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TECHNICAL MEMO

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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

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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*.

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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.

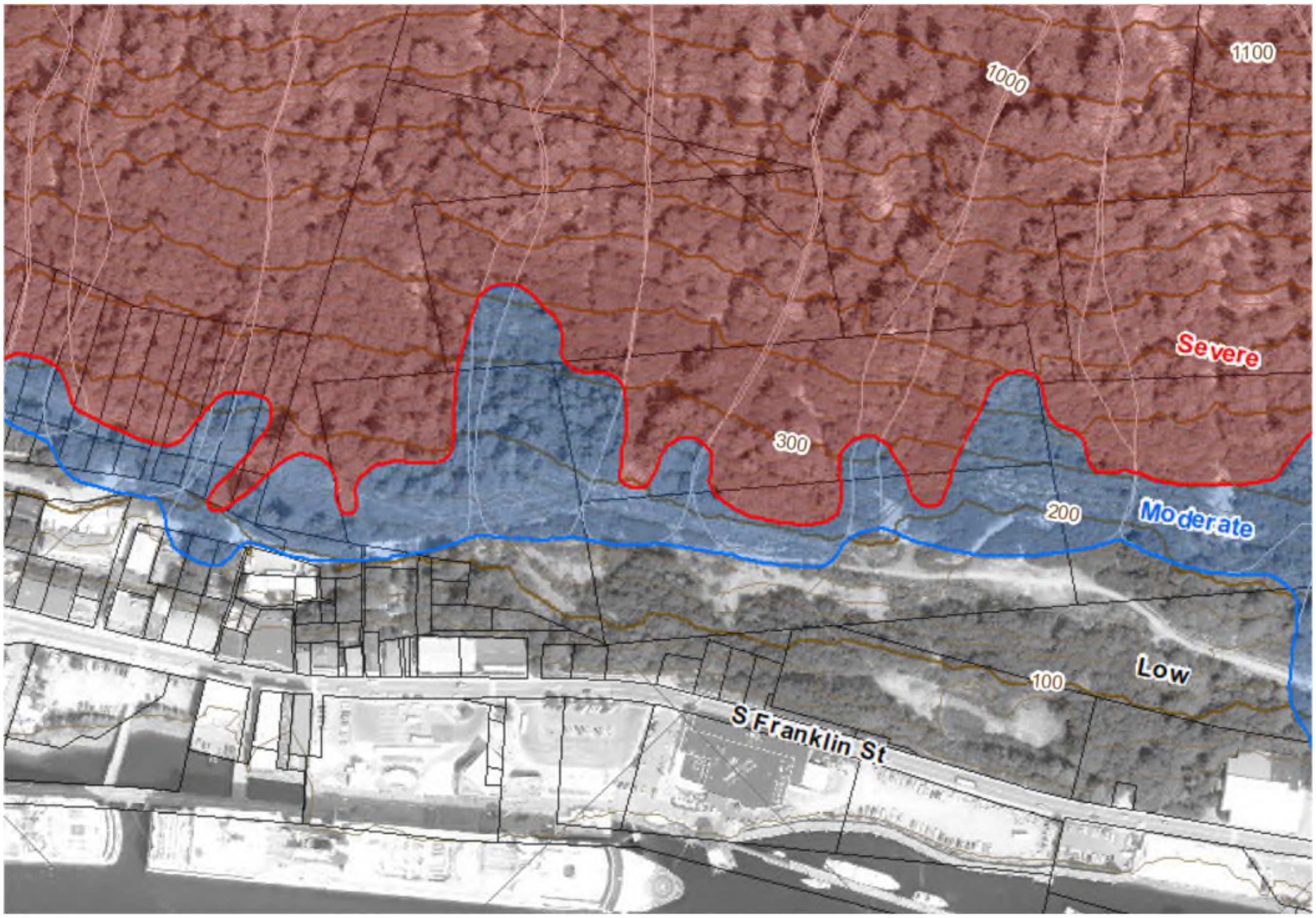

Figure 3: Excerpt from Figure 2.4d in the main report, showing avalanche paths G003 to G009 and T000 (from left to right). The blue fringe shows terrain designated as having *Moderate* avalanche hazard along the toe of Mt. Roberts. In this area, the *Moderate* hazard does not reach South Franklin Street, 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.

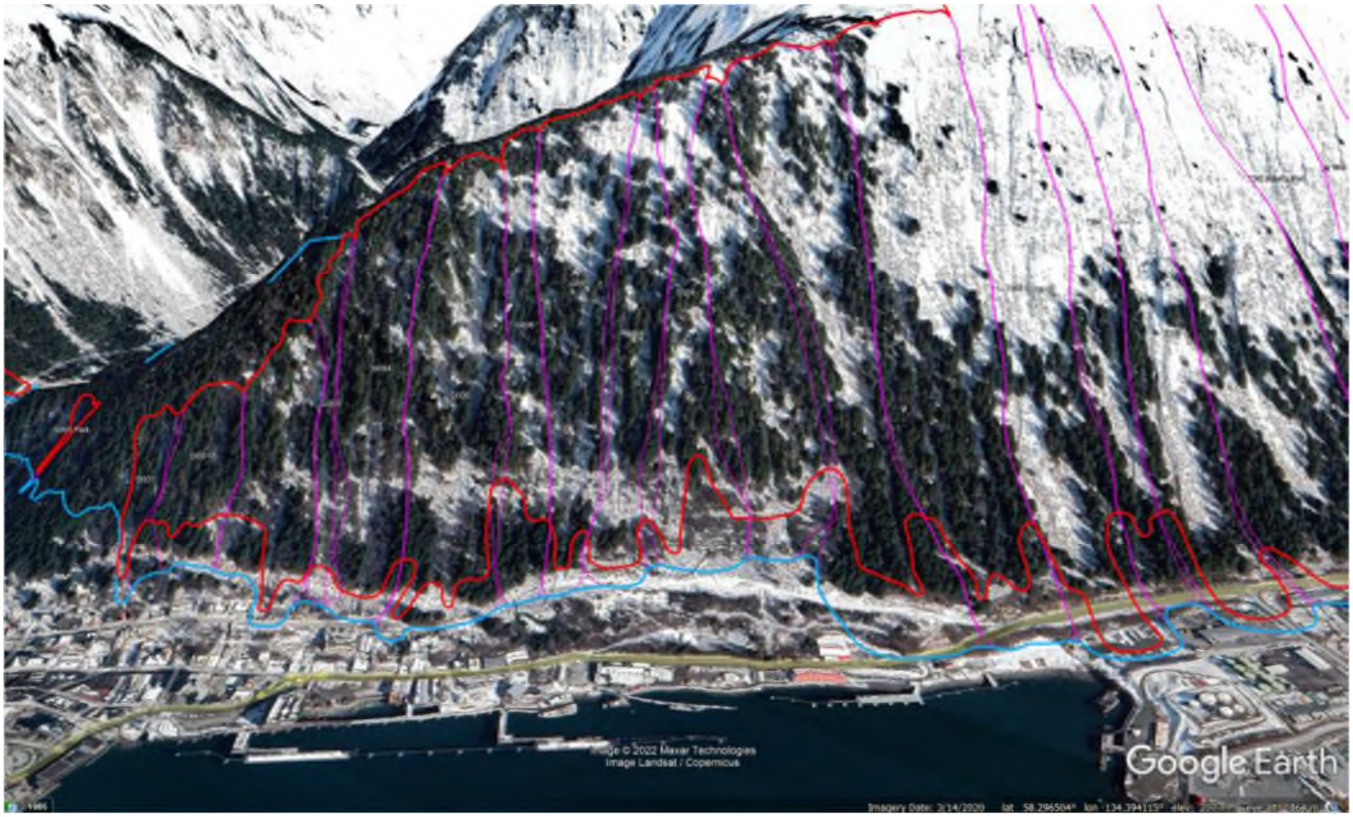

Figure 4b: View of the northern part of Mount Roberts along Gastineau Avenue and South Franklin Street, with avalanche paths and *Moderate*/*Severe* hazard boundaries shown. Note the increasing height (and length) of slope from left to right (northwest to southeast), which increases the runout distance 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.

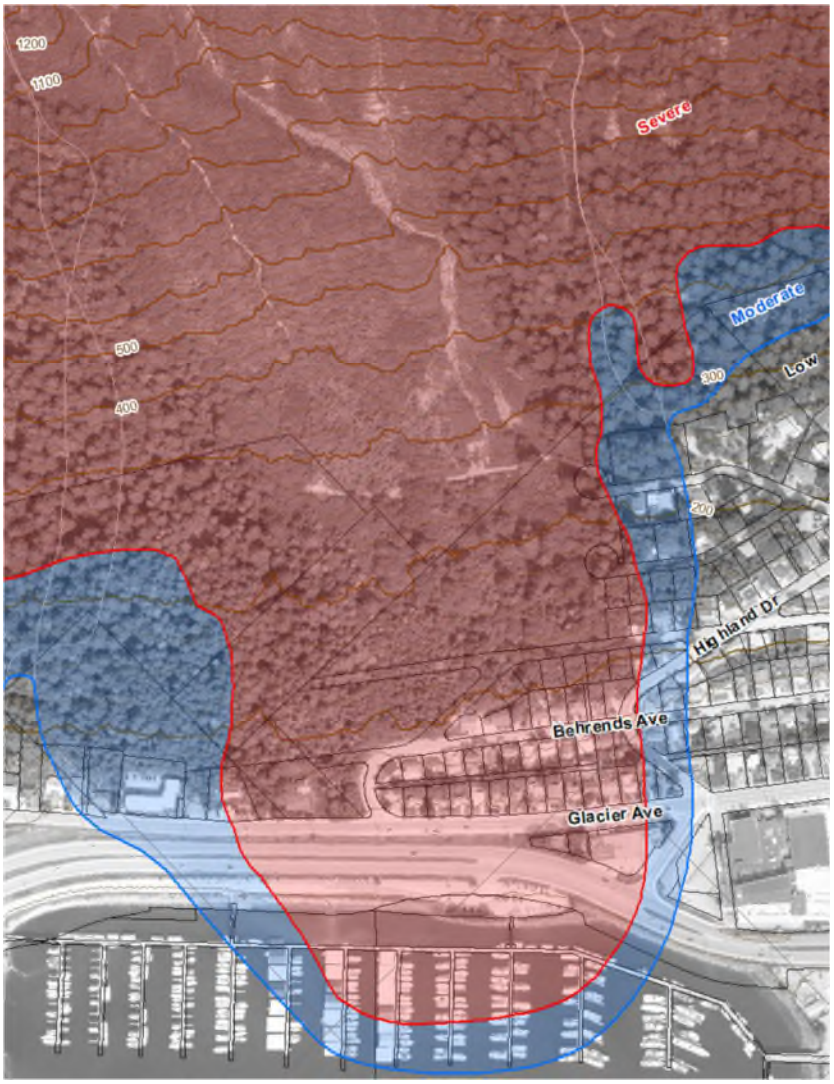

Figure 5: Excerpt from Figure 2.4b showing the major avalanche path at J010 Behrends. Note the distinct trimlines that define the edges of this path, indicating regular avalanche activity within the central part of the path and less frequent avalanche activity on the outside (lateral boundaries) of the 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.

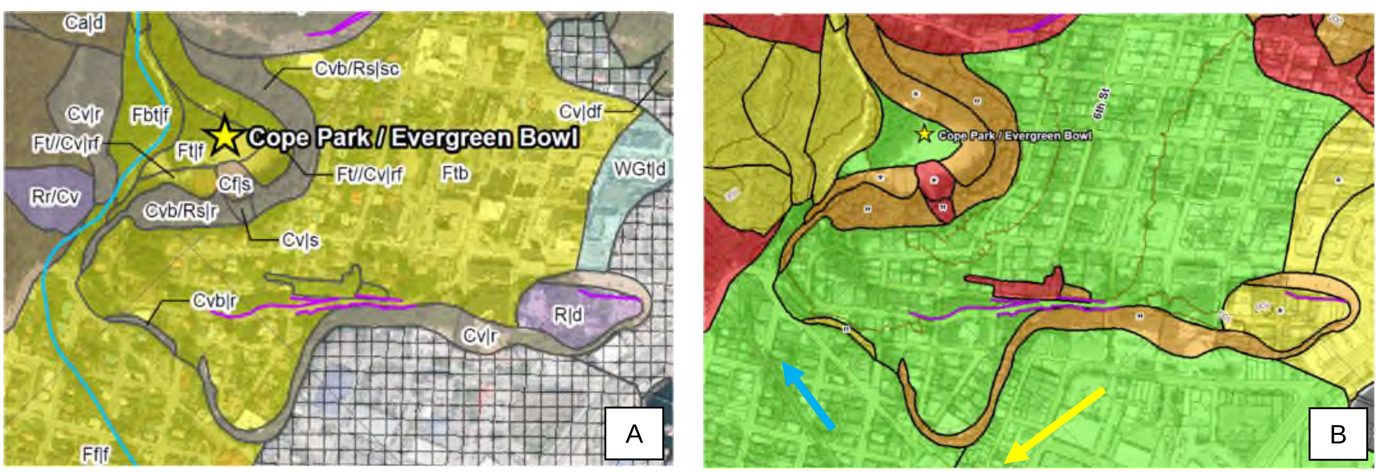

Figure 9: These two map excerpts are from the mapping across the approximate middle of the downtown area. Figure 79A shows the surficial geology, and Figure 9B shows the landslide hazard mapping. Gold Creek is marked as a blue stream along the left side of Figure 9A. Willoughby Avenue is in the cross-hatched 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).

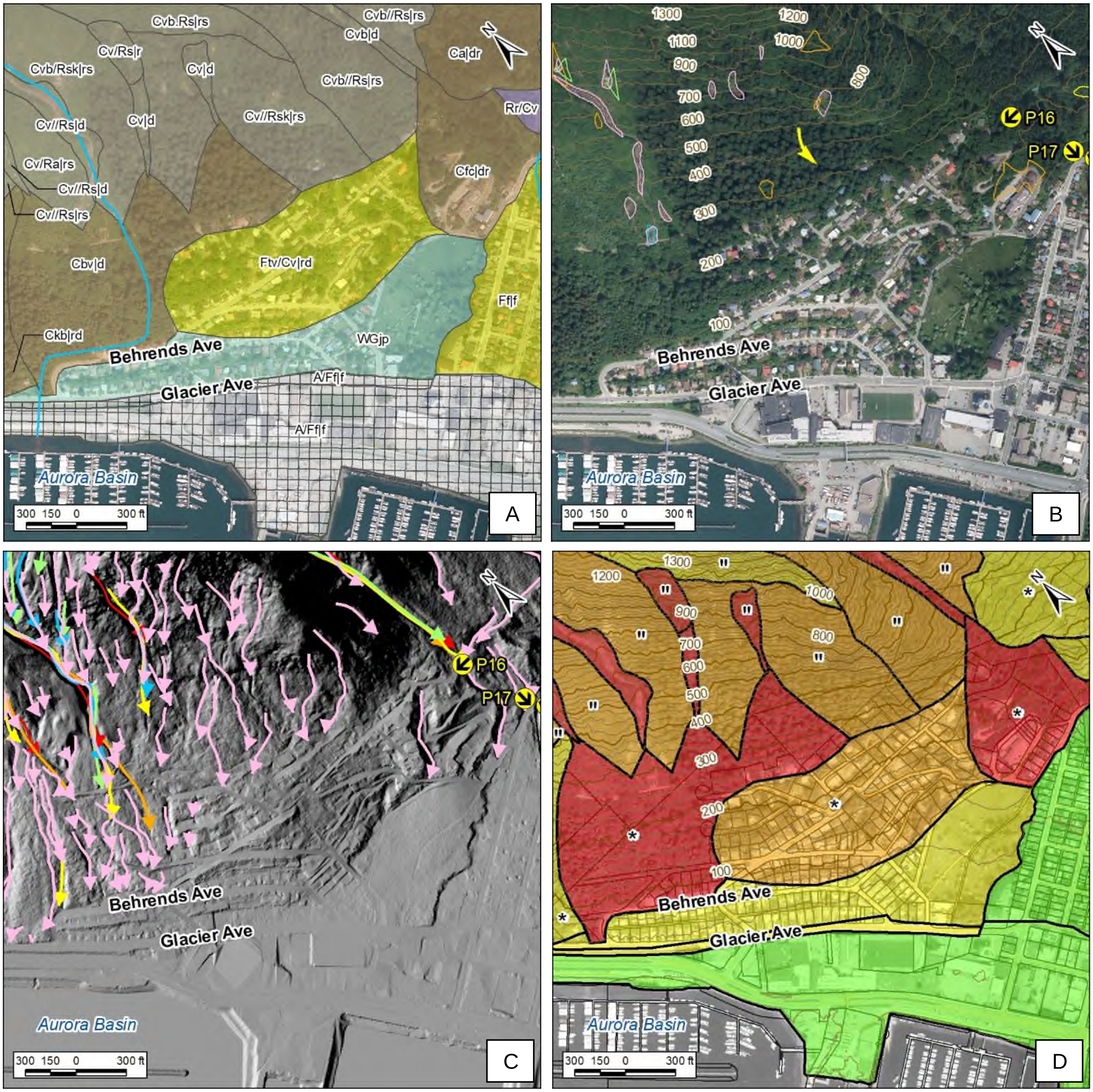

Figure 11: These mapping excerpts show *Moderate* hazard terrain from part of the Juneau Study Area. Figures 11A through 11D. The terrain mapped as glaciomarine (WG) in Figure 11A reveals no slope movement features in Figure 11B, and no gully erosion features in Figure 11C. That results in a landslide 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.

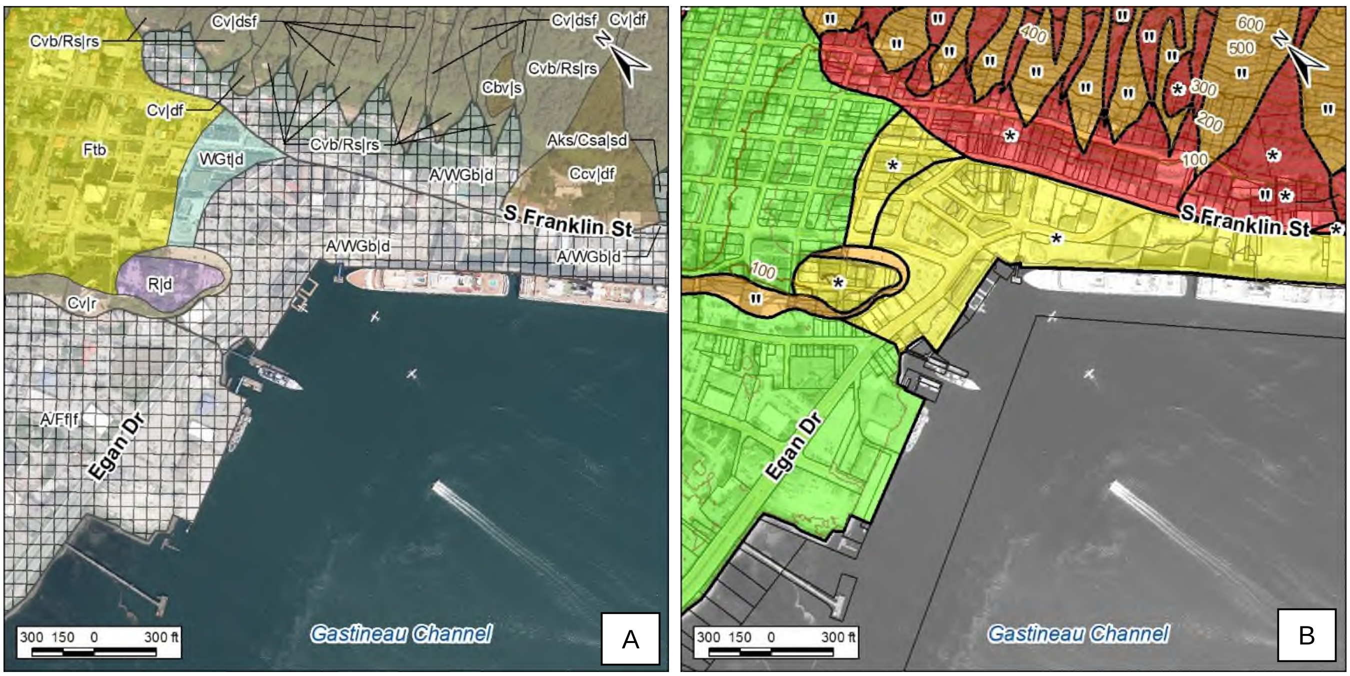

Figure 12: These mapping excerpts show *Moderate* hazard terrain from another part of the Downtown Juneau Study Area. Figures 12A and 12B are from the Downtown Historic District, the east leg of Tidelands, and the top of Telephone Hill. At center-left of Figure 12A, there is glaciomarine terrain (WG), 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).

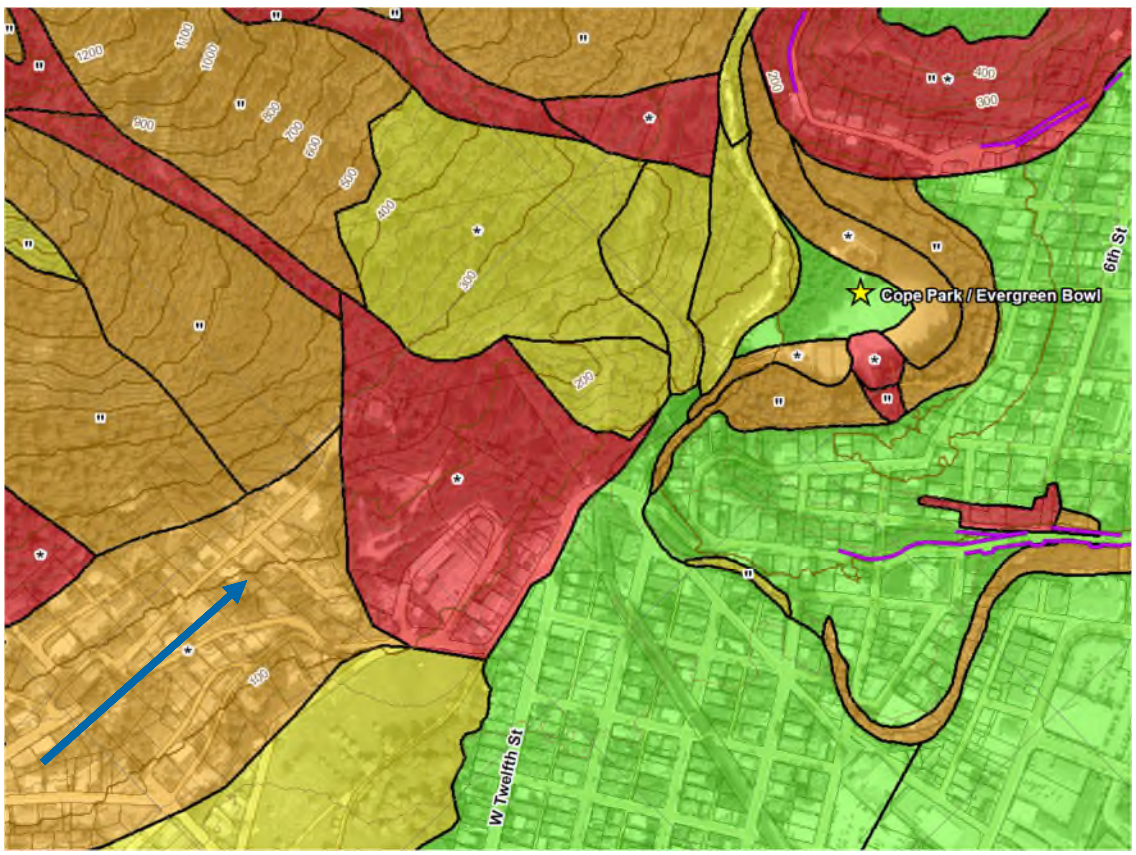

Figure 14: Excerpt from the landslide hazard mapping. Blue arrow on Figure 14 is direction of look on Figure 15, and back end of arrow is lower edge of photo in Figure 15. (See also Figures 9 and 11 for connecting map areas.)

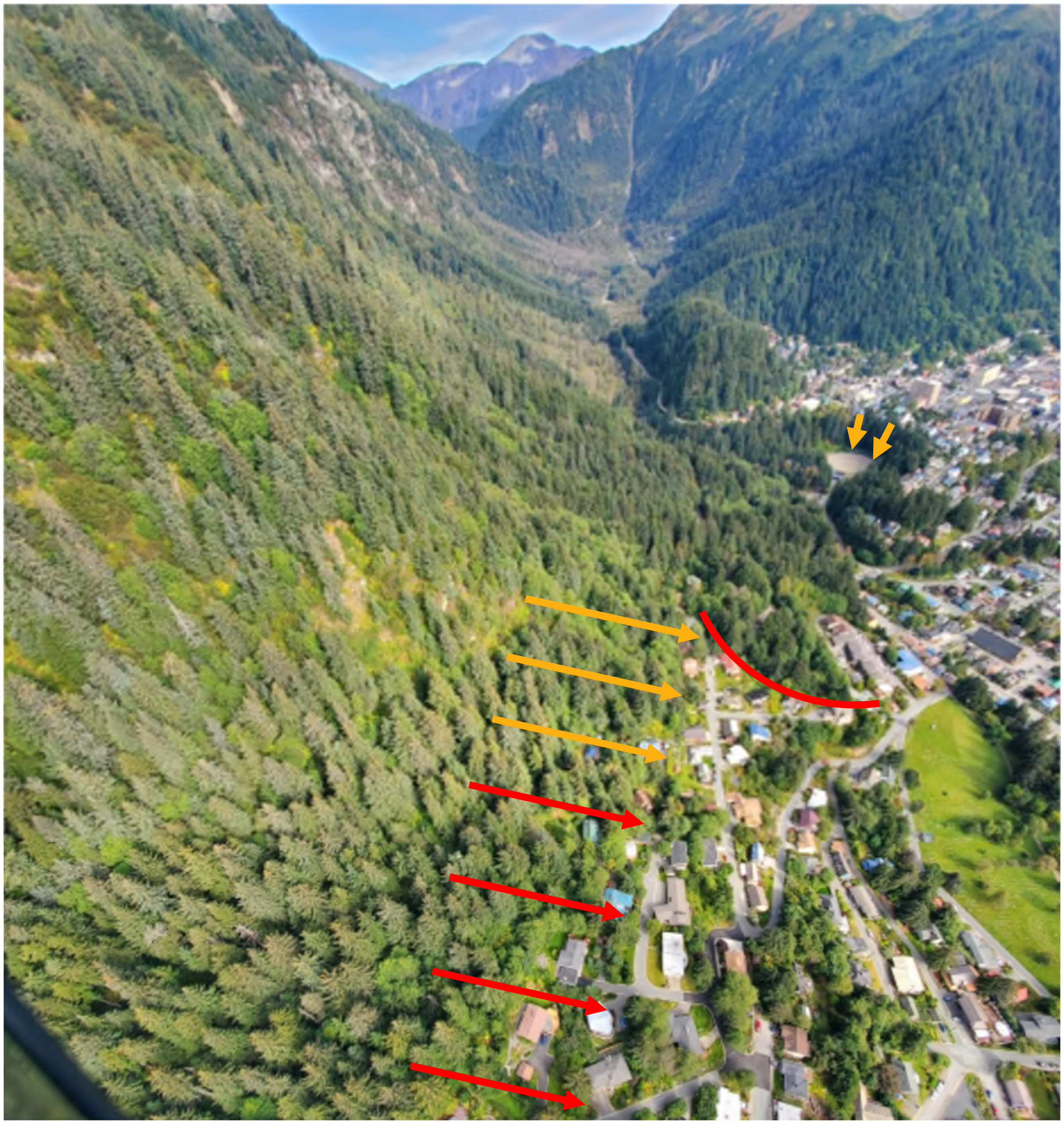

Figure 15: View from the helicopter looking east towards Last Chance Basin (see direction of look on Figure 14). Upper Evergreen Avenue is approximately in line with direction of look.

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.

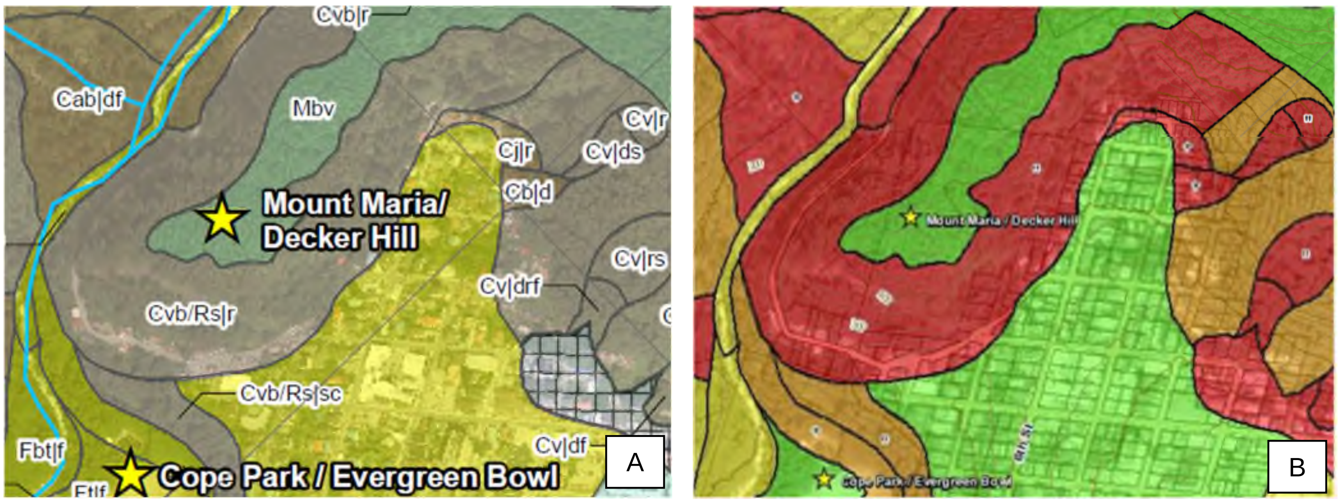

Figure 17: These two map excerpts are from the mapping slopes above Starr Hill. Figure 17A shows the surficial geology, and Figure 17B shows the landslide hazard designation mapping. Around Starr Hill, the green signifies *Low* hazard, the orange is *High* hazard, and the red is *Severe* hazard. See 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.

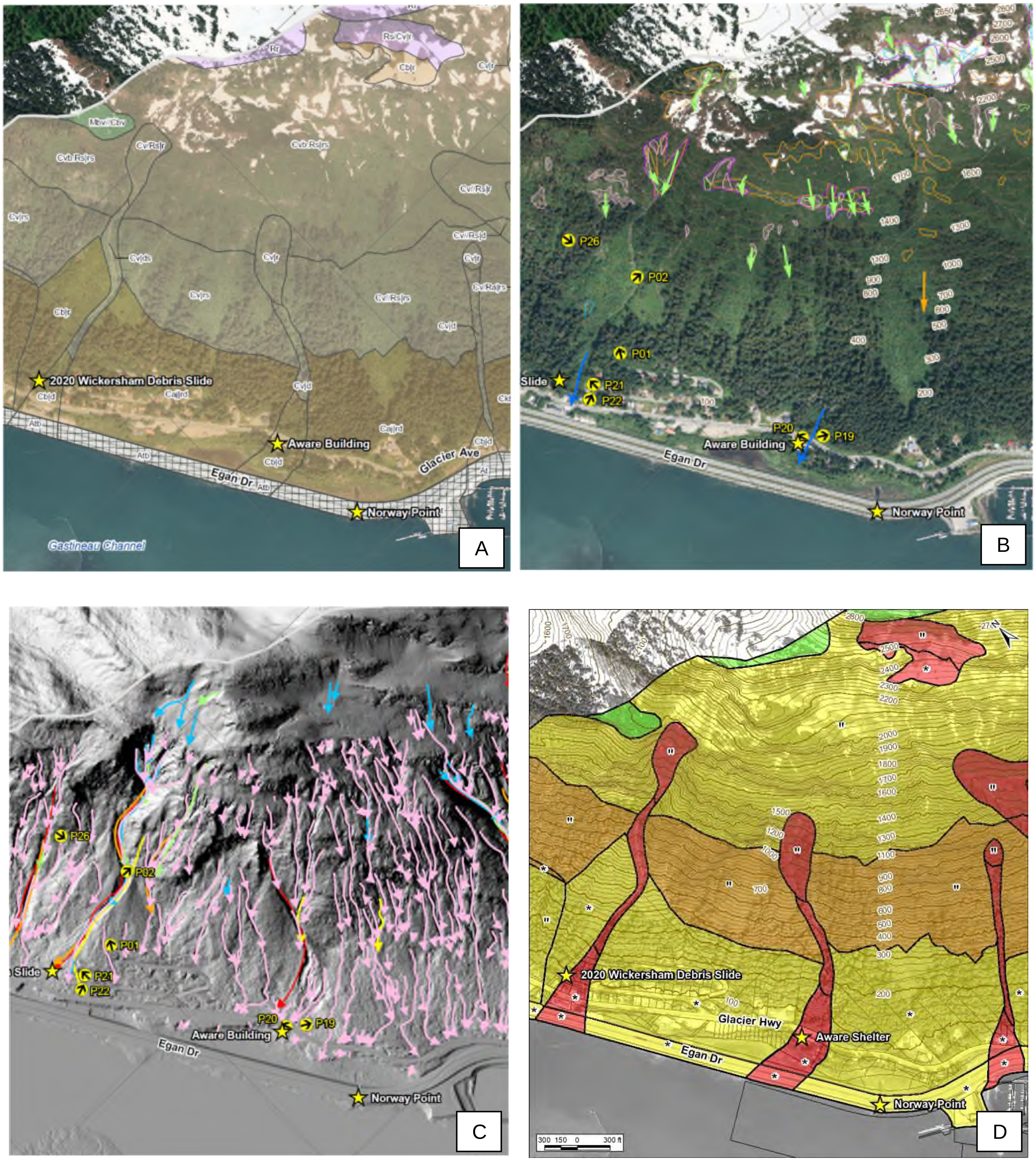

Figure 19: These excerpts are from the mapping at the slopes at the White Subdivision. Figure 19A shows the surficial geology, Figure 19B shows the slope movement features, Figure 19C shows the gully erosion features, and Figure 19D shows the landslide hazard mapping. The Wickersham slide (Figure 20) 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.

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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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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.