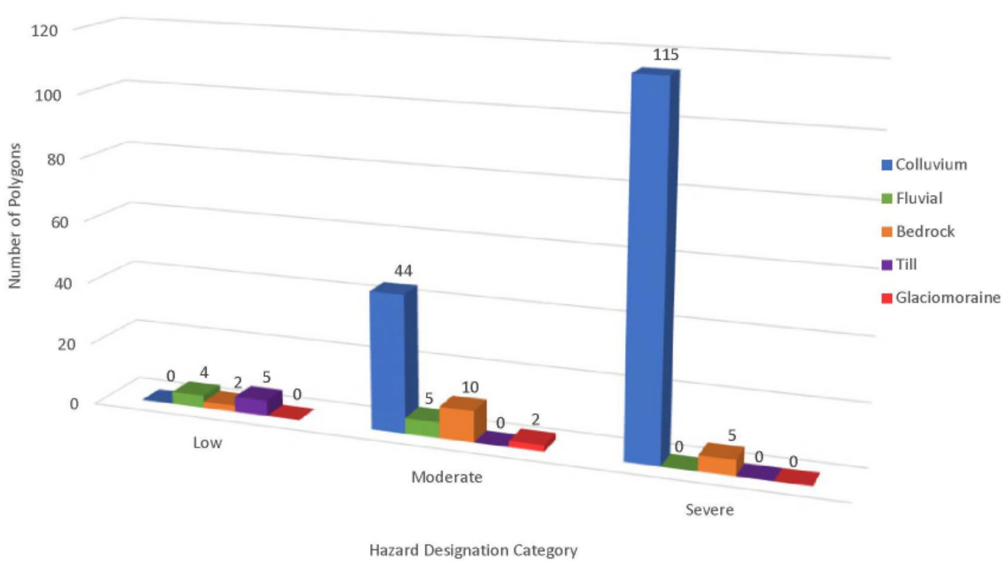

Figure B.1: Number of Polygons vs. Hazard Designation Categories for Surficial Geology Descriptions.

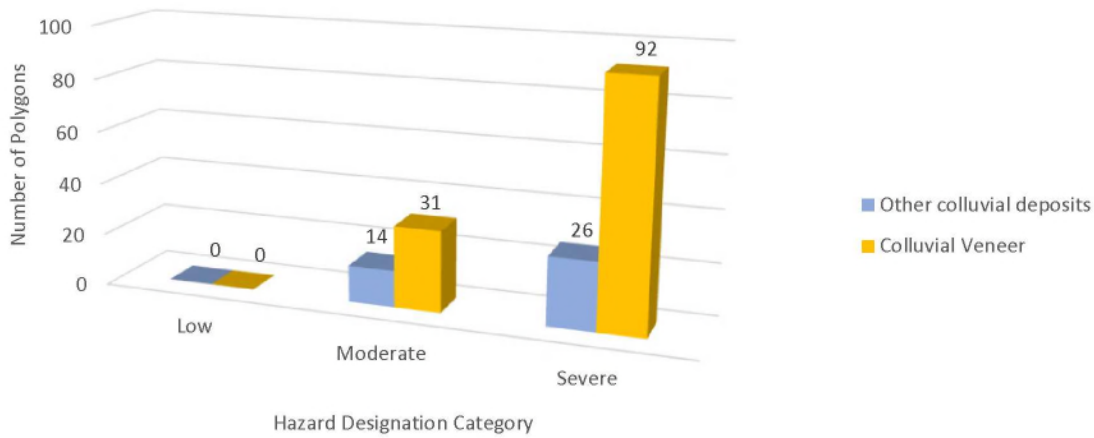

Figure B.2: Type of Colluvial Deposit vs. Hazard Designation Categories.

Figure B.2 also shows that in *Moderate* hazard category terrain, the hazard was 2.2 times as likely to be related to a colluvial veneer than other types of colluvium, while for *Severe* hazard terrain, the ratio was 3.5:1. This suggests that slope angle may be an important factor to consider.

Next, polygon slope angle was compared to hazard designation, using slope categories divided into 10° increments. The mean slope of each polygon vs. its hazard designation is shown in Figure B.3. Two important factors can be identified from this figure:

1. Most of the slopes in the Study Area were steeper than 30°; and
2. Slopes of 30° or more dominated the *Severe* hazard designation, outnumbering those in the *Moderate* category by approximately 3:1. In particular, slopes of 40° to 50° in the *Severe* category outnumbered the slopes of 40° to 50° in the *Moderate* category by almost 5:1.

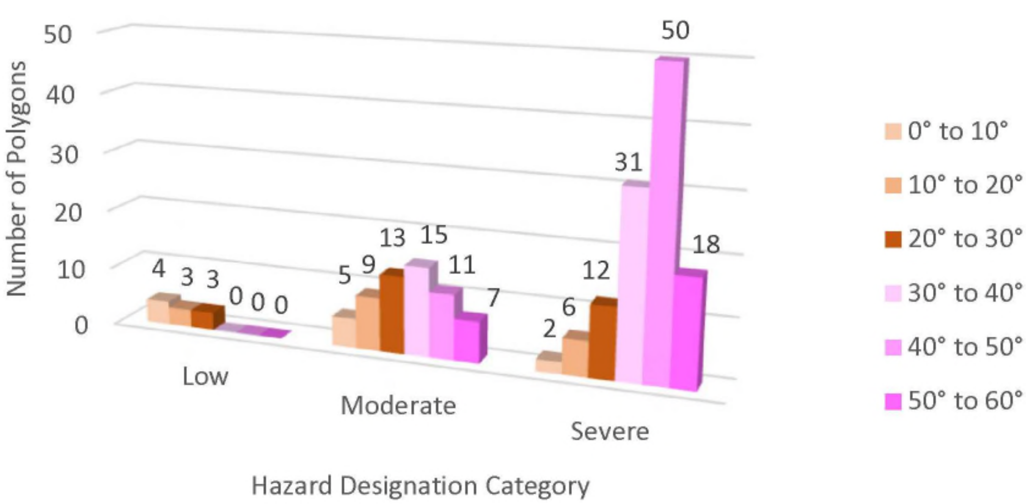

Figure B.3: Mean Slope Angle vs. Hazard Designation Categories.

A similar relationship was observed for the maximum slope angle in each polygon vs. hazard designation (Figure B.4), but with a 2.4:1 ratio for the three highest slope ranges combined. In particular, maximum slopes of 70° to 80° in the *Severe* category outnumbered maximum slopes of 70° to 80° in the *Moderate* category by 3.6:1. The minimum slope angles for each polygon were not analyzed as they were considered unlikely to relate to slide susceptibility.

Additionally, the number of polygons with 80° to 90° maximum slope angles was very similar in the *Moderate* and *Severe* categories. This suggested that competent, near-vertical bedrock cliffs were equally likely to pose *Moderate* and *Severe* hazards. This relationship could be due to local variations in the bedrock, such as number and direction of joints and faults.

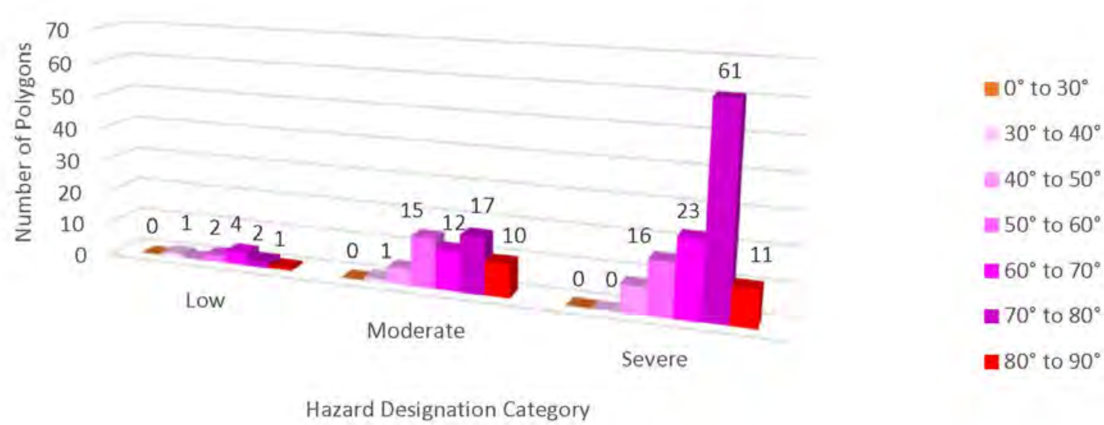

Figure B.4: Maximum Slope Angle vs. Hazard Designation Categories.

Finally, slope aspects were determined using ArcGIS, which produced a raster map image of slope aspect. This map was too complex to compare to individual polygons numerically, so the hazard designation map was compared to the slope aspect map visually.

Some correlation between smaller east- and southeast-facing slopes (within the larger overall slopes) and the *Severe* hazard designation was noted. Field observations did not provide an obvious reason for this correlation, however. No correlations were obvious for the remaining slopes in the project area: that is, for those slopes that have overall southwest or north aspects. The poor correlation between slope aspect and landslide hazard designation category was considered likely to be due to the local weather conditions: cloudy, rainy days are prevalent throughout the year. On average, there are only 86 sunny days per year in Juneau compared to the USA average of 205 sunny days (https://www.bestplaces.net/climate/city/alaska/juneau). It is therefore not surprising that slope aspect in the Study Area was determined to be a less significant determinant for triggering slope instability than the other variables.

The results of these semi-quantitative analyses suggested that polygons with thin colluvium (Cv), a maximum slope of 70° to 80°, a mean slope of 40° to 50°, and smaller east- and southeast-facing slopes within the larger southwest-facing slope areas would generally be better correlated with a *Severe* hazard designation. A map showing the first three features (not shown) was produced and compared to the initial hazard designation mapping (Figure B.5). Many of the polygons that were initially of concern (e.g., where rockfall occurs but does not destroy trees) also showed at least two of these three features. It was determined, therefore, that a *High* hazard designation category was warranted, because these slopes (where rockfall is *much* less likely to destroy trees) pose less significant hazards than those identified as *Severe* during the mapping and fieldwork for this project (where rockfall most certainly *does* destroy trees), and should be recognized as such.

An algorithm was run in ArcGIS to convert any non-*Severe* designated polygons to a designation of *High* if at least two of the three semi-quantitative criteria were met (Figure B.6). The result was that most of the areas that were initially of concern, i.e., those initially mapped with a *Moderate* hazard category, plus a few more, are now mapped as having a *High* hazard designation (Figures B.5 and B.6).

Figure B.5: Initial Landslide Hazard Designation Map.

(Red = *Severe*, Yellow = *Moderate*, and Green = *Low* hazard)

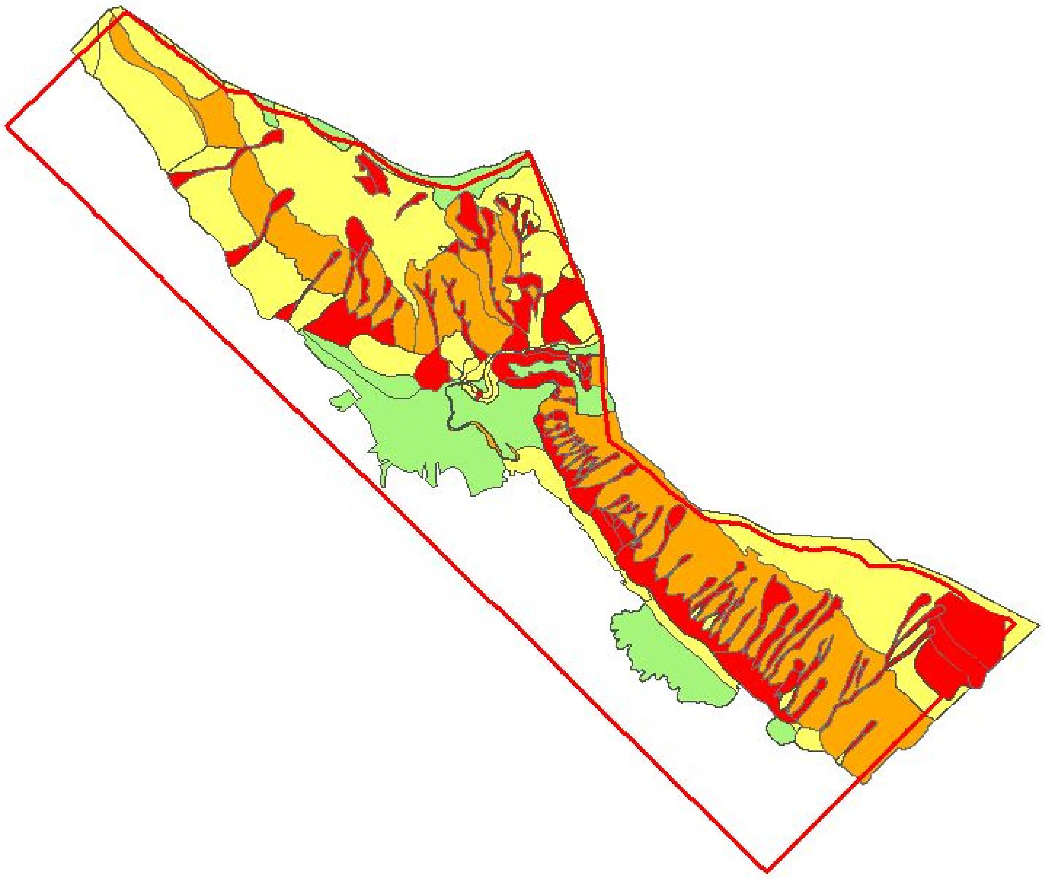

Figure B.6: Revised Landslide Hazard Designation Map.

(Red = *Severe*, Orange = *High*, Yellow = *Moderate*, and Green = *Low* hazard)

The updated landslide hazard designation system used in this study is presented in Table B.1 below. Table B.1 also appears in the main text as Table 1.4 in Section 1.2.4.2.4.

Table B.1: Refined Landslide Hazard Designation System

Hazard Designation[2]	Symbol	Hazard Attribute Description
Low	L	▪ Gentle to moderate slopes (0° to 26°) ▪ No signs of historical landslide activity on the air photos ▪ No written record of property damage or loss of life ▪ Surficial geology and texture for Classes I, II, and III as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is "Unlikely to Very Unlikely," with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future[2]

Table B.1: Refined Landslide Hazard Designation System

Hazard Designation[2]	Symbol	Hazard Attribute Description
Moderate	M	▪ Moderate to Moderately steep slopes (27° to 35°) ▪ May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on the air photos) ▪ Can include low-lying areas within the runout zones of slides from nearby slopes ▪ No apparent written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is “Possible,” with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events. Therefore, landslide events could happen in the future[2]
High	H	▪ Steep slopes (>35°) ▪ Areas where rockfall activity impacts individual trees but does not knock them over or destroy them[3] ▪ May have written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 (Tetra Tech 2021a) ▪ At least two of the following criteria are met: – Thin layer of colluvium (Cv) present – A maximum polygon slope of 70° to 80° – A mean polygon slope of 40° to 50° ▪ Estimated event probability is “Likely,” with a return period of 5 to 30 years. This is the return period estimated for Class IV terrain where slopes are known to be susceptible to landslides, and where there are signs of recent and/or historical landslide events. Therefore, landslide events are likely to keep happening in the future[2]
Severe	S	▪ Steep to vertical slopes (>35°) ▪ Signs of recent activity either in aerial photographs or from field inspection (rockfall tracks, debris slide activity, debris flow paths etc.) ▪ May have written record of property damage or loss of life ▪ Signs of repeated historical activity ▪ Surficial geology and texture for Class V as shown in Table 1.2 (Tetra Tech 2021a) ▪ Estimated event probability is “Very Likely to Almost Certain,” with a return period of 1 to 20 years. This is the return period estimated for Class V terrain, where the slopes are highly susceptible to landslides, and where there are signs of recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are very likely to almost certain to keep happening in the future[2]

Notes:

1. Landslide hazard designations (*Low*/*Moderate*/*High*/*Severe*) correspond to green/yellow/orange/red on Figures 1.6a through 1.6j, and Figure B.6 in Appendix B.
2. Estimated event probability based on observed and recorded slope movement activity level. Note that this is not an indication of consequence (potential for damage), nor is it a magnitude/frequency study, which can determine return periods with more accuracy.
3. This type of rockfall can be highly active but has a small enough impact not to be readily visible on the air photos or satellite imagery.

For the last step of the hazard designation refinement, east- and southeast-facing slopes on the main southwest-facing mountain sides were compared visually to the new mapping (since the aspect data is a raster data set). It was noted that the majority of these slopes now fall into either *High* or *Severe* hazard designation categories. Since the correlation for this data set was not as strong as for the others, the few that fell into polygons formerly mapped as *Moderate* were left as is.

As a final check on the hazard designations, the written records of property damage or loss of life (CBJ 2012; Mears et al. 1992; Swanston 1972) were reviewed and compared to the Landslide Hazard Designation Mapping. Correlation between the written record and mapped *Severe* hazard areas was good, but the slopes of Evergreen Bowl and the runout areas below them were upgraded from a designation of *Moderate* to *High* due to a number of small slide events recorded there that were not visible on the historical air photos selected for this study

.

APPENDIX C

TECHNICAL MEMOS

Technical Memo #1 Landslide Mapping Accuracy and Modelling

Technical Memo #2 Landslide Designations and Boundaries – Bathe Creek and Highlands

Technical Memo #3 Mapping Overview Starr Hill Subdivision and Additional Information

Technical Memo #4 Guide to Avalanche and Landslide Hazard Designations

Technical Memo #5 Landslide Hazard Designations at Telephone Hill and Gastineau Avenue

Technical Memo #6 Severe Landslide Hazard Designations at Starr Hill and Gastineau Avenue

Technical Memo #7 Considerations for Anthropogenic Terrain at Starr Hill and Gastineau Avenue

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Alix Pierce (CBJ)	**Memo No.:**	1
From:	Rita Kors-Olthof, Vladislav Roujanski, Shirley McCuaig	**File:**	704-ENG.EARC03168-01 / 704-ENG.EARC03168-02A
Subject:	Landslide Mapping Accuracy and Modelling Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

This technical memo addresses some of the comments and questions that arose from Tetra Tech Canada Inc.'s (Tetra Tech) Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment, dated May 28, 2021, and the Landslide and Avalanche Hazard Public Meeting that took place on July 21, 2021.

The City and Borough of Juneau (CBJ) has requested a response for each of three key points, as described in CBJ's email dated July 27, 2021. This memo responds to the commentary from a local representative of the U.S. Forest Service and a mapping consultant/software/data vendor, about landslide mapping accuracy and lack of modelling.

2.0 LANDSLIDE MAPPING ACCURACY AND LACK OF MODELLING

Two sets of comments were received from these commenters:

- Comments dated July 21, 2021, received during the question-and-answer session of the Neighborhood Meeting (copied below).
- Comments dated August 8, 2021, received via email (summarized below).

Question/Comment #1: Quinn Tracy's maps and Tetra Tech's summary is clear, but the accuracy of the maps is a serious problem. Specific to the landslide hazard mapping portion of the study, there was no indication of any modern landslide modelling techniques. The references cited are over 30 years of age. Clearly efforts were focused on simply using a combination of old landslide maps and new LiDAR. Modern landslide evaluations include statistical models (calling this a statistical effort is inaccurate) and physically based models. Many models are used in the Pacific northwest and Alaska and could have been used in this study. Technically sound scientific examination of landslides, including debris slides and debris flows, would include analysis of hydrologic contributing area and evaluation of the sediment volumes in initiation and runout zones. An understanding of these parameters would aid in the understanding of landslide runout. My question to CBJ: Will you add modern landslide modelling to serve the community of Juneau?

Question/Comment #2: Tetra Tech's analysis provides "low, moderate, high, severe" landslide hazard zones without any quantitative description of what those hazards mean. To make rational and defensible zoning decisions requires consideration of the costs and the benefits of those decisions: comparison of the costs of precluding housing versus the probability of preventing property damage and loss of life. Why was a useful quantitative analysis conducted for snow avalanches while such an analysis was not conducted for landslides? Quantification of landslide occurrence includes utilization of the physical parameters controlling initiation and runout of landslides, establishing

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probabilities of landslide initiation and runout, and an analysis of the costs entailed when an event occurs, in both dollar amount and the costs in human lives. Further, a system is needed to better inform the public of high-risk precipitation events associated with enhanced landslide activity, i.e., an early warning system for landslides.

Response: The first comment reflects four primary concerns, including mapping methodology and accuracy of the mapping, the age of the references, the perception that the mapping simply used a combination of old landslide maps and new LiDAR, and the lack of landslide modelling techniques. These were briefly addressed during CBJ's recorded Question-and-Answer (Q&A) session following Tetra Tech's presentation for the Landslide and Avalanche Hazard Public Meeting on July 21, 2021. The second comment reflects the desire for a quantitative analysis, a risk analysis, and an early warning system. These concerns are addressed as follows:

1. Mapping methodology and accuracy of the maps:

    a. As described in Tetra Tech's report, the mapping was completed in PurVIEW, an add-on to ArcGIS that allows the mapper to view three-dimensional (3D) air photo images on the computer screen in spatially-accurate locations. Mapping can then be completed for various air photo years with a high level of confidence in the location of the various features. For example, surficial geology was mapped at a scale of 1:2,000 to 1:4,000. This scale is a significant improvement over the scales that were available to previous mappers. For example, Swanston (1972) and Miller (1972 and 1975) would presumably have had access to air photos from 1948 at 1:40,000 scale, and from 1962 at 1:21,600 scale. Mears et al. (1992) would also have had access to some higher-resolution air photos: 1977 at 1:6,000 scale, and 1988 at 1:4,800, and appear to have used the 1977 air photos in two of their figures. However, none of these references identify the air photos used, and most do not acknowledge the use of air photos. Any images listed in Tetra Tech's Table 1.1 after 1988 would not have been available to either Swanston or Mears et al.

    b. Digital air photos were acquired from CBJ, Quantum Spatial, Inc. (QSI), the U.S. Department of Agriculture (USDA), and the U.S. Geological Survey (USGS). The air photos were georeferenced and aerially triangulated for viewing in PurVIEW. Hardcopy air photos were first scanned at high resolution (12 µm) for this purpose, and then georeferenced in 3D. Satellite and LiDAR images of the Study Area were supplied by CBJ. No mention is made in Swanston (1972) or Mears et al. (1992) of aerial imagery being ortho-rectified for use in mapping, which would have been necessary for them to reliably identify and control the locations of observed features. For example, stereo-pair images that are not ortho-rectified can have significant distortions in the images, including "compressed" or "elongated" terrain when hillslopes are viewed from different angles. This results in images that can be difficult to compare even within the same air photo year, let alone with imagery from different years. Therefore, because the old mapping was not based on ortho-rectified imagery, it was not possible for Tetra Tech to reliably overlay "old" and "new" mapping. In contrast, Tetra Tech's mapping was based on georeferenced images, allowing very accurate overlays of the different years of imagery.

    c. Surficial geology was mapped using the 1948 air photos to provide a baseline for the maps that extends as far back in time as the air photo coverage of the Study Area allows. Given the limited capabilities of photographic equipment in 1948, the 1962 air photos were used to check the base historical mapping and the surficial geology mapping. Then, the 1962 and later air photos and satellite images were used to determine slide activity visible on the dates of those images, using lack of vegetation as a proxy for slide activity.

    d. The LiDAR bare-earth hillshade model images were primarily used to refine and show the locations of such major terrain features as gullies and debris flow fans. Due to the high resolution of the LiDAR data, it was possible to map a large number of gullies. Gully erosion, as a hazardous geomorphic process, was given close attention in this landslide hazard assessment study because gully erosion plays a significant role in mass movement on the slopes, with some of the gullies being conduits for conveying debris flows, debris slides, and wet avalanches.

   e. Historical records and incident reports, as well as contemporary photographs and news reports, were used to supplement the mapping in specific localities. However, the main components of the mapping are based on the historical air photo record review, the LiDAR images review, and the fieldwork completed by Tetra Tech.

   f. Preliminary field maps were prepared for use during the site reconnaissance visit and were updated in accordance with the observations made in the field.

   g. The site reconnaissance included the following tasks:

      i. A helicopter fly-over of the Study Area was conducted to provide a wider perspective of suspected areas of slope instability, to target specific areas for ground-truthing, and to provide access to otherwise inaccessible or difficult-to-access areas.

      ii. A foot-traverse inspection of a large portion of the Study Area was done for field mapping of landslide areas and ground-truthing of geomorphic features/hazards (e.g., landslides), key terrain features, and vegetation damage (slope instability-related) identified from air photo and LiDAR data analysis.

      iii. Measurements, photographs, and Global Navigation Satellite System (GNSS such as GPS/GLONASS) data were collected for landslide initiation and runout zones to help define hazard types and mechanisms.

      iv. Additional emphasis was placed on field observations in residential areas, resulting in a much greater density of field observations and time spent in residential subdivisions, e.g., the Behrends, White, and Starr Hill Subdivisions.

   h. Several landslide events that occurred subsequent to the completion of Tetra Tech's mapping served to confirm the accuracy of the mapping.

2. The references cited were over 30 years of age:

   a. Numerous references cited are less than 30 years of age.

   b. Age alone is not considered a valid reason to reject the use of references that provide valuable information for the project. For example, some of the older references provided very useful historical context that would have otherwise required considerably more research to acquire.

   c. All references, including those that were over 30 years old, were evaluated for quality in accordance with the technology that was available at the time, and used or referenced (or not) as appropriate for the goals of the current mapping project.

3. The perception that the mapping simply used a combination of old landslide maps and new LiDAR:

   a. It is clear from the description of the actual mapping methods presented in the report, and from the summary provided above, that this perception is incorrect.

   b. This is not to say that the old mapping was ignored in the production of the new mapping. The old mapping, from several sources, was reviewed to confirm that landslides presented in the older work were either represented in the new mapping (and appropriately updated to the present day, if/as required); *OR* that specific features had been reviewed and, on the basis of findings using higher-resolution technology, considered not applicable.

4. Lack of landslide modelling techniques:

   a. Landslide modelling was not in the project scope.

b. Geotechnical drilling was not in the project scope.

c. For a landslide model to provide an estimate of landslide runout more convincing than that already provided by the direct evidence seen on the ground or from air photos would require significantly more effort than was feasible with the available project funding. This judgment is confirmed by the comparison of Tetra Tech's mapping with a set of slope stability models prepared by others for a local Juneau watershed.

d. If Tetra Tech were to carry out landslide modelling on selected debris slides, debris flows, rockfalls, or rockslides (for example), the scope would require not just modelling, but the collection of additional supporting field data, including, but not limited to:

   i. Detailed engineering geology mapping for rockfalls or rockslides, including identification of structural domains, faults, discontinuity sets/orientations, rock mass quality;

   ii. Collection of detailed topographic data, preferably including a topographic survey; information on surface conditions including vegetation, surface drainage, signs of ponding or erosion, tension cracks, observations of ground deformations etc.; field identification of initiation and runout zones; characteristics and performance of adjacent or nearby slopes; identification of landslide terrain that contributes to debris flows; noting possible changes since the previous inspection;

   iii. Detailed characteristics of suspected or known debris flow gullies, such as upslope gradients and/or terrain stability class; stepped gully configuration (i.e., sediment stored in debris wedges); debris flow levees, avulsions; fan destabilization potential as indicated by number of channels, degree of incision; water transport potential as indicated by channel width, size/presence of woody debris, maximum sediment particle size; consideration of headwall/sidewall failure potentials based on slope gradients and surficial materials, gully geometry potential for debris flows based on sidewall slope lengths and channel gradients;

   iv. Geotechnical drilling and/or testpitting, potentially with several testholes at each site location. Depending on location, achieving access could require tracked drills or heli-portable drills;

   v. Collection of soil/rock samples from boreholes or test pits. Successful sampling will depend on the anticipated materials to be sampled and on the choice of sampling method, e.g., drill type;

   vi. Installation and long-term monitoring of instrumentation such as slope inclinometers, piezometers, and remote access data acquisition systems;

   vii. Laboratory index testing to classify and determine engineering properties of soils, and strength testing on selected samples (soil or rock);

   viii. Analysis and modelling, potentially including (depending on the type of landslide):

      1. Visual slope retrogression analysis based on air photos and current site observations;

      2. Semi-quantitative slope analysis, beginning with back-analysis to determine the slope parameters (several models available for evaluation); and/or

      3. Debris flow analysis (several models available for evaluation).

   ix. A detailed geotechnical investigation, instrumentation monitoring and analysis/modelling program could require an additional budget ranging from $250,000 to $1,000,000 per site to be investigated, depending on the complexity of the landslide and access, the type of drill required and where it is mobilized from, and the instrumentation to be installed. Each site also requires long-term monitoring and data analysis, at an additional annual cost that could reach $125,000 to $500,000. Tetra Tech notes that mobilizing a suitable drill from Whitehorse, Anchorage, or further away, would entail significant costs. For example, for two Alaska Department of Transportation projects with challenging access conditions (the Juneau Access Road and a new section of the Sterling Highway), a geotechnical drilling contractor from Washington State conducted the exploration work. It is anticipated that to further investigate and analyze even a few sites would rapidly result in a budget exceeding several million dollars; and

x. It is noted that Tetra Tech conducted a semi-quantitative analysis specifically to compare various geotechnical parameters and associated landslide prevalence against the hazard designation categories. This was not intended to be a detailed statistical analysis, for example, such as could have been prepared based on the results of a much more extensive field investigation throughout the map area, including a geotechnical drilling program in selected locations. Accounting for the high resolution with which the surficial geology and landslide mapping was accomplished, and the proven accuracy of that mapping as seen from later landslide events that confirmed the mapping, the semi-quantitative analysis is considered to have been a value-added contribution to the mapping process.

5. Lack of quantitative analysis:
   a. Determination of “the physical parameters controlling initiation and runout of landslides” requires the acquisition of additional site-specific information, which was not in the project scope.
   b. See Item 4 above.
6. Risk analysis:
   a. A risk analysis includes not only an assessment of hazards; but also consequences, e.g., costs related to property damage, injury, or loss of life; and the resulting risk.
   b. Determination of the probabilities of landslide initiation and runout is a task that would be greatly facilitated with the acquisition of more site-specific information, which was not in the project scope (see Items 4 and 5 above).
   c. This task would also entail a magnitude-frequency analysis, which was not in the project scope.
   d. The determination of consequences and risk were not in the project scope.
7. Early warning system:
   a. The development of an early warning system would require a detailed analysis of climate and climate change, which was not in the project scope.
   b. Development of the early warning system itself was not in the project scope.

3.0 LIMITATIONS OF REPORT

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4.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

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The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

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While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

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This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Alix Pierce (CBJ)	**Memo No.:**	2
From:	Rita Kors-Olthof, Vladislav Roujanski, Shirley McCuaig	**File:**	704-ENG.EARC03168-01 / 704-ENG.EARC03168-02A
Subject:	Landslide Designations and Boundaries – Bathe Creek and Highlands Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

This technical memo addresses some of the comments and questions that arose from Tetra Tech Canada Inc's (Tetra Tech) Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment, dated May 28, 2021, and the Landslide and Avalanche Hazard Public Meeting that took place on July 21, 2021.

The City and Borough of Juneau (CBJ) has requested a response for each of three key points, as described in CBJ's email dated July 27, 2021. This memo responds to commentary from a local avalanche expert, as well as from other residents with questions about the Bathe Creek and/or Highlands mapping areas.

2.0 LANDSLIDE DESIGNATIONS AND BOUNDARIES

Some detailed commentary about the mapping was provided to CBJ in a letter dated July 26, 2021. The writer deemed the avalanche mapping generally accurate and well-done. The remaining commentary was mostly concerned with landslides, offering some general critique for the overall landslide mapping, as well as some specific observations in the Bathe Creek and Highlands areas. Questions and concerns have been documented below in a question-and-answer format beginning with general mapping questions, followed by Bathe Creek/Highlands-specific questions from several people. In cases where questions were similar or related, these have been combined for the response.

Overall Landslide Mapping:

1. **Question/Comment:** Incorrect classifications based on recorded return intervals:

    a. Areas shown as *Severe* that have recorded frequencies in the *High* range; and

    b. Areas that have become inactive as drainages have changed, suggesting that they should be designated as *Moderate* to *High*, instead of *Severe*, if the stated standard of mapping for current conditions is followed.

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Response: As noted in Section 1.2.4.2.5 of the main report, the analysis of magnitude/frequency was *not* part of this high-level study. There appears to be reasonably good correspondence between the levels of historical activity identified and typical event probabilities, particularly in many of the highly-active landslide features. For that reason, Tables 1.3, 1.4, and B.1 in the main report include some very high-level estimates that could be helpful for visualizing the differences between the hazard designations. These estimates have now been revised to correspond more closely to the format of the estimates used in the avalanche study. However, it should be noted that these estimates are based solely on the level of activity observed in slope movement features and gully erosion features identified from the historical air photo record analysis and the LiDAR data analysis, as well as field observations and, where available, incident reports. A magnitude-frequency analysis will be required to produce more reliable estimates for event probabilities than is currently possible. See "A Guide to Avalanche and Landslide Hazard Designations" for additional information and examples (Technical Memo #4 in Appendix C of the main report; Tetra Tech 2022d).

It should also be noted that the frequency or return period of an event (or the mapping proxy of visual evidence of repeated slide activity) does not mean that an event of a specified size or severity will return every X number of years. For example, a debris flow of a certain size typically depends on two events coinciding: a storm event large enough to mobilize debris in a gully, and enough debris accumulated in the gully from previous events to mobilize the debris. Furthermore, a 1 in 30-year rainstorm event (for example) could happen at *any* time in a 30-year period. It could happen this year, and it could also happen again next year. (Though if it keeps happening, the meteorologists might eventually decide that the new normal for that size of storm is a 1 in 10-year event.)

In general, the hazard designation mapping is not intended to indicate event probability (whether an event is likely to occur within a specified number of years), but rather whether a hazard is expected at some point in the future, generally based on evidence that it has already done so in the past. These maps provide the locations of hazardous areas, which is important information for planning purposes. More detail, such as determining the potential frequency and magnitude of the events that could occur in those areas is a logical next step; however, it is not without significant cost.

Additionally, an area is given a hazard designation of *Severe* if:

- A cone or fan of colluvium is present at the base of a slope, no matter how old it is, because the hazard still exists (Howes and Kenk 1997); and/or
- Evidence of slope instability (exhibited on air photos as a lack of vegetation in a formerly vegetated area with an obvious downslope movement component; incident reports; and/or field observations) is identified within the same feature in more than one air photo/LiDAR year and/or field investigation year.

Note that numerous gullies show evidence of slope instabilities in several years (sometimes every year) of imagery, incident report data, or field observation data that was reviewed.

In one area, located southeast of Snowslide Creek near the top of slope, visual evidence of bedrock movement seen at ground surface during the fieldwork indicated the possibility of an impending deep-seated bedrock slide that could reach Gastineau Channel. Because it has not yet failed, a level of activity could not be determined for that site but, due to the very large size of the feature and the notable consequence of its failure, it was given a *Severe* hazard designation.

For changed drainages, or map areas that appear not to have had an obvious slope instability for decades, e.g., 60 years, this does *not* mean that the area is now "inactive." Also, there may be other factors that account for the feature being designated as a higher level of hazard, including the type of feature and the amount of historical instability on the slopes above it.

Debris cones (steeper conical features) and fans (more gently sloping fan-shaped features) develop by the accumulation of unconsolidated surficial material (debris) that is transported and deposited in ever-shifting flow channels that migrate from one side of the cone/fan to the other. This is how the fan or cone shape forms. A debris flow entering at the top ("apex") of a cone is capable of flowing *anywhere* on that cone, even if it has flowed for many years in the same incised channel. A new debris flow provides its own, sometimes very viscous clayey/silty soil matrix, which can incorporate or entrain boulders and large woody debris, and it can block its own direction of movement with that material. Unless the flow can be controlled and diverted from the very top of the feature (usually an expensive proposition), what happens below the apex is not entirely predictable. The behaviour of debris flows that are not well-incised is even less predictable. The smallest disruption in the ground surface, like a fallen tree or a bit of debris blocking the usual flow direction, can result in an abrupt change of flow direction, or a splitting of the flow into several channels.

2. **Question/Comment:** Placement of very different hazard designations together, e.g., *Severe* next to *Low*, rather than the designations progressing downslope from *Severe-High-Moderate-Low*, that the writer would have expected with the higher frequency of smaller, shorter-running slides.

   Response: Landslide hazards are generally not downgraded in a downslope direction. If there is a history of slide activity, or if it is a runout zone (i.e., a deposition zone), an area is considered to pose a *Severe* hazard. Note that not all landslide events begin at the top of the mapped feature, nor do they necessarily extend to the bottom of the feature, which can be seen clearly in the historical air photo record and LiDAR data analysis, in both the slope movement features (Figures 1.4a to 1.4c) and the gully erosion features (Figures 1.5a to 1.5c). Landslide modelling could be used to refine the runout zones and potentially downgrade the designated hazards in some locations. However, as noted in Technical Memo #1 (in Appendix C of the main report; Tetra Tech 2022a), landslide modelling was not part of the scope of this project.

3. **Question/Comment:** Mapping polygons appear oddly-shaped, not corresponding to the lobate flow features or runouts expected in areas without strong topographic controls. Areas of criticism include "odd little pointy bits," and abrupt changes in direction.

   Response: In several instances, the apparent odd shapes of some of the terrain units result from the shapes of the adjacent terrain units. One example is the Bathe Creek drainage above Irwin Street and Gold Creek, where the shape of the east edge of the colluvial cone/fan is affected by an area of bedrock (shown in purple and marked Rr/Cv on Figure 1.3b). Immediately upslope of the bedrock area is another area of colluvium marked Ca|dr that apparently encroaches into the Bathe Creek drainage. So, even though the Bathe Creek fan/cone looks a little odd on the east side, the adjacent landforms are the cause of this peculiar boundary (see excerpts of the figures in Item 6 below).

4. **Question/Comment:** Deglaciation was relatively recent in our region, and the retreat of the ice was followed by a period of enhanced mass wasting, as the glacially-oversteepened slopes came to a new equilibrium and became vegetated. Most of the present-day colluvium dates back to that period. The bulk of the fan area of concern would appear to be from then. The volume exceeds what would have likely come from Bathe Creek; it is far more likely that the bulk of the material came from the steep slopes directly above Evergreen, than from cross-slope movement from Bathe Creek. It is a more reasonable interpretation that the recent activity apparent from air photos and LIDAR is the surface veneer, showing only the most recent activity, now obscured by development.

   Response: Tetra Tech respectfully disagrees, given the amount of activity seen in the historical landslide mapping. If a series of small debris slides or flows occurs in the same area repeatedly, there is a hazard. It may be smaller than the hazard of major slides or flows that are very old, but it is still a hazard to the slopes below. Loose material builds up on the slopes with each small event, eventually leading to a larger event that incorporates that material and adds some of its own. Whether a landslide consists of a debris slide or a debris flow, and regardless of the source of the materials (e.g., “old” colluvium or “new” colluvium), it is a significant hazard to the slopes below and should not be downgraded.

Questions/Comments – Bathe Creek along Irwin Street and up Highlands:

To document their local knowledge of the Bathe Creek / Irwin Street / Highlands area, the writer reported that they have lived since the early 1990’s on the upper part (northeast end) of 12th Street. Due to the lack of mapping at that time, the writer explored the slopes above this area, as well as the slopes throughout the Highlands area, during their house-hunting efforts. The following site-specific questions/comments were provided.

5. **Question/Comment:** Bathe Creek is known to produce debris flows, but the historical frequency is only in the 10- to 30-year range, not the 1- to 10-year range suggested in the report for a *Severe* designation. The writer suggests that the historical frequency is high enough to even out possible anomalies and that the return interval is the most reliable basis for mapping hazard.

   Response: See response to Item 1 above for general remarks about frequency and historical activity. Specific to Bathe Creek, this feature is a very active debris flow gully, according to the historical air photo record and LiDAR analysis, and it is therefore rated *Severe*.

6. **Question/Comment:** The mapped boundaries [of the *Severe* hazard zone] are noted to be irregular, with curlicues and projections on the [east] side that do not resemble the mapped lobate avalanche boundaries, which may better define the landslide hazard area.

   Response: See response to Item 3 above regarding the irregular “curlicues and “projections.” Bathe Creek is an example of where adjacent terrain units affect the shape of this terrain unit. In general, because the processes are not the same, avalanche path boundaries should not be expected to match landslide hazard boundaries. Compare the excerpts from the avalanche path and hazard mapping in Figures 2.2c and 2.3a (Figure 1 below) with the surficial geology and major gully features in Figures 1.3b and 1.5b (Figure 2 below). The boundaries of wet avalanches might sometimes approximate the boundaries of debris flows in the same terrain feature, a resemblance that would necessarily depend on the size and mobility of each event. In this case, they could be similar but not identical.

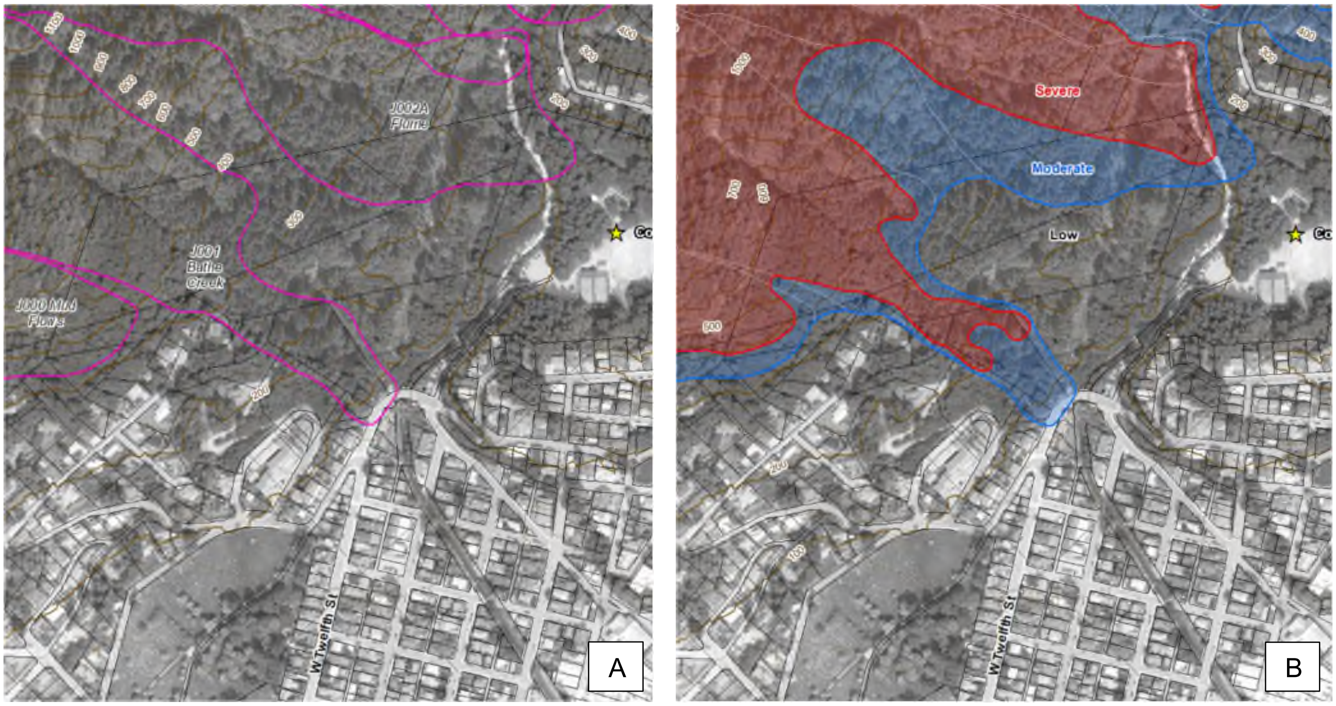

Figure 1: Excerpts from Figure 2.2c Avalanche Path Mapping Detail (Figure 1A) and Figure 2.3a Avalanche Hazard Designation Mapping Overview (Figure 1B).

Compare the surficial geology and the major gully features shown in excerpts from Figures 1.3b and 1.5b (Figures 2A and 2B below). In the case of Bathe Creek, the shape of the *Severe* area reflects the shape of the cone/fan and the upslope gully that is the source of the debris, as shown below in the excerpt from Figure 1.6c (Figure 2D). Finally, even though the fan itself only displays occasional activity (remobilization of old debris flow material), as shown in the excerpt from Figure 1.4b (Figure 2C), the debris flows originating from upslope govern the hazard designation, as they are what has formed the fan and what will continue to do so in the future.

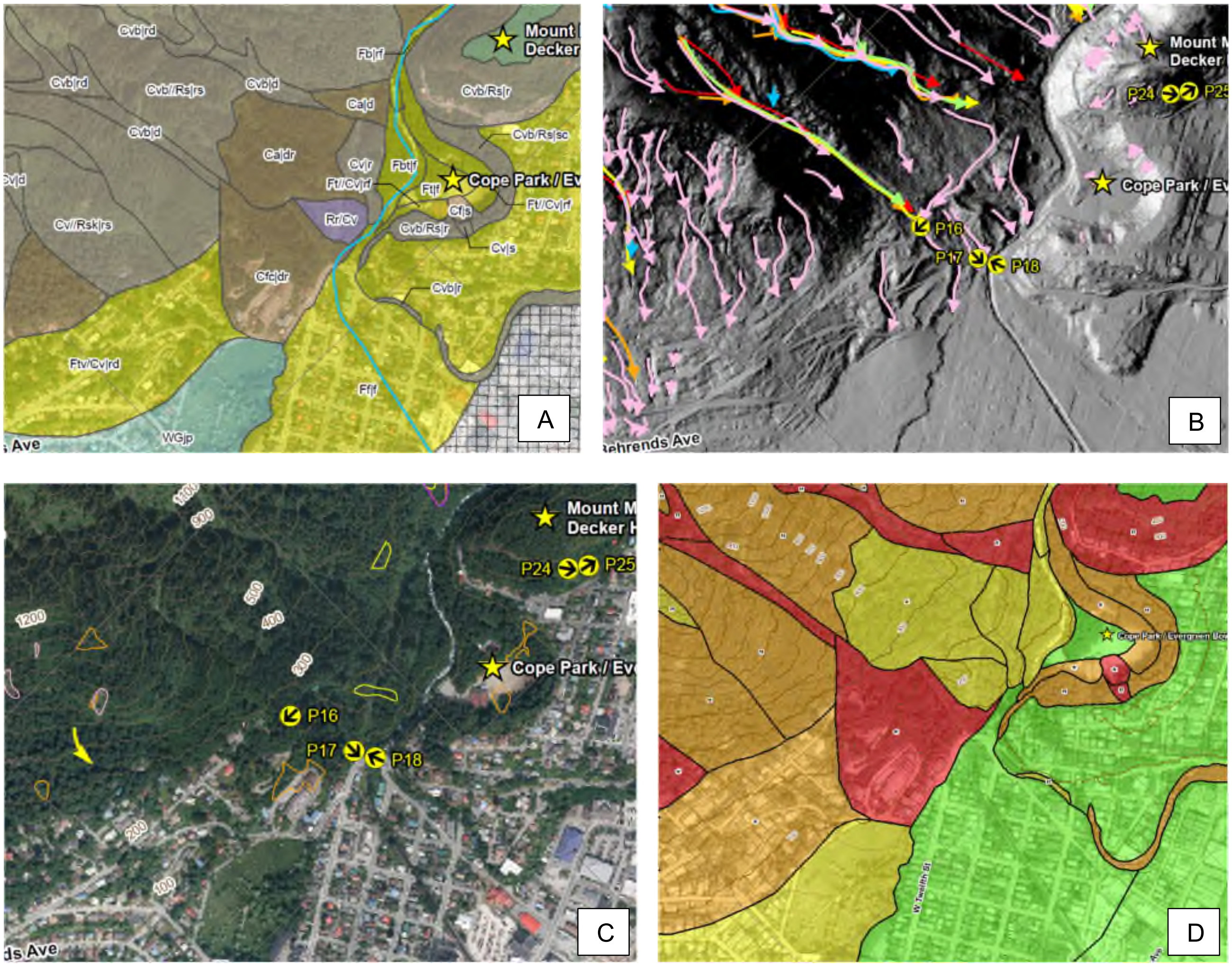

Figure 2: Excerpts from Figure 1.3b Surficial Geology (Figure 2A) and Figure 1.5b Historical Air Photo Record and LiDAR Data Analysis – Gully Erosion Features (1948-2013) (Figure 2B), and excerpts from Figure 1.4b Historical Air Photo Record – Slope Movement Features (1948-2020) (Figure 2C) and Figure 1.6c Landslide Hazard Designation Mapping (Figure 2D).

7. **Question/Comment:** Swanson's study seems to indicate that flow from Bathe Creek was turning sharply enough to make that south and west area part of the runout, either when he did his 1972 study, or in the recent past. But the topography at the mouth of the Bathe Creek canyon is now incised enough that it would take a major change to divert it south and west again. This mapping is supposed to be for current conditions and topography, not speculation on how it might change in the future.

   Response: See the last paragraph in the response to Item 1, which describes how debris flow cones and fans are formed. Specific to Bathe Creek, the mouth of the creek is not the location where the most significant changes in flow direction are likely to occur. Instead, it would be the apex of the cone/fan, i.e., above Evergreen Avenue. See Item 6.

8. **Question/Comment:** Residents of the area extending from above the east end of upper Evergreen Avenue downslope through Hermit Street, Rheinhardt Street, and Irwin Street, are concerned about the *Severe* hazard designated for this area as a result of the new mapping, instead of the *Moderate* hazard that applied before in most (but not all) of the subdivision. The changes in assumptions between the 1987 adopted hazard maps and

the proposed 2021 maps are not well understood, resulting a lack of confidence in the results. A few residents thought that the new study was based on the old study. Some residents stated that they would not have purchased their property if they had known that it was in a *Severe* hazard zone. Another resident on Hermit Street owned a house whose original owner had a site-specific review done prior to construction for their proposed building site, due to the previous mapping (Swanston 1972) that had identified a hazard in the area. The current owner has commented that they might do the same.

Some residents also noted that they were not aware of a landslide event that had affected their address, nor did it seem to them that there had been a change in topography or vegetation in the area over the years. Other residents acknowledged the presence of the nearby Bathe Creek gully but felt that the topography protected the residential areas from landslides or avalanches. A few residents wondered if existing structures or trees would reduce the likelihood of impacts from landslides or avalanches.

How can homeowners in this area reconcile the old mapping with the new mapping, and better understand what the new mapping means?

Response: Additional areas of *Severe* and *High* hazard were added to the hazard map, because of the types of landforms and the amount of landslide activity that was seen on the air photos, on the LiDAR images, and during the fieldwork. A *High* or *Severe* hazard designation is not always well represented by what one sees happening (or not happening) on the slopes adjacent to one's property. The hazard designation may have been assigned because of what is happening on the slope well upslope of a particular property. This is true for Bathe Creek and the surrounding terrain. See the last paragraph of the response to Item 1, and also Items 4 and 7. The debris flow potential of the slope above is one part of the rationale that results in the *Severe* hazard designation for this area. The debris flow paths on the fan/cone can easily be shifted by a debris flow if something happens higher up near the fan/cone apex that changes the direction of flow. This area was reviewed in detail during the field work.

The debris initiation and runout zones appear to have been missed in the Swanston (1972) study, although the main gully was identified as being a *High* hazard path (the same as the 1987 *Severe* hazard designation) from the east end of Evergreen Avenue all the way to Gold Creek. Swanston identified superimposed deposits along the main gully that showed repeated landslide activity. He also commented on two debris flows that ran an hour apart down the gully, badly damaging a home and filling Irwin Street with debris. Swanston further noted that there were two smaller gullies that led down into the gravel quarry (now the residential area) above Martin Road. Tetra Tech notes that this residential area has all the hallmarks of a runout area, since it is downslope of the initiation and transition zones of a prominent and very active debris slide/debris flow path.

It seems possible, if not likely, that the presence of the former gravel pit obscured some of the signs of the debris flow fan at the time of Swanston's study. However, a soils study conducted prior to the development of the Westridge Condominium project, carried out by R&M Engineering in 1980 and 1981, encountered 10 feet of silty sand colluvium upslope of the project, at about 160 feet above sea level. The back of the condo project was noted to be at about 140 feet elevation. Ten feet of colluvium is not an insignificant amount of material. Beneath the colluvium was sandy gravel of glaciofluvial/deltaic origin, which would have been the type of material preferred for gravel pit operations. Notably, if the residential area is located within the former gravel pit (as it is understood to be), R&M Engineering would not have encountered the colluvium there, because it would have been stripped off the site before excavating the gravel for use. Once again, the presence of a hazard from upslope was not recognized.

Further consultation did not reveal any further reasons for caution (Swanston 1990), since the 1972 study had been intended for use as a planning-level tool, not a site-specific investigation. He also felt that the "alluvial cone deposits" beneath the property, and the bedrock-controlled gully would keep avalanches or debris flows away from the site. Swanston (1990), understandably, stated that the "results and recommendations derived from more detailed site investigations by competent, licensed engineering geologists or geotechnical engineers" should govern.

Knowing what we know now, however, it is important to remember that a debris flow can occur *anywhere* on a colluvial cone, not just in the current incised channel. Furthermore, existing structures and even very large trees do not reduce the hazard; instead, trees and structures are often simply broken or crushed and entrained into the debris. It is important to recognize the true hazard represented by the debris flow terrain, and the *Severe* hazard designation was not arrived at lightly.

9. **Question/Comment:** The [west] side of the *Severe* hazard zone is noted to include a large area of colluvium in the Irwin Street to Highlands area, despite no recorded slide history since houses were built there. If the Swanston (1972) study is intended to support the *Severe* designation, maps and quotes from that study should be included in the report.

   Response: The basis for the *Severe* hazard designation is not Swanston's report, but rather Tetra Tech's independent determination of the characteristics of the terrain units based on surficial geology mapping, historical air photo record analysis of slope movement features and gully erosion features, as well as incident reports and field observations. See also responses to Items 1 and 4 above. Specific to the *Severe* areas mapped in this part of the study area (Figure 1.6b and 1.6c), these are all colluvial areas (Figure 1.3b) that receive debris from several active gullies upslope (Figure 1.5b), including the previously mentioned Bathe Creek gully (see Figure 2 above), and several active gullies above Behrends Avenue and the west end of Highland Drive (see Figure 3 below). Several of the two dozen debris slides that occurred in various years in the immediate map area (Figure 1.4b) happened within gullies (compare Figures 3B and 3C below). The excerpt from Figure 1.4b (Figure 3B below) is also a good example of an avalanche track (area with no trees) that does not correspond perfectly with landslide activity and location.

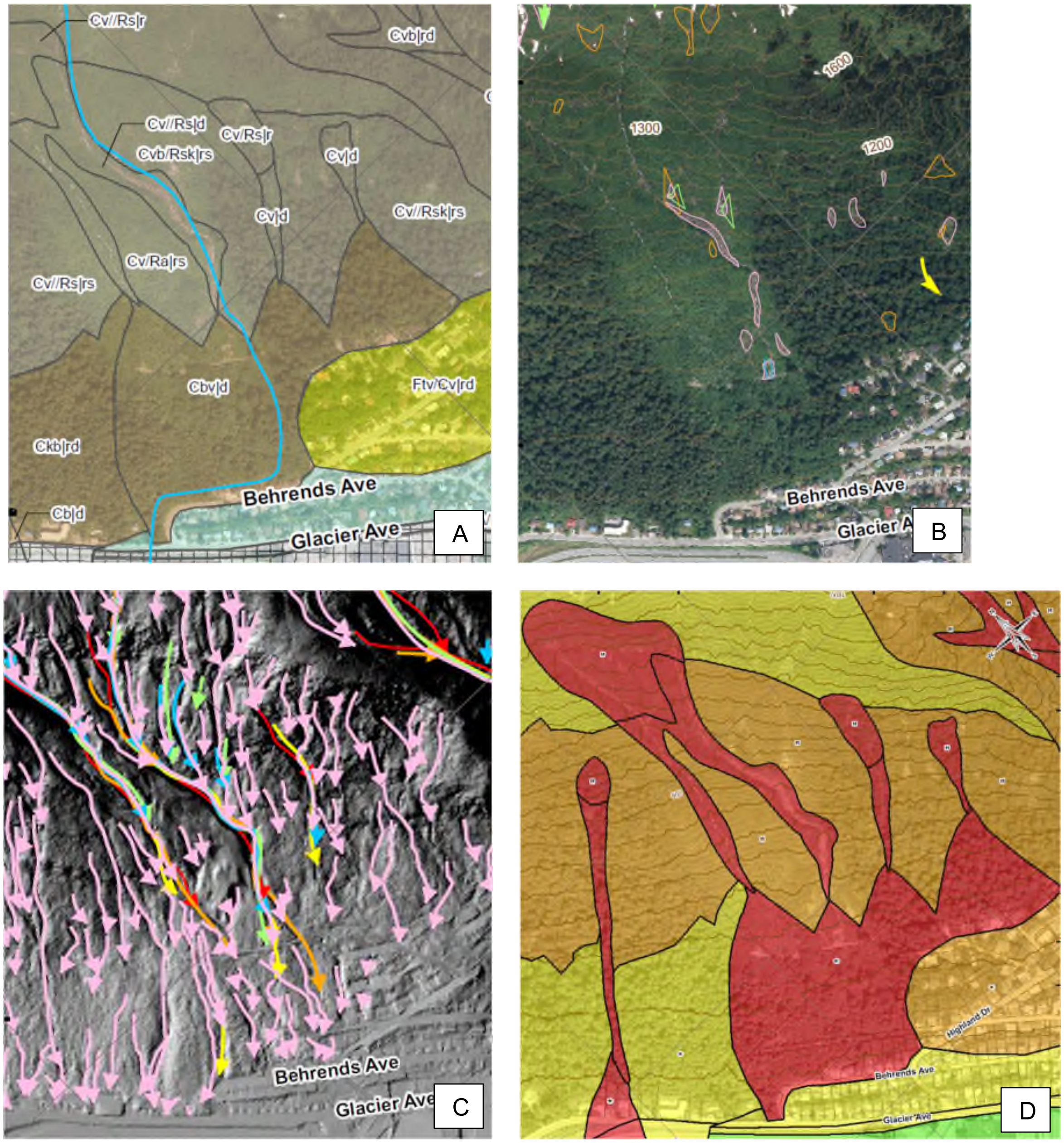

Figure 3: Excerpts from Figure 1.3b Surficial Geology (Figure 3A) and Figure 1.4b Historical Air Photo Record – Slope Movement Features (1948-2020) (Figure 3B), and excerpts from Figure 1.5b Historical Air Photo Record and LiDAR Data Analysis – Gully Erosion Features (1948-2013) (Figure 3C) and Figure 1.6c Landslide Hazard Designation Mapping (Figure 3D).

While it is possible that houses have stood in one location for many years without being affected by a landslide, it does not mean there is nothing going on above them on the slope. If that activity has not reached a particular house yet, the resident may just have been lucky so far.

These are hazard maps, which indicate areas that are potentially hazardous. If there was a lot of potentially hazardous geomorphic process activity on a slope, or if new activity was identified in the field, that area was mapped as having a *Severe* hazard. For instance, debris could be building up on the slope directly above a house, or in a location where debris can potentially run towards a house (see Figure 4 below), and where it could become a more serious hazard in the future. Smaller debris slides and debris flows tend to accumulate debris and store it in wedges within gullies. Eventually, when a critical level of debris is reached, or a rainstorm of a particular size occurs, all that stored debris is scoured out of the gully, potentially resulting in a very large debris flow event. Similar events can occur on open slopes where slide debris piles up in lobes over days, months, or years, sometimes separated by channels of faster-flowing debris. These debris lobes can slowly be creeping downslope, until the critical moment when there is enough mass and enough water to make the debris flow rapidly downslope.

Figure 4: Looking down towards the Gold Creek Flume Trail from the Bathe Creek debris flow gully. Note the large amount of debris in and alongside the gully, as well as the scarring on the tree beside the road that extends to at least 6 feet above ground surface. This gully is very active, and the debris that is deposited at the road crossing is regularly cleaned up. This road crossing has the potential to divert debris flows into the residential community downslope and to the west, especially if more than one surge of debris occurs before the debris can be cleaned.

3.0 LIMITATIONS OF REPORT

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4.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

STATE OF ALASKA
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M.I. Kors-Olthof
April 27/22
No.CE8567
REGISTERED PROFESSIONAL ENGINEER

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/jf

Enclosure: Limitations on Use of this Document

REFERENCES

Tetra Tech. (2022a). Technical Memo #1. Landslide Mapping Accuracy and Modelling, Downtown Juneau Landslide and Avalanche Hazard Assessment. Prepared for CBJ. Tetra Tech File: 704-ENG.EARC03168-02A. April 27, 2022.

Tetra Tech. (2022d). Technical Memo #4. Guide to Avalanche-Landslide Hazard Designations, Downtown Juneau Landslide and Avalanche Hazard Assessment. Prepared for CBJ. Tetra Tech File: 704-ENG.EARC03168-02A. April 27, 2022.

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GEOTECHNICAL

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1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Scott Ciambor (CBJ)	**Memo No.:**	3
From:	Rita Kors-Olthof, Vladislav Roujanski, Shirley McCuaig	**File:**	704-ENG.EARC03168-01 / 704-ENG.EARC0168-02A
Subject:	Mapping Overview at Starr Hill Subdivision and Additional Information Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

This technical memo addresses some of the comments and questions that arose from Tetra Tech Canada Inc.'s (Tetra Tech) Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment, dated May 28, 2021 (Tetra Tech 2021), and the Landslide and Avalanche Hazard Public Meeting that took place on July 21, 2021.

The City and Borough of Juneau (CBJ) has requested a response for each of three key points, as described in CBJ's email dated July 27, 2021. Two of these items were addressed in Technical Memos #1 and #2, which have since been updated (in Appendix C of the main report; Tetra Tech 2022a, 2022b). This Technical Memo #3 responds to commentary and requests for additional information about hazards surrounding the Starr Hill subdivision. It includes the information provided in the Issued-for-Review memo dated September 16, 2021, as well as the supplementary information for Question #5 provided by email on September 17, 2021, as well as some additional mapping information compiled since April 1, 2022. A few additional remarks have also been provided for Question #14.

2.0 LANDSLIDE HAZARD DESIGNATIONS AND BOUNDARIES

2.1 Mapping Overview at Starr Hill Subdivision

2.1.1 Comparing Adopted (1987) and Proposed (2021) Mapping

The residents of the Starr Hill Subdivision have been concerned to discover that landslide hazards designated *High* and *Severe* have been identified on the slopes around the subdivision. These hazards had not been identified in the 1987 adopted hazard mapping, in which only *Moderate* hazards had been shown at existing structures along most of the adjacent portion of Basin Road, 6th Street, Nelson Street, and several houses on 5th Street and in a zone upslope of 5th Street beyond the built roads of Kennedy and East Streets, as shown in Figure 1A below. Only a few structures further upslope of Kennedy, East, and Harris Streets were already mapped within a *Severe* zone in 1987, although continuing south and then southeast onto the main slope of Mt. Roberts, many more structures were mapped within *Severe*.

As seen in Figure 1 below, the main difference between the 1987 adopted hazard mapping and the new 2021 proposed hazard mapping is that many of the former *Moderate* areas surrounding Starr Hill (colored in pale lavender on Figure 1A) are now designated *High* or *Severe* (colored in dark pink on Figure 1B).

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The 1987 adopted hazard mapping is understood to have been based on Swanston (1972). However, the 1987 mapping follows property lines, resulting in numerous right-angle corners in the hazard boundaries. The 2021 mapping does *not* follow property lines. It follows hazard designations based on terrain features, such as surficial geology, geomorphology (evidence of past and more recent slope movement types accentuated by vegetation patterns), and activity levels for slope instabilities as seen from the air photos and confirmed by field observations. For instance, along 6th Street, between East Street and Nelson Street, the lower boundary of the new 2021 proposed hazard zone does *not* arbitrarily stop at the upslope property lines of the affected properties as it does in the 1987 mapping. The same is true upslope of Nelson Street, and upslope of 5th Street, where the lower boundary of the 2021 proposed hazard mapping does *not* arbitrarily stop at the upslope property lines of the affected properties.

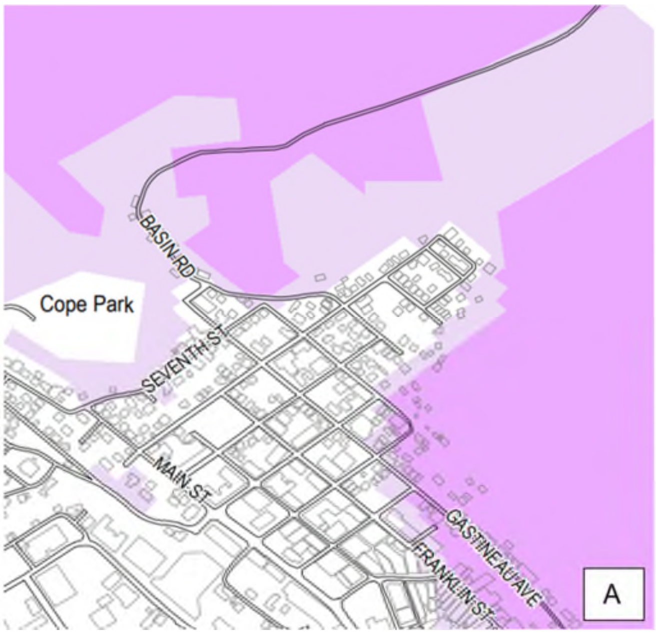

Figure 1: Excerpts from CBJ's 1987 adopted hazard mapping (Figure 1A) and comparison of 1987 adopted hazard mapping and 2021 proposed hazard mapping (Figure 1B) at the Starr Hill subdivision.

Since Tetra Tech has identified some important differences in the mapping methodology seen in the 1987 adopted mapping and Tetra Tech's 2021 mapping, it is useful to show the origins of that 1987 mapping, as discussed further in Section 2.1.2.

2.1.2 Comparing Swanston (1972) and Tetra Tech's (2021) Mapping

This section has some general comments comparing the mapping from Swanston (1972) and Tetra Tech (2021), followed by a few comments for specific slope sections above Starr Hill.

Swanston (1972) did not create arbitrary transitions in hazard designation based on property lines. Despite the poor scan quality of this old report, it is clear that Swanston based his 1972 hazard designations on geology and landslide features, *not* on property lines, as seen below in Figure 2.

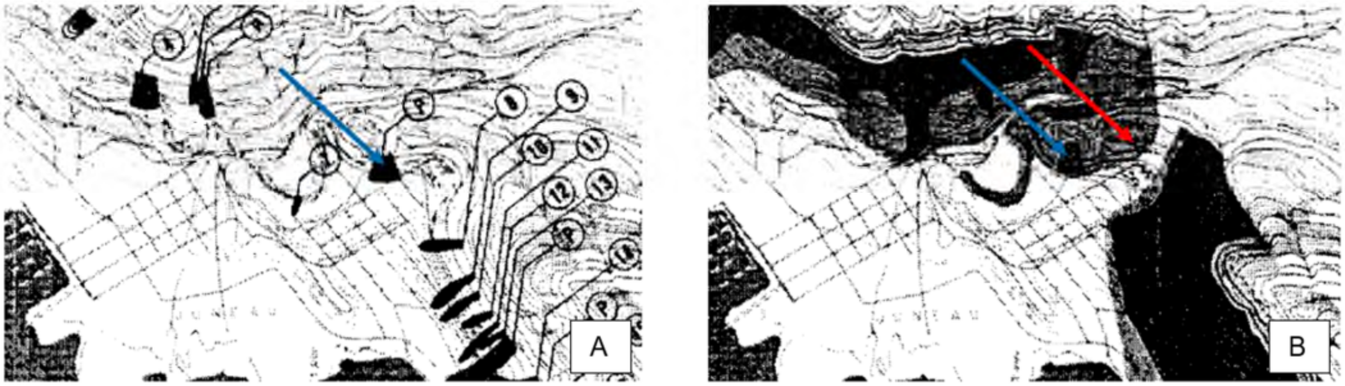

Figure 2: Excerpts from Swanston (1972) – Figure 5 – Historic Landslide Deposits (Figure 2A) and Figure 6 – Mass Wasting Hazard Areas (Figure 2B).

In Swanston's Figure 5, "P" means "Prehistoric" (before 1880). A prehistoric slide area was noted on the south side of Mt. Maria (blue arrow in Figure 2A). In Swanston's Figure 6 (Figure 2B), hazards for mass wasting (landslide) hazard areas are shown, with *Potential* Hazards marked in gray, and *High* Hazards marked in black. The prehistoric slide is shown as a *High* Hazard area (blue arrow in Figure 2B). A small cliff with a talus deposit above the corner of 6th and Nelson Streets was also designated as being in a *High* Hazard area (red arrow in Figure 2B).

Comparing Swanston's hazard mapping (Figure 2B) with the 1987 adopted mapping (Figure 1A), CBJ renamed Swanston's "*Potential* Hazard" as *Moderate* Hazard and renamed Swanston's "*High* Hazard" as *Severe* Hazard.

A summary of Tetra Tech's mapping of the Starr Hill area and the adjacent portion of Basin Road is shown below in Figure 3, with surficial geology in Figure 3A and landslide hazard designation mapping in Figure 3B. There is a clear correlation between the shapes of the surficial geology units and the associated landslide hazard designations.

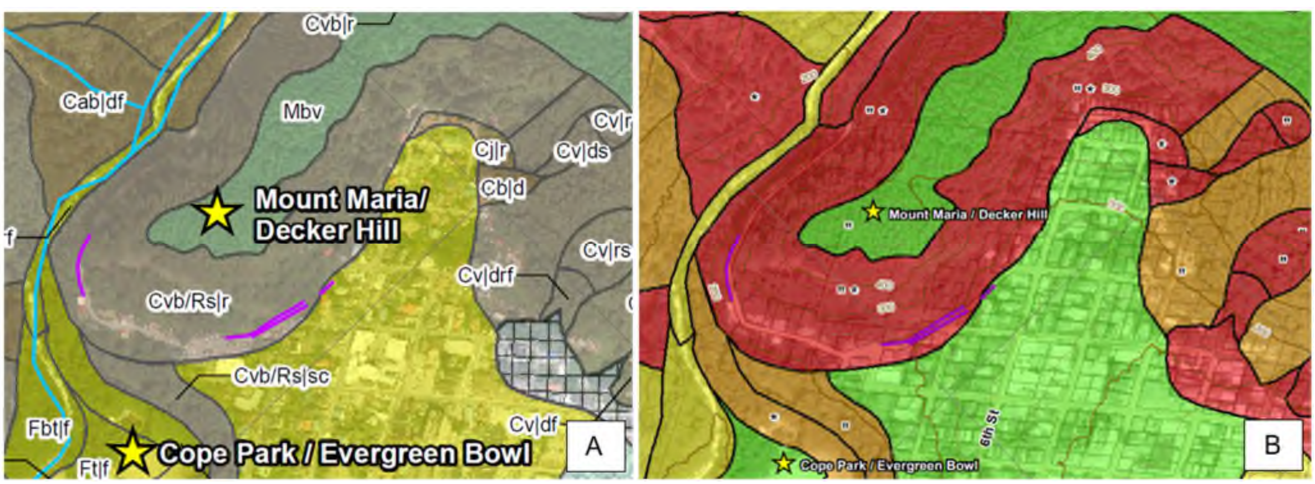

Figure 3: Excerpts from Tetra Tech Figure 1.3b Surficial Geology (Figure 3A), and Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (Figure 3B).

Some parallels can be seen in the locations of the mapping boundaries of Swanston (1972) and Tetra Tech (2021), in that they appear to follow the terrain (in contrast to the 1987 mapping which defers to nearby property lines). However, there are some significant differences in the details, due to better quality data, i.e., higher resolution imagery and new LiDAR data available to Tetra Tech, and more advanced mapping techniques used in the current study (Figure 4).

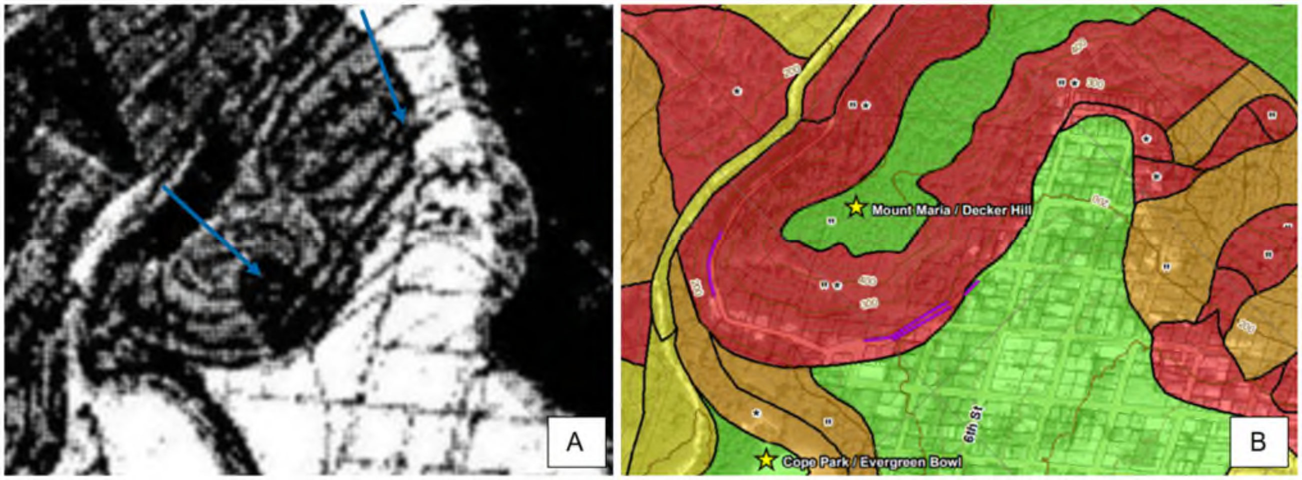

Figure 4: Comparison of Swanston's Figure 6 (Figure 4A) and Tetra Tech's Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (Figure 4B). Swanston (1972) uses *Potential* Hazard (gray) and *High* Hazard (black), designated in the 1987 adopted mapping as *Moderate* and *Severe* hazards. Tetra Tech uses *Low* (green), *Moderate* (yellow), *High* (orange), and *Severe* (red) hazard designations.

As shown in Figure 4A, Swanston mapped most of Mt. Maria on the Starr Hill side as having a *Potential* Hazard (gray area), except at the prehistoric slide area and a small cliff above the corner of 6th and Nelson Streets, which were designated as being in *High* Hazard areas (blue arrows). These two areas are also shown with blue arrows in Figure 5. Heading northeast along 6th Street from Basin Road towards Nelson Street, the lower boundary of Swanston's *Potential* Hazard area was mapped progressively closer to 6th Street.

Along the entire southeast edge of Starr Hill, including a portion of the mapped lots, Swanston (1972) marked an area of *Potential* Hazard, with *High* Hazard marked further upslope on Mt. Roberts. The lower boundary of Swanston's *Potential* Hazard area begins at about Harris and 4th Streets, becoming progressively closer to 5th Street heading northeast. The northeast corner of Swanston's mapped landslide hazard area curves to the north to encompass the terrain southeast and northeast, upslope of the corner of Nelson and 5th Streets. Swanston did not designate hazards along or above the northwest part of Nelson Street. CBJ's 1987 adopted map called that area *Moderate* (Figure 1A).

The sections that follow provide some additional details about the slope sections for which hazard designation changes have been proposed.

Nelson Street (between 5th and 6th Streets)

Swanston's mapped rockslide hazard appears to continue around the corner to Nelson Street (more red arrows in Figure 5), although that is less clear due to the poor scan quality of Swanston's mapping. The presence of rockfall/ rockslide hazard areas along Nelson Street did not appear to be reflected in Swanston's hazard mapping (Figure 4A).

The findings in Swanston (1972) are generally consistent with Tetra Tech's findings on the northwest and northeast sides of the Starr Hill Subdivision, except for the gap in Swanston's hazard mapping along Nelson Street.

Corner of Nelson Street and 5th Street to Harris Street

Tetra Tech identified some additional debris slide and debris flow features on the southeast side of the Starr Hill Subdivision that were not specifically identified by Swanston, but which do appear to account for Swanston's overall hazard designations for that slope (Figure 2B; Figure 4A).

Debris Flows above 5th Street between Park and Kennedy Streets and Kennedy and East Streets

On the southeast side of the subdivision, Swanston (1972) also found a record of a "slump" that occurred on November 27, 1935, at "5th Street above Kennedy" Street that did not cause damage. Swanston did not map that feature; however, nor did he detail the active slope processes at that location. The debris flow feature identified by Tetra Tech between Kennedy and Park Streets and upslope (southeast) of 5th Street, might be related to the "slump" mentioned by Swanston (located at approximately the orange arrow on Figure 5). That significant debris flow gully (called G000 Park in the new avalanche mapping) appears to be a different debris flow than the feature identified by Miller (1975), which is located slightly to the southwest, between East and Kennedy Streets (green arrow on Figure 5).

At that location, Miller (1975) showed a debris flow about 85 yards long that he reported as a 1972 event. Due to this location being located at the edge of one of the air photos, and possibly due to regrowth of vegetation since 1972, Tetra Tech's review of the 1977 air photos was inconclusive. However, Google Street View (July 2011 imagery), near the southeast end of the paved part of East Street, clearly shows the aftermath of a recent debris flow and/or erosion type event from upslope of the road at 415 East Street. The 2013 imagery also suggests disturbed ground between the house closest to the road and the next house located almost due east at 622 4th Street.

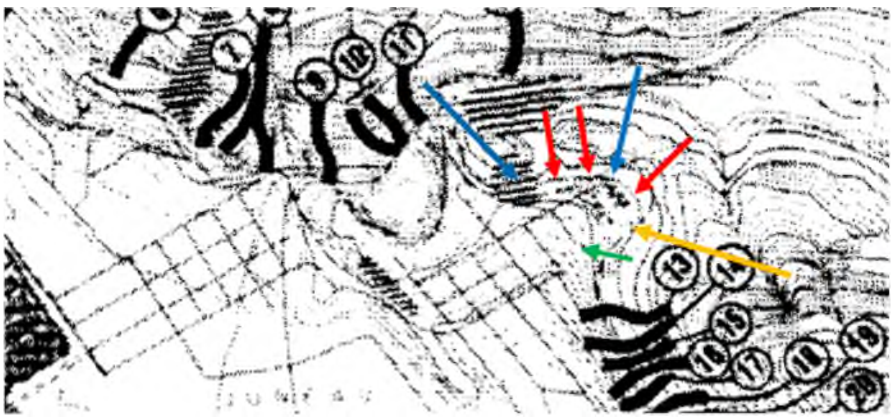

Figure 5: Excerpt from Swanston (1972) Figure 7 – "Mass Wasting Channels and Rock Slide Areas." Striped map areas are rockslide hazard areas; heavy numbered lines are mass movement channels.

2.1.3 Reasons to Update the Landslide Hazard Designations around Starr Hill

Swanston (1972) *specifically* identified many of the rockfall/rockslide hazards on the Basin Road and 6th Street boundaries of Mt. Maria, and along Nelson Street, and *generally* identified landslide hazards between Nelson Street and Harris Street above 5th Street, near the northwest end of the Mt. Roberts ridge.

However, Swanston's hazard designation system was slightly less conservative than Tetra Tech's designation system. This difference is partly due to Tetra Tech's modern mapping capabilities identifying more features than might have been detected in 1972, particularly on the southeast side of the subdivision, and partly due to the Four-Tier Landslide Hazard Designation System developed by Tetra Tech.

The other main difference in hazard designation mapping is that Swanston's hazard mapping between Nelson Street and Harris Street on the southeast side of Starr Hill shows a lower level of hazard activity along the toe of slope than upslope. Swanston's mapping transition; however, does *not* entirely reflect the actual landslide hazards in the area. For example, landslide hazard is associated with the *deposition zone* of landslide debris just as much as it is with the initiation zone or the path of the debris. If the residences are located within the natural deposition zone, then, logically, damage *could* occur if a landslide does happen. Therefore, the *Severe* hazard designations *should* extend into the deposition zones along Basin Road, 6th Street, Nelson Street, and around the corner along and above 5th Street. Similarly, the debris flow deposition zone between Park and Kennedy Streets widens towards the toe of slope, due to the way that debris flow cones or fans are formed (as explained in Technical Memo #2). The deposition zone of the debris flow gully (the lower cone/fan-shaped area) *should* also be designated as a *Severe* hazard.

Tetra Tech has mapped the slope in the vicinity of 415 East Street and 622 4th Street as being within a *High* landslide hazard designation zone. However, given the findings of an apparent debris flow feature at that location, the judgement of whether to upgrade the landslide hazard designation to *Severe* should be made after a site-specific investigation in that area. It does appear possible that the debris flow might be related to a cutline upslope (apparently a former powerline alignment), and the problem might be solved by remediating the surface water drainage at the cutline. However, if the feature is not related to water drainage problems originating at the cutline, this area should be mapped as *Severe*.

Based on Tetra Tech's mapping of surficial geology, slope movement activity, gully erosion features, and field observations, as well as some recent landslide events documented in the past 10 to 12 years, it appears that much of the *Moderate* hazard terrain in this area should be reclassified to *High* or *Severe* hazard, as was done in the 2021 hazard designation mapping. *Furthermore, arbitrary hazard boundaries along property lines should be removed as not reflecting the true threat to the public safety, i.e., hazard designations based on property lines do* ***not*** *adequately describe the hazards.*

Severe hazard designations are assigned to the areas subject to rockfall, debris slides, and debris flows, as shown on the surficial geology map in Figure 3A. Areas with a *High* hazard rating were assigned based on the results of the semi-quantitative analysis. These areas are expected to experience rockfall that damages but does not always knock out trees, and as such are a less severe hazard than a debris flow or debris slide that removes everything in its path. Evidence of this type of rockfall activity was identified during the field investigation.

2.2 Requests for Additional Information for Starr Hill Subdivision

Numerous comments and questions were received from residents about the Starr Hill mapping area. These comments and questions have been excerpted and documented below in a question-and-answer format. In cases where questions were similar or related, these have been combined for the response. Tetra Tech has also incorporated and greatly appreciates several anecdotal observations and photos from Starr Hill residents that provide additional context for the slopes around the subdivision.

1. **Question/Comment:** I've seen the rockfall above Basin Road, and I can see why that slope is in a *Severe* hazard zone, but what about the slope above 6th Street? Why is that *Severe*?

   Answer: Let's start with the work done by Swanston (1972) to understand why that is. Along the south side of Mt. Maria, Swanston (1972) identified rockfall/rockslide hazards primarily at the prehistoric rockslide and at the corner of 6th and Nelson Streets where a talus deposit was observed (blue arrows in Figure 5). Swanston also reported small deposits of angular rock fragments and talus above 6th Street from Basin Road to Nelson Street, which apparently correspond to the rockfall/rockslide hazard mapped above 6th Street (red arrows point to the hazard in Figure 5). These observations were confirmed by Tetra Tech's fieldwork, during which numerous unstable rock cliffs and bluffs were also observed above 6th Street (Figures 6 and 7). Swanston (1972) further noted that, although the bedrock dips into Last Chance Basin (on the north side of Mt. Maria), freeze-thaw action in the fractures and joints of the exposed bedrock, and water acting as a lubricant in the cracks, result in instabilities. The elevated level of slope movement activity on this slope, including several well-established slide paths below prominent bedrock bluffs and cliffs, requires the slopes below the cliffs to be designated as *Severe* hazard. These are the kinds of processes that have been ongoing since long before Swanston's observations and are expected to continue.

The prehistoric slide area (Figure 5, blue arrow on left side) appears to be in the same place where a rockfall/ rockslide was reported on October 18, 1913 (Swanston 1972, Figure 6), and where a distinct landslide scar is still present despite reforestation of the slope (Figure 13). Swanston reported that several houses had been destroyed, and that a deposit of angular rock fragments had been created above Basin Road between 6th and 7th Streets.

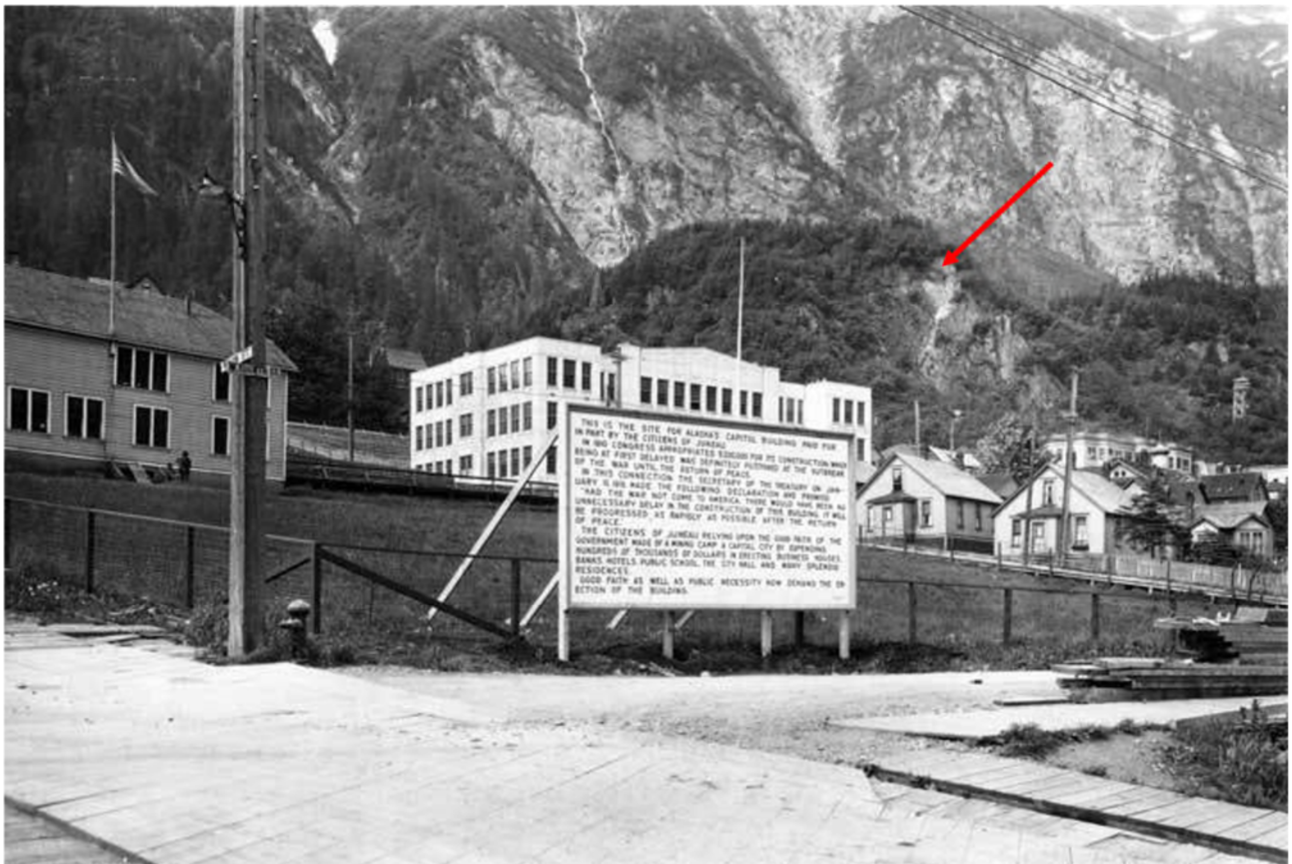

Figure 6: Looking north towards the Juneau Public School. Rockfall/rockslide scar on Decker Hill/Mt. Maria in the background was the likely origin of the October 18, 1913 landslide event (red arrow). The rock slope immediately to the right of the red arrow appeared more active (less reforestation) than the slope to the left in 1918, and some of the debris might also have originated from there. See Figure 13 for present-day view of Mt. Maria. (Photo credit: Alaska State Library – Historical Collections, [ASL-Juneau-Capitol-Building-1](), Alaska State Library Place File. Photographs. ASL, ca. 1918.)

A news story about the 1913 event reported two large rocks, each several tons in weight, falling from the cliff on the side of Decker Hill facing town and above Basin Road (Figure 6). One of these rocks impacted a huge boulder below, which had lain there for many years and, although the falling rock lifted the existing boulder up on edge, it was prevented from travelling further downslope. That existing boulder was reported to be located at the edge of the road, opposite the Nelson home, protecting it. The other large rock that fell was deflected and crossed the road to crush a woodshed below Basin Road, at the Price home. The power poles along Basin Road were also snapped, resulting in a short circuit (The Alaska Daily Empire October 20, 1913). The Nelson home is likely Structure C-8 Nelson House II, located downslope of Basin Road at the northeast corner of Harris Street and 6th Street, as shown by the purple arrow on Figure 12 (CBJ 1986). The Price home was not listed in the inventory, so its exact location is not known.

To summarize the results of Tetra Tech's mapping and fieldwork upslope of 6th Street and Nelson Street and continuing along Basin Road on the slopes of Mt. Maria/Decker Hill, there are unstable bedrock bluffs that are considered a *Severe* hazard due to observed features and potential rockfall activity that comes close to or into residential areas (Figures 7 and 8). There is also a talus deposit at the corner of 6th and Nelson Streets (Figure 8D). Exposed talus means that there is still rockfall coming down from above. If the rockfall activity had ceased, there would be much more regrowth of vegetation than is apparent now, nearly 50 years after Swanston first described the talus deposit. Above the houses in the rockfall area, trees show damage from being hit by large angular boulders, many of which are so large they could easily injure or kill a person who happened to be in their paths (Figure 7). Along the houses on 6th Street, the *Severe* zone affects the backyard, but might or might not affect the house. Figure 8 shows examples of rock bluffs, slide tracks, and talus. The housing itself obscures the effects of the rockfall activity – if a boulder rolls into a yard or onto the road, it is typically removed, so the evidence is no longer available for mapping. The boundary of the *Severe* hazard area for Mt. Maria is thus very conservative and may well extend further southeast than that shown.

See also Question #3 below for more information on what the rockfall/rockslide paths look like on this slope.

Figure 7: Photos from Tetra Tech's main report, at the southwest end of Mt. Maria above Basin Road at Harris and 7th Street. Photo P24 (Figure 7A) shows a tree damaged by rockfall. Photo P25 (Figure 7B) shows the typical size of some of the fallen rocks.

Figure 8: Rockslide track and cliff above rockfall at left-hand blue arrow on Figure 5 (Figure 8A); typical rock bluff above 6th Street at red arrows on Figure 5 (Figure 8B); rock cliff with detached blocks above corner of 6th Street and Nelson Street at right-hand blue arrow on Figure 5 (Figure 8C); and talus deposit below rock cliff, 6th Street visible below (Figure 8D).

2. **Question/Comment:** Could you please explain the slope hazards above Nelson Street? I've noticed several fallen trees and continued evidence of mudslides in this area.

   Answer: Upslope of Nelson Street, there are debris slides and rockfall (Figures 12 and 15). Due to additional information about landslides above Nelson Street and around the corner above 5th Street that was received during the public review process, the hazard in this area is now mapped as *Severe* (Figure 3B). Figure 9 shows some examples of active debris slide paths and rock bluffs above Nelson Street. See Question #3 for information on the effects of historical forestry activities on this slope and to see where the most prominent landslide paths are located. See Questions #5 and #6 for information on the slopes above the corner of Nelson and 5th Streets. See Question #12 for information on the possible effects of the old Mt. Roberts Trailhead.

Figure 9: Active debris slide paths above Nelson Street are shown in Figures 9A and 9B; rock bluffs and broken or damaged trees above Nelson Street are shown in Figures 9C and 9D.

3. **Question/Comment:** Starr Hill/Mt. Maria were clearcut early on, and the area is gradually becoming reforested. These historical conditions would have exaggerated the landslide risks and frequencies during that time, while reforested conditions should reduce the risks, even with climate change-driven precipitation events. There was no discussion about that in the report.

   Answer: Residents provided two historical photos from 1901 and 1940 with perspectives close enough to the slopes for good comparisons to be made with more recent imagery. Tetra Tech has added another photo from 1902 showing Mt. Maria, two recent Google Earth oblique views to compare how the slopes appear now, and the 2013 LiDAR that clearly shows the bedrock outcrops on Mt. Maria.

   It is important to recognize that the slopes around Starr Hill were not uniformly treed prior to clearcutting (Figures 10 through 14). Tetra Tech agrees that increased interception from reforestation would help to reduce the infiltration of surface water onto slopes that are sensitive to the input of additional water, particularly slopes with thin colluvium over bedrock. Equally important is the reduction of water that would otherwise flow from the reforested slopes – as surface water drainage or subsurface water drainage – into the swales and gullies that are (and always were) sparsely treed or lacking tree cover altogether. Reforestation would be expected to have some benefit to slope stability.

   The evaluation of climate change effects was not in the project scope, so the effects of climate change on precipitation in Juneau are not known in any detail. If (as suspected) the likelihood of extreme precipitation and/or wind events is increasing due to climate change, reforestation is likely not enough to reduce slope instability hazards, especially on slopes with shallow bedrock. Comparing Tetra Tech's observations from 2019 to the observations from residents in 2021, landslide activity above Starr Hill is clearly ongoing.

Figure 10: Looking east-northeast toward Starr Hill from top of Chicken Ridge, 7th and Franklin Streets, July 1901. Slopes appear to have been recently clearcut (within the previous few years) with numerous stumps visible. There are some swales and slope sections with few or no stumps, indicating that this slope was not uniformly forested prior to clearcutting (red arrows). At least two recent soil debris slides are visible above what appears to have been Park Street in 1901. (Photo credit: Alaska State Library – Historical Collections, ASL-P1-506, Vincent Soboleff Photograph Collection, ca. July 1901.)

Landmarks shown in Figure 10 include the Distin-Dawes-Pelto House at 529 East Street (blue arrow), St. Ann's Hospital staff residence (green arrow) at the south corner of 6th and Harris Streets, apparent precursors to the Lund Houses I and II at 504 and 510 Kennedy Street (yellow arrow), and the Mitchell House at 715 – 6th Street (aqua arrow), based on the Inventory of Historic Sites and Structures (1986) and various historical photos from the Alaska State Library. Some of the dates and descriptions are uncertain in the inventory, and it is possible that changes or additions have been made to some of the structures that still exist. As well, some of the structures present in this photo no longer exist, or were replaced with other structures. Park Street appears to have been the approximate upper end of the developed area in 1901, since the earliest houses above Nelson Street were built in 1928.

Figure 11: Looking east-northeast, this view of Starr Hill in 1940 is from a little further southwest of the view in Figure 10, and somewhat foreshortened. After more than 40 years of tree growth after clearcutting, the swales and gullies where no coniferous trees grow are especially clear in this photo. Selected swales and gullies are shown with red arrows; several other swales and gullies are also visible between the red arrows. (Photo credit unknown.)

Landmarks shown in Figure 11 include the Distin-Dawes-Pelto House at 529 East Street (partly obscured, blue arrow); St. Ann's Hospital (green arrow) at the south corner of 6th and Harris Streets, with the newer concrete section northeast of the green arrow (replacing the former staff residence), and the older wooden section to the southwest; the Lund Houses I and II at 504 and 510 Kennedy Street (yellow arrow); and the Mitchell House at 715 – 6th Street (aqua arrow), based on the Inventory of Historic Sites and Structures (1986) and various historical photos from the Alaska State Library. Some of the dates and descriptions of structures are uncertain in the inventory, and it is possible that changes or additions have been made to some of the structures that still exist. As well, some of the structures present in this photo may no longer exist, or were replaced with other structures. Nelson Street was the upper end of the developed area in 1940, with most of the houses above Nelson Street built by then.

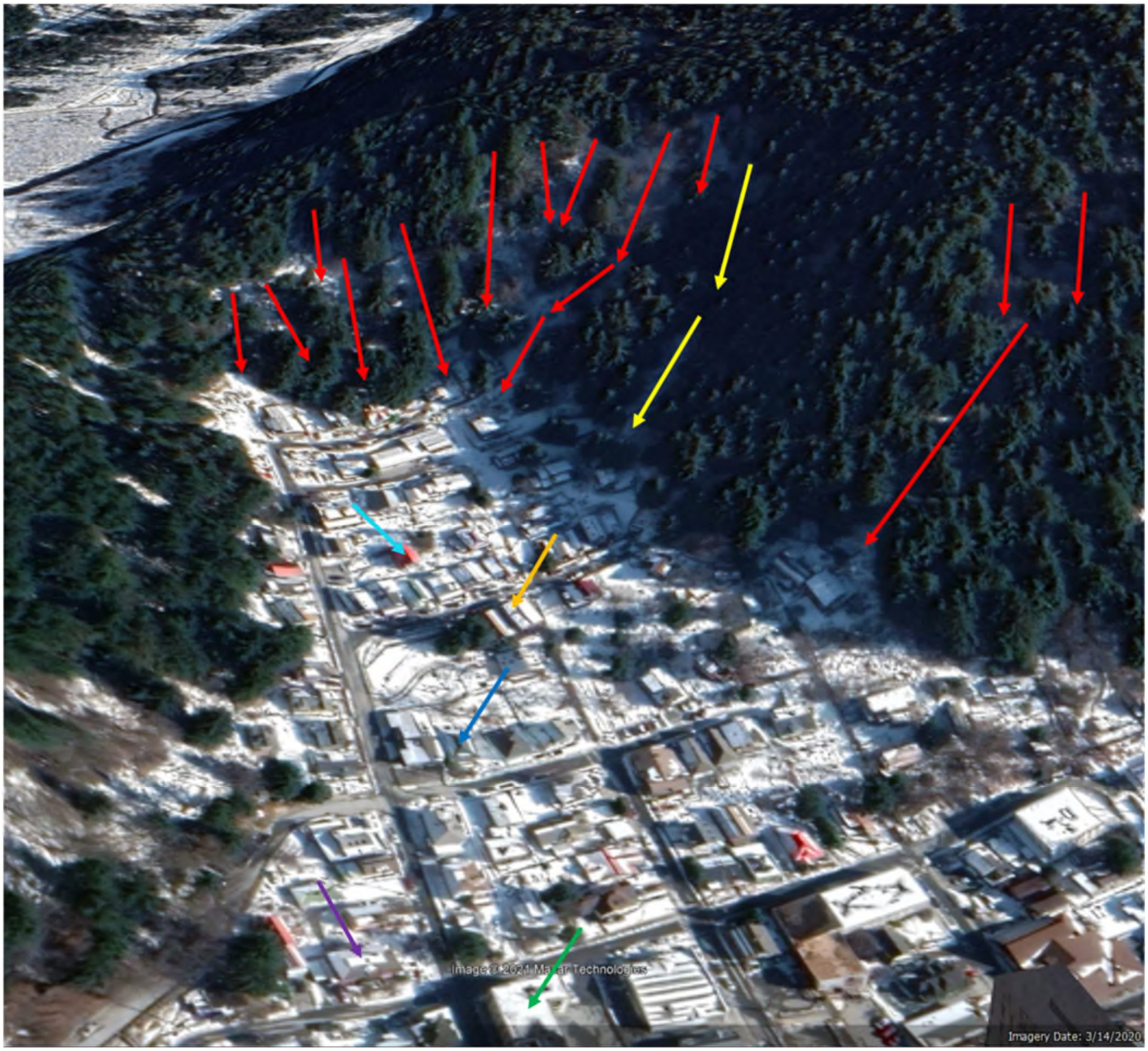

Figure 12: Looking east-northeast, this Google Earth view is from an eye elevation of about 1,100 feet and at a snowy time of year (March 2020), so that the areas without coniferous trees can be seen more easily. The same swales and gullies that lack tree cover that were seen in the 1940 photo (Figure 11) are still visible in 2020, along with a few more. The landmarks are the same as in Figure 11, although St. Ann's Hospital is now called St. Ann's Center, and a new landmark at Nelson House II has been added below Basin Road (purple arrow). (Image credit: Google Earth 2022.)

In Figure 12, one of the main gullies (shown with two bright yellow arrows, ending between Park and Kennedy Streets) is the G000 Park debris flow gully. See Figure 15 for more information about this gully.

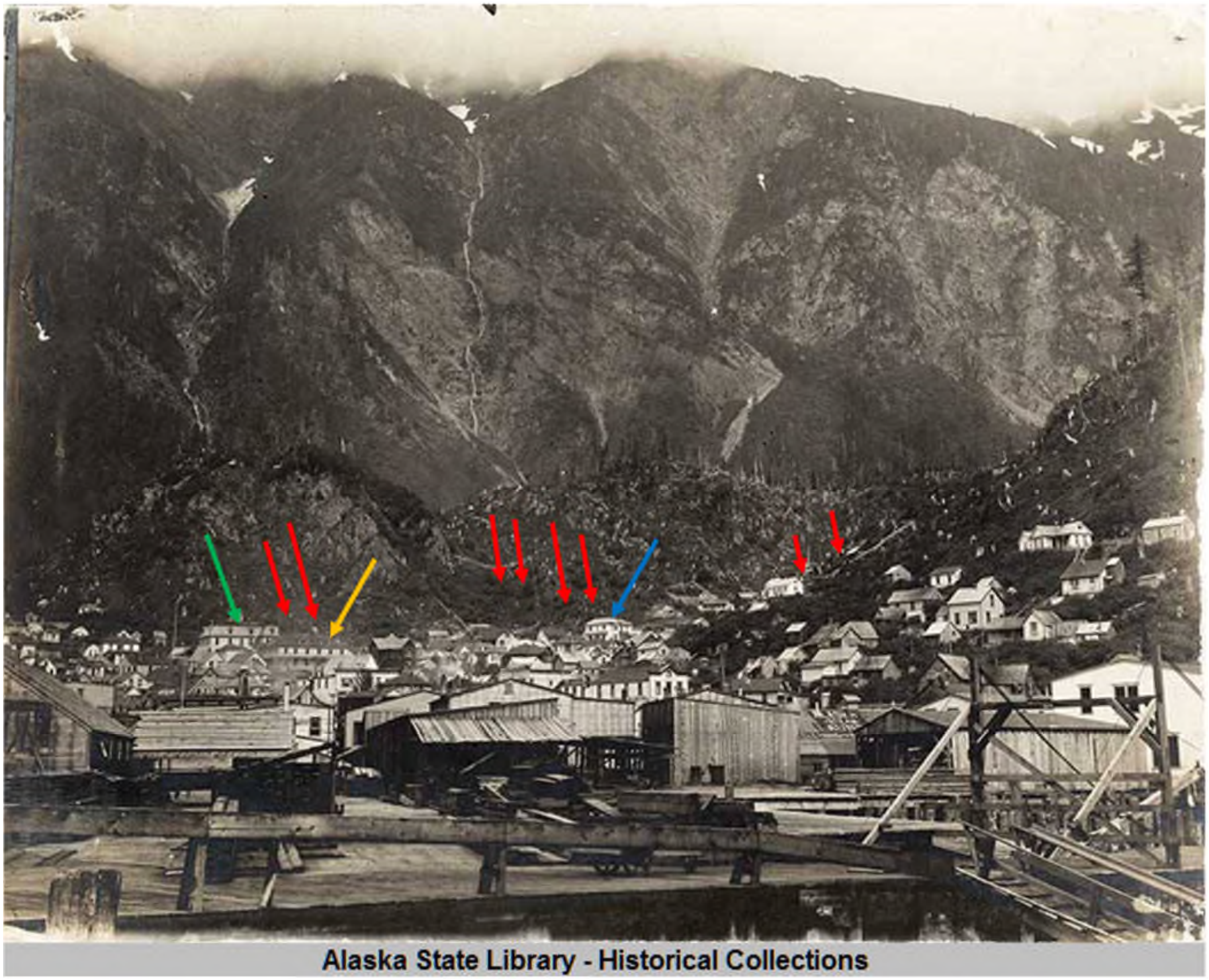

Figure 13: Looking north toward Starr Hill from the waterfront. Mt. Juneau is in the background. Slopes appear to have been recently clear-cut with numerous stumps visible above the buildings. The exposed rock slope on the west end of Mt. Maria (Decker Hill) is the location of the pre-historic rockslide, where in 1913 another major rockfall event would occur. (Photo credit: Alaska State Library – Historical Collections, ASL-P334-16, Ark A. Tower Photograph Collection, June 8, 1902.)

The perspective of the 1902 photo (Figure 13) makes it more difficult than the 1901 photo (Figure 10) to see the slope details, and apparent logging debris remaining above the upper end of 6th Street also obscures the slope. However, there are some swales and slope sections with few or no stumps visible, indicating that the Mt. Maria slope was not uniformly forested prior to clearcutting (red arrows). Above 6th Street, areas lacking forest cover appear to be associated with the rock bluffs visible upslope. Landmarks include 529 East Street at the blue arrow, St. Ann's Hospital staff residence (green arrow). Just to the southeast along 5th Street (in the foreground of the staff residence) were the Church of the Nativity, the chancellery, and St. Ann's Hospital (later the school, and now the Parish Hall, orange arrow), based on the Inventory of Historic Sites and Structures (1986) and various historical photos from the Alaska State Library.

Figure 14: Looking north-northwest, this Google Earth view is from an eye elevation of about 1,100 feet in early spring (April 2020), so that the slopes currently lacking coniferous trees can be seen more easily. Several of the swales and slope sections lacking tree cover that were seen in the 1902 photo (Figure 13) are still visible in 2020, along with a few more slide paths (red arrows). The apparent alignment of the paths lacking trees is slightly different in Figures 13 and 14, due to the different perspectives of the images. The landmarks in Figure 14 are the same as those in Figure 12. (Image credit: Google Earth 2022.)

At the top ends of all the paths are rock bluffs or cliffs (Figure 14), which are the source of the rockfalls and rockslides that periodically scour out lower-growing vegetation along the paths, or damage mature trees alongside the paths if the debris is large enough. A couple of the paths seen in 1902 between Kennedy and Park Streets are obscured by trees in 2020 but are likely still present under the tree canopy. Some of the swales that seem to end mid-slope in this image likely continue further downslope under the tree canopy. In some areas of the slope, there are still some trees below rock bluffs, but they tend to be smaller than the trees on slopes not regularly affected by rockfall or rockslide debris (Figure 7). On the far left, the path shown crossing Basin Road represents the rock debris that impacted 712 Basin Road about 12 years ago (CBJ 2020).

Three cutlines are visible in Figure 14: on the left, the powerline above Basin Road; in the middle, where an old cutline crosses over to the north side of Mt. Maria; and, on the right, parallel to 6th Street, another old cutline crosses above the corner of 6th and Nelson Streets into Last Chance Basin. The latter two cutlines may be related to old mining infrastructure, and/or powerlines.

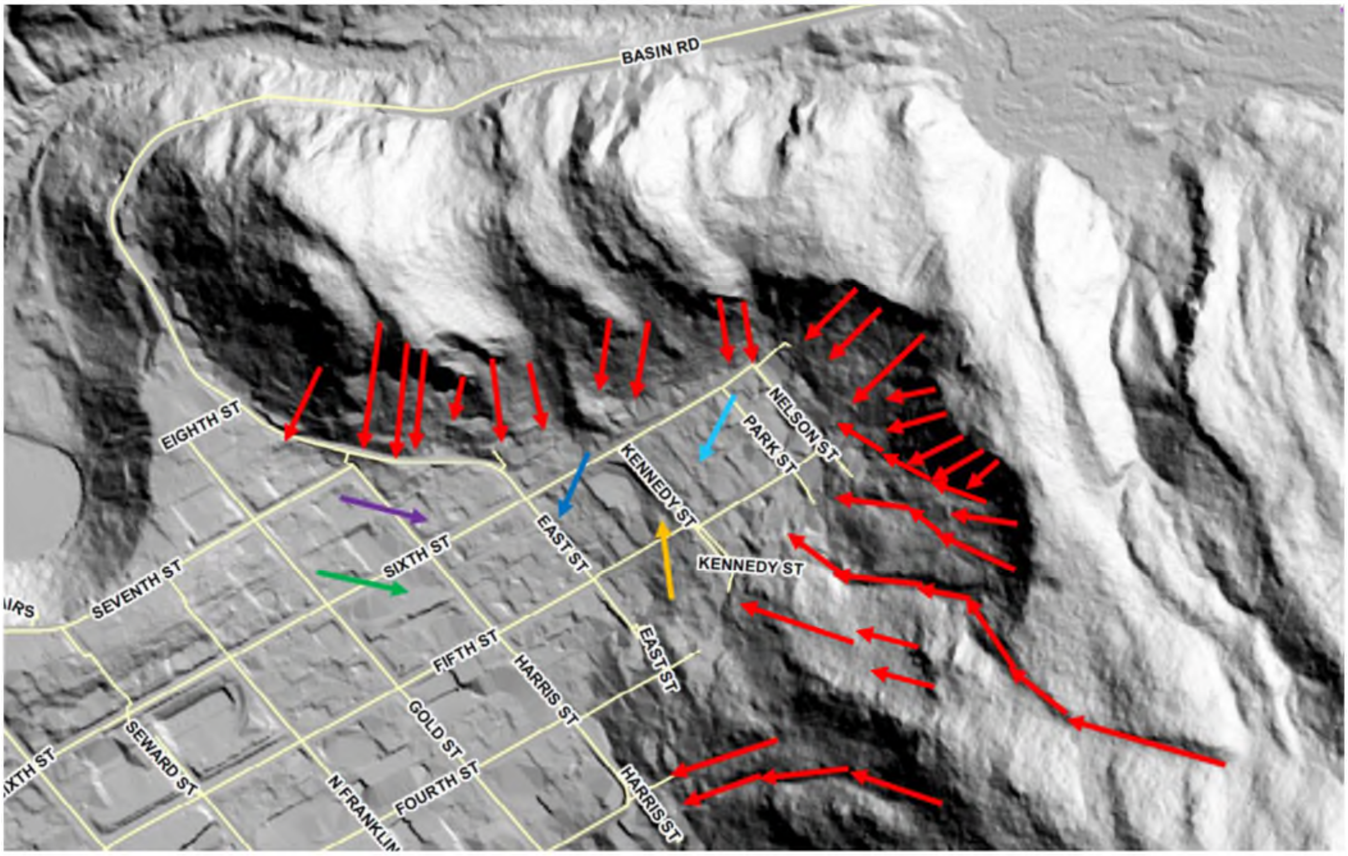

Figure 15: This excerpt from the 2013 LiDAR image shows several bedrock cliffs and bluffs above Basin Road, 6th Street, Nelson Street, and the north end of 5th Street. Fieldwork identified numerous active rockfalls/rockslides as well as some debris slide areas that confirm the observations from the LiDAR and the air photo mapping (Figures 6, 7, and 8). Apparent landslide locations shown are based on poorly-vegetated slopes, swales and gullies seen on Google Earth that are also visible on LiDAR hillshade models (red arrows). Landmarks are as for Figure 14. (Image credit: CBJ 2013.)

The longest red arrow in Figure 15 shows the location of the debris flow gully within the G000 Park avalanche path. This gully appears to receive water and debris not only from the local slopes immediately above 5th Street, but also from surface drainage swale or gully that originates further upslope along the Mt. Roberts crest.

4. **Question/Comment:** We agree that there is landslide activity in the [G000] Park gully, but properties have largely been protected by maintenance and instream mitigation structures and drains. The structures were installed by homeowners… with materials that were supplied by the City and Borough of Juneau. Some of these structures need to be repaired or replaced in order to continue proper drainage of this creek through the city-installed culvert that runs under the 725 5th Street home.

   The area designated as *Severe* (red) has resulted in two debris flow events in the last 35 years… A debris flow incident occurred in the late 1980s, as a result of the drain above 725 5th Street becoming plugged because the home was vacant and there was no one to monitor/maintain the drain. In 2019, the gully creek undercut a bank, causing a flowerpot to fall and temporarily block the flow.

   Answer: The review of the slopes in Question #3 provides some useful background in the overall slope processes that are happening in this area of Starr Hill. Specifically, between Park Street and Kennedy Street, there is a debris flow gully that was not identified in any of the previous studies, except possibly as the “slump” reported in Swanston (1972), as discussed in Section 2.1.2.

Although the residents have reported only two debris flow events in the past 35 years, this does not mean that the hazard is not significant. Based on the field observations, this debris flow gully has a high potential to affect downslope residences. Clearly, residents were concerned enough about the debris flow hazard to build structures to control debris flows, but these structures are not by any means engineered structures (Figure 16). Routing a debris-flow creek under a house also seems fraught, considering that the drain upslope has become plugged in the past, and that the slightest misstep upslope can create further havoc. (Case in point, the creek undercutting the stream bank and a fallen flowerpot blocking the flow in 2019.) Furthermore, as shown in Figure 15, it appears that this debris flow gully could potentially receive significantly more debris and water than just from the local slopes. As it stands, due to these multiple sources of hazard, Tetra Tech considers that this debris flow gully has been correctly designated as *Severe*.

Figure 16: Photos from the fieldwork in September 2019 showing one of the existing debris-flow mitigation structures that were built by homeowners living below the G000 Park debris flow path above Starr Hill. This structure has captured debris material from one or more mass-wasting events and measured about 8 feet wide by 7 feet long by 2 feet deep.

Depending on the size of the next debris flow, the structure shown in Figure 16 could retain a little more debris or, instead, it could collapse, be overrun by debris, or even be completely scoured out by a larger debris flow that could originate from further up the gully. The same applies to the other structures documented by residents. Debris can incorporate both large and small woody debris, as seen in these photos and the photos supplied by residents of the mid and upper reaches of the gully. The upslope portion of this debris flow feature is bowl-shaped, indicating the potential for small debris slides from the side slopes to fail and entrain debris in the gully, of which there is a significant amount. The particle size of the material that can be moved by a debris flow is also important – some cobble- and boulder-sized material is also visible in the residents' photos. Despite the mitigation attempts, debris slides/flows could result in enough volume to impact the houses below.

5. **Question/Comment:** We question the high risk [orange] designation adjacent to the gully, as the topography is relatively dry, stable, and does not seem to foster conditions for any landslide, debris flow, or erosion.

   Answer: The answer to this question can be applied to both areas mapped as *High* hazard terrain (orange) beside the G000 Park gully: the open slopes located to the southwest and northeast of the debris flow gully. The bowl-shaped terrain located upslope of the corner of Nelson and 5th Streets is now mapped as *Severe*, so this discussion no longer applies to that terrain (see Question #2). The surficial geology is the same in both areas. The review of the slopes in Question #3 provides some useful background in the slope processes that are happening in this area of Starr Hill. Figure 15 shows clearly the very rough and disturbed terrain that has resulted from highly active slope processes, particularly on the northeast side of the G000 Park gully. Figures 10, 11, and 12 show the paths along which the most frequent landslides (debris slides/flows) tend to occur northeast of the gully, and Figure 12 also shows the paths southwest of the gully.

   On the right-hand side of Figure 12, for the area southwest of the G000 Park gully, there are two red arrows high on the slope and a longer red arrow on the lower slope. The two upper red arrows on Figure 12 show the main areas of slope instability activity higher on the slope and, as seen on Figure 15, this instability is related to the rock bluffs/cliffs upslope, resulting in rockfall/rockslides. The geology mapping shows that debris slides can occur in this terrain too. The lower longer arrow indicates a transition zone where most of the rockslide or debris slide material continues downslope. Due to the open-slope environment, this slope is not as hazardous as the debris flow gullies on either side. However, the prominent toe of slope at the edge of the residential area clearly shows the edge of this terrain unit, and the considerable proportion of ground with sparse or no tree cover upslope is indicative of ongoing slope instabilities. This is why this slope section has a *High* hazard designation.

Figure 17: Compare Tetra Tech's photo from September 10, 2019 (Figure 17A) with residents' photo from August 1, 2021 (Figure 17B) at the same location. Slope instabilities appear to be ongoing in the historical slide path locations.

Note that local material volumes incorporated in debris slides can often be relatively small, but they are cumulative, and just as for debris flows, debris slides can include large and small woody debris. Eventually, there will be enough new or built-up debris combined with enough precipitation to bring the debris downslope to an elevation where it can cause damage. One recent example is the landslide that occurred on these slopes in November 2020 that was reported by a nearby resident in the online comments of the July 21, 2021, Neighborhood Meeting.

The primary distinction in hazards between slopes with debris slides and slopes with debris flow gullies is the mobility of the debris material. Debris flows are generally much more mobile than debris slides, and would be expected to run out further downslope, potentially affecting a much larger area, and thus warranting a *Severe* rating. However, every report from residents about landslides that have impacted their properties is important and will be taken into account when finalizing the landslide hazard designations in the Issued-for-Use report.

6. **Question/Comment:** The boundaries between the *Low*, *Moderate*, *High*, and *Severe* landslide hazard zones do not seem to match the land.

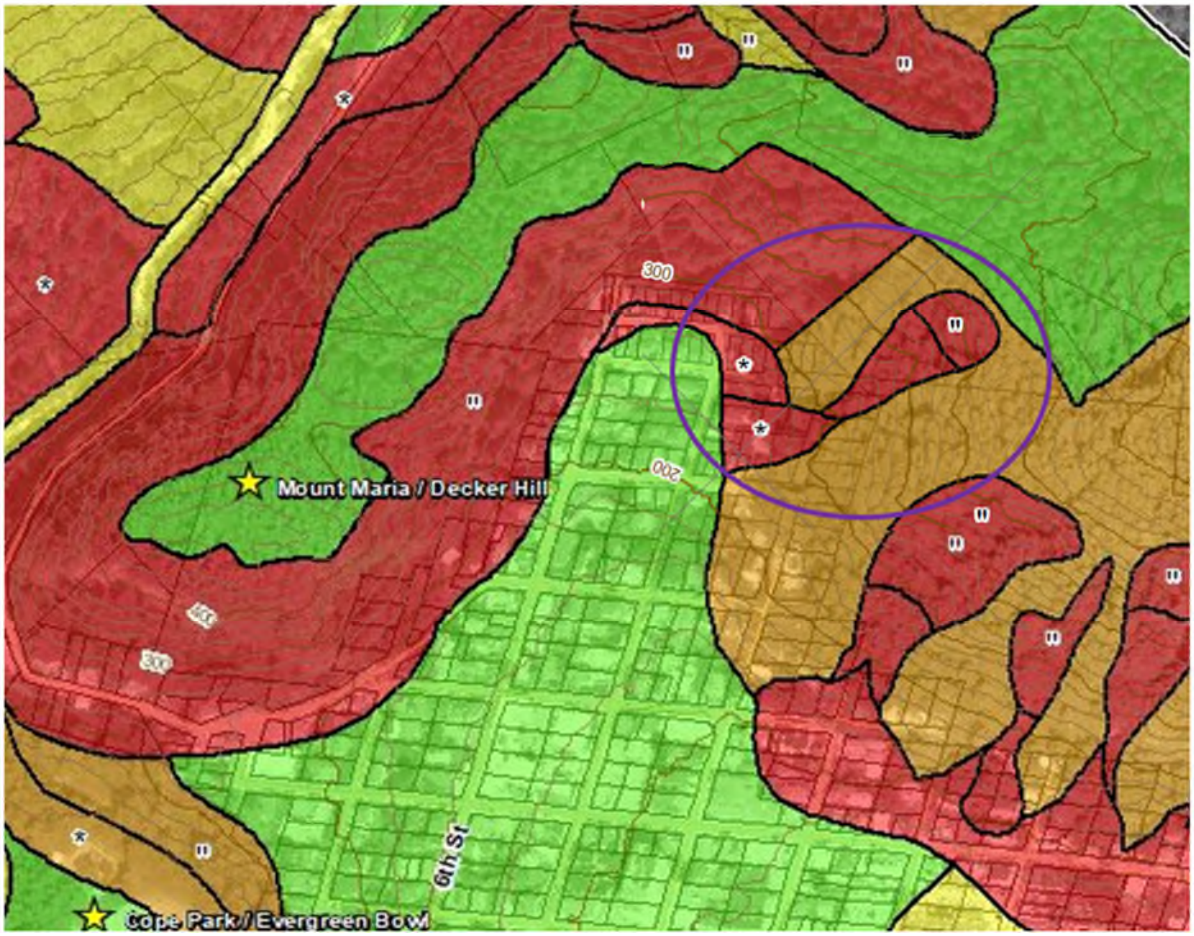

Figure 18: Excerpt from the landslide hazard designation mapping. The purple outline shows an area where residents requested more information to understand the shapes of the mapping units and the reasons supporting the hazard designations.

Answer: The boundaries between the different landslide hazard designation zones are closely related to the surficial geology mapping terrain unit boundaries (Figure 3A). The reason for this relationship is that the different soil and rock features have a large influence on how the slopes behave. For shapes that do not seem to make sense, it is helpful to look at the features beside that odd shape. Usually, it will be a terrain feature whose characteristics will govern the shape of the boundary between the two units, like a bedrock outcrop, or a terrain unit that overlaps a previous unit. Sometimes, the odd-looking boundary is only because there is a corner or curve in the slope, so that debris from one side falls down in one direction, and material from the other side falls down in a different direction. These two debris areas might then meet at the bottom of the slope, like the southeast corner of Starr Hill, where debris can fall or slide from above Nelson Street, and it can also fall or slide or flow from above 5th Street. Since this part of the subdivision is essentially the shape of a bowl, the mapping of the unit boundaries can also reflect slope contours and fall-lines, as well as the surficial geology unit boundaries. See also Technical Memo #2, Question #3, for more explanation on how apparently odd-shaped boundaries are determined.

Specific to this area of Starr Hill, it is now known that a resident has identified a recent landslide event in a *High* hazard zone (see Question #6 above), which also happened to be within one of the apparently odd-shaped hazard units (Figure 18, purple outline). This area has now been updated, resulted in a shifting of the hazard boundary above the corner of Nelson Street and 5th Street. Note that the *Severe* hazard zone mapped at the toe of slope is due to this area being a deposition zone for slide debris.

If other property owners have experienced landslide events – rockfalls, rockslides, debris slides, debris flows, and so on – at their properties, not just in Starr Hill, but anywhere in the downtown Juneau study area, this is the time to report those landslides, to help finetune the mapping. When reporting landslides, please report if there was damage and, if so, what was damaged and to what extent, for example, structures or landscaping. If quantities of debris removed or cleaned up are known, please report approximate quantities also.

7. **Question/Comment:** The maps raise significant questions as to how areas were given certain designations. Houses that have had tree slides damaging the structure have been included in lower hazard zones than those below with no tree slide history. How are some areas adjacent to severe hazard zones rated as low hazard zones without a transition area? What site specific analysis was done in each area, such as Starr Hill?

   Answer: As noted above in the answers to Questions #3, #4, and #6, information about landslide events is important to improve the accuracy of the mapping, especially where these events may not be visible on the air photos or the LiDAR, or events that are not part of the historical record. Where such information has been provided, it is used to confirm or update the mapping, as applicable.

   Landslide hazards are generally not downgraded in a downslope direction. If there is a history of slide activity, or if it is a runout zone (i.e., a deposition zone), an area is considered to pose a severe hazard. Note that not all landslide events begin at the top of the mapped feature, nor do they necessarily extend to the bottom of the feature, which can be seen clearly in the historical air photo record and LiDAR data analysis, in both the slope movement features (Figures 1.4a to 1.4c) and the gully erosion features (Figures 1.5a to 1.5c). See also Technical Memo #2, Question #2.

   For general information on how the landslide designations are determined, Technical Memo #2 provides a good summary. In general, the landslide hazard mapping shapes follow the shapes of the types of ground that they represent, and this is true for Starr Hill also. Using the air photos and other imagery, Tetra Tech targeted the areas that specifically needed to be visited in the field. A foot traverse was done around the slopes of the Starr Hill subdivision to confirm, correct, or add to the information collected from the imagery. A greater concentration of field observations were made on slopes above residential areas.

8. **Question/Comment:** How are severe hazard zones with a 300 foot run from the ridge above a residence compare to those with 3,000 foot runs? Are these actually comparable situations?

   Answer: When comparing debris slides, the length of the mountain slope does not necessarily determine the length of the debris slide. For example, comparing the sizes of debris slides mapped above Nelson and 5th Streets to the sizes of debris slides further southeast on the main slope of Mt. Roberts, most of them are very similar. Where the debris slides do tend to be larger (or longer) on the larger slopes, they are usually associated with gullies that have steeper sideslopes, or with large open avalanche slopes (more typically on Mt. Juneau, but also south of Snowslide Creek), and usually on high-elevation terrain – see Figures 1.4a, 1.4b, and 1.4c in Tetra Tech's report. This can be important where high-elevation debris slides end up in long gullies where debris flows are active, and the size of the initiation zones reflect that.

   When comparing gullies, long gullies do not always mean that a debris flow event will extend along the entire length of the gully every time it flows – notice all the shorter arrows of different colours on Figures 1.5a, 1.5b, and 1.5c in Tetra Tech's report. However, there are some major gullies which do experience debris flows, at least some of the time over a significant proportion, if not all, of the gully length. The degree of the hazard is shown not only by the hazard designation – always *Severe* for debris flows, but also by the size of the cone/fan that receives debris from the gully – the runout or deposition zone. For example, compare the size of the cone/ fan at Bathe Creek to the size of the cone/fan below 3rd and Harris Streets, or between Kennedy and Park Streets above 5th Street. The size of the receiving area for debris at the toe of slope correlates roughly to the upslope terrain providing debris to the gullies, within or along the gullies.

In general, an area is given a hazard designation of *Severe* if:

- A cone or fan of colluvium is present at the base of a slope, no matter how old it is, because the hazard still exists (Howes and Kenk 1997); and/or
- Evidence of slope instability (exhibited on air photos as a lack of vegetation in a formerly vegetated area with an obvious downslope movement component; incident reports; and/or field observations) is identified within the same feature in more than one air photo/LiDAR year and/or field investigation year.

These criteria are met for numerous landslide features around the Starr Hill subdivision. Technical Memo #2 provides more information on how landslides are evaluated.

9. **Question/Comment:** I don't understand why my property is now in a *Low* hazard zone. My property never used to be in any zone at all, and now I don't know if my property is at risk for landslides. I would also like to know more about the geology and hazards that are present directly above my property.

   Answer: In the current adopted hazard mapping system, two hazard zone designations were specifically mapped: *Moderate* Hazard Zone (or Special Engineering Zone in some of the references) and *Severe* Hazard Zone (or *High* Hazard Zone in some of the references). Anything outside those two mapped zones was not specifically considered in the old mapping. Including the new hazard designation of *Low* for both avalanche and landslide hazards will make the mapping system consistent with numerous internationally accepted hazard mapping systems. In the case of avalanche hazards, everything not mapped as *Moderate* or *Severe* is considered *Low*. In the case of landslide hazards, everything not mapped as *Moderate*, *High*, or *Severe* is considered *Low*.

   This does not mean that the hazard has changed for properties that are now designated as being in a *Low* hazard zone. It just means that it has been given a name that recognizes that a hazard is never "zero," but the hazard is low enough that owners of properties within the *Low* hazard zone should not have to do anything extra to protect their properties from avalanches or landslides, except for being attentive, i.e., observing and recording anything unusual at or around their properties, such as ground settlement, cracking etc. See the definitions for Avalanche Hazard Designation and Landslide Hazard Designation in the glossary of the Tetra Tech report. Note that the estimated event probabilities for landslide hazard designations have been updated to a format similar to the return periods reported in the avalanche study. See also the discussions in Technical Memo #2, Question #1, and Technical Memo #4 (both in Appendix C of the main report; Tetra Tech 2022b, 2022d).

   The only caveat to this answer is that if there was a landslide (like a rockfall, rockslide, debris slide, or debris flow) that resulted in debris ending up at, beside, or very close to, your property; or a house upslope of your property was damaged due to a landslide and now that house is gone, the boundary between hazard zones might need to be adjusted. For debris that is cleaned up after a landslide happens, or for former houses that did not appear on any of the air photos, the mapping cannot always detect where landslides might have occurred. That means the mapping also needs to be supported by good historical records, including property owner reporting, if applicable and available.

10. **Question/Comment:** My house is over 90 (or 100) years old and still standing. How can I be in a *Severe* hazard zone? I don't recall anything happening to my house in the 25 (or 50) years I've lived here, and the neighbours don't remember anything either.

    Answer: See the bottom part of the answer to Question #6 above, about how an area is designated as being in a *Severe* hazard zone. Sometimes the hazard is not related to what is happening right around your house, but what is happening higher on the slope or around your neighbour's house. That is especially true for hazards related to debris flows, because where the debris will end up is not always predictable. See also Technical Memo #2, Question #8 for more information. Also, residents might not always know what happened to their lot or house before they moved there.

11. **Question/Comment:** I feel the historical timeline and perspective on how the mapped risk areas have changed is not given enough consideration. How can we get more information on how changing conditions, geology, and climate affect slope stability? Some of the changes are due to human-altered landscapes, like clearcut logging or rock cuts. Has the city reached out to geotechnical experts on rock type behavior, slope angles, vegetation, and historical and future angle of repose? Often those questions can only be answered by drilling and core analysis.

    Answer: Tetra Tech's project team of engineers and geoscientists provided expertise for this project. Tetra Tech's report provides a full description of the procedures used to evaluate the slopes, such as mapping of surficial geology and confirmation of surface materials during the fieldwork, including areas mapped as anthropogenic (human-modified) terrain. Information on changing vegetation (for example, as a result of landslides), slope angles, and surficial geology can all be obtained by means of desktop study terrain analysis (which included air photo and LiDAR data analysis), mapping, and confirmatory fieldwork. Rock types and characteristics were recorded by Tetra Tech's highly qualified and experienced engineering geologist/ geotechnical engineer where bedrock was exposed at ground surface. The evaluation of engineered rock cuts or other engineered slope mitigations like retaining walls was not in the project scope. Geotechnical drilling was also not in the project scope, nor was an evaluation of climate change. See Tetra Tech's report, as well as Technical Memos #1 and #2 for additional information on the methods of evaluation, as well as the limitations of the work. Question #1 above addresses clearcutting.

12. **Question/Comment:** Although the old Mt. Roberts trailhead at the top of 6th Street was supposedly abandoned years ago, it continues to receive regular, year-round (and likely daily) use by locals and visitors alike. This use by hikers and runners is likely destabilizing the hillside above the Nelson Street homes and worsening the landslide conditions, especially because the trail is no longer maintained, and hikers have made their own shortcuts. The current signage and availability of stair access does more to invite users than it does to discourage them. The CBJ should consider removing the stairs and placing signage that strongly discourages users by explaining that foot traffic is causing erosion, destabilizing the hillside, and threatening the homes below. Other strategies could include educational outreach to local hiking clubs and local guides, and updating local trail maps.

    Answer: Figures 9 and 17 show some typical slope sections above Nelson Street. Eliminating access to sensitive slopes that also pose a safety hazard to trail users is an important strategy used in many jurisdictions. Even after the stairs have been removed, physically blocking access with sections of fencing might also be necessary to deter ambitious hikers. Interpretive signage can also help, especially if there are other elements of value that would be preserved by deterring foot traffic.

    The trail should not be simply abandoned and ignored. Control of surface water drainage may be very important on the deactivated trail section, especially where there are switchbacks with no intermediate water management provisions along the trail. This is because trails (especially in-sloped ones) tend to concentrate surface water drainage over long sections of trail, until accumulated water from numerous small streams and swales all run downslope at the end of a switchback. Shortcutting is particularly common on trails with switchbacks and, in addition to erosion resulting from foot traffic, shortcuts can result in additional slope sections with concentrated surface water drainage. At best, concentrated water can result in soil erosion; at worst, it can result in slope failures. Therefore, when deactivating the trail, the original drainage paths across the trail should be restored. These same considerations apply to active trail sections – good control of surface water drainage will improve slope stability.

13. **Question/Comment:** The study (or at least the new regulations) should address how structures factor into landslide hazards. The new zones were drawn agnostic of human-made structures, like buildings, above us. But realistically the structures exist and will mitigate landslides. That means many, if not hundreds of homes not actually at risk of a landslide will be classified as if they were, which benefits no one.

    Answer: The premise of this comment is that upslope structures will always protect the structures downslope. However, this is not always true. Sometimes the upslope structures are simply incorporated into the debris, adding more mass to damage or destroy the downslope structures. A classic example of this kind of event is the January 2, 1920 landslide that occurred between Decker Way and Bulger Way, destroying 16 buildings from Gastineau Avenue to Front Street (now South Franklin Street). That landslide resulted in numerous buildings sliding downslope with the debris, overrunning other structures and destroying them too. See Question #14 and Technical Memos #5 and #7 (in Appendix C of the main report; Tetra Tech 2022e, 2022g)for more information about the landslide.

14. **Question/Comment:** Why are past landslides used as indicative, without accounting for the fact that some were on deforested slopes undergoing blasting and water discharge from mining?

    Answer: A detailed review of mining practices including blasting and water discharges was not within the project scope. However, terrain where the ground surface was drastically modified by human activities such as mining, cutting into slopes or placing fill, where visible on the air photos, was mapped as “anthropogenic” terrain. These modifications of geological material have been mapped along a significant length of the map area along the toe of Mt. Roberts, as seen in the cross-hatched areas shown on Figures 1.3b and 1.3c in the Tetra Tech report. The closest anthropogenic terrain to the Starr Hill subdivision is located southeast of 4th Street and northeast of Gold Street, just around the corner onto the main slope of Mt. Roberts, where a cone/fan-shaped area is the runout zone for debris from the upslope debris flow gully. Most of the modifications of this terrain appear to be related to residential development.

    It is understood that the Alaska Juneau Gold Mining Company (AJGMC) had its mill on the slope of Mt. Roberts near the southeast end of the historical downtown area. The AJGMC mill began operating in 1917, with the mine operating 24 hours per day and 363 days per year by 1930. The mine was closed in 1944.

    Drilling and blasting would have been part of the operations associated with the Alaska-Juneau mine, along with the Ebner and Perseverance workings, accessed from Last Chance Basin along Gold Creek or from the Sheep Creek Tunnel. There was also a tunnel upslope of the former office above Gastineau Avenue, with the first portal completed in 1913 near the north end of the tramway, and the second portal completed in 1916 about 500 feet further to the southeast, between the north portal and the AJGMC Mill. Blasting would not have taken place at the mill, although crushing of the ore might well have resulted in some vibrations during operations. The Starr Hill subdivision was about 0.5 miles and 0.7 miles west of the entrances of the Ebner and AJGMC adits, respectively, roughly 2.0 miles to 2.5 miles west of the top ends of all the adits at Silverbow Basin, 0.3 miles to 0.5 miles northwest of the AJGMC tunnel, and about 0.7 miles northwest of the AJGMC Mill, based on the 1914 topographic map of Juneau. No blasting-related or vibration-related slope instabilities were mentioned in any news reports so far reviewed for the landslides at Mt. Roberts specifically, nor for Juneau in general.

The AJGMC flume was reported to have overflowed at the time of the January 2, 1920 landslide. Since there was also melting snow and nearly 2 inches of heavy rain in 24 hours (Swanston 1972), the overflow of the flume might have contributed to that debris slide but was likely not the only cause. In a photo from the Gastineau Channel, at least two streams of concentrated water were running downslope, one within the landslide area and one to the north (Alaska State Library, Photo ASL-P87-1223).

Surficial geology mapping by Miller (1975) shows that another landslide occurred on October 1, 1952 at the same location as the 1920 landslide, again after nearly 2 inches of rain in 24 hours. Since the mine had closed eight years prior, water from the flume should not have been a factor in the 1952 landslide, and no mine-related complaints have been found thus far in relation to the 1952 slope failure. That landslide resulted in the closure of South Franklin Street by the old Columbia Lumber Co. kiln. The exact location of the kiln is not known, but it could have been either between Decker Way and Bulger Way, or in the vicinity of 475 South Franklin Street, and likely belonged to the new plywood plant of its subsidiary Columbia Plywood Co. Two structures were also destroyed in 1952, due to landslides at 261 Gastineau Avenue and 475 South Franklin Street, located further southeast along Mt. Roberts (Swanston 1972). Notably, a small house was built at 261 Gastineau Avenue sometime after 1920 – at the same location where two houses had been destroyed in the 1920 landslide. The 475 South Franklin Street landslide would have been located within, or very close to, the path of the major landslides that occurred on November 22, 1936.

In the November 22, 1936, landslide, a tension crack was noted at a slope failure below the flume, and this location also appears to have been the approximate initiation zone for that event, based on the appearance of the vegetation on the 1971 map of Juneau. Water from the flume was not directly implicated in that event, however. If there was a leak, it might or might not have been significant compared to the nearly 4 inches of rain that fell in 24 hours (Swanston 1972). In any case, the initiation zone for the overall debris flow feature is nearly at the top of the ridge, indicating that no leaky flume would be necessary to trigger another landslide. No reports so far reviewed have implicated flume leakage in any of the landslide areas on the slopes above Starr Hill.

Upslope of almost all this human-modified terrain, there are debris flow gullies, originating in natural terrain. Those natural debris flow gullies are the source of the material that runs out onto the cones/fans along the toe of slope. Even after the removal of all mining-related structures and activities, those upslope debris flow gullies remain as the most significant sources of landslide hazards on this slope.

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4.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

STATE OF ALASKA
49TH
M.I. Kors-Olthof
Apr. 27/22
No.CE8567
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GEOTECHNICAL

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TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Scott Ciambor (CBJ)	**Memo No.:**	4
From:	Rita Kors-Olthof, Alan Jones, Vladislav Roujanski	**File:**	704-ENG.EARC03168-02A
Subject:	Guide to Avalanche and Landslide Hazard Designations Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) has prepared an Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment for the City and Borough of Juneau (CBJ), dated May 28, 2021 (Tetra Tech 2021); and participated in three Landslide and Avalanche Hazard Public Meetings that took place on July 21, August 10, and September 20, 2021.

Tetra Tech has provided a series of technical memos to respond to comments and questions that arose from the from the report and the public meetings. All the completed memos will be appended to the Final Draft Report.

This Technical Memo #4 provides a "Guide to Avalanche and Landslide Hazard Designations." More in-depth explanations for landslides are also provided to respond to questions and concerns from the public, and in recognition of the larger number of variables and challenges in predicting behavior for landslides compared to avalanches. The primary objective of this memo is to help Juneau residents and CBJ better understand the meanings of the avalanche and landslide hazard designations. The secondary objective is to provide some additional background to help understand the limitations of those hazard designations. A quick-reference table for the contents of this memo is presented in Table 1.

Table 1: Quick-Reference Table for the Contents of the Guide

Section Number	Section Heading	Page Number
1.0	Introduction	1
2.0	Avalanche Hazard Designations and Descriptions	2-14
3.0	Landslide Hazard Designations and Descriptions	14-29
4.0	Hazard from Above or Hazard from Below	29-30
5.0	Limitations of a Hazards-Only Assessment	30
6.0	Requests for Additional Information	31-32

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2.0 AVALANCHE HAZARD DESIGNATIONS AND DESCRIPTIONS

2.1 General

This section will provide information on avalanches, including:

- The definition of an avalanche;
- Definitions of the avalanche hazard designations;
- Excerpts from the mapping to show examples of each designation;
- Photos with examples of the terrain in each of the hazard designations; and
- An explanation of the limitations of a hazards-only assessment.

2.2 What is an Avalanche?

An avalanche means a snow avalanche, unless otherwise specified, and is it usually just called an "avalanche." A snow avalanche is a volume of snow moved by gravity, that is visibly moving downslope. Snow avalanches can contain rock, broken trees, soil, ice, or other material in addition to snow (after CAA 2016).

2.3 How are Avalanche Hazards Designated?

Avalanche hazard designations are based on review of snow climate data, previous reports and studies, historic avalanche occurrence records, magnitude-frequency analyses, air photos, satellite imagery, LiDAR data, field investigation, meetings and data provided by local experts, and dynamic and statistical avalanche modelling.

The Downtown Juneau Study Area was divided into areas with *Low, Moderate,* and *Severe* avalanche hazard designations, according to the results of the analysis for each of the avalanche areas. The *Low, Moderate,* and *Severe* zones are often called White, Blue, and Red hazard zones in other jurisdictions (as they are in several of the references used for this project), and those are the colors assigned to them in the mapping shown on Figures 2.3a, 2.3b, and 2.4a through 2.4j. This system is based on a combination of magnitude (impact pressure) and frequency, with CBJ designations consistent with those used in Europe and Canada. Avalanche paths were mapped to delineate a 300-year hazard boundary for destructive flow (dense and/or powder avalanches). Table 2 shows the avalanche hazard designation system. This table is the same as Table 2.3 in the main report.

Table 2: Avalanche Hazard Designation System

Hazard Designation	Symbol	Hazard Attribute Description
Low	L	▪ Return period greater than 300 years; OR ▪ Impact pressures less than 20 lbs/ft^2 (1 kPa) with a return period greater than 30 years.
Moderate	M	▪ Return period between 30 and 300 years; AND ▪ Impact pressure less than 600 lbs/ft^2 (30 kPa).
Severe	S	▪ Return period less than 30 years; AND/OR ▪ Impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa).

There are some important differences between the new hazard designation mapping and the adopted 1987 hazard designation mapping:

- The 1987 mapping and the current mapping have slightly different boundaries due to different project areas. These differences resulted in some areas being flagged as concerns, when the differences were in fact due to new areas being mapped that had not been mapped before (additional Study Area northwest and southeast, and to reach the top-of-slope or ridge crest), or areas being omitted in the new mapping because they were beyond the top-of-slope boundary line of the new Study Area. Different modelling methods also led to differences in estimated runouts, which were particularly prominent where they extended into Gastineau Channel.

- The 1987 mapping combined avalanche and landslide hazard designations into one map. As it turns out, avalanche hazard designations and landslide hazard designations tend to be very different, and they should not be grouped together into the same maps. The new maps show landslide and avalanche hazard designations on different maps, so that they can be managed independent of each other.

- The 1987 mapping follows property lines, resulting in numerous right-angle corners in the hazard boundaries. Avalanches do *not* respect property lines, instead running right over them, and forming boundaries that relate only to the conditions that create avalanches, such as slope gradients, topography, snow conditions, wind, winter storms, rain-on-snow events, and rapid spring melt conditions, among other factors. The new avalanche hazard mapping does not follow property boundaries, but rather reflects observed and modelled avalanche behavior combined with historical observations.

- Structures located in avalanche paths do not provide protection, and thus the avalanche hazard lines are “agnostic” to the structures.

- Due to these limitations, arbitrary hazard boundaries that follow property lines should be removed as not reflecting the true threat to the public safety, i.e., hazard designations based on property lines do **not** adequately describe the hazards.

The level of assessment prepared for this project is suitable for determining whether land areas could be affected by avalanches. A more detailed site-specific investigation and evaluation would be required to determine appropriate mitigations for specific properties.

2.4 Avalanche Hazard Designation - *Low*

An avalanche hazard designation of *Low* is used for avalanches that have a return period of more than 300 years, OR avalanches with impact pressures of less than 20 lbs/ft^2 (1 kPa) with a return period of more than 30 years. Allowing a low impact pressure means that non-destructive powder avalanches can enter *Low* hazard areas, which is common in Juneau (e.g., Snowslide Creek path on Thane Road) and should be considered acceptable. For reference, 20 lb/ft^2 or 1 kPa could be capable of breaking windows or snapping tree branches but, for the most part, is not considered harmful to people or structures, which is why it is used as part of the *Low* hazard designation.

An estimate of the return period of 300 years or 30 years for an avalanche is the same as calling it a 1 in 300-year event or a 1 in 30-year event. Note that the return period of an avalanche does *not* mean that an event of a specified size or severity will return *every* X number of years. It just means that, on average, one could expect an avalanche of about that size or severity about that often, but the actual return period could be shorter or longer. For a 30-year return period, for example, the typical range in the return period is 20 years to 50 years, as shown in Table 2.1 in the main report. However, if one observes consistently longer or shorter return intervals than the average, the avalanche experts might eventually decide to assign a different return period to that size of avalanche. A change in return period could occur due to a number of reasons, including climate change, changes in forest cover, or terrain modification by natural (e.g., landslides) or human-induced (e.g., mining) causes.

On the avalanche hazard designation mapping, a *Low* avalanche hazard zone is considered to be the same as the White zone, which means there is no extra color added to the map. The *Low* avalanche hazard zones are located anywhere that is not colored blue or red on the accompanying avalanche hazard maps.

Residents who suddenly find their property assigned a *Low* hazard designation, after never being in a named zone before, might wonder what that means. Including a *Low* hazard designation makes the mapping system consistent with numerous internationally-accepted hazard mapping systems. This does not mean that the hazard has changed for properties that are now designated as being in a *Low* hazard zone. It just means that it has been given a name that recognizes that a hazard is never “zero,” but the hazard is low enough that owners of properties within the *Low* hazard zone generally should not have to do anything extra to protect their properties from avalanches, except for being attentive, i.e., observing and recording anything unusual at or around their properties, such as avalanche debris coming closer to the house than usual etc. The caveat to that logic could be if something changes around your property, like a structure being removed, or if the debris from an avalanche wasn’t recorded before it was removed, making it difficult to detect where it occurred. See Question #9 on Tech Memo #3 for more information.

One example of terrain with an avalanche hazard designation of *Low* is most of the Starr Hill subdivision, as shown in Figure 1. Figure 2 shows a view of Starr Hill from the helicopter.

Figure 1: Excerpt from Figures 2.4c and 2.4h in the main report, showing the northeast end of the Starr Hill subdivision. Almost all of the lots are mapped with an avalanche hazard designation of *Low (i.e., not colored as red or blue)*, with the only encroachment being the G000 (Park) avalanche path on the right (marked *Severe*, with *Moderate* terrain below). All the existing houses are currently located in areas designated as *Low*.

Figure 2: Looking southeast at the Starr Hill subdivision. Nelson Street is near the top left of the photo, East Street is near the photo center, Gold St. is near the photo right edge. 6th Street is in the foreground left, and the next road to the southeast is 5th Street.

2.5 Avalanche Hazard Designation - *Moderate*

An avalanche hazard designation of *Moderate* is used for areas that have a return period between 30 and 300 years AND have an impact pressure of less than 600 lbs/ft^2 (30 kPa). To compare, Table 2.2 in the main report describes some typical avalanche sizes, and what an avalanche of a specified size might be expected to do.

For example, a Size D2 avalanche that could produce a typical impact pressure on the order of 200 lbs/ft^2 (10 kPa) could bury, injure, or kill a person (e.g., a person outside of a house in their back yard). On the other hand, a Size D3 avalanche [typical impact pressure on the order of 2,000 lbs/ft^2 (100 kPa)] could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees. An impact pressure of 600 lbs/ft^2 is typically used as a threshold between the *Severe* and *Moderate* hazard designations because it is close to the threshold that destructive avalanches (i.e., Size D3 or larger) typically can destroy wood-frame structures and thus kill people within them, whereas below this threshold they typically just damage rather than destroy the structures (and thus are less likely to kill the occupants). It's important to point out that avalanches with impact pressures less than 600 lbs/ft^2 (30 kPa) can still cause considerable damage to residences and kill people, but would be expected to do so less frequently (or, alternatively, less severely) than in areas designated as red (*Severe*) hazard zones. Table 3 provides a summary of impact pressures associated with various types or extent of damage.

Table 3: Impact Pressures Associated with Damage (modified from CAA 2018)

Potential Damage	Impact Pressure	
	lbs/ft^2	kPa
Break windows	21	1
Push in doors, damage walls, roofs	62-125	3-6
Severely damage wood frame	209	10
Destroy wood frame structures, break trees	418-626	20-30
Destroy mature forests	1,044-2,090	50-100
Uproot mature spruce	2,090	100
Move large boulders	6,262	300
Move reinforced concrete structures	20,900	1,000

Avalanche areas mapped with a hazard designation of *Moderate* are shown in blue on the mapping. Typically, the *Moderate* zone on the larger mountain slopes forms a fringe downslope and alongside the main avalanche paths (mapped in red) that is less likely to experience an avalanche, and if an avalanche does reach *Moderate* terrain, the impact pressures are expected to be lower, and are impacted less frequently. Figure 3 is an example of this type of avalanche terrain adjacent to the southern section of Gastineau Avenue and upslope of South Franklin Street.

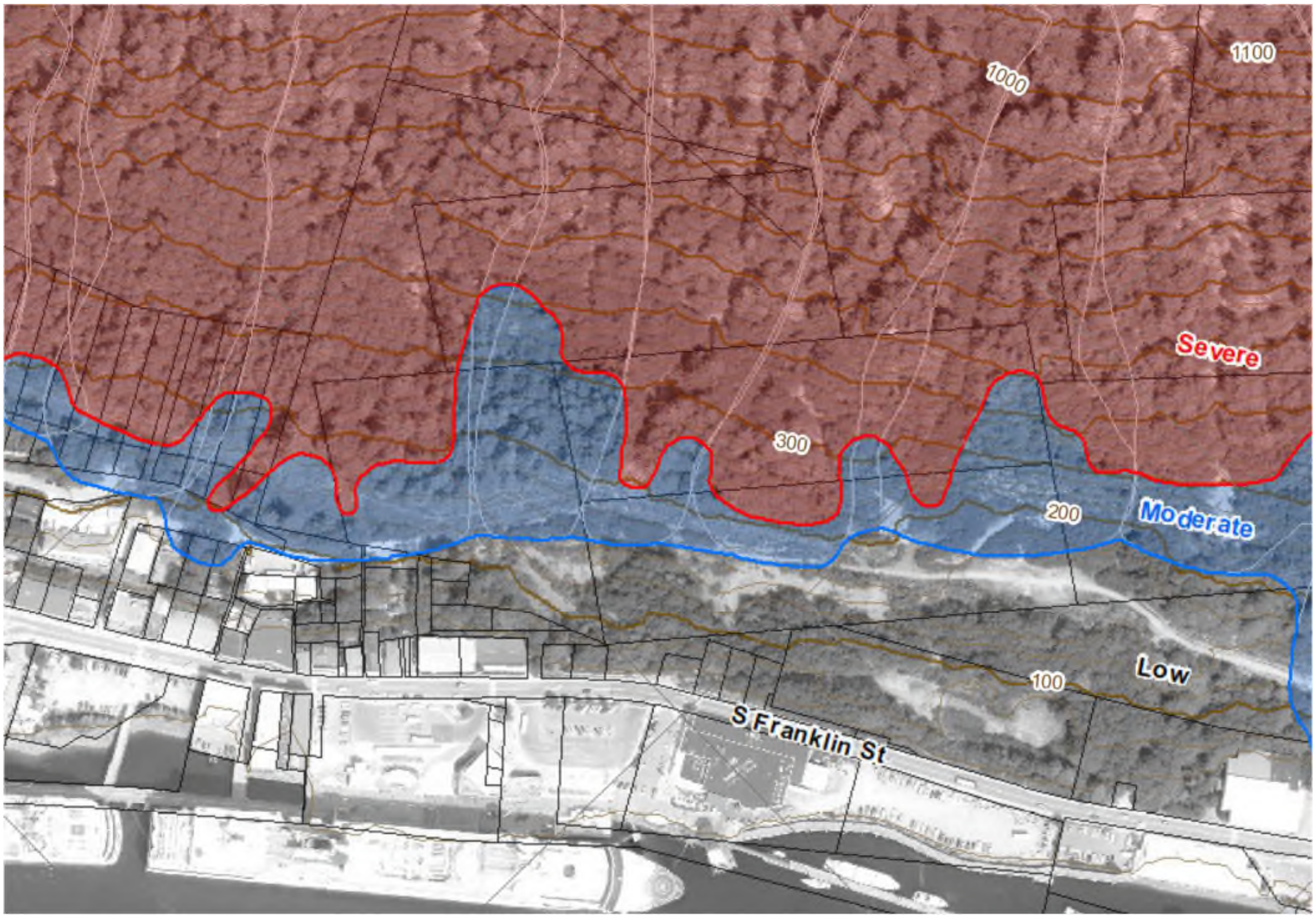

Figure 3: Excerpt from Figure 2.4d in the main report, showing avalanche paths G003 to G009 and T000 (from left to right). The blue fringe shows terrain designated as having *Moderate* avalanche hazard along the toe of Mt. Roberts. In this area, the *Moderate* hazard does not reach South Franklin Street, but it does reach Gastineau Avenue in several locations. Further southeast (off the right-hand side of this map excerpt), the slopes of Mt. Roberts become higher and are affected by unforested alpine terrain, and the Moderate avalanche terrain reaches further downslope, past Thane Road, and sometimes into Gastineau Channel.

Figure 4a below shows the slope from the helicopter, which is vegetated with a relatively dense forest cover in this area. Avalanche hazards are present within the gullied parts of the slopes, and have historically affected areas close to Gastineau Avenue. Figure 4b provides a view from Google Earth that shows distinct avalanche paths and start zones within the gullies that are easily seen on the winter imagery, which highlights the differences in coniferous versus deciduous forests.

Figure 4a: View of Mt. Roberts from the helicopter showing part of the slope mapped in Figure 3. Note the increasing height of slope from left to right (northwest to southeast). The slope is fairly well-treed but is still prone to avalanching. Gullies tend to increase avalanche runouts. See also Figure 4b.

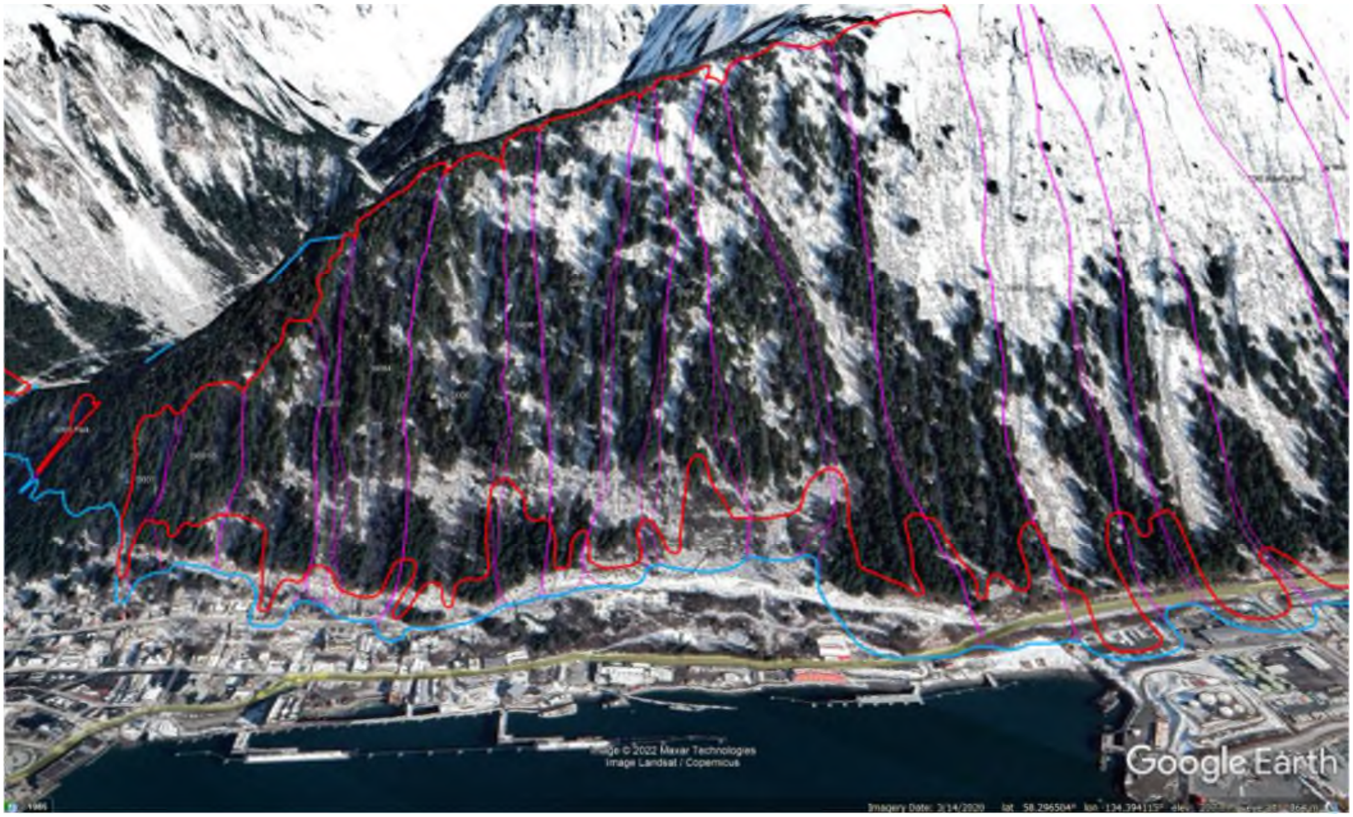

Figure 4b: View of the northern part of Mount Roberts along Gastineau Avenue and South Franklin Street, with avalanche paths and *Moderate*/*Severe* hazard boundaries shown. Note the increasing height (and length) of slope from left to right (northwest to southeast), which increases the runout distance and hazard to lower elevation areas towards the industrial park. Although the Gastineau Avenue area is forested, distinct avalanche paths and start zones within the gullies can be observed on the winter imagery, which highlights the forest cover differences (coniferous versus deciduous forests). (Image credit: Google Earth 2022.)

2.6 Avalanche Hazard Designation - *Severe*

An avalanche hazard designation of *Severe* is used for avalanches that have a return period of less than 30 years AND/OR have an impact pressure greater than or equal to 600 lbs/ft^2 (30 kPa). Severe hazard areas could include areas that are affected by frequent, but lower impact pressure avalanche hazards, for example, an area that is affected on average every 5 to 10 years by avalanches with 200 lb/ft^2 to 400 lb/ft^2 (10 kPa to 20 kPa) impact pressures that could damage, but not destroy a wood-frame structure – this would be the case for some residential areas within the White Subdivision. Or it could include areas that, on average, are not affected by avalanches more frequently than at 30-year intervals but, should they be affected, would be impacted by large destructive avalanches with impact pressures well in excess of 600 lbs/ft^2 (30 kPa). This scenario applies to areas within the Behrends Subdivision. Although some parts of the subdivision have not been impacted since the large avalanche event of 1962 (e.g., some residences on Behrends Avenue), should a similar event occur within a 30- to 300-year return period, it would be expected to be large with impact pressures greatly exceeding 600 lbs/ft^2 (30 kPa). Areas that are affected by avalanches that are both frequent and destructive (i.e., less than a 30-year return period and with more than 600 lb/ft^2 of impact pressure) are clearly within the *Severe* hazard designation.

Avalanche areas mapped with a hazard designation of *Severe* are shown in red on the mapping. Typically, the *Severe* zone on the larger mountain slopes incorporates the main avalanche paths (mapped in red) that are the most likely to experience an avalanche (i.e., higher frequency), and experience the highest impact pressures. In many cases within the Juneau area, this occurs within distinct gullies. Figure 5 is an example of this type of avalanche terrain in the Behrends avalanche path and subdivision. Figure 6 shows the slope from the helicopter. Figure 7 shows the lower part of the slope after a very large avalanche in 1985.

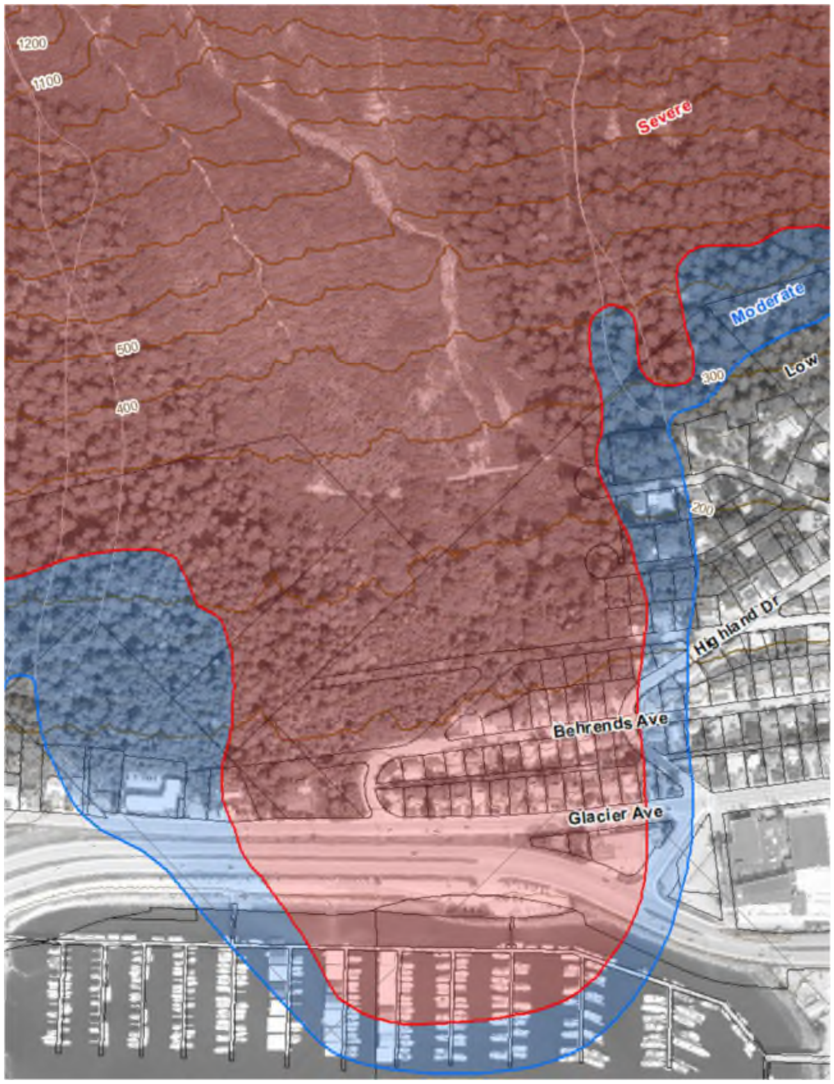

Figure 5: Excerpt from Figure 2.4b showing the major avalanche path at J010 Behrends. Note the distinct trimlines that define the edges of this path, indicating regular avalanche activity within the central part of the path and less frequent avalanche activity on the outside (lateral boundaries) of the path.

Figure 6: Looking north-northeast at the lower end of the J010 Behrends Avenue avalanche path. Note the differences in vegetation within the path, beside the path, and below it, mostly due to regular and destructive avalanche activity. The large building in the lower right corner of the photo is the high school at the corner of Glacier Avenue and Highlands Drive. The school is located just outside of the *Moderate* hazard zone. Most of the other areas (with the exception of the densely forested upper right part of the photo) are within either *Severe* or *Moderate* hazard zones.

Figure 7: The aftermath of 1985 avalanche, looking north from just south of Behrends Avenue and Highland Drive. This event was the longest running avalanche in the Behrends Subdivision since the destructive 1962 event. The photo clearly shows the destructive potential of this avalanche and the way it came right into the community and was close to damaging/destroying many structures. However, it only damaged one house on Troy Avenue, the one on the right. (Photo credit: Dan Bishop 1985.)

Figure 8 shows another avalanche event that occurred in 2012 further to the east of the Behrends Subdivision, at the Bathe Creek avalanche path.

Figure 8: This photo illustrates a Size D3 avalanche within a *Severe* (red) hazard zone. The avalanche occurred in 2012 in the Bathe Creek avalanche path. This highlights a hazard area that is both frequent (more frequent than a 30-year return period) and destructive, with an impact pressure greater than 600 lbs/ft2 (30 kPa), capable of both burying/destroying a car and destroying a wood frame residence. (Photo credit: Mike Janes (AELP).)

3.0 LANDSLIDE HAZARD DESIGNATIONS AND DESCRIPTIONS

3.1 General

This section will provide:

- Definitions of the landslide hazard designations;
- Excerpts from the mapping to show examples of each designation;
- Photos with examples of the terrain in each of the hazard designations;
- Information on the difference in potential hazards from landslides above or below a property; and

- An explanation of the limitations of a hazards-only assessment.

3.2 What is a Landslide?

A landslide is a gravity-induced mass movement of upslope materials, including rockfall, rockslide, debris slide, debris flow, and creep. In general, landslide types include falls, topples, slides, spreads, flows, and slope deformations. Landslides can also contain broken trees, structures (whole or crushed), vehicles, or other materials, as well as water, in addition to soil and rock debris.

3.3 How are Landslide Hazards Designated?

Landslide hazard designations are determined based on collecting and reviewing previous mapping and reporting; historic landslide occurrence records including newspaper reports; air photos, satellite imagery, LiDAR data; mapping of surficial geology, historical slope movement activity, historical gully erosion activity; and fieldwork to confirm or correct the mapping.

The Downtown Juneau Study Area has been divided into areas with *Low, Moderate, High*, and *Severe* landslide hazard designations, according to the results of the historical air photo record analysis, mapping and the field investigation, as well as a semi-quantitative analysis to help sort out which terrain types belong to which landslide hazard designation. Areas mapped with *Low, Moderate, High*, and *Severe* landslide hazard designations are shown with green, yellow, orange, and red colours, respectively, in the mapping on Figures 1.6a through 1.6j, as well as Figure B.6 in Appendix B in the main report, and in the mapping excerpts shown in this memo. Table 4 provides a description of each hazard designation. Sections 3.4, 3.5, 3.6, and 3.7 provide some examples of the mapping for each hazard designation, and photos of the areas shown in the map excerpts. Table 4 in this memo is the same as Table 1.4 in the main report. This table includes some additional explanations of the typical sizes and event probabilities that would be anticipated for each of the landslide hazard designations. These same explanations are provided in the following sections for each level of hazard. These explanations are *not* based on a magnitude-frequency analysis for the slopes, because this type of analysis has not been completed for Juneau yet, as discussed in Section 5.0 of this Memo. Instead of a magnitude-frequency analysis, proxies based on slope activity identified on air photos were used to help determine the appropriate divisions between the different landslide hazard designations. The only landslide information considered reasonably reliable or predictable in attempting to determine typical return periods for each of the designations is the historical landslide information that has been reviewed, as listed at the beginning of this section. When results of a magnitude/frequency analysis are available, the return periods should be reviewed and adjusted as needed to more reliably reflect the frequency of landslides of particular sizes.

Note that sometimes the hazard is not related to what is happening right around your house, but what is happening higher on the slope or around your neighbour’s house. That is especially true for hazards related to debris flows, because where the debris will end up is not always predictable. See also Technical Memo #2, Question #8 (Appendix C of the main report; Tetra Tech 2022b) for more information. Also, residents might not always know what happened to their lot or house before they moved there.

Table 4: Refined Landslide Hazard Designation System

Hazard Designation[1]	Symbol	Hazard Attribute Description
Low	L	▪ Gentle to moderate slopes (0° to 26°) ▪ No signs of historical landslide activity on the air photos ▪ No written record of property damage or loss of life ▪ Surficial geology and texture for Classes I, II, and III as shown in Table 1.2 in the main report ▪ Estimated event probability is "Unlikely to Very Unlikely," with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future[2]
Moderate	M	▪ Moderate to Moderately steep slopes (27° to 35°) ▪ May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on the air photos) ▪ Can include low-lying areas within the runout zones of slides from nearby slopes ▪ No apparent written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 in the main report ▪ Estimated event probability is "Possible," with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events. Therefore, landslide events could happen in the future[2]
High	H	▪ Steep slopes (>35°) ▪ Areas where rockfall activity impacts individual trees but does not knock them over or destroy them[3] ▪ May have written record of property damage or loss of life ▪ Surficial geology and texture for Class IV as shown in Table 1.2 in the main report ▪ At least two of the following criteria are met: – Thin layer of colluvium (Cv) present – A maximum polygon slope of 70° to 80° – A mean polygon slope of 40° to 50° ▪ Estimated event probability is "Likely," with a return period of 5 to 30 years. This is the return period estimated for Class IV terrain where slopes are known to be susceptible to landslides, and where there are signs of recent and/or historical landslide events. Therefore, landslide events are likely to keep happening in the future[2]
Severe	S	▪ Steep to vertical slopes (>35°) ▪ Signs of recent activity either in aerial photographs or from field inspection (rockfall tracks, debris slide activity, debris flow paths etc.) ▪ May have written record of property damage or loss of life ▪ Signs of repeated historical activity ▪ Surficial geology and texture for Class V as shown in Table 1.2 in the main report ▪ Estimated event probability is "Very Likely to Almost Certain," with a return period of 1 to 20 years. This is the return period estimated for Class V terrain, where the slopes are highly susceptible to landslides, and where there are signs of recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are very likely to almost certain to keep happening in the future[2]

Notes:

1. Landslide hazard designations (*Low*/*Moderate*/*High*/*Severe*) correspond to green/yellow/orange/red on Figures 1.6a through 1.6j of the main report, and Figure B.6 in Appendix B of the main report.
2. Estimated event probability based on observed and recorded slope movement activity level. Note that this is not an indication of consequence (potential for damage), nor is it a magnitude/frequency study, which can determine return periods with more accuracy.
3. This type of rockfall can be highly active but has a small enough impact not to be readily visible on the air photos or satellite imagery.

Although the landslide hazard designations as shown in Table 4 do include a numerical figure to distinguish the estimated event probabilities of each of the landslide hazard designations, these very high-level approximations are based *only* on the observed slope movement activity levels from air photo analysis and observations made by Tetra Tech's geotechnical engineer in the field. In view of the information that is currently available, even more important are the other hazard attributes that help to better identify the types of terrain described by each hazard designation. For example, *Severe* hazard designations are assigned to the areas subject to rockfall, debris slides, and debris flows, as shown on the surficial geology maps. Areas with a *High* hazard rating were assigned based on the results of the semi-quantitative analysis. These areas are expected to experience rockfall that damages but does not always knock out trees, and as such are a less severe hazard than a debris flow or debris slide that removes everything in its path. Evidence of this type of rockfall activity was identified during the field investigation. See Sections 3.6 and 3.7 for more information about *High* and *Severe* hazard designations.

It should also be noted that the frequency or return period of an event (or the mapping proxy of visual evidence of repeated slide activity) does *not* mean that an event of a specified size or severity will return every X number of years. For example, a debris flow of a certain size typically depends on two events coinciding: a storm event large enough to mobilize debris in a gully, and enough debris accumulated in the gully from previous events to mobilize the debris. So, when a return period of 30 years is estimated for a rainstorm or a landslide, that means that a rainstorm or a landslide could happen at any time in a 30-year period, *not* that it will always happen every 30 years like clockwork. It could happen this year, and it could happen again next year. But if that rainstorm or landslide starts happening consistently more often (or less often) than predicted, so that the average is no longer 30 years, it might be time to reassess the return period for those events.

There are some important differences between the new hazard designation mapping and the adopted 1987 hazard designation mapping (CBJ 2021):

- The 1987 mapping and the current mapping have slightly different boundaries due to different project areas. These differences resulted in some areas being flagged as concerns, when the differences were in fact due to new areas being mapped that had not been mapped before (additional Study Area northwest and southeast, and to reach top-of-slope), or areas being omitted in the new mapping because they were beyond the top-of-slope boundary line of the new Study Area. Some areas were also inadvertently flagged as concerns, due to confusion resulting from the colour scheme used in the comparison, with the salmon pink being mistaken for red.
- The 1987 mapping combined avalanche and landslide hazard designations into one map. As it turns out, avalanche hazard designations and landslide hazard designations tend to be very different, and they should not be lumped together. The new maps show landslide and avalanche hazard designations on different maps, so that they can be managed independent of each other.
- The 1987 mapping follows property lines, resulting in numerous right-angle corners in the hazard boundaries. Landslides do *not* respect property lines, instead running right over them, and forming boundaries that relate only to the conditions that create landslides, such as slope gradients, topography, surficial geology, large storms (usually with record precipitation), rapid spring melt conditions, among other factors. The new landslide hazard designation mapping does not follow property boundaries, but rather reflects historical observations of landslide behaviour.
- *Due to these limitations, arbitrary hazard boundaries along property lines should be removed as not reflecting the true threat to the public safety, i.e., hazard designations based on property lines do* ***not*** *adequately describe the hazards*.

The level of assessment prepared for this project is suitable for determining whether land areas could be affected by landslides. A more detailed site-specific investigation and evaluation would be required to determine appropriate mitigations for specific properties.

3.4 Landslide Hazard Designation - *Low*

A landslide hazard designation of *Low* is assigned to terrain that has the following characteristics:

- Gentle to moderate slopes (0° to 26°);
- No signs of historical landslide activity on the air photos;
- No written record of property damage or loss of life;
- Surficial geology and texture for Classes I, II, and III as shown in Table 1.2 of the main report; and
- Estimated event probability is “Unlikely to Very Unlikely,” with a return period of more than 100 years. Class I, II, and III terrain is generally not prone to active slope processes, and no landslide events were observed or reported, so it is unlikely that landslide events would happen in the future.

Residents whose property is assigned a *Low* hazard designation, after never being in a named zone before, might wonder what that means. Including a *Low* hazard designation makes the mapping system consistent with numerous internationally accepted hazard mapping systems. This does not mean that the hazard has changed for properties that are now designated as being in a *Low* hazard zone. It just means that it has been given a name that recognizes that a hazard is never “zero,” but the hazard is low enough that owners of properties within the *Low* hazard zone generally should not have to do anything extra to protect their properties from landslides, except for being attentive, i.e., observing and recording anything unusual at or around their properties, such as ground settlement, cracking etc. The caveat to that logic could be if something changes around the property, like a structure being removed, or if the debris from a landslide was not recorded before it was cleaned up, making it difficult to detect where it occurred. Ideally, the mapping would be supported by good historical records, including property owner reporting, if applicable and available. See Question #9 on Tech Memo #3 for more information.

Figure 9 shows the surficial geology and the landslide hazard mapping for two areas of Downtown Juneau that are designated as having a *Low* landslide hazard. Figure 10 shows a photo for each of those areas.

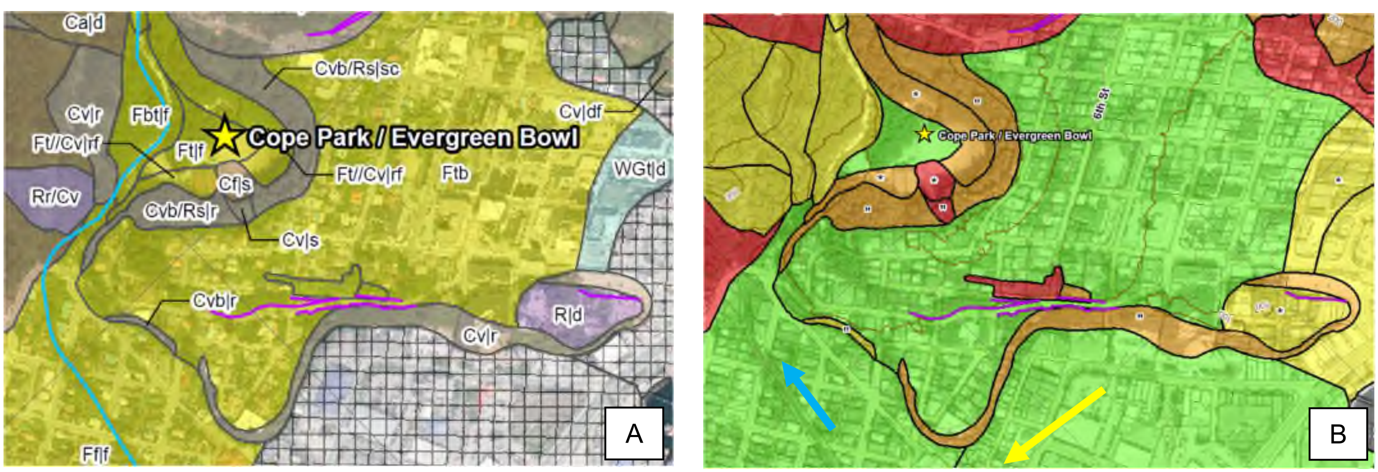

Figure 9: These two map excerpts are from the mapping across the approximate middle of the downtown area. Figure 79A shows the surficial geology, and Figure 9B shows the landslide hazard mapping. Gold Creek is marked as a blue stream along the left side of Figure 9A. Willoughby Avenue is in the cross-hatched area on Figure 9A, where fill was placed to extend the land area of the city. The yellow arrow on Figure 9B shows the direction of look in Figure 10A. The blue arrow on Figure 9B shows the direction of look in Figure 10B.

Figure 10: Views of Juneau in terrain mapped with landslide hazard designation of *Low*. Figure 10A: Looking west from Telephone Hill at the east-west leg of Willowby Avenue. Figure 10B: Looking upstream at the Gold Creek flume, with terrain mapped in *Low* on both sides of the creek. (Photo credits: Figure 10A: Alaska State Library – Historical Collections, ASL-P417-040, Caroline Jensen 1948. ASL 2022a. Figure 10B: CBJ December 4, 2020.)

3.5 Landslide Hazard Designation - *Moderate*

A landslide hazard designation of *Moderate* is assigned to terrain that has the following characteristics:

- Moderate to Moderately steep slopes (27° to 35°);
- May be signs of historical activity (scars on trees, vegetated debris lobes or scarps, historical activity visible on the air photos);
- Can include low-lying areas within the runout zones of slides from nearby slopes;
- No apparent written record of property damage or loss of life;
- Surficial geology and texture for Class IV as shown in Table 1.2 of the main report; and
- Estimated event probability is “Possible,” with a return period of 10 to 100 years. This is the return period estimated for Class IV terrain where slopes are susceptible to landslides, and where there might already be signs of landslide events or deposits from slides upslope. Therefore, landslide events could happen in the future.

Two sets of examples are provided for terrain designated with a *Moderate* landslide hazard: downslope of the Behrends Subdivision (Figures 11 and 13A), and downslope of South Franklin Street (Figures 12 and 13B).

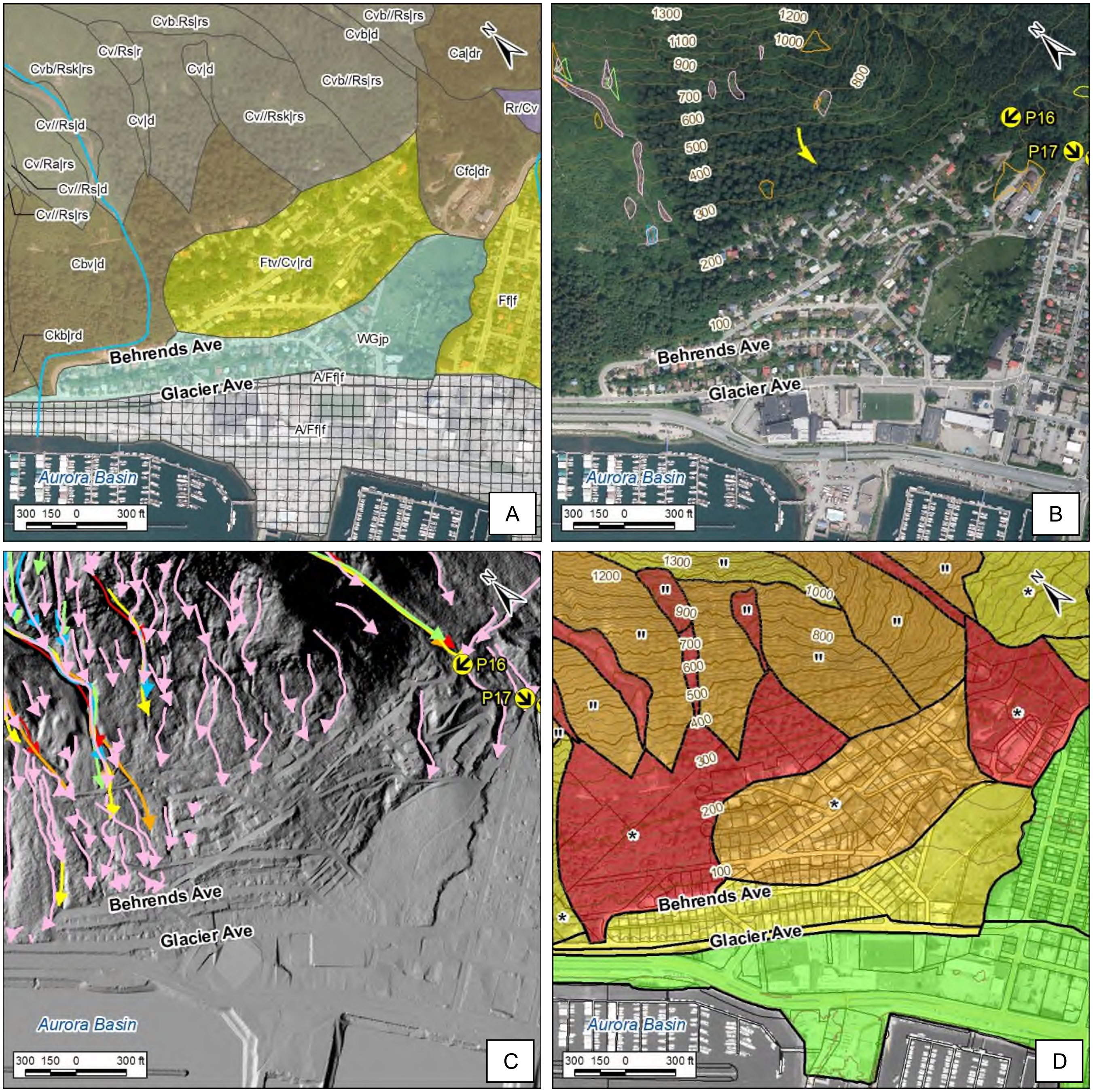

Figure 11: These mapping excerpts show *Moderate* hazard terrain from part of the Juneau Study Area. Figures 11A through 11D. The terrain mapped as glaciomarine (WG) in Figure 11A reveals no slope movement features in Figure 11B, and no gully erosion features in Figure 11C. That results in a landslide hazard designation of *Moderate*, as shown on Figure 11D. See also Figure 13 for examples of *Moderate* terrain. Events that affect mainly roads (e.g., Figure 13A) tend to be cleaned up promptly and are generally not seen on the air photos.

As shown on Figure 11D, Glacier Avenue at Ross Way is just below the *Severe* landslide designation zone at the Behrends Subdivision, at the northwest end of Behrends Avenue (left side of figure). That means Glacier Avenue could receive some smaller water-borne debris and muddy water that runs down the road, but it should not experience the more serious impacts generally seen further upslope. However, because some effects are still possible, such as erosion (red arrow on Figure 13A), the landslide hazard designation here cannot be considered *Low*. As shown on Figure 11B, no other historical slope movement features were observed on the imagery, and on Figure 11C, the gullies appear not to extend across Behrends Avenue or Glacier Avenue, although the debris may flow onto them. Therefore, a landslide hazard designation of *Moderate* is considered appropriate.

Similar conditions apply downslope of South Franklin Street. The runouts of the several landslides on this slope are represented by surficial geology shown in Figure 12A and the *Severe* landslide hazard designations shown in Figure 12B.

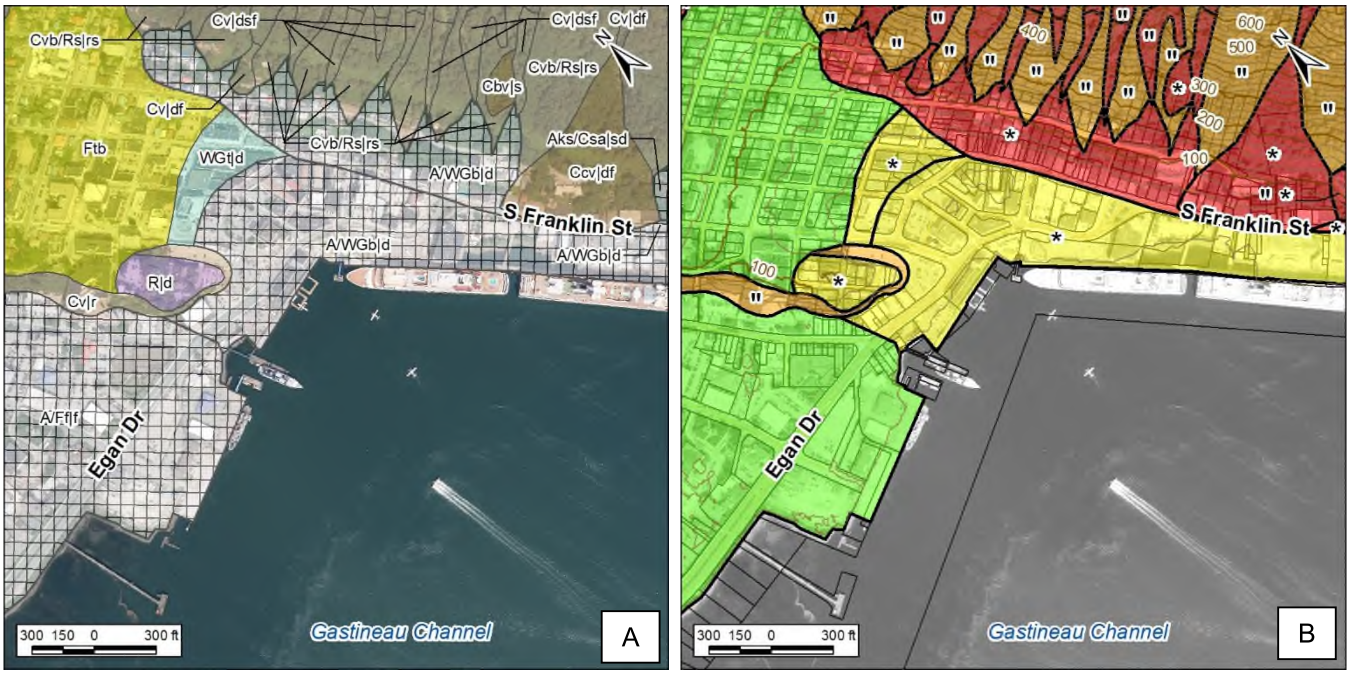

Figure 12: These mapping excerpts show *Moderate* hazard terrain from another part of the Downtown Juneau Study Area. Figures 12A and 12B are from the Downtown Historic District, the east leg of Tidelands, and the top of Telephone Hill. At center-left of Figure 12A, there is glaciomarine terrain (WG), and a rock outcrop (R) at Telephone Hill. Southeast of these two upslope areas, the terrain has been extensively human-modified (A). In this case, new ground was made from fill to create more space for the townsite development. These three areas together (except for the steep colluvial sideslopes of Telephone Hill) result in a *Moderate* hazard designation along the shoreline. In this case, a large landslide originating from the *Severe* terrain upslope of South Franklin Street (including the apparently mining-related events of 1920 and 1936) could have the potential to affect the *Moderate* terrain, but no obvious signs remain below South Franklin Street.

No mass movement events appear to have crossed South Franklin Street recently, and it is possible that the drainage and retaining structures erected along Gastineau Avenue could mitigate the extent of future landslides, at least at the 1920 landslide location. Nevertheless, the lower edge of the *Severe* terrain has been adjusted to be located downslope of South Franklin Street to account for the possibility of debris having been cleaned up and not seen on the imagery (Figure 12B). See Technical Memos #3, #6, and #7 (Appendix C in the main report; Tetra Tech 2022c, 2022f, 2022g) for more information about the slopes on Mt. Roberts.

Figure 13: These photos are of *Moderate* terrain. Figure 13A is looking southeast along Glacier Avenue on December 4, 2020, where Ross Way enters. Ross Way carried debris and water from Behrends Avenue to Glacier Avenue. Debris can also run southeast on Behrends Avenue. Note the apparently eroded and failed section of the sidewalk (at red arrow) where a section of concrete slab was missing. Figure 13B is looking downslope towards South Franklin Street (formerly Front Street) on January 2, 1920, after a major landslide from upslope of Gastineau Avenue. The red circle shows possible landslide debris across the street. (Photo credits: Figure 13A: CBJ December 4, 2020. Figure 13B: Alaska State Library – Historical Collections, ASL-P109-42, Katherine Shaw 1920. ASL 2022b.)

On South Franklin Street (formerly Front Street), debris has sometimes crossed the road, for example, during the November 22, 1936 major landslide when debris reached the Juneau Cold Storage building, or as seems to have happened during the January 2, 1920 landslide, based on the photo in Figure 3B. However, these appear to be relatively rare events and, in the case of the 1920 landslide, seem to have been aggravated by a leaky flume from the Alaska Juneau Gold Mining Company (AJGMC) and, in 1936, was possibly aggravated by an oversteepened fill/spoil slope, also mining-related. The October 1, 1952 landslide resulted in debris blocking South Franklin Street.

Another major landslide on November 7, 1900 caused damage to a flume and the Juneau Iron Works building on the upslope side of South Franklin Street (Front Street), immediately southeast of where a later landslide on October 16, 1936 damaged the back of the Alaskan Hotel and destroyed several houses, and about 350 feet southeast of a landslide on September 25, 1918 that damaged the back of the Gastineau Hotel (now the New Cain Hotel) and destroyed several other buildings (Bayers 2022; Sanborn 1904, 1914; Swanston 1972; The Alaska Daily Empire 1918a).

Bayers also reported a “land & mud slide in the usual place back of the Manhattan Hotel, McMillan Bros. Grocery and Solomon the Tailor on S. Franklin St.” on November 7, 1918 (Bayers 2022; The Alaska Daily Empire 1918b, 1918c; Sanborn 1914). Those structures appear to have been located about where the Nor’Westerly, Frontier Gifts, and Tanzanite International are currently located, upslope of South Franklin Street.

3.6 Landslide Hazard Designation - *High*

A landslide hazard designation of *High* is assigned to terrain that has the following characteristics:

- Steep slopes (>35°);
- Areas where rockfall activity impacts individual trees but does not knock them over or destroy them, resulting in an impact small enough not to be easily noticed on the air photos or satellite imagery;

- May have written record of property damage or loss of life;
- Surficial geology and texture for Class IV as shown in Table 1.2 of the main report;
- At least two of the following criteria are met:
  - Thin layer of colluvium (Cv) present;
  - A maximum polygon slope of 70° to 80°; and
  - A mean polygon slope of 40° to 50°.
- Estimated event probability is "Likely," with a return period of 5 to 30 years. This is the return period estimated for Class IV terrain where slopes are known to be susceptible to landslides, and where there are also signs of recent and/or historical landslide events. Therefore, landslide events are likely to keep happening in the future.

Two example areas are provided for terrain designated with a *High* landslide hazard in the vicinity of Evergreen Avenue and around the slopes of Cope Park (Figures 14, 15, and 16).

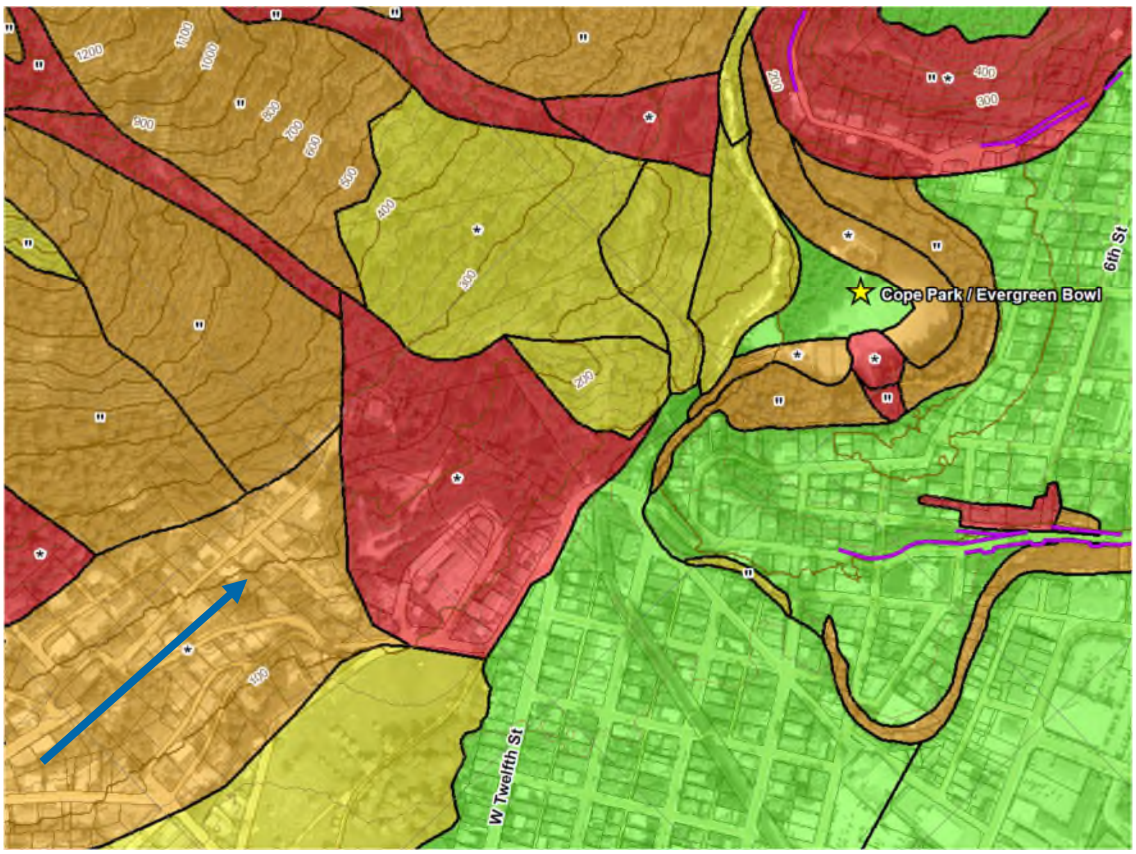

Figure 14: Excerpt from the landslide hazard mapping. Blue arrow on Figure 14 is direction of look on Figure 15, and back end of arrow is lower edge of photo in Figure 15. (See also Figures 9 and 11 for connecting map areas.)

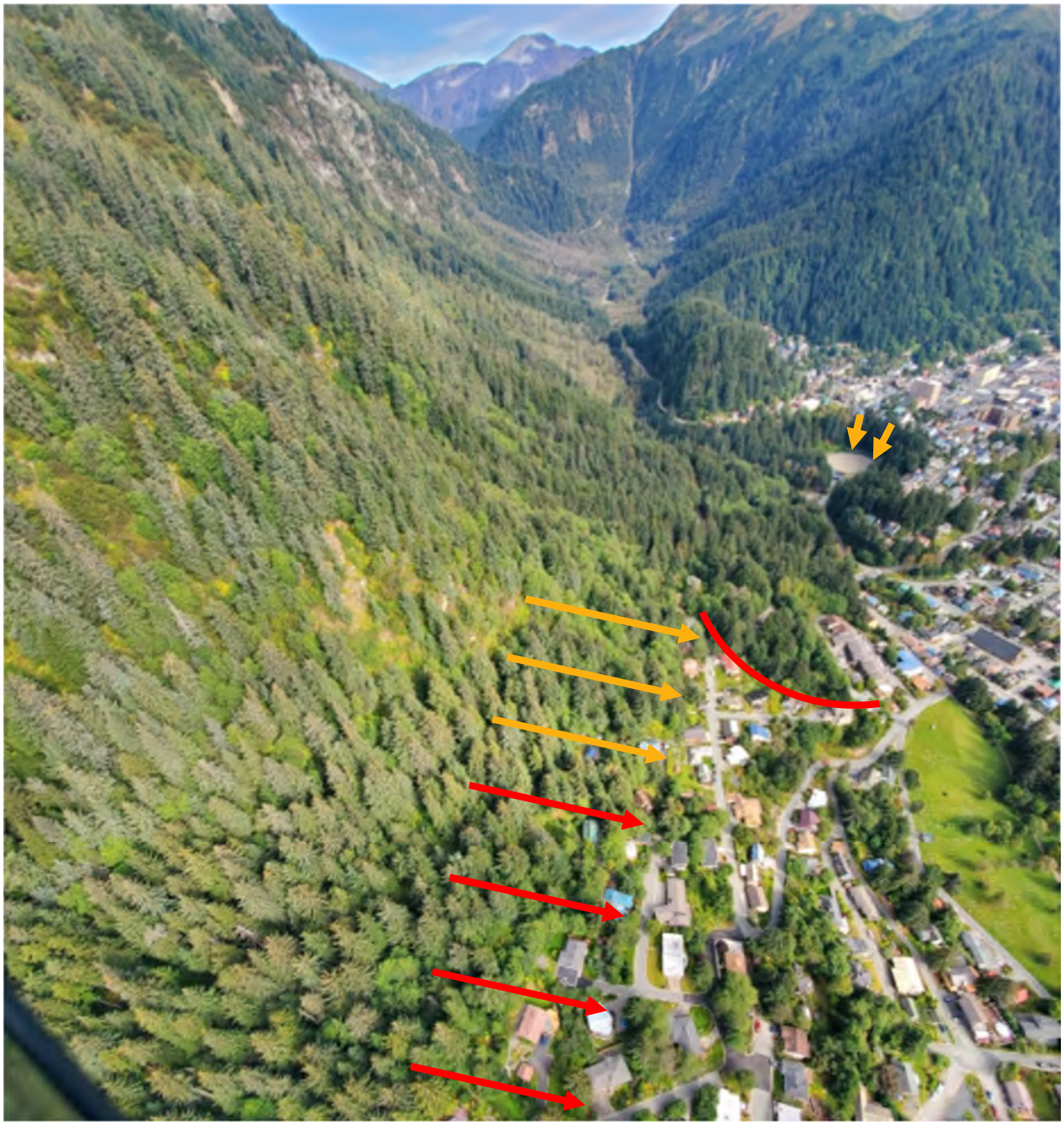

Figure 15: View from the helicopter looking east towards Last Chance Basin (see direction of look on Figure 14). Upper Evergreen Avenue is approximately in line with direction of look.

Most of the residential area in the foreground of Figure 15 is in *High* hazard zone. The upper ends of the road stubs in the foreground are mapped as *Severe* hazard (red arrows). Moving further east of the hairpin turn of Evergreen Avenue (further away from the camera), the upslope terrain is in *High* hazard zone (orange arrows) until the Bathe Creek fan/cone, where trees obscure the east end of Evergreen Avenue along the west edge of a large gully (near side outlined in red). The cemetery, which is the verdant green space at the lower right edge of the photo, is in *Moderate* hazard zone. The orange arrows at Cope Park (in the middle distance) show that most of the slope around the park is mapped as *High* hazard. See Figure 14 for more hazard mapping details. See Figure 16 for a close-up view of the slopes at Cope Park. See Technical Memo #2 (Appendix C in the main report; Tetra Tech 2022b) for more information about the Bathe Creek area.

Figure 16: Looking southeast at the steep slopes around Cope Park at the ball diamond. Note the retaining wall at the toe of slope here, which is mapped as having a *High* hazard. (Photo credit: CBJ Parks & Recreation 2022.)

3.7 Landslide Hazard Designation - *Severe*

A landslide hazard designation of *Severe* is assigned to terrain that has the following characteristics:

- Steep to vertical slopes (>35°);
- Signs of recent activity either in aerial photographs or from field inspection (rockfall tracks, debris slide activity, debris flow paths etc.);
- May have written record of property damage or loss of life;
- Signs of repeated historical activity;
- Surficial geology and texture for Class V as shown in Table 1.2 of the main report; and
- Estimated event probability is "Very Likely to Almost Certain," with a return period of 1 to 20 years. This is the return period estimated for Class V terrain, where the slopes are highly susceptible to landslides, and where

there are signs of recent landslide activity as well as repeated historical landslide activity. Therefore, landslide events are very likely to almost certain to keep happening in the future.

Two sets of examples are provided for terrain designated with a *Severe* landslide hazard: at the northeast end of the Starr Hill subdivision, above Nelson Street (Figures 17 and 18), and at the northwest end of the White Subdivision (Figures 19 and 20). As these examples show, *Severe* landslide hazards can occur on relatively short slopes or on very long slopes.

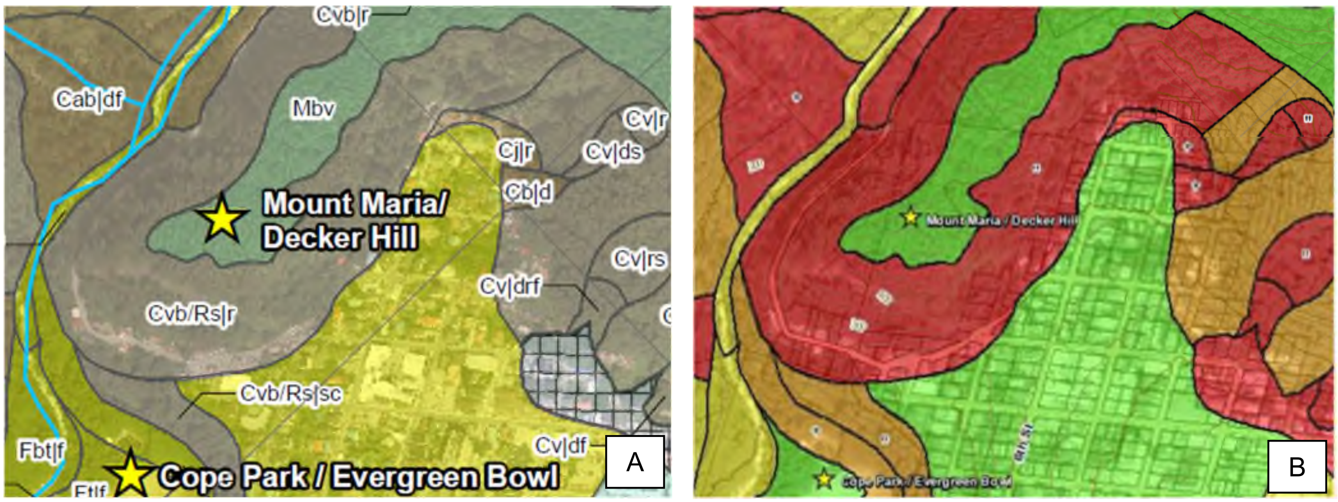

Figure 17: These two map excerpts are from the mapping slopes above Starr Hill. Figure 17A shows the surficial geology, and Figure 17B shows the landslide hazard designation mapping. Around Starr Hill, the green signifies *Low* hazard, the orange is *High* hazard, and the red is *Severe* hazard. See Figure 18 for the landslide seen in the *Severe* hazard area above Nelson Street. More information about this area is available in Technical Memo #3.

Figures 17B and 19D are hazard maps, which indicate areas that are potentially hazardous. If there was a lot of potentially hazardous geomorphic process activity on a slope, or if new activity was identified in the field, that area was mapped as having a *Severe* hazard. For instance, debris could be building up on the slope directly above a house (Figure 18), or in a location where debris can potentially run towards a house, and where it could become a more serious hazard in the future (Figures 20B and 20D). Smaller debris slides and debris flows tend to accumulate debris material in wedges within gullies. Eventually, when a critical level of debris accumulation is reached, or a significant precipitation event occurs, all that stored debris is scoured out of the gully, potentially resulting in a very large debris flow event. Similar events can occur on open slopes where slide debris piles up in lobes over days, months, or years, sometimes separated by channels of faster-flowing loose material. These debris lobes can slowly be creeping downslope, until the critical moment when there is enough mass and enough water to trigger the debris flow rapidly downslope. See also Technical Memo #2 for more mapping examples (Appendix C in the main report; Tetra Tech 2022b).

Figure 18: Compares Tetra Tech's photo from September 10, 2019 (Figure 18A) with residents' photo from August 1, 2021 (Figure 18B) at the same location. Slope instabilities appear to be ongoing in the historical slide paths located above Nelson Street on a slope with a landslide hazard designation of *Severe*. See Technical Memo #3 for more information about the slopes around Starr Hill.

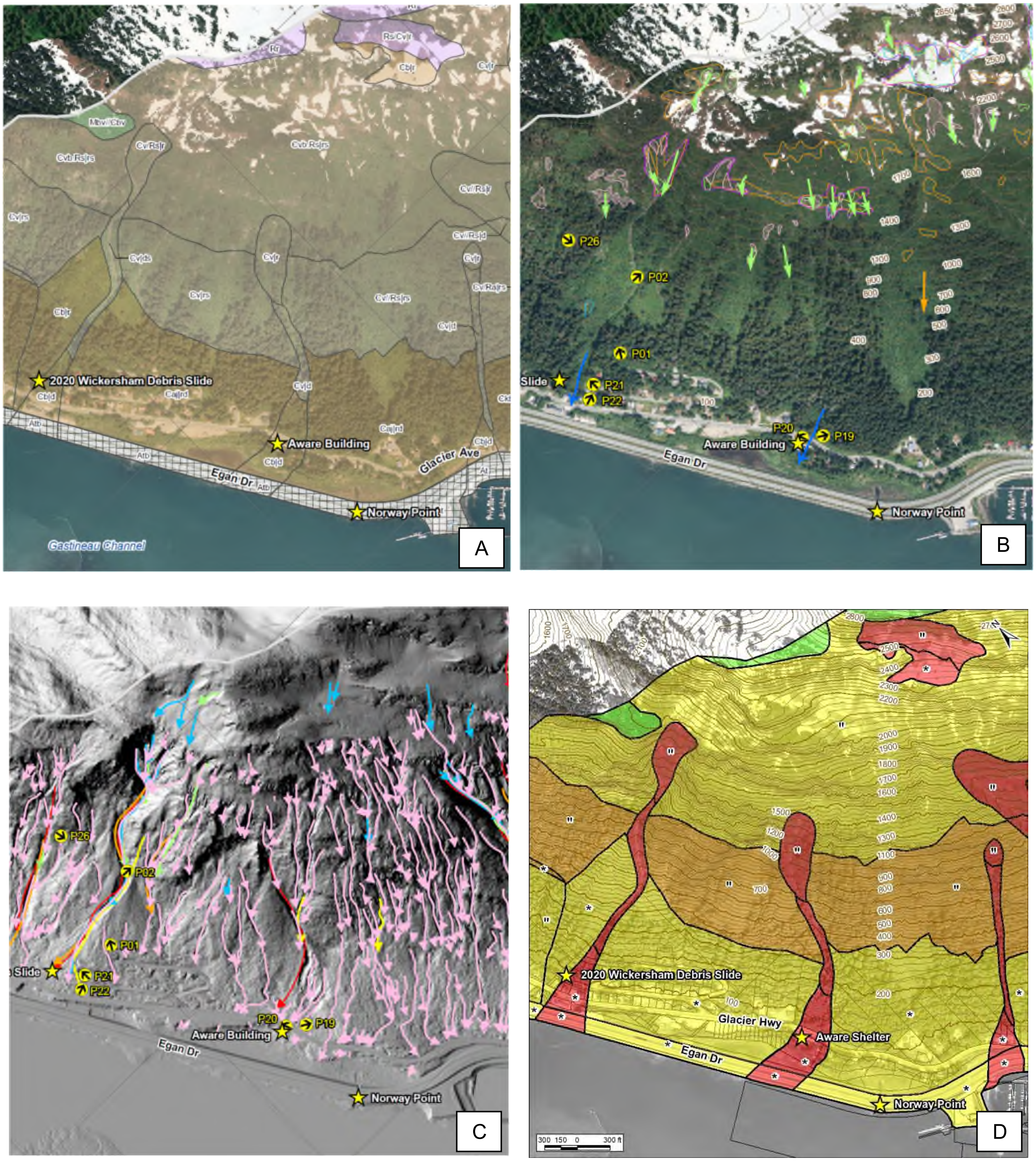

Figure 19: These excerpts are from the mapping at the slopes at the White Subdivision. Figure 19A shows the surficial geology, Figure 19B shows the slope movement features, Figure 19C shows the gully erosion features, and Figure 19D shows the landslide hazard mapping. The Wickersham slide (Figure 20) is related to a very active gully erosion feature in *Severe* hazard.

Figure 20: The Wickersham debris slide in the White Subdivision is an example of a landslide in terrain with a *Severe* landslide hazard designation. Figure 20A: Part of the debris deposit at the northwest end of Wickersham Avenue on the uphill side; Figure 20B: Debris on the downhill side of Wickersham Avenue; Figure 20C: Debris running down along the swale between Wickersham and Glacier Highway; Figure 20D: Debris deposit at Glacier Highway, filling a concrete sump behind the railing. (Photo credits: CBJ December 4, 2020.)

Figure 20 shows the aftermath of a large debris slide, after the roads had been mostly cleared. The debris was up to 8 feet thick at Wickersham Avenue, crossing Wickersham to impact a residence, filling a drainage path to Glacier Avenue, filling a drainage sump, and flowing out onto Glacier Avenue. By the time the photo in Figure 20C was taken, the water was running clear again. More debris is visible on the right, where it ran down to Glacier Highway.

4.0 HAZARD FROM ABOVE OR HAZARD FROM BELOW

Landslide hazards can affect properties from both upslope and downslope. Landslide hazards that affect properties from upslope are landslides that have the potential to run down a slope and impact a property, overrun it, damage it, or destroy it. Landslide hazards that affect properties from downslope are landslides that have the potential to remove part of a property when the ground falls downslope away from the property. For example, part of the backyard falls down the hill, or so much ground falls away that the foundation of the building is endangered. The worst case would be if so much ground falls away that the building can no longer be supported, and it too will topple or slide downhill.

A few examples of areas of Juneau where landslide hazards from above can potentially affect property include Tidelands, Starr Hill, Gastineau Avenue, Behrends, Highlands, and the White Subdivision. A few examples of areas where landslide hazards from below can potentially affect property include Chicken Ridge, Telephone Hill, and the northwest corner of Juneau Townsite (as shown on the Historical Neighborhoods website (CBJ 2022)). Chicken Ridge is also the main area where landslides can affect property from both above and below, for example, along Basin Road, and in a few places along Goldbelt Avenue.

5.0 LIMITATIONS OF A HAZARDS-ONLY ASSESSMENT

A detailed risk assessment would generally include the following basic steps:

- Hazard assessment;
- Magnitude/frequency analysis;
- Consequence assessment; and
- Risk assessment.

Depending on the requirements of the project, more data is acquired to satisfy each of the steps. The Downtown Juneau Landslide and Avalanche Hazard Assessment project has completed the first step – the hazard assessment. The other three steps were not part of the scope for this project. The thorough hazard assessment completed by Tetra Tech (Tetra Tech 2021, 2022) provides important information on where the past, present, and future slope instability areas are located in Downtown Juneau. This information can be used to progress to the other three steps.

Future phases of the project would allow more information to be collected and analysed, but each task also requires considerably more work and funding to acquire the necessary data before each subsequent task can be completed. See Technical Memo #1 for more information (Appendix C of the main report; Tetra Tech 2022a).

For example, the magnitude/frequency analysis would allow the slope activity data to be refined so that it could be used to help predict return periods for landslides of a specific type and size for a particular site, like a debris flow gully. Consequences could then be evaluated. For instance, if a specific gully experiences debris flows, i.e., acts as a conduit for conveying debris downslope, what happens downslope if it is only a small debris flow? What happens if it is a very large debris flow? Maybe nothing happens, because there are no buildings below, or maybe several buildings are destroyed when the debris runs into them.

Finally, a risk assessment can be done with a combination of all the data gathered in the previous steps. Land management decisions can then be made based on what is considered to be a tolerable risk, such as having to occasionally clean debris off the road; or what is considered to be an intolerable risk, such as a debris slide overrunning a house with someone in it.

The main challenge for CBJ at present is managing questions that require a risk assessment to be answered satisfactorily when the only data available so far are the results of the hazard assessment (Tetra Tech 2021).

6.0 REQUESTS FOR ADDITIONAL INFORMATION

A few specific questions were asked and are addressed specifically in this section. With the background information provided in the previous sections, the reader will understand the context of the answers. With limited data, it is not always possible to find a complete answer, but it will also help to understand what the landslide hazard designations mean when describing what could happen.

- **Question:** Does a *Severe* landslide hazard designation mean it would be a catastrophic failure?

  Answer: A *Severe* landslide hazard designation only describes the hazard. A description of the hazard can include information like the type of landslide (debris slide, debris flow, rockfall etc.), the size, and the location. If there is lots of data, such as many years of air photos, satellite imagery, cleanup reports, damage reports, that helps to give an idea of landslide activity and size. That is, out of 10 historical air photos of a particular slope taken over 70 years, does a landslide scar appear only once? Twice? Every year that is checked? How large is the area affected? How much debris needs to be cleaned up? Which structures are damaged and where are they located?

  A *Severe* landslide hazard designation does *not* specifically mean a catastrophic failure. In the case of this study, there are two main criteria that are used to decide whether an area needs to be designated as *Severe*:

  - Evidence of slope instability within the same feature in more than one air photo or LiDAR year and/or field investigation year; and/or

  - A cone or fan of colluvium is present at the base of a slope, no matter how old it is, because the hazard is still present.

  Numerous gullies in Juneau show evidence of slope instabilities in several years (sometimes every year) of imagery, incident report data, or field observation data that was reviewed.

  More steps are needed to determine whether a landslide in an area designated *Severe* would be catastrophic or not. One of the most important steps would be a consequence assessment, summarized in Section 6.0. See Question #1 in Technical Memo #2 for more information on how a *Severe* landslide hazard designation is determined (Appendix C of the main report; Tetra Tech 2022b).

- **Question:** What about the *Moderate* areas of the Highlands and Downtown Juneau – are they low probability, high consequence? Wouldn't any landslide damage be catastrophic?

  Answer: A *Moderate* landslide hazard designation only describes the hazard; it does not describe the consequence. Estimating the probability of a landslide requires a magnitude/frequency analysis. Evaluating the consequence of a landslide requires a consequence analysis. Neither of those tasks was in the scope and they not been done.

  However, let's compare the different landslide hazard designations shown in Table 1.4 in Section 3.0 above. The description for a *Moderate* landslide hazard might be somewhat reassuring compared to the description for *High* or *Severe* landslide hazards. Since there is insufficient data to determine a return period for a possible landslide of a particular size, the only basis for comparison is to consider the other characteristics of the designation. To summarize, landslides are possible, and there might (or might not) be signs of past landslides, but there is no apparent record of damage or loss of life.

  Although the natural terrain in some parts of Juneau has been obscured by construction-related earthworks, very large events in the past have left traces, like the very large prehistoric landslides mapped along the valley slopes (Swanston 1972). In contrast, the large suspected deep-seated bedrock failure southeast of Snowslide Creek is rated *Severe*, even though it has not yet happened. Despite these exceptions, even if a landslide happens only rarely, it does not necessarily mean that a rare event is always going to be the "big one." Conceivably, land managers could decide to avoid all areas in which a landslide could occur, including those with a designation of *Moderate*, but the priority should be to avoid the *Severe* and *High* designated areas first, because those areas will usually be affected more often and more seriously than the *Moderate* ones.

See also Section 3.5 for examples of *Moderate* terrain and mapping.

- **Question:** Can you provide additional explanatory terms that reference a general timeframe for a specific landslide hazard designation, e.g., *Low* – geologic time, *Moderate* – 100 to 1,000 years etc.?

  Answer: Without a magnitude/frequency analysis, it is not possible to definitively tie the landslide hazard designation to a specific timeframe. The activity level observed during the historical air photo record analysis and the fieldwork, as well as occasional reported events, provide the only information about frequency that is currently available. The activity level does have some correlation to frequency (i.e., more active landslide areas experience landslides more frequently), but that is not the same as having the results of a more rigorous magnitude/frequency analysis. Based on the activity levels, it is only possible to tie the landslide hazard designations to a much shorter timeframe, as described in Section 3.0.

- **Question:** Can you tell me more about the proxies that are being used instead of a magnitude/frequency analysis?

  Answer: A useful proxy for magnitude is the size of the unvegetated slope area (or range of sizes), based on the typical sizes of the events seen on the available air photos, satellite images, and evidence seen during the field work. Another proxy for magnitude is whether any damage or loss of life was reported for a specific landslide event. (In risk studies – *not* part of the current scope – reports of size, damage or loss of life would also contribute to an understanding of consequence.)

  The proxy for frequency is activity: the proportion of air photo or satellite images (or field observations) that show a lack of vegetation on a slope that would ordinarily be vegetated. The more often a slope section or gully has no vegetation on it, the higher the rating it will receive. Areas showing activity in two or more air photo years were identified and given a hazard designation of *Severe* on the hazard designation maps due to their higher activity levels. In fact, many of the areas designated as *High* or *Severe* in the mapping turned out to have several instances of lack of vegetation, with numerous gullies showing evidence of slope instabilities for all, or almost all, observation dates. See Section 3.3 in this memo, and additional discussion in the answer to Question #1 in Technical Memo #2 (Appendix C of the main report; Tetra Tech 2022b).

7.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the City and Borough of Juneau and its agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the City and Borough of Juneau and its agents, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

8.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

STATE OF ALASKA
49TH
M.I. Kors-Olthof
April 27/22
No.CE8567
REGISTERED PROFESSIONAL ENGINEER

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Enclosure: Limitations on Use of this Document

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LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

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The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

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This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Scott Ciambor (CBJ)	**Memo No.:**	5
From:	Rita Kors-Olthof, Vladislav Roujanski	**File:**	704-ENG.EARC03168-02A
Subject:	Landslide Hazard Designations at Telephone Hill and Gastineau Avenue Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) has prepared an Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment for the City and Borough of Juneau (CBJ), dated May 28, 2021 (Tetra Tech 2021); and participated in three Landslide and Avalanche Hazard Public Meetings that took place on July 21, August 10, and September 20, 2021.

Following CBJ's initial email request of July 27, 2021, Tetra Tech responded to comments and questions that arose from the July 21, 2021, Public Meeting with a series of three technical memos. These memos were Issued-for-Review to CBJ, along with an email providing supplemental information, and have since been updated (Appendix C of the main report; Tetra Tech 2022a, 2022b, 2022c).

CBJ has now requested a further series of memos to address additional landslide hazard-related questions, as well as a review of historical avalanche data, to address further questions that arose following the August 10 and September 20, 2021, Public Meetings; as well as some follow-up questions from CBJ. The scope is as described in Tetra Tech's proposal of December 9, 2021, with a few modifications as discussed during the kick-off meeting with CBJ on February 8, 2022. All the completed memos will be appended to the Final Draft Report.

This Technical Memo #5 provides some additional explanation for anticipated future slope instabilities within the landslide hazard designations mapped as *High* or *Severe* on the slopes of Telephone Hill (Figures 1 and 2) compared to the areas mapped as *High* or *Severe* on the slopes along and above Gastineau Avenue.

2.0 SCOPE AND METHODS

The primary objective of this memo is to address the question, "The area of Telephone Hill and the bluffs below is mapped as a *High* hazard. What is the difference between Telephone Hill and the steep slopes on Gastineau in terms of hazard and potential for damage?" Specific tasks included the following:

- Review landslide hazard designation mapping completed by Tetra Tech;
- Locate suitable photographs illustrating landslide hazards in the above-noted map areas, if/as needed;
- Prepare map excerpts, if/as needed;
- Refer to information presented previously in other technical memos, as applicable; and
- Prepare Technical Memo, providing descriptions and/or comparisons, as needed.

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The surficial geology mapping shows that the colluvial terrain at Telephone Hill is connected to the northwest leg of the Juneau townsite, which is in turn connected to the northwest leg of Chicken Ridge on the southwest side of Cope Park. Therefore, it is logical to consider these areas together in addressing this question.

3.0 TELEPHONE HILL, JUNEAU TOWNSITE, AND CHICKEN RIDGE

3.1 Summary of Historical Landslides in Areas Mapped *High* or *Severe*

It is useful to first consider a view of Telephone Hill from Mt. Maria in the historical photo taken in about 1896, prior to the Juneau development that has gradually obscured the slopes (Figure 1). The prominent bedrock ridge seen in this photo was mapped by Miller (1975) as undifferentiated Tertiary or upper Mesozoic rock with an unconformity, suggesting that some material was scoured off at some point in geological history, and the bottom of the upper layers does not match the top of the lower layers. Although the top of the ridge is gently sloped, the sides of the ridge are quite steep. In locations where a thin veneer of colluvium covers the bedrock, this material could be more prone to mass movement than other materials such as a blanket of colluvium or glacial till (Tetra Tech 2021a).

Figure 1: Looking south towards Telephone Hill and Gastineau Channel from Mt. Maria, circa 1896, early in the development of Juneau, when structures along the toe of slope at Willoughby Avenue were supported on wharfs, and before fill began to be placed along the shoreline to extend the useable land area. (Photo credit: Excerpted from Alaska State Library – Historical Collections, ASL-P87-0753, Winter & Pond, ca. 1896.)

Adjacent to the Main Street Garage (a multi-level parkade) at the southeast end of Telephone Hill, on the northeast side of the bedrock ridge, the bedrock slope was cut to make room for the structure, with some rock-bolting also done to protect a residence on top of the ridge. The bedrock face at that location is regularly inspected and scaled if/as needed. The State Archives and Records Center, on the Willoughby Avenue side, is built into the ridge, with an adjacent retaining structure just southeast of the back of the building. The State Office Building appears to have been built alongside and across the top of the ridge. Several other residences remain on top of the ridge. Numerous bedrock outcrops are present along Dixon Street in this area. Heading northwest along Dixon Street, Calhoun Avenue, Goldbelt Avenue, and Main Street into the Juneau Townsite and Chicken Ridge areas, retaining walls and buildings set into the slope are common, as well as bedrock outcrops.

Only a few historical landslides have been documented in this part of Juneau. These landslides are plotted on Figure 2 for information and comparison.

On September 7, 1923, the Juneau Daily Empire reported that a landslide "of about 100 feet occurred on the hill between Calhoun Avenue and Willoughby Avenue, at the foot of Dixon Street." The slide had occurred early that morning due to the heavy rainfall of the preceding few days. The slide pushed a large unoccupied two-storey frame house off its foundations, moving it several feet. No damage was reported to the house, except that its "underpinnings" had been torn out. In addition, the slide also destroyed "part of the stairway leading from Calhoun Ave. to the Indian village" (The Alaska Daily Empire 1923). This landslide occurred in colluvium and appears to have been directly downslope of the fork at Dixon Street and Calhoun Avenue, in an area that still experiences periodic landslides, at the northwest corner of the Juneau Townsite in CBJ's Historic Neighborhoods mapping.

Figure 2 Excerpt of map of Downtown Juneau's Historic Neighborhoods (CBJ 2022), showing selected historical landslide locations. The 1923 landslide is shown running downslope from Calhoun Avenue and the southeast end of Dixon Street to a little above the present-day Willoughby Avenue (red arrow). Landslides still occur at Calhoun Avenue, originating upslope of Dixon Street (green arrow).

CBJ has reported that debris slides occur regularly at the fork between Dixon Street and Calhoun Avenue, between the northwest end of the retaining wall on Calhoun, and just downslope of the West 6th Street cul-de-sac. This location overlaps the southwest corner of Chicken Ridge, and the northwest corner of the Juneau Townsite in CBJ's Historic Neighborhoods (CBJ 2022) mapping, and its location is shown in Figure 2. Rocks on the road have been reported after large storm events in at least the past two years. Trees or pieces of large woody debris are less frequent, occurring at roughly five-year intervals (email communications: July 20, 2021; A. Pierce, T. Camery, Q. Tracy, V. Roujanski, and R. Kors-Olthof). Google Street View suggests that debris appears to originate at a bedrock bluff partway upslope towards West 6th Street, and could consist of soil, rocks, trees, or other large woody debris, and other organic debris that typically lands on Dixon Street, requiring cleanup to restore road access, as seen in Figure 3. Part of the slope, between Dixon Street and Main Street upslope, is occupied by a building, but some debris seems to originate from the lower slope below the building too.

Figure 3: Typical debris slide deposit at the fork between Dixon Street and Calhoun Avenue. In the left-hand photo, note the fork in the road at center-right, and the northwest end of the retaining wall at the right edge of the photo. The downslope edge of Calhoun at the railing is supported by another retaining wall. In the right-hand photo, note the presence of a steep cutslope into apparent weathered bedrock, with a thin veneer of colluvium. The debris from this landslide event extends an estimated 40 feet northwest of the end of the metal railing. The distance along the toe of slope along Dixon/Calhoun is about 110 feet between the northwest edge of the debris and the northwest corner of the upslope retaining wall. (Photo credits: CBJ, provided July 16, 2021.)

There are a great many retaining walls visible on Dixon Street, Calhoun Avenue, Goldbelt Avenue, parts of Main Street, and connecting streets. Some of these retaining walls were apparently used to construct houses and associated landscaping to make more efficient use of the slope, but numerous retaining walls along roads appear to be necessary to create or maintain access to properties, or to reduce landsliding along steep slopes. In adjacent locations that lack retaining walls, many slope sections have either deciduous trees or grasses, suggesting that shallow debris slides might be fairly common. However, the specific location shown in Figure 3, and the landslide downslope in 1923 at almost this exact location, do suggest that there is something particular about this site that causes it to be exceptionally prone to slope failure. An excerpt of the LiDAR in this area provides a possible explanation (Figure 4).

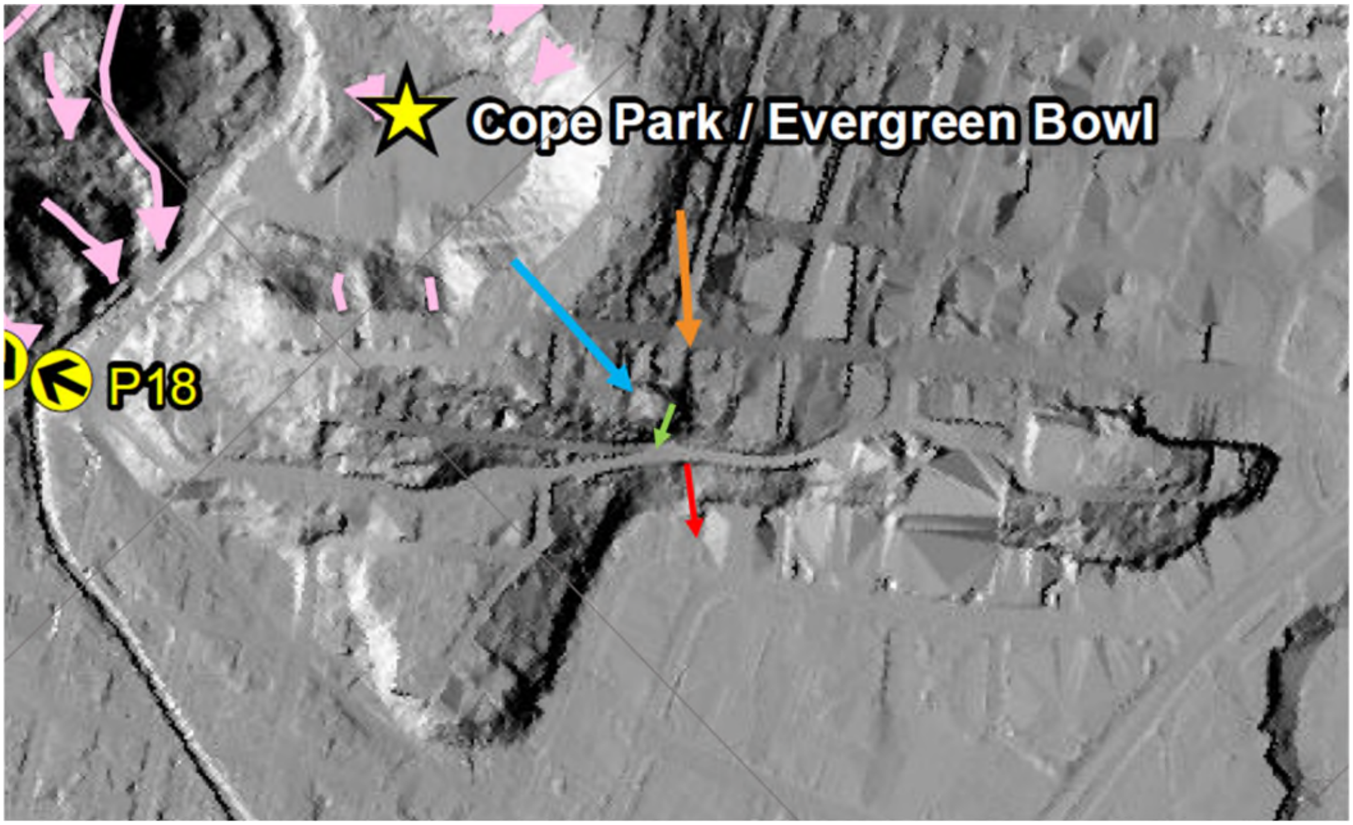


Figure 4: Just off the southwest end of West 6th Street, there is a prominent bedrock knoll (blue arrow), and an adjacent gully (downslope of the orange arrow) that both potentially contribute to repeated debris slides at this location that regularly run out onto Dixon Street (green arrow). The gully is also directly in line with what appears to be a scar from the 1923 landslide that moved from Calhoun Avenue down to Willoughby Avenue (red arrow). See also Figure 2.

3.2 Comparison of Map Excerpts

A summary of Tetra Tech's mapping along Telephone Hill, Juneau Townsite, and Chicken Ridge is shown in Figure 5, with surficial geology on the left and landslide hazard designation mapping on the right. There is a clear correlation between the types and shapes of the surficial geology units and the landslide hazard designations at that location. In Figure 6, the colluvial areas are distinguished by the vegetation visible along slopes where it is difficult to construct housing or other structures.

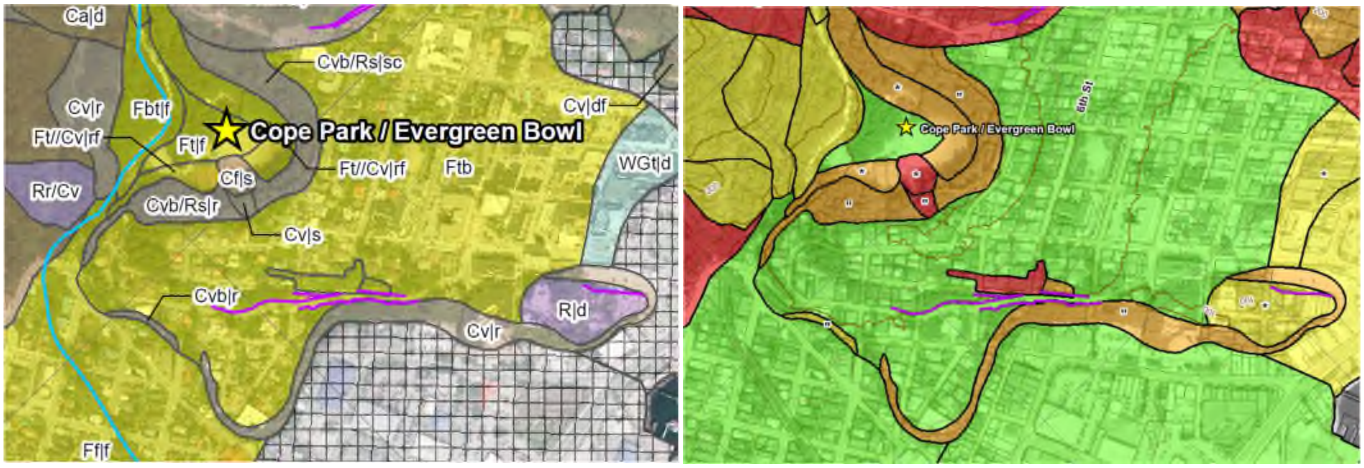


Figure 5: Excerpts from Figure 1.3b Surficial Geology (left) and Figures 1.6c Landslide Hazard Designation Mapping (right). Surficial geology corresponds closely to landslide hazard designations.

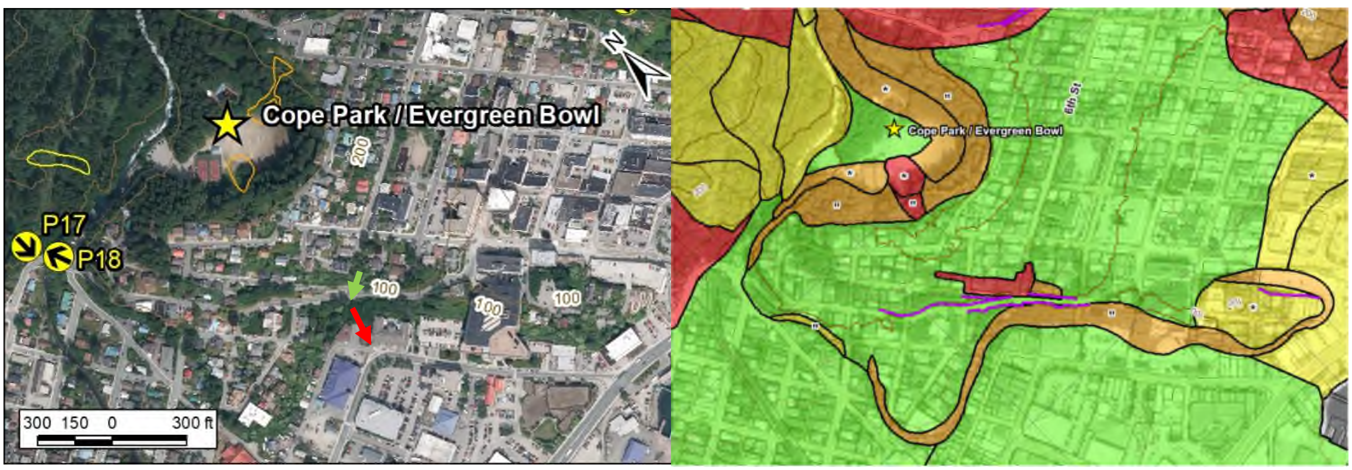


Figure 6: Excerpts from Figure 1.4b Slope Movement Features and Figure 1.6c Landslide Hazard Designation Mapping. On the left-hand image, the 1923 landslide is shown running downslope from Calhoun Avenue and the southeast end of Dixon Street to a little above the present-day Willoughby Avenue (red arrow). Landslides still occur at Calhoun Avenue, originating upslope of Dixon Street (green arrow). On the right-hand image, the hazard mapping from 1987 has been restored and updated above Calhoun Avenue, based on the debris slides reported by CBJ.

Depending on the date of construction of the Calhoun Avenue upslope retaining wall, the area currently shown as *High* in Figure 6 could be downgraded to *Moderate*, but the area shown as *Severe* should remain as is due to the high frequency of debris slides at that location.

4.0 GASTINEAU AVENUE (SLOPES OF MT. ROBERTS)

4.1 Summary of Historical Landslides in Areas Mapped *High* or *Severe*

Much of the slope along Gastineau Avenue and South Franklin Street has a landslide hazard designation of *Severe*, due to being in the runout zone of numerous major debris flow paths. For debris slides that initiate within *Severe* zones upslope, the likelihood is very high that they will also run out in *Severe* zones downslope. As for debris slides in areas designated as *High* that occur between those *Severe* zones upslope, e.g., on open slopes between debris flow gullies, these slides can be small enough that they will initiate and run out all within the same *High* zone. Depending on the location; however, some slides that initiate in the *High* zones could run out into the *Severe* zones.

It would be useful to determine whether any of the well-documented major landslides on the slopes of Mt. Roberts that initiated in a *High* zone, and ended up in *Severe*, also reaching structures along Gastineau Avenue or further downslope. For comparisons of less well-known landslides, side-by-side comparisons can help in this task, as further discussed in Section 4.2. Technical Memos #3, #6, and #7 provide additional information on specific findings on Mt. Roberts (Appendix C of the main report; Tetra Tech 2022c, 2022f, 2022g). Figures 7, 8, and 9 provide some side-by-side mapping comparisons for surficial geology, mass movement features, and gully erosion features compared to landslide hazard designations near the northwest end of Mt. Roberts. Figures 10, 11, and 12 provide the same side-by-side comparisons at the southeast end of the Study Area at Snowslide Creek. Details for two major landslides near the northwest end of Mt. Roberts are discussed below.

Landslide of January 2, 1920: Most of this landslide area is mapped in *Severe*, including the two houses that were destroyed above Gastineau Avenue (see Tetra Tech 2021a, Figure 1.6c, the first complete debris flow path from the right). Consider the report of overflowing water from the Alaska Juneau Gold Mining Company (AJGMC) flume in the time leading up to the landslide (The Alaska Daily Empire 1921). If that water came from Portal #1 (Figures 1a,1b in Technical Memo #7), does that mean it poured down the northwest side of the fill/spoil slope, triggering a slope failure in *High*? (See Figure 5 in Technical Memo #7.) It seems possible, mainly because AJGMC lost a court case in 1921 that contested whether or not AJGMC's leaky flume had contributed to that slide. On the other hand, AJGMC won three other court cases about the exact same landslide. A debris slide was not visible on the 1948 air photos on the southeast side of the 1920 gully; however, it is plausible that the scar from that event must have been fully revegetated by 1948, when the earliest set of air photos used in this project were taken (Figure 1.4b in the main report). In contrast, debris slide activity *was* mapped to the northwest of the 1920 debris flow gully on the 1977 air photos (suggesting that it occurred sometime after 1962, but before 1977). That debris slide area was located partly in *High* and partly in *Severe*, crossing several narrow hazard designation zones across its width (Figures 7 and 8). The toe of the debris slide area was about 100 feet in elevation above the cutline for the powerline above Gastineau Avenue.

Landslides of November 22, 1936: The tension crack reported below the AJGMC tramline (presumably within the fill/spoil slope) seems suspicious, suggesting initiation of the slope failure in *High*. However, the slide seems to have entered the runout in *Severe* along the southeast edge of the runout cone encompassing the former AJGMC office (for 1936B), and the adjacent slide (1936A) seems to have been entirely within *Severe* (Figures 1a, 1b in Technical Memo #7). Several debris slides were mapped in this area thereafter, apparently on the fill/spoil slope, in 1962, 1977 (confirming the 1971 air photo mosaic map from the State of Alaska, Department of Highways (ASL 2022)), and in 2013 and 2019 (Figure 8; Tetra Tech 2021a, Figure 1.4b). All but one of these later debris slides ran out to approximately the upper edge of the cleared powerline right-of-way, and the 2019 debris slide ran out to the lower edge of the right-of-way (Figure 8). Another debris slide or flow was mapped on the 1977 air photos, originating from upslope of the tramline, apparently flowing along the northwestern edge of the 1936B debris slide path, but running out well above the powerline right-of-way (Figure 8).

Landslide events that reach the lower slopes of Mt. Roberts tend to consist of debris flows or debris slides, and runouts are typically mapped in *Severe* on this slope. Those debris flows or debris slides could incorporate debris originating from areas mapped as *High* within the colluvium on the mid- to lower slopes, as noted above. The length of the slopes on Mt. Roberts means that there could be a few different types of landslide events between the top and bottom of the slope (Figures 7, 8, and 9 at the northwest end of Mt. Roberts; Figures 10, 11, and 12 at Snowslide Creek). Just as for Telephone Hill, and the adjacent Juneau Townsite and Chicken Ridge in terrain representing the same geological feature as Telephone Hill, wherever debris slide or debris flow processes are occurring now, these are the kinds of mass movement processes that have been ongoing for decades and centuries, and they are expected to continue.

The processes described for Telephone Hill and the adjacent Juneau Townsite and Chicken Ridge are the same as those occurring on the slopes of Mt. Roberts, though the slope length is greater on Mt. Roberts, and although debris slides on open slopes can be similar in size to those above Telephone Hill and the adjacent areas, larger-scale events are possible, particularly for debris flows or debris slides within gullies (Figures 7, 8, 9, 11, and 12 below; Figures 1.4b, 1.5b, 1.4c, and 1.5c in Tetra Tech 2021a). However, many of the debris slides in *High* zones on Mt. Roberts terminate well above residential or commercial areas, and it is mainly where the debris slides coincide with *Severe* zones that they become more concerning.

4.2 Comparison of Map Excerpts

A summary of Tetra Tech's mapping near the northwest end of Mt. Roberts is shown in Figure 7, with surficial geology on the left and landslide hazard designation mapping on the right. There is a clear correlation between the types and shapes of the surficial geology units and the landslide hazard designations at that location. The same correlations can be seen in the side-by-side comparisons of slope movement features (Figure 9) and gully erosion features (Figure 10).

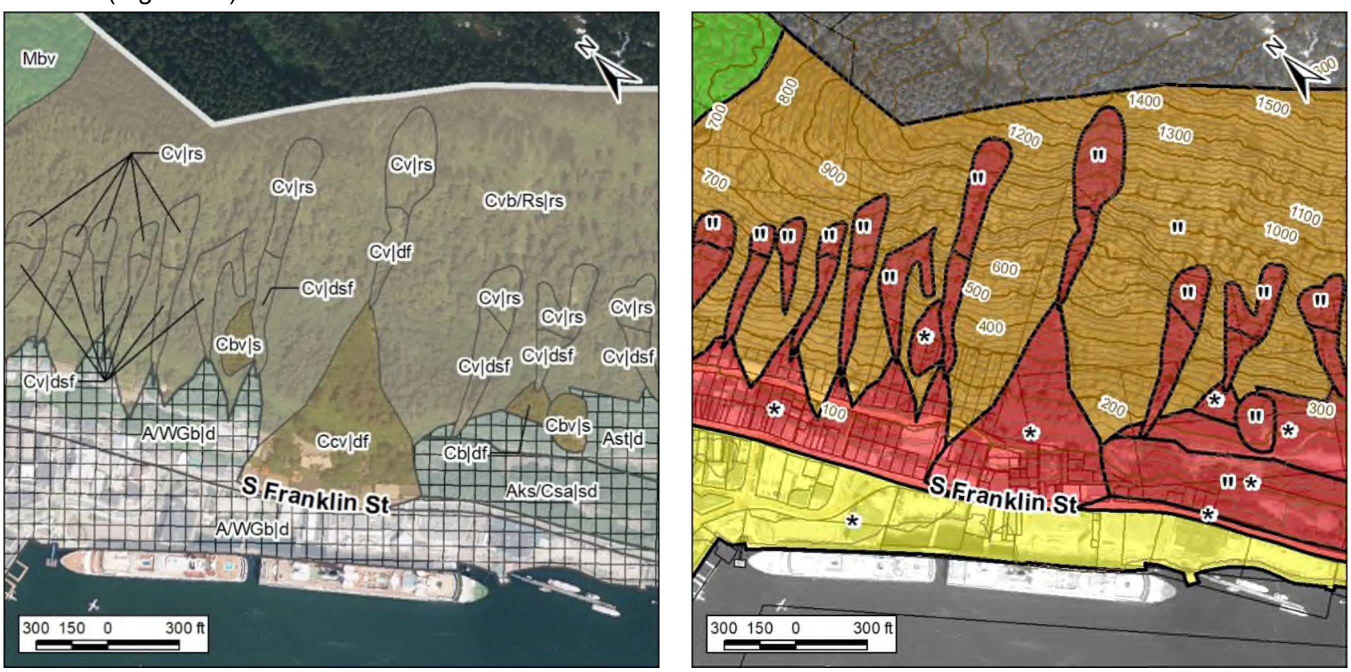


Figure 7: Excerpts from Figure 1.3b Surficial Geology (left) and Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (right) near the northwest end of Mt. Roberts. Surficial geology corresponds closely to landslide hazard designations.

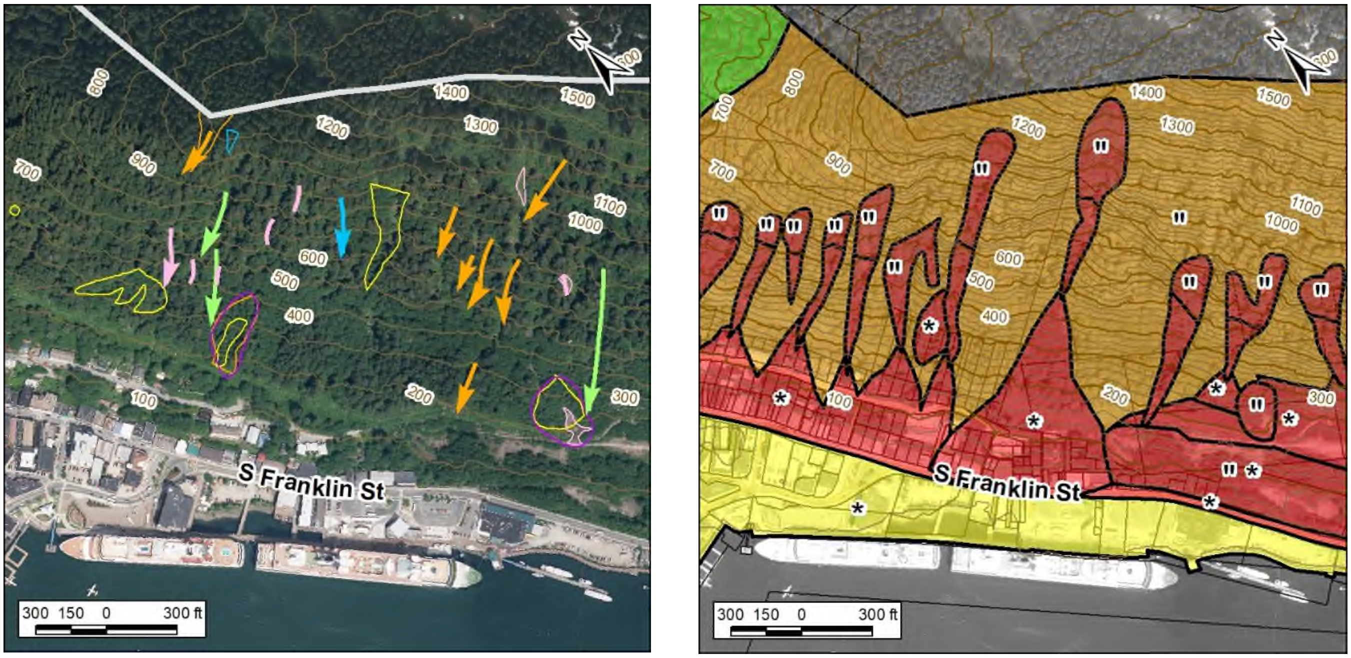


Figure 8: Excerpts from Figure 1.4b Slope Movement Features (left) and Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (right) near the northwest end of Mt. Roberts. Note outlines of several colours at center-left, indicating several years of landslide events at the same location, just upslope of the powerline right-of-way.

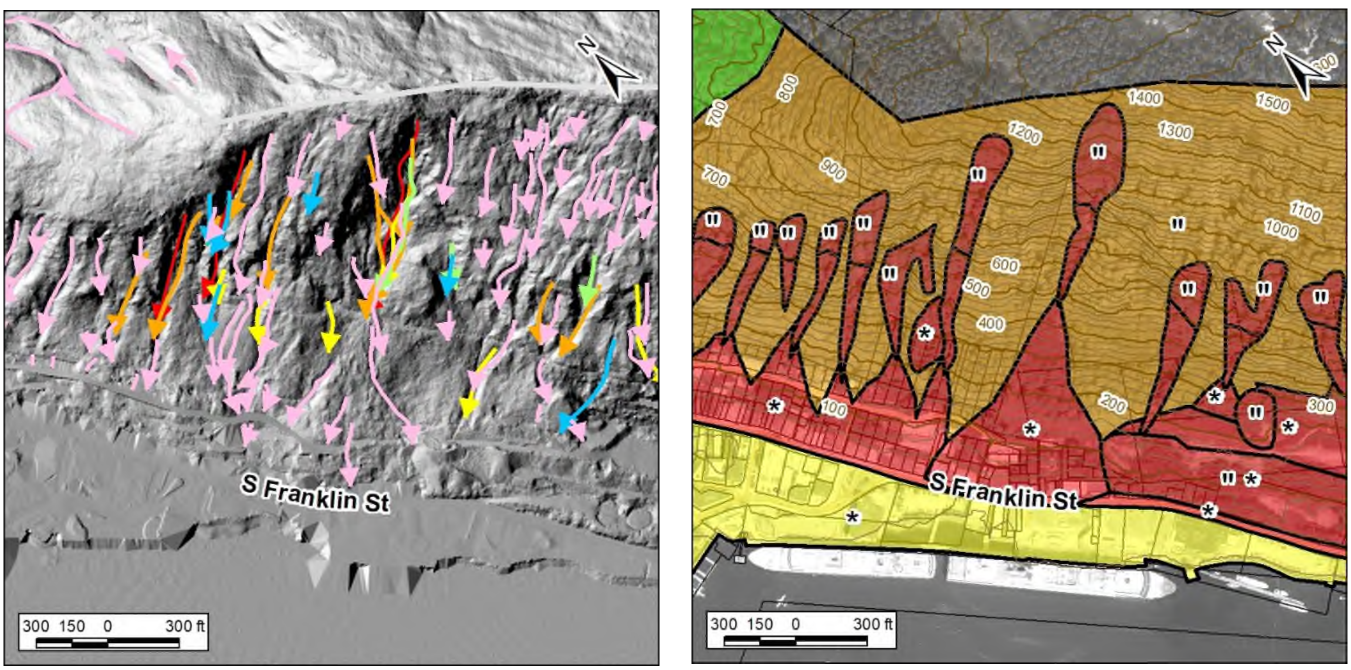


Figure 9: Excerpts from Figure 1.5b Gully Erosion Features (left) and Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (right) near the northwest end of Mt. Roberts. Multiple colours in gullies mean more activity than gullies that only have one colour.

The same comparisons can be made further southeast along the slope, for example, for the terrain at Snowslide Creek, with surficial geology on the left and landslide hazard designation mapping on the right (Figure 10). Once again, there is a clear correlation between the shapes of the surficial geology units and the associated landslide hazard designations, as well as the type of geology and the resulting hazard designation. The same correlations can be seen in the side-by-side comparisons of slope movement features (Figure 11) and gully erosion features (Figure 12).

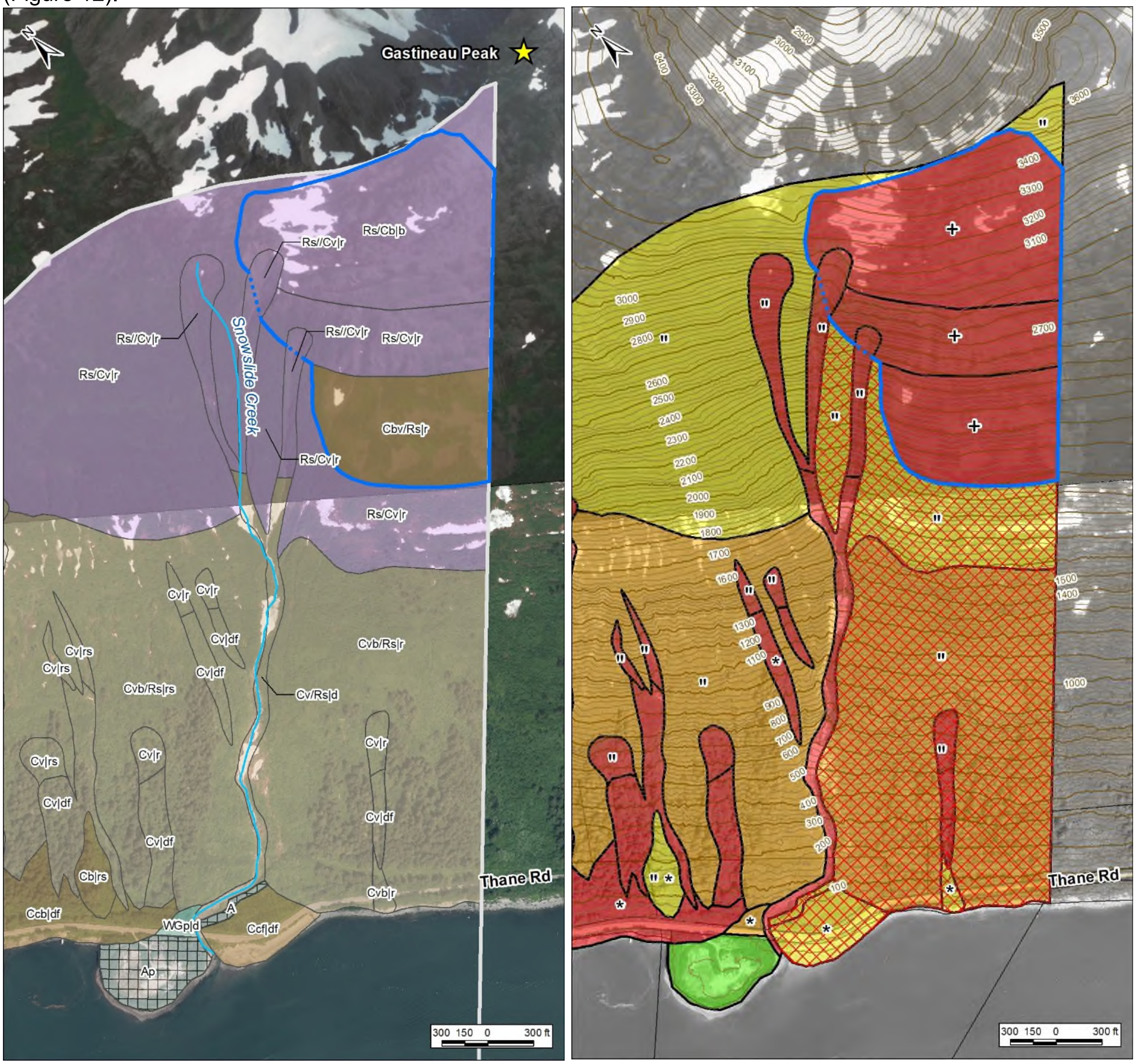
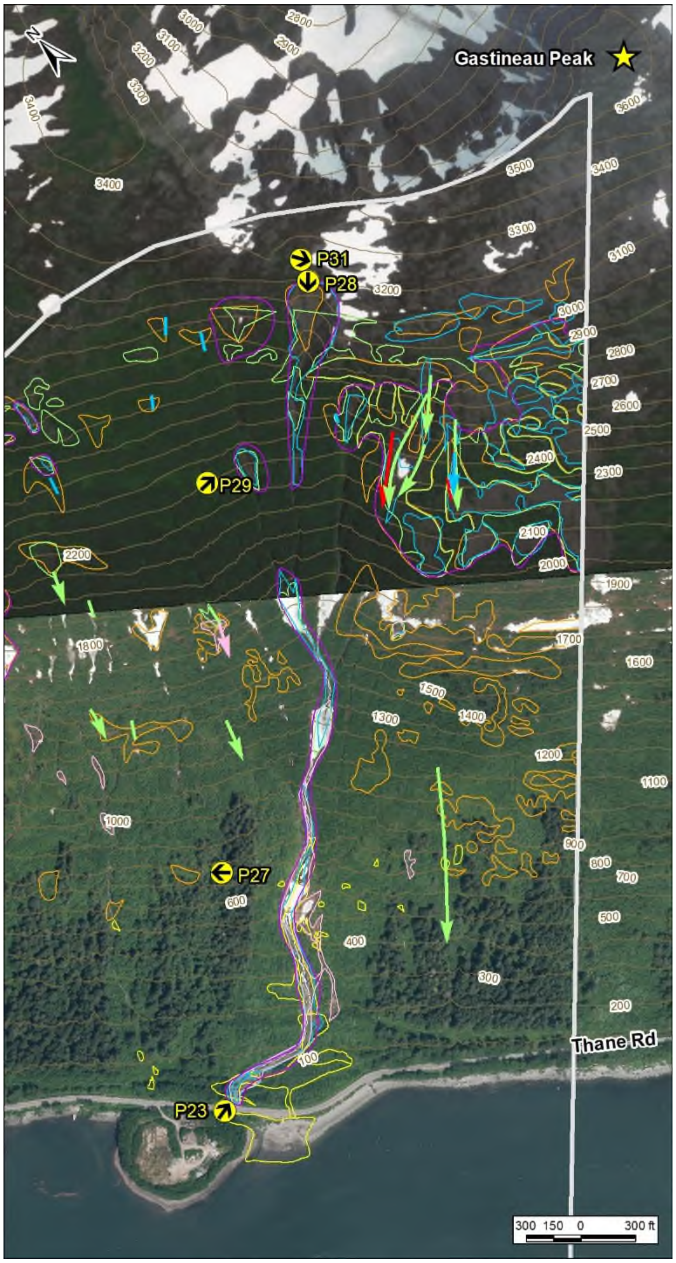


Figure 10: Excerpts from Figure 1.3c Surficial Geology (left) and Figures 1.6e and 1.6f Landslide Hazard Designation Mapping (right) at Snowslide Creek at the southeast end of the Study Area. Again, surficial geology corresponds closely to landslide hazard designations.



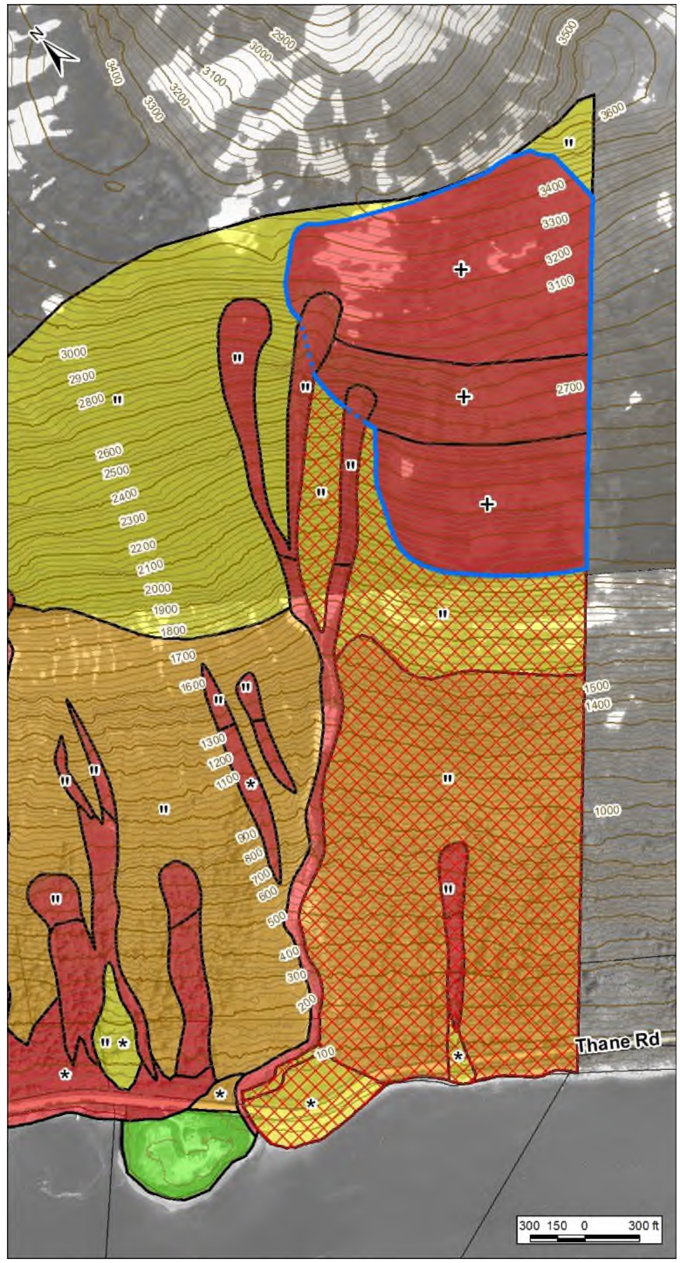


Figure 11: Excerpts from Figure 1.4c Slope Movement Features (left) and Figures 1.6e and 1.6f Landslide Hazard Designation Mapping (right) at Snowslide Creek at the southeast end of the Study Area. This comparison shows that many slope movement features, such as debris slides, are located on open slopes that typically have a *Moderate* or *High* landslide hazard designation. The exception in this part of the Study Area is the suspected deep-seated bedrock slide on the open slope at the top right of each image, with lots of slope movement features and a *Severe* landslide hazard designation. Slope movement features that take place within gullies contribute to a *Severe* landslide hazard designation, shown dramatically here at Snowslide Creek.

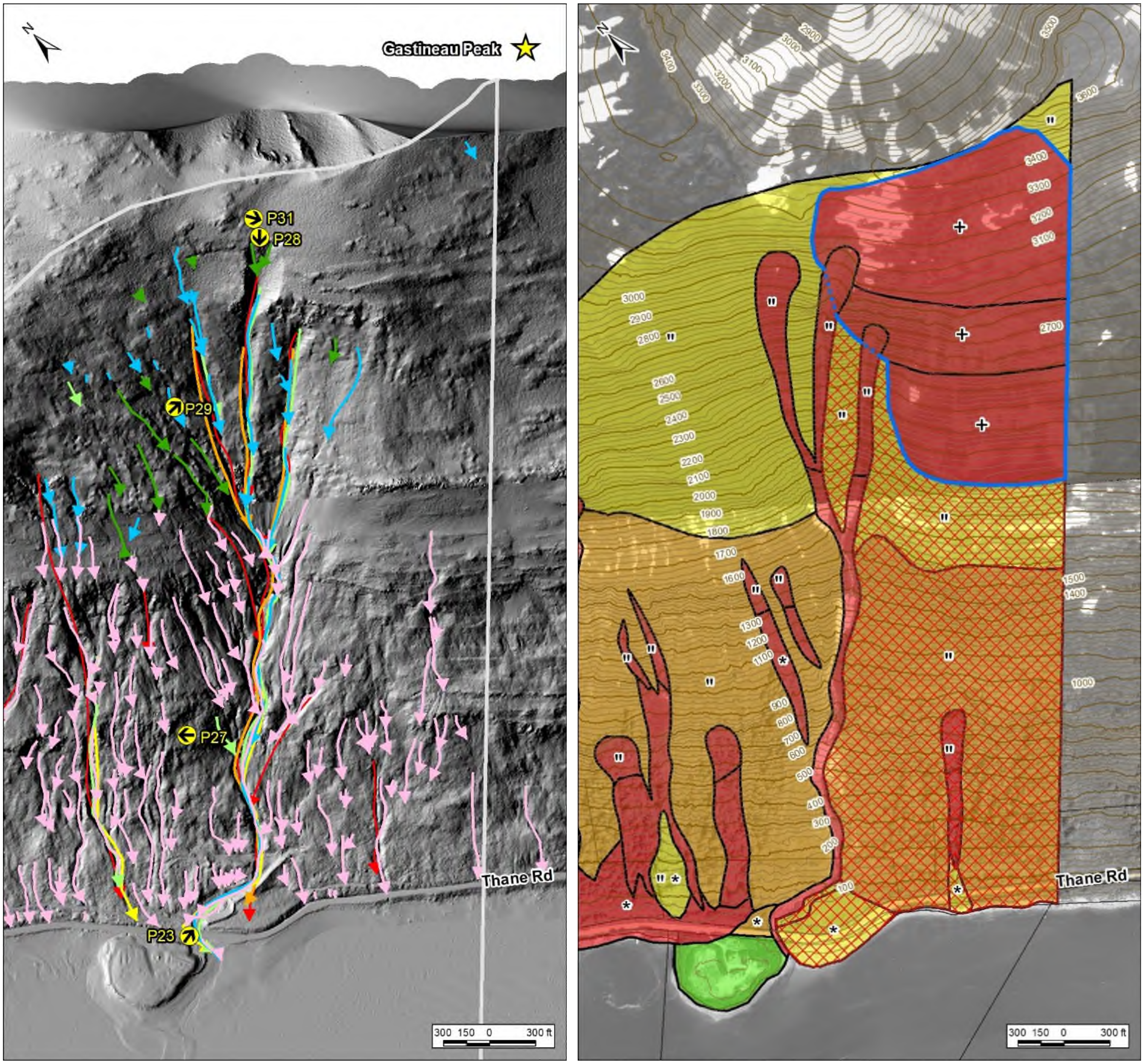


Figure 12: Excerpts from Figure 1.5c Gully Erosion Features (left) and Figures 1.6e and 1.6f Landslide Hazard Designation Mapping (right) at Snowslide Creek at the southeast end of the Study Area. In this comparison, the reason for the *Severe* landslide hazard designation at highly active gullies becomes clear. The more colours of arrows (representing different years of air photos in which erosion was observed), the more likely that a *Severe* rating is required. Note that minor gullies on otherwise open slopes do not elevate the rating for the open slopes, which are generally rated *High* for the lower slopes and *Moderate* for the upper slopes.

The presence of major active gullies on Mt. Roberts shows the main difference between Mt. Roberts and Telephone Hill, where gullies are not so prevalent (or obvious). As shown by the landslide hazard designation mapping, Telephone Hill and nearby neighborhoods to the northwest generally have lower hazard ratings than Mt. Roberts.

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We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

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TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Scott Ciambor (CBJ)	**Memo No.:**	6
From:	Rita Kors-Olthof, Vladislav Roujanski	**File:**	704-ENG.EARC03168-02A
Subject:	Severe Landslide Hazard Designations at Starr Hill and Gastineau Avenue Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) has prepared an Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment for the City and Borough of Juneau (CBJ), dated May 28, 2021 (Tetra Tech 2021); and participated in three Landslide and Avalanche Hazard Public Meetings that took place on July 21, August 10, and September 20, 2021.

Following CBJ's initial email request of July 27, 2021, Tetra Tech responded to comments and questions that arose from the July 21, 2021, Public Meeting with a series of three technical memos. These memos were Issued-for-Review to CBJ, along with an email providing supplemental information, and have since been updated (Tetra Tech 2022a, 2022b, 2022c).

CBJ has now requested a further series of memos to address additional landslide-related questions from the public, as well as a review of historical avalanche data to address further questions that arose following the August 10 and September 20, 2021, Public Meetings; as well as some follow-up questions from CBJ. The scope is as described in Tetra Tech proposal of December 9, 2021, with a few modifications as discussed during the kick-off meeting with CBJ on February 8, 2022. All the completed technical memos will be appended to the Final Draft Report.

This Technical Memo #6 provides some additional explanation of anticipated continued slope instabilities within the landslide hazard designations mapped as *Severe* on the slopes above Starr Hill and Gastineau Avenue.

2.0 SCOPE AND METHODS

The primary objective of this technical memo is to address the question, "The chutes mapped as *Severe* above Gastineau/Starr Hill scour down to bedrock over and over – is a bedrock failure anticipated, or just more flushing from small landslides?" Specific tasks included the following:

- Review completed landslide hazard mapping;
- Locate suitable photographs illustrating landslide hazards in the above-noted map areas, if/as needed;
- Prepare map excerpts, if/as needed;
- Refer to information presented previously in other technical memos, as applicable; and
- Prepare Technical Memo, providing descriptions and/or comparisons, as needed.

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3.0 STARR HILL

3.1 General Considerations

The slope conditions around the Starr Hill subdivision were discussed in detail in Technical Memo #3 (Appendix C of the main report; Tetra Tech 2021d). Rockfalls and rockslides are most prevalent on the slopes above 6th Street, but there are also areas of rockfalls and rockslides above other areas of the subdivision, as described in Technical Memo #3.

3.2 Rockfalls and Rockslides

As noted in Technical Memo #3, Question #1, locations with numerous unstable rock cliffs and bluffs above 6th Street can be expected to continue experiencing rockfalls and rockslides. Swanston (1972) noted that, although the bedrock dips into Last Chance Basin (on the north side of Mt. Maria), cyclical freeze-thaw of water in the fractures and joints of the exposed bedrock, and water acting as a lubricant in the cracks, result in instabilities. The elevated level of slope movement activity on this slope, including several well-established slide paths below prominent bedrock bluffs and cliffs, requires the slopes below the cliffs to be designated as *Severe* hazard. Similar processes can be anticipated anywhere in those locations where bedrock outcrops are present. Depending on the structural orientation of the bedrock (e.g., dipping into the slope or out of the slope), the mass movement process at the outcrop may look more like rockfall (including toppling), or rockslides. Tetra Tech's field records include numerous photos of bedrock outcrops, cliffs, or bluffs, many of which have detached blocks, indicating the likelihood of future rockfall, rockslides, or toppling.

Once in motion, rocks might tend to bounce and roll (for example, where loose rocks can move independently and stop against trees, or structures, or other objects that block them or slow them down (e.g., above much of 6th Street), or they could fall or slide as a larger mass and end up in a large talus cone downslope (e.g., corner of 6th and Nelson Streets). These are the kinds of processes that have been ongoing since long before Swanston's observations and are expected to continue, as shown in the photos from Tetra Tech's recent fieldwork (Tetra Tech 2021a, 2021d).

Some of the slide paths above 6th Street appear to be smooth and open, suggesting that rockfall and/or rockslides are relatively frequent, scouring the area with each event, and vegetation cannot readily become re-established. In some cases, the very steep slopes could also reduce the rate of revegetation. In other locations, deciduous vegetation has become re-established, but rockfall continues.

Where debris accumulates in gullies, for example, from bedrock cliffs or bluffs upslope, and/or from debris slides within the gullies, the potential exists for that debris to eventually become part of a debris flow. Small debris flows tend to accumulate in wedges in gullies, until a combination of debris and extreme precipitation or rapid snowmelt results in much larger debris flow event that can scour out the gully. Also, the addition of more debris from ongoing failures upslope could potentially result in slope failures resulting from overloading of debris on the slope, especially if combined with heavy rainfall or a rapid snowmelt. See also the discussions about debris flows in Technical Memo #2, Question #9, and Technical Memo #3, Question #4 (Appendix C of the main report; Tetra Tech 2022b, 2022c).

See Technical Memo #3 for excerpts from the mapping and photos from the slopes around Starr Hill.

4.0 GASTINEAU AVENUE (SLOPES OF MT. ROBERTS)

4.1 General Considerations

Two general areas are considered along Mt. Roberts with respect to rockfall or rockslides:

- Past and probable future natural slope instabilities originating on natural terrain, and becoming incorporated into debris lobes on open slopes or in gullies (most of the length of the current Mt. Roberts Study Area); and
- The potential very large deep-seated bedrock slide southeast of Snowslide Creek.

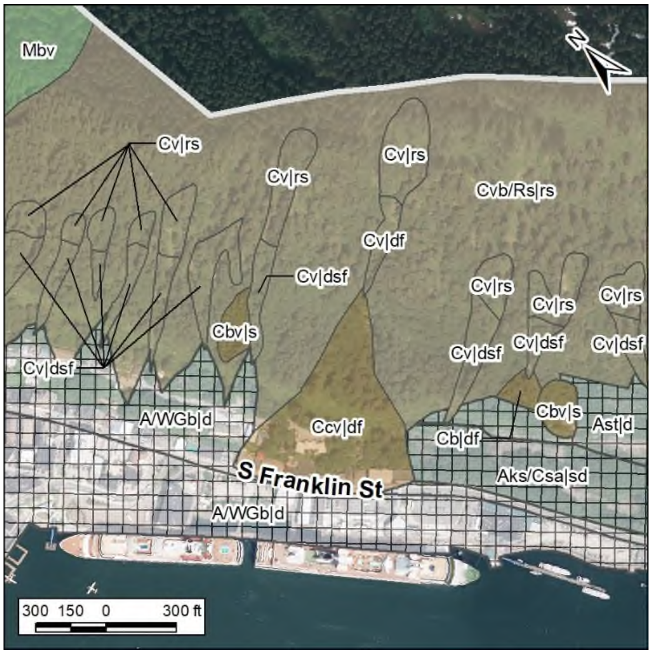
In the context of the question to be answered from Section 2.0, only the first of these items can be addressed with the information currently available. The evaluation of natural slope instabilities is based on the slope observations made during the mapping project and is applicable to the entire slope of Mt. Roberts within the Study Area (Tetra Tech 2021a).

4.2 Rockfalls and Rockslides

In general, the same considerations as noted in Section 3.0 for Starr Hill also apply to Mt. Roberts. For example, the bedding planes of the bedrock on Mt. Roberts also dip into the slope, in this case, towards the northeast. However, the findings in Tetra Tech (2021a) suggested that although rockfall and rockslides (along with debris slides) could initiate in the upper portions of the slide paths on Mt. Roberts, landslide events that reach the lower slopes tend to consist of debris flows or debris slides. Those debris flows or debris slides could incorporate rock fragments originating from areas of bedrock outcrops within the colluvium on the mid to lower slopes or, in the case of Snowslide Creek, also from further upslope where the surficial materials consist mostly of bedrock. This does not mean that such events are less severe than rockfall or rockslide events, only that the length of the slope means that there could be a few different types of landslide events between the top and bottom of the slope. Just as for Starr Hill, wherever rockfall and rockslide processes are occurring now, these are the kinds of processes that have been ongoing for decades and centuries, and they are expected to continue.

The processes described for Starr Hill are the same as on Mt. Roberts, though the slope length is greater on Mt. Roberts, and although debris slides on open slopes are often similar in size to those above Starr Hill, larger events are possible, particularly for debris flows or debris slides within gullies (see Figures 1.4b, 1.4c, 1.5b, and 1.5c in Tetra Tech 2021a). In general, however, along the upper slopes of Mt. Roberts, where bedrock is more common at ground surface than colluvium (60% to 75% bedrock), or *much* more common than colluvium (80% to 95% bedrock), the slopes are considered more stable (rated *Moderate*) than the lower slopes that have more colluvium than bedrock (rated *High* or *Severe*). The only places where that rule-of thumb does not apply on Mt. Roberts is the potential very large deep-seated bedrock slide southeast of Snowslide Creek, and the three very large debris-flow initiation zones leading into Snowslide Creek itself (all rated *Severe*).

A summary of Tetra Tech's mapping near the northwest end of Mt. Roberts is shown in Figure 1, and the southeast end of the Study Area along Mt. Roberts is shown below in Figure 2, both with surficial geology on the left and landslide hazard designation mapping on the right. There is a clear correlation between the type and shapes of the surficial geology units and the landslide hazard designations.



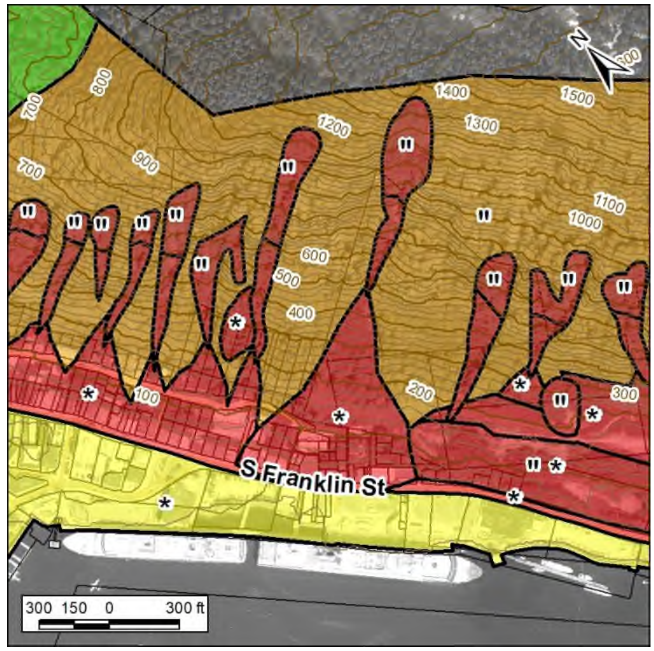


Figure 1: Excerpts from Figure 1.3b Surficial Geology (left) and Figures 1.6c and 1.6h Landslide Hazard Designation Mapping (right).

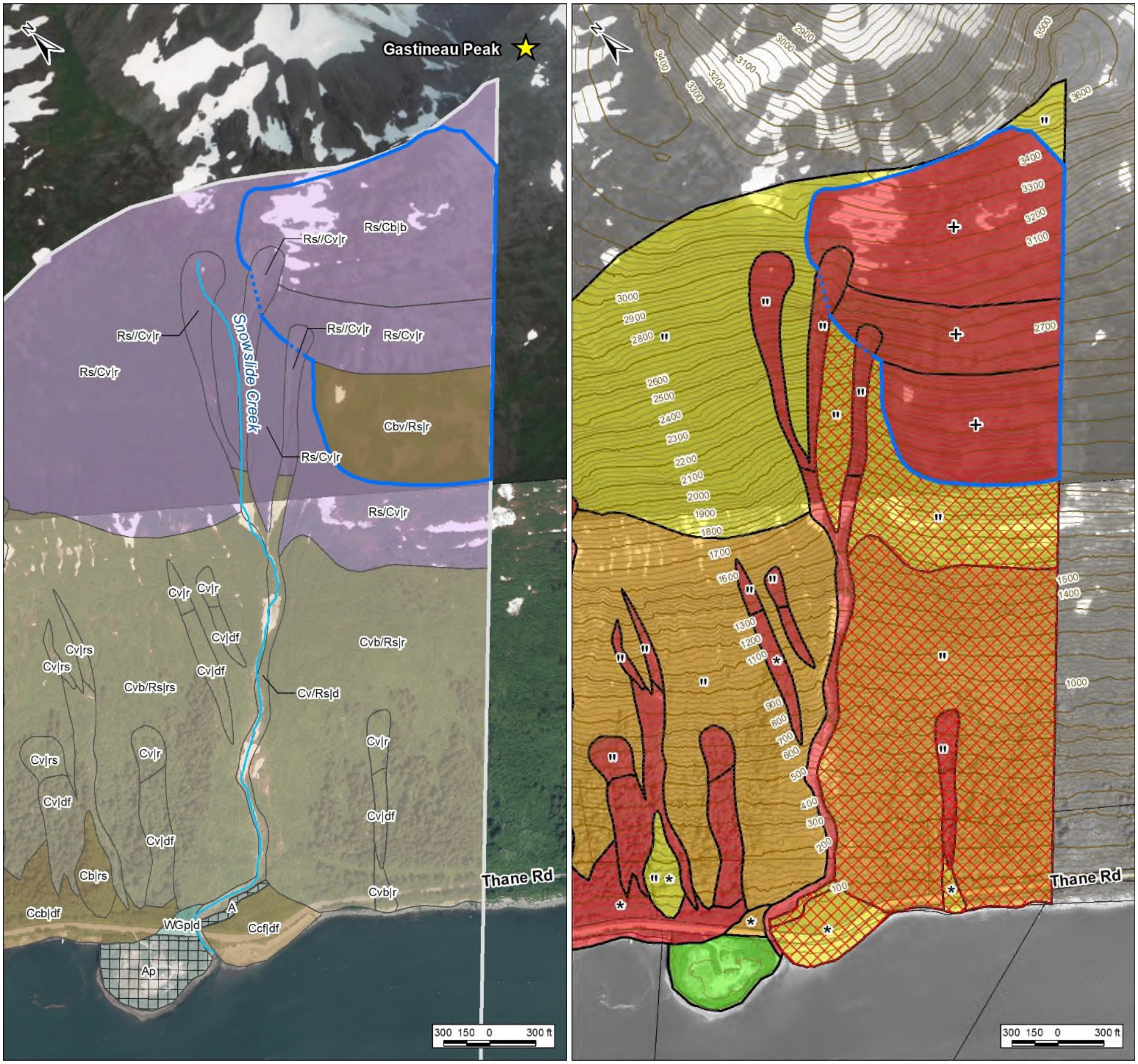


Figure 2: Excerpts from Figure 1.3c Surficial Geology (left) and Figures 1.6e and 1.6f Landslide Hazard Designation Mapping (right).

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This report and its contents are intended for the sole use of the City and Borough of Juneau and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the City and Borough of Juneau and its agents, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

6.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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Prepared by:
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REFERENCES

Swanston, D. (1972). Mass Wasting Hazard Inventory and Land Use Control for the City and Borough of Juneau. Appendix II. Report to the City and Borough of Juneau, Alaska.

Tetra Tech Canada Inc. (Tetra Tech), 2021. Downtown Juneau Landslide and Avalanche Assessment. Prepared for the City and Borough of Juneau (CBJ), Issued for Review (3rd Draft). Dated May 28, 2021. File Number: 704-ENG.EARC03168-01.

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GEOTECHNICAL

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TECHNICAL MEMO

ISSUED FOR USE

To:	Teri Camery (CBJ)	**Date:**	April 27, 2022
c:	Scott Ciambor (CBJ)	**Memo No.:**	7
From:	Rita Kors-Olthof, Vladislav Roujanski	**File:**	704-ENG.EARC03168-02A
Subject:	Considerations for Anthropogenic Terrain at Starr Hill and Gastineau Avenue Downtown Juneau Landslide and Avalanche Hazard Assessment		

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) has prepared an Issued-for-Review (3rd Draft) Report, Downtown Juneau Landslide and Avalanche Assessment for the City and Borough of Juneau (CBJ), dated May 28, 2021 (Tetra Tech 2021); and participated in three Landslide and Avalanche Hazard Public Meetings that took place on July 21, August 10, and September 20, 2021.

Following CBJ's initial email request of July 27, 2021, Tetra Tech responded to comments and questions that arose from the July 21, 2021, Public Meeting with a series of three technical memos. These memos were Issued-for-Review to CBJ, along with an email providing supplemental information, and have since been updated (Appendix C in the main report; Tetra Tech 2022a, 2022b, 2022c).

CBJ has now requested a further series of memos to address additional landslide-related questions, as well as a review of historical avalanche data, to address further questions that arose following the August 10 and September 20, 2021, Public Meetings; as well as some follow-up questions from CBJ. The scope is as described in Tetra Tech's proposal of December 9, 2021, with a few modifications as discussed during the kick-off meeting with CBJ on February 8, 2022. All the completed memos will be included in an appendix of the Final Draft Report.

This Technical Memo #7 provides some additional discussion about past and anticipated future slope instabilities potentially related to the past human activities, which shaped anthropogenic, i.e., human-modified terrain within the landslide hazard designations mapped as *Severe* on the slopes above Starr Hill and Gastineau Avenue.

2.0 SCOPE AND METHODS

The primary objective of this memo is to provide some additional background for responding to Question #14 in Technical Memo #3 (Appendix C in the main report; Tetra Tech 2022c). Since the potential influences of anthropogenic (human-modified) terrain can also affect the performance of these slopes, some additional interpretation and evaluation of these types of influences has also been considered. Specific tasks included the following:

- Review landslide hazard mapping;
- Locate suitable photographs illustrating landslide hazards in the above-noted map areas, if/as needed;
- Prepare map excerpts, if/as needed;
- Refer to information presented previously in other technical memos, as applicable; and

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- Prepare Technical Memo, providing descriptions and/or comparisons, as needed.

3.0 STARR HILL

3.1 General Considerations

The slope conditions around the Starr Hill subdivision were discussed in detail in Technical Memo #3 (Appendix C in the main report; Tetra Tech 2022c). Portions of these slopes are potentially affected by anthropogenic changes (human-made modifications). Above Starr Hill, such modifications mostly include the presence of trails, some of which are related to recreational hiking and access to the views from Mt. Roberts, and some of which are related to powerline alignments and/or possible former mining-related trails.

3.2 Effects of Human-Modified Terrain

Technical Memo #3 provides an overview of the overall slope conditions above the Starr Hill subdivision, along with numerous photos and map excerpts. The main influence of human-modified terrain on the slopes around Starr Hill is the likelihood that earthworks along trails (and possibly the powerline alignments) might have blocked some of the natural swales and gullies that would ordinarily carry surface water runoff. Oversteepened cutslopes, or oversteepened or sidecast fillslopes, if present, also have the potential to result in, or contribute to, slope failures. The presence of human modifications on slopes also has implications for anticipating which slopes or slope sections might be more susceptible to landslides in the future, particularly if surface water drainage modifications or cuts and fills have disrupted the natural slope conditions. Figures 1 through 3 below present a few examples of former and/or active trails and other linear infrastructure on the slopes above Starr Hill. Conceivably, there could be still more trails not yet discovered on the imagery or historical photos.

As noted in Technical Memo #3, Question #12, surface water drainage along trails and other linear infrastructure, whether abandoned or actively in use, should be purposefully managed, so that the original natural drainage paths across these human-made features can be preserved or restored. For a detailed evaluation and recommendations for possible mitigations in human-modified terrain, a purpose-specific field investigation would be needed and is not part of the current scope. Recommendations for future investigation and evaluation are provided below in Section 5.0.

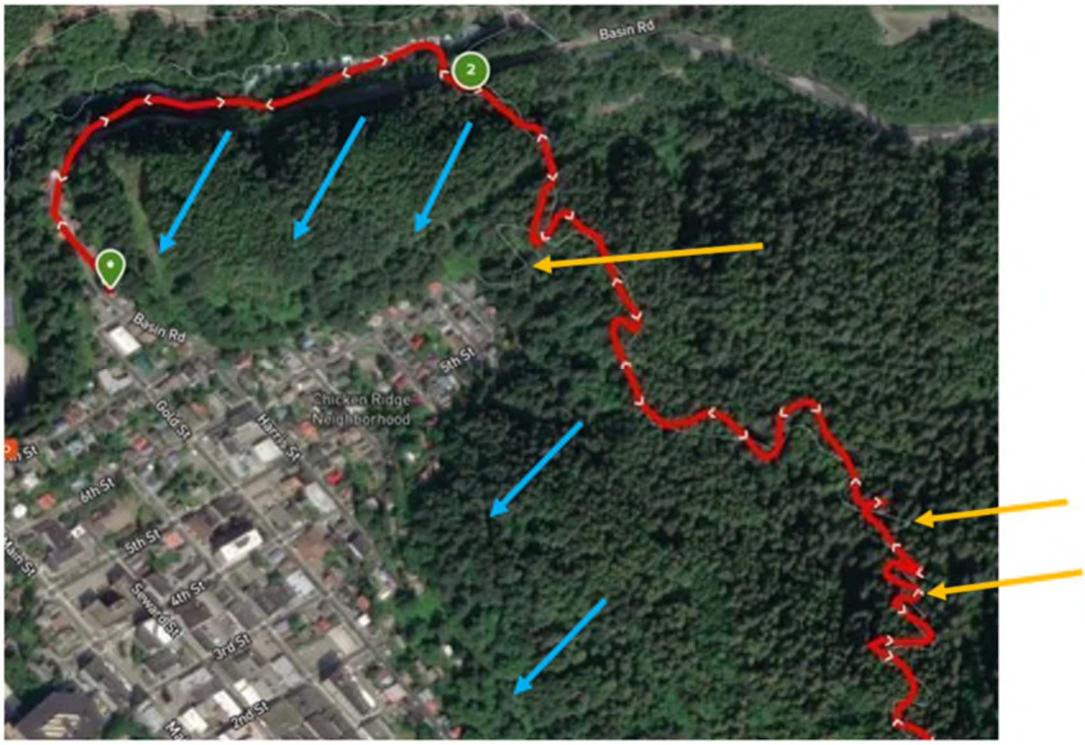

Figure 1: Current Mt. Roberts hiking trail (red) and former hiking trail (pale gray). Switchbacks along new and old trails (orange arrows). Powerline cutlines are also visible (blue arrows). (Image credit: AllTrails 2021.)

Figure 2: Topographic map, showing the same trail alignments as the pale gray lines on Figure 1. Dotted trail above Nelson Street is the trail section officially no longer used. Note switchbacks. (Image credit: AllTrails 2022).

Figure 3: View of Mt. Maria and Mt. Roberts from Mt. Juneau, circa 1935. Note possible old forestry trail on the slopes above Starr Hill (red arrow) and the former Alaska Juneau Gold Mining Company (AJGMC) tramway (blue arrow). (Photo credit: Alaska State Library – Historical Collections, ASL-P87-0542, Winter & Pond. ASL 2022a.)

4.0 GASTINEAU AVENUE (SLOPES OF MT. ROBERTS)

4.1 General Considerations

Several past landslides on the slopes above Gastineau Avenue and South Franklin Avenue on Mt. Roberts were considered in Technical Memo #3, Question #14 (Tetra Tech 2021d). Of particular interest in that question was whether past landslides, such as those on deforested slopes in the vicinity of the siteworks of the former Alaska Juneau Gold Mining Company (AJGMC), should be considered representative of the potential for future landslides. The implication was that, because the logged slopes had revegetated, and mining-related blasting and water discharge were no longer taking place, landslides might not be as common as they once were on this slope. The answer to that question in Technical Memo #3 was that some of the landslides appeared to have been directly attributable to the mining-related siteworks or operations (e.g., the leaky flume apparently contributing to the January 2, 1920 landslide), or possibly suspicious (e.g., the tension crack seen below the flume in the November 22, 1936 landslide), but on the other hand, the cause of some of the landslides (e.g., the 1952 landslide) could *not* be directly attributed to the former mining infrastructure or operations.

What has not yet been directly considered for the Mt. Roberts slope is the possibility that the remnants of the tramway/railway grade, as well as roads, trails, or powerlines on Mt. Roberts might *still* potentially affect slope stability on a large portion of the lower slope of Mt. Roberts, between the north flank at Starr Hill to at least as far south as the northwest end of Thane Road (Figure 1a, 1b), even though the mine has not been operating for decades (since 1944). The premise for the slopes on Mt. Roberts is the same as that for the slopes above Starr Hill. It is important to account for the following:

- Past and probable future natural slope instabilities originating on natural terrain, not specifically modified or influenced by human activities, addressed in Technical Memos #3 and #6 for this slope (Appendix C in the main report; Tetra Tech 2022c, 2022f); and
- Past and potential future slope instabilities in anthropogenic (human-modified) terrain, including areas of previous logging, old roads, trails, powerlines, and tramway/railway grades (this memo).

The evaluation of natural slope instabilities is based on the slope observations made during the mapping project and is applicable to the entire slope of Mt. Roberts within the Study Area (see main report).

At this time, only a preliminary evaluation of the effects of human-modified terrain is possible, based on the slope observations made during the mapping project, a subsequent LiDAR data review and air photo 3D-analysis in PurVIEW, and a review of historical photos and records from the Alaska State Archives – Historical Collections (2022a through 2022e), documenting a range of mass movement events on this slope. For a detailed evaluation and recommendations for possible mitigations in human-modified terrain, a purpose-specific field investigation would be needed and is not part of the current scope. Recommendations for future investigation and evaluation are provided below in Section 5.0. Some of the observed effects of human-induced terrain disturbance are described in Section 4.2.

4.2 Effects of Human-Modified Terrain

Some of the potential and documented human-induced slope instabilities were discussed in Technical Memo #3 (Appendix C in the main report; Tetra Tech 2022c). Subsequent desktop evaluation on the slope along Gastineau Avenue has revealed some additional useful information, which has been used to update Question/Comment #14 in Technical Memo #3, and is discussed in detail here.

Tetra Tech used numerous historical photos from the Alaska State Archives – Historical Collections (2022a through 2022e), maps, plans, and the LiDAR mapping for the landmarking of several major landslides that took place on the southeast (Gastineau Channel) side of Mt. Roberts, and previously described in Technical Memo #3, Question #14 (Appendix C in the main report; Tetra Tech 2022c). In one case, for the January 2, 1920 landslide, it was possible to directly compare a documented “before-and-after” set of photos (Figures 4 and 5), with confirmation of most of the structures available from the 1914 survey plans. In other cases, such as the November 22, 1936, landslide, for which photos of the slope had uncertain dates, a timeline of photos and maps was developed based on structures or slope features that were present or absent.

Figures 4 through 7 below present a few examples of former and/or active linear infrastructure, such as old roads, trails, powerlines, and tramway/railway grades, on the slopes above Gastineau Avenue on Mt. Roberts where landslides have occurred. Figure 1a, 1b, attached, provides some additional interpretation of the current slope conditions, the locations of some of the old mining infrastructure, and the locations of a few of the major slides over the past century. Conceivably, there could be more such features on the slope that have not yet been discovered on the imagery or historical photos. To reduce the likelihood of unexpected contributions from infrastructure to landslide occurrences or severity, more information could be collected on those features, and a decision-making process implemented to decide what to do about them, if anything.

Figure 4: This "before" photo is from after 1914 but before 1920, and possibly from the summer of 1919. The stairway at center-right is Bulger Way. The pier-like structure is Gastineau Avenue. Decker Way (a stairway) is located just beyond the left edge of the photo. Note the numerous structures between Decker Way and Bulger Way before the landslide. Just up and left of the smoking-chimney building is the tenement building that tipped and rotated clockwise during the landslide (see Figure 5). Top right is the former Alaska Juneau Gold Mining Company (AJGMC) office building. (Photo credit: Alaska State Library – Historical Collections, PCA0154-295, Snow Family Photograph Collection. ASL 2022b.)

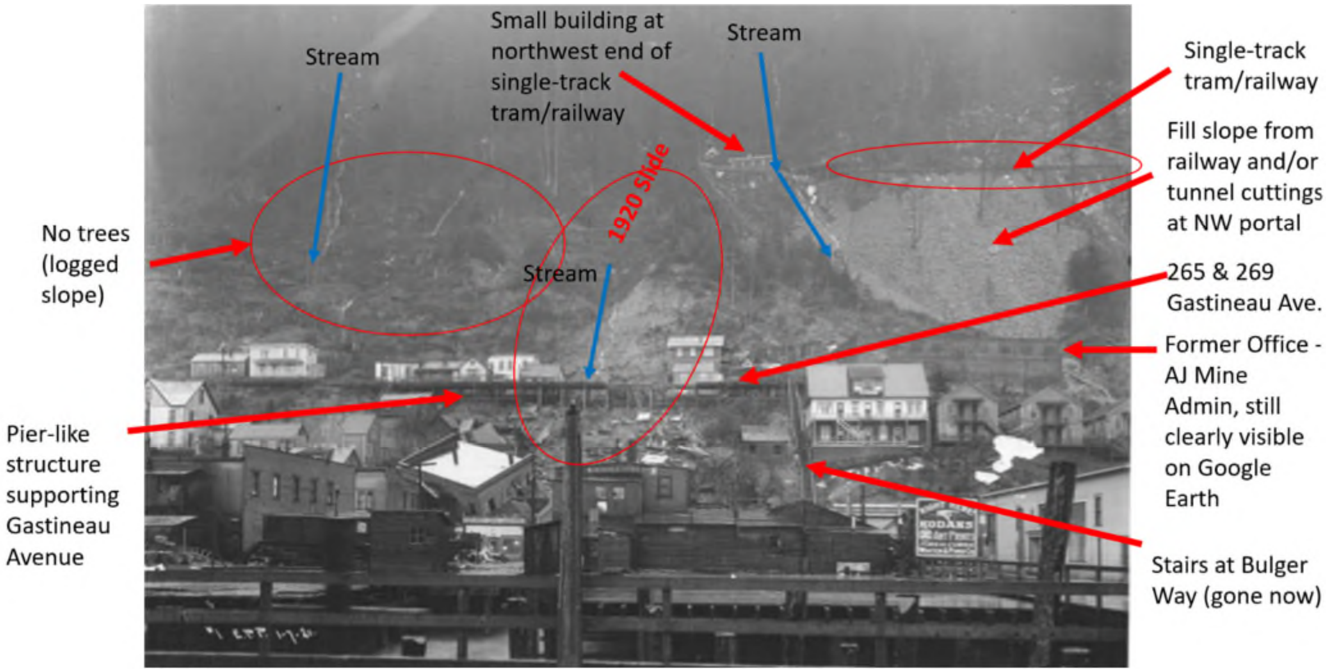

Figure 5: Compare to Figure 4 and note numerous missing, destroyed and/or shifted structures. Slope right of small building failed in November 22, 1936 landslide. (Photo credit: Alaska State Library – Historical Collections, ASL-P87-1223, Winter & Pond, January 7, 1920; cropped to fit page, markups from CBJ and Tetra Tech. ASL 2022c.)

Figure 6: Two apparent debris paths from November 22, 1936, landslide (red arrows, see also Figure 1a, 1b attached). Structure at center-left was the Juneau Cold Storage Company building, later replaced. Debris ran up against the S. Franklin St. side of Juneau Cold Storage, moved the Madsen Building downslope, destroyed several buildings, and killed 15 people. (Photo credit: Alaska State Library – Historical Collections, ASL-P134-312-4, date uncertain, cropped to fit. ASL 2022d.)

Figure 7: Excerpt from 1971 air photo mosaic showing a reactivated slope failure at the site of the 1936 landslide (red arrow). Since the 1968 air photo mosaic showed little exposed soil at this location, this slope might continue to slough and ravel periodically over time, confirmed by Tetra Tech's mapping of mass movement features (Tetra Tech 2021a). (Image credit: Alaska State Library – Historical Collections, ASL-_Map_Case_Juneau_1971, ALS 2022e.)

5.0 RECOMMENDATIONS FOR FUTURE WORK

A forestry road-deactivation format for slope review and the preparation of recommendations for proposed mitigations could be considered for future work.

The intent of the work would be to mitigate or reduce the potential for damage resulting from slope instabilities that are attributable to abandoned or active infrastructure on the slope, especially linear infrastructure that tends to alter surface water drainage. It might not be possible to prevent all infrastructure-related slope instabilities but could reduce the likelihood that the infrastructure triggers slope instabilities or that it makes the effects of natural slope instabilities worse.

6.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of City and Borough of Juneau and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than City and Borough of Juneau and their agents, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

7.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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Enclosure: Limitations on Use of this Document
Figures 1a, 1b

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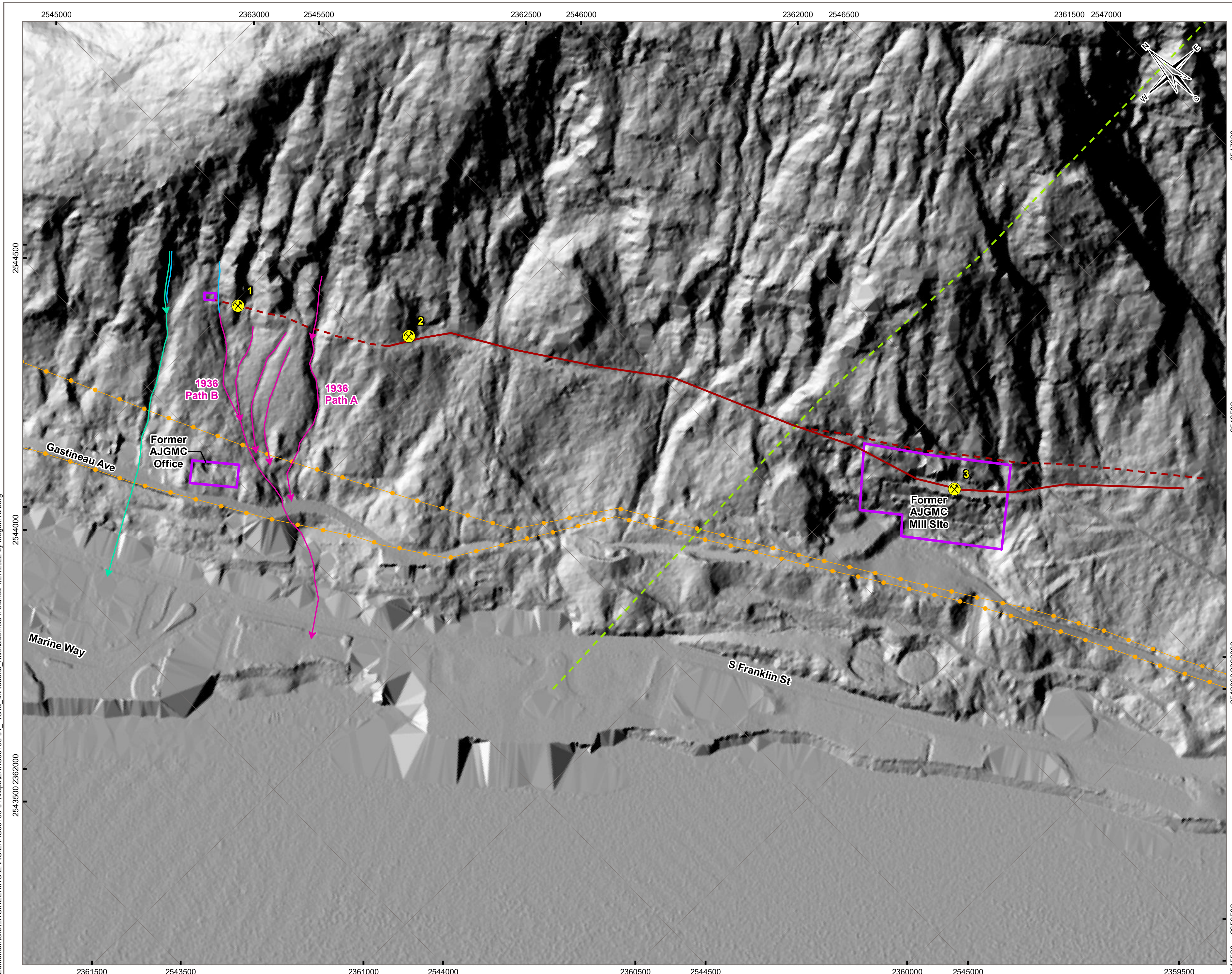

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LEGEND

- Mine Portal
- 1 Interpreted from the 1948 air photos and 1916 drawing from Alaska-Juneau Gold Mining Co. (see References)
- 2 Interpreted from the 1948 air photos and 1916 drawing from Alaska-Juneau Gold Mining Co. (see References), and confirmed by Tetra Tech in the field
- 3 Interpreted from Juneau historical photos (Alaska State Library) and confirmed by Tetra Tech in the field
- 1920 Landslide - Interpreted from the 1948 air photos, historical photos (Collections from Alaska State Library), news reports, summary from Swanston (1972), and geologic mapping from Miller (1975)
- 1936 Landslide - Interpreted from the 1948 air photos, historical photos (Collections from Alaska State Library), summary from Swanston (1972), and geologic mapping from Miller (1975)
- Tramway/Railway Grade - Interpreted from the 1948 air photos and confirmed by Tetra Tech in the field
- Tramway/Railway Grade - Interpreted from the 1948 air photos and Juneau historical photos (Alaska State Library)
- Stream
- Gondola
- Power Line
- Building Footprint

NOTES
Base data source:
Hillshade derived from 2013 LiDAR data provided by CBJ.

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Locations of Infrastructure and Landslides on Mt. Roberts (LiDAR)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	City and Borough of Juneau

Scale: 1:3,000

200 100 0 200
Feet

FILE NO.
EARC03168-01_FIG1a_MtRoberts_Hillshade.mxd

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Figure 1a

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2361500 2543500 2361000 2544000 2360500 2544500 2360000 2545000 2359500

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2547000 2546500 2546000 2360000 2545500 2359500

LEGEND

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- Tramway/Railway Grade - Interpreted from the 1948 air photos and Juneau historical photos (Alaska State Library)
- Stream
- Gondola
- Power Line
- Building Footprint

NOTES
Base data source:
Primary imagery provided by CBJ, 2013.

STATUS
ISSUED FOR USE

JUNEAU LANDSLIDE AND AVALANCHE ASSESSMENT

Locations of Infrastructure and Landslides on Mt. Roberts (Air Photos)

PROJECTION	DATUM	CLIENT
State Plane Alaska Zone 1 5001	NAD83	CITY AND BOROUGH OF JUNEAU

Scale: 1:3,000
200 100 0 200
Feet

TETRA TECH

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DATE
April 27, 2022

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Figure 1b

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The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

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The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary investigation and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to investigate, address or consider and has not investigated, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historic environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional investigation and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

There is a direct correlation between construction activity and structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, as well as the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Where temporary or permanent drainage systems are installed within or around a structure, the systems which will be installed must protect the structure from loss of ground due to internal erosion and must be designed so as to assure continued performance of the drains. Specific design detail of such systems should be developed or reviewed by the geotechnical engineer. Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function.

1.16 BEARING CAPACITY

Design bearing capacities, loads and allowable stresses quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition assumed. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions assumed in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client’s expense upon written request, otherwise samples will be discarded.

APPENDIX D

AVALANCHE MODELLING PARAMETERS AND ASSUMPTIONS

The following Table D.1 presents the main input parameters and assumptions for each of the five avalanche models which were utilized in the avalanche hazard assessment. The avalanche paths were grouped into three main modelling scenarios based on the relative scale of the avalanche paths (large, medium and small scale).

Figures D.1 and D.2 present the polygons used for RAMMS modelling including the release areas and the forest polygons. The release areas are colour-coded based on the path scale and release depth.

Figures D.3 and D.4 present the RAMMS maximum velocity results, with inclusion of the forest polygons.

Table D.1: Statistic and Dynamic Avalanche Modelling Inputs

	α-β	Runout Ratio	PCM	PLK	RAMMS
Large Scale Paths J003, J004, J010, J011, J015, West A-J, T009, T011, T014	Range: Coastal Alaska (McClung and Mears 1991) $\alpha = 0.74\beta + 3.67°$ P = 0.5 and 0.85 Se = 0	Range: Coastal Alaska (McClung and Mears 1991) $\Delta x/X_\beta = u - b \cdot \ln(-\ln(P))$ P = 0.5 and 0.85 u = 0.185 b = 0.108	μ = 0.2-0.4 μ_{powder} = 0.155 M/D = 690-860	μ = 0.25 log(M/D) = 2.75-2.9 R = 0.3	Release depth = 2.0 m Friction Volume: Large Friction Return Period: 300-year Friction Elevations: 700/200 m Release Areas1: 19,257 m² to 149,662 m²
Medium Scale Paths J001, J002A, J005A, J005B, J012, J014, J016 T004, T005, T006, T007, T008			μ = 0.2-0.4 μ_{powder} = 0.155 M/D = 310-690	μ = 0.28-0.32 log(M/D) = 2.35-2.85 R = 0.25-0.3	Release depth = 1.5 m Friction Volume: Medium Friction Return Period: 300-year Friction Elevations: 500/200 m Release Areas1: 3,634 m² to 39,422 m²
Small Scale Paths J000, J002B, J013, J017, J018, J019, J020, J021, J022, J023, J024, J025, J026, G000, G001, G001.5, G002, G003, G004, G005, G006, G007, G008, G009, T000, T001, T002, T003, T010, T012, T013			μ = 0.2-0.4 μ_{powder} = 0.155 M/D = 200-350	μ = 0.28-0.32 log(M/D) = 2.3-2.55 R = 0.2-0.3	Release depth = 1.0 m Friction Volume: Small Friction Return Period: 300-year Friction Elevations: 300/150 m Release Areas1: 391 m² to 11,623 m²

Definitions and Assumptions

- μ: basal sliding friction parameter, increases with segment distance from start zone to runout zone
- M/D: mass to drag ratio (turbulent friction parameter)
- R: Random term in the PLK model
- P: non-exceedance probability
- Δx : Runout distance; $X\beta$: horizontal length from start zone to the β point; u: Location parameter; b: Scale parameter
- α: Alpha angle; β: Beta angle; Se: Standard error
- [1] Release Area is measured as the planimetric area

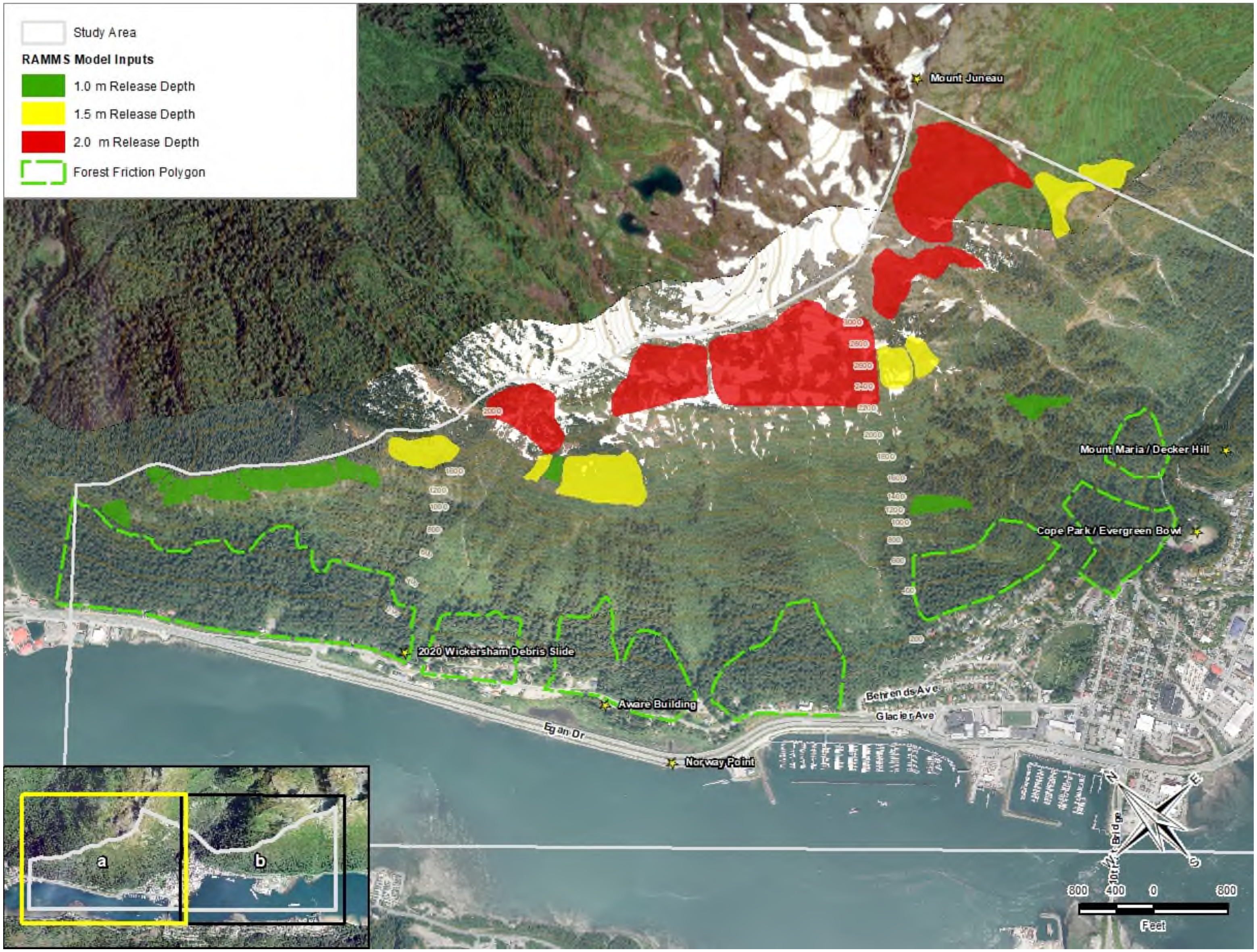

Figure D.1: RAMMS release areas and forest polygons.

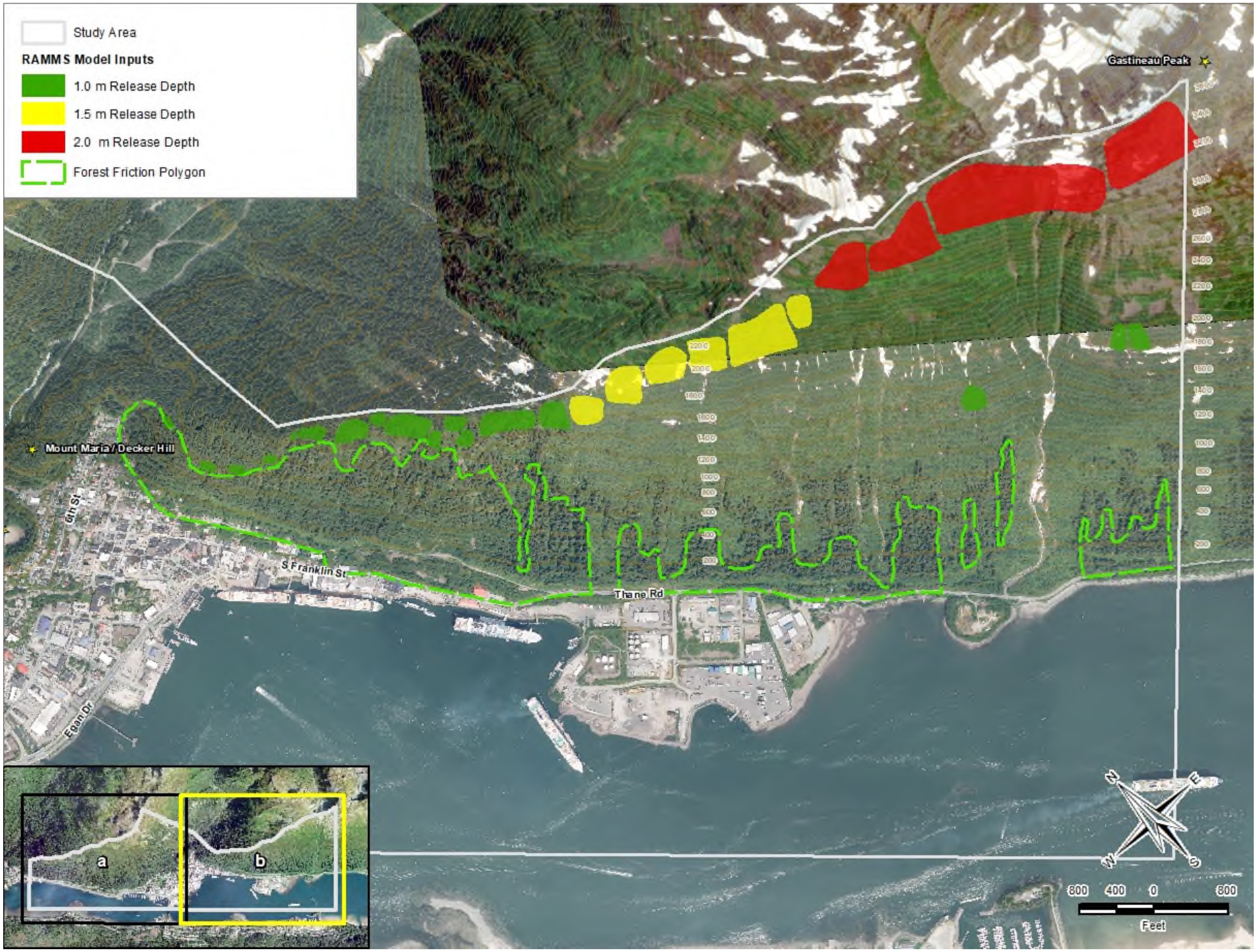

Figure D.2: RAMMS release areas and forest polygons.

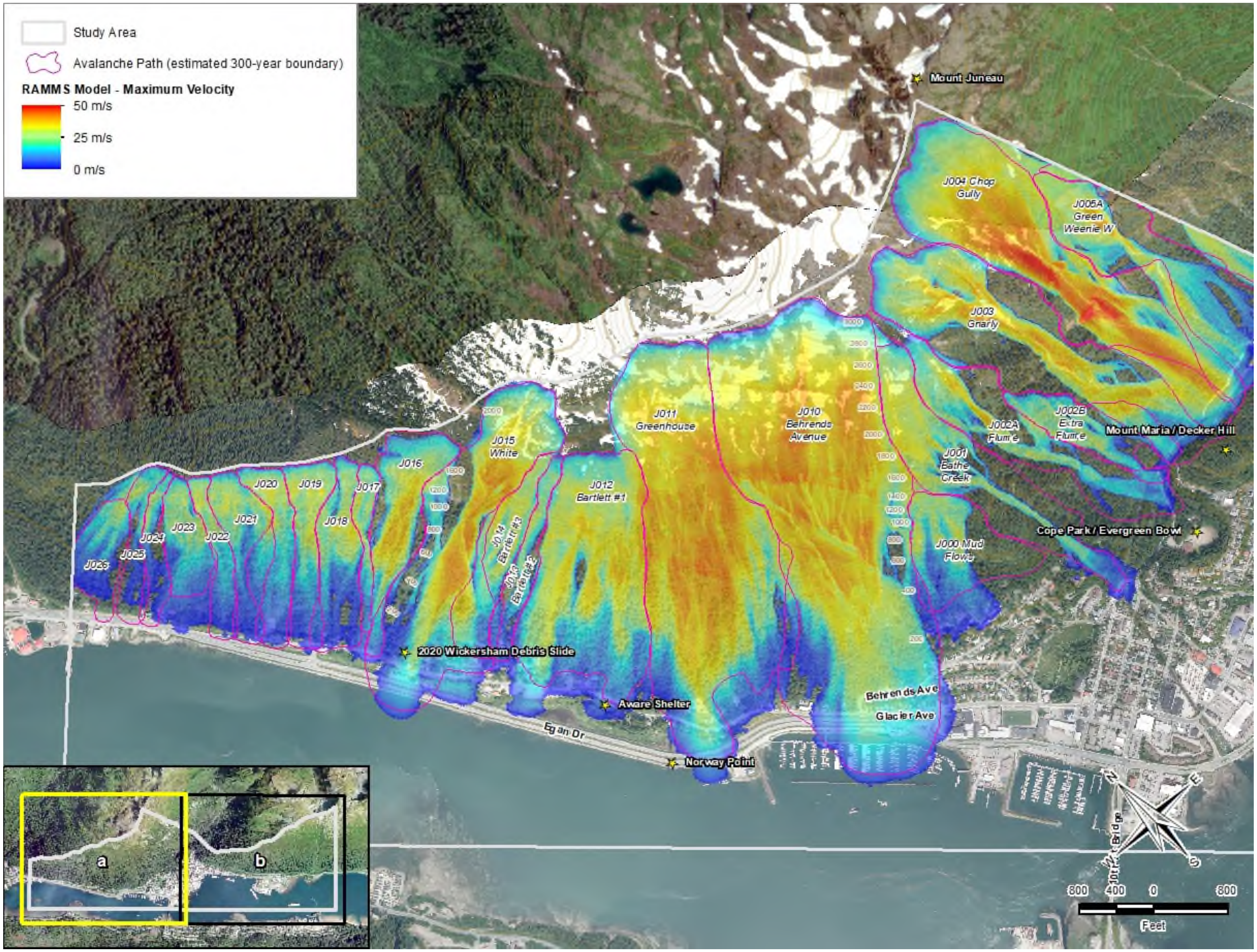

Figure D.3: RAMMS maximum velocity results.

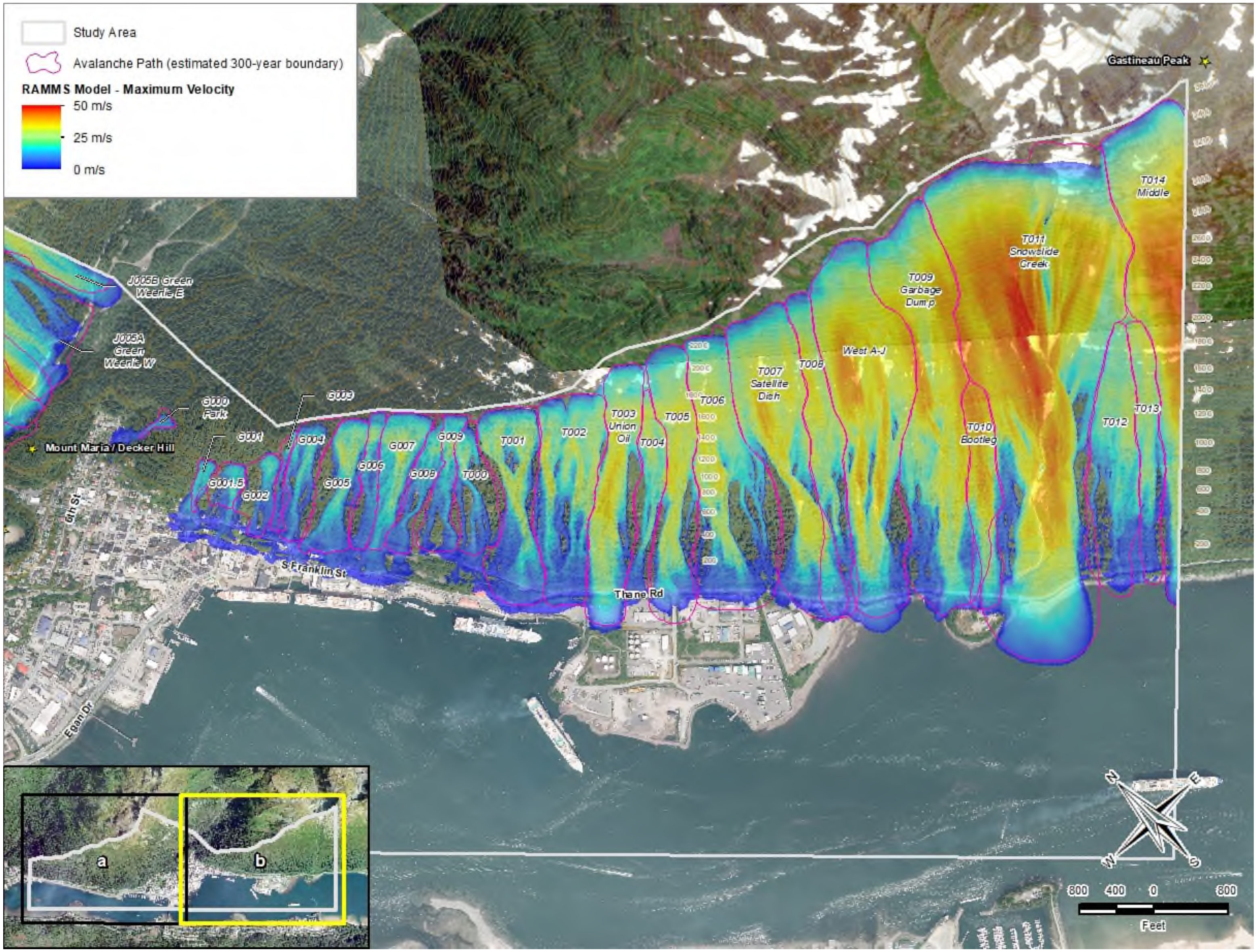

Figure D.4: RAMMS maximum velocity results.

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