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.

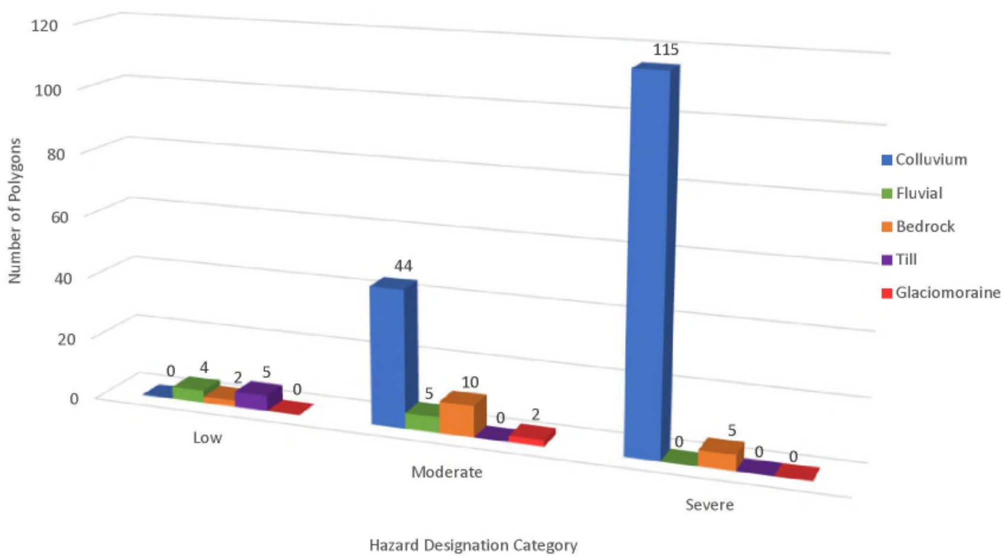

Figure B.1: Number of Polygons vs. Hazard Designation Categories for Surficial Geology Descriptions.

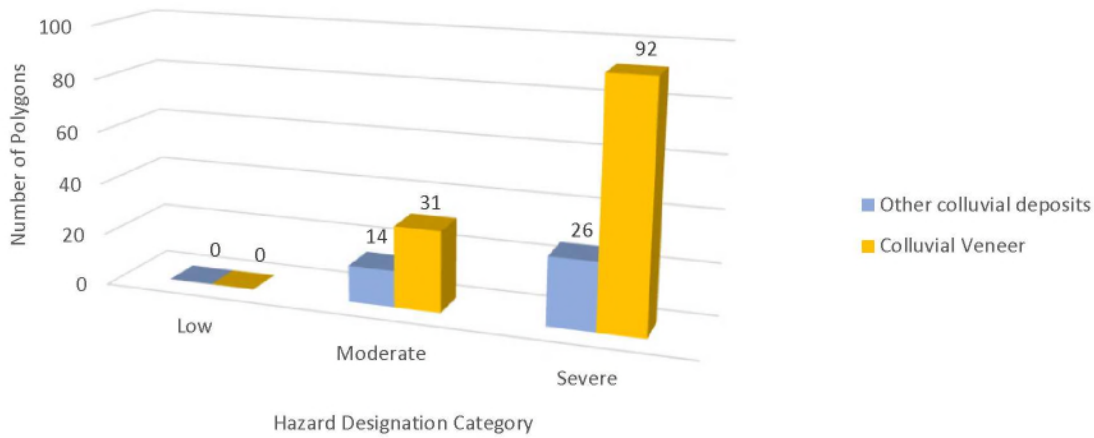

Figure B.2: Type of Colluvial Deposit vs. Hazard Designation Categories.

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.

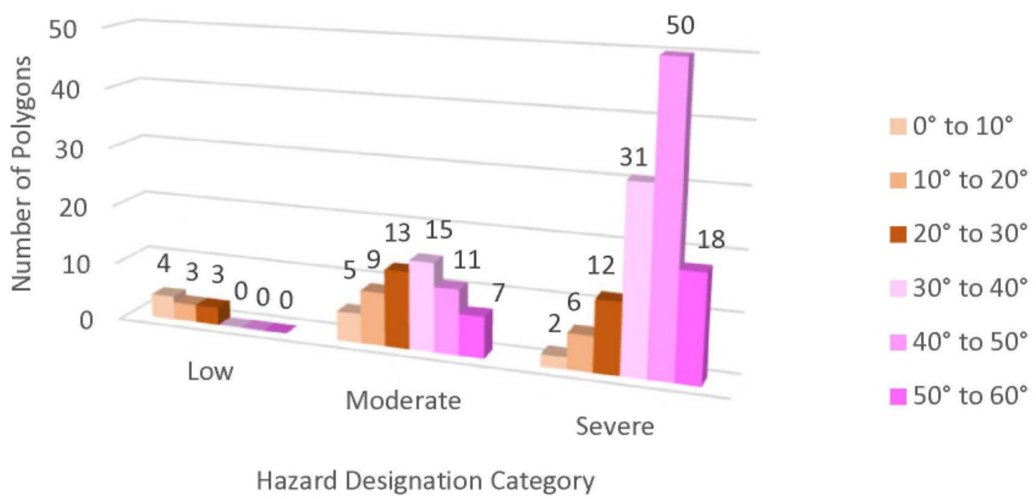

Figure B.3: Mean Slope Angle vs. Hazard Designation Categories.

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.

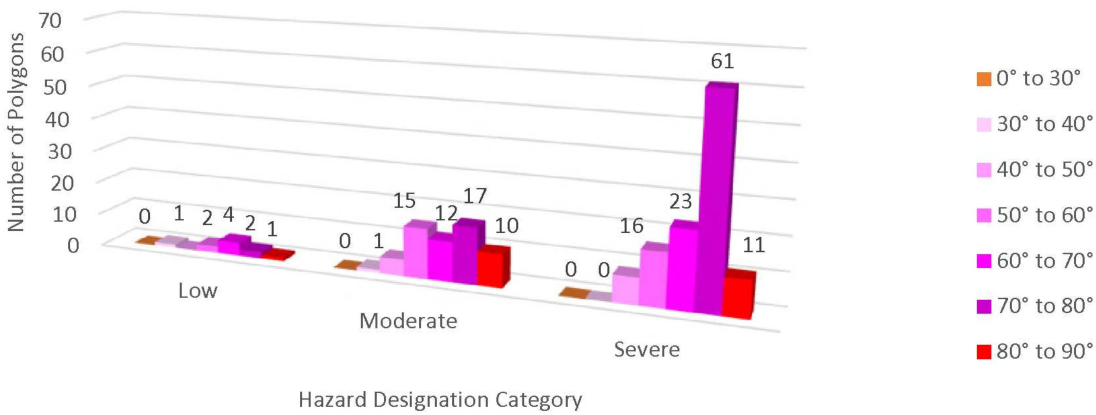

Figure B.4: Maximum Slope Angle vs. Hazard Designation Categories.

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)

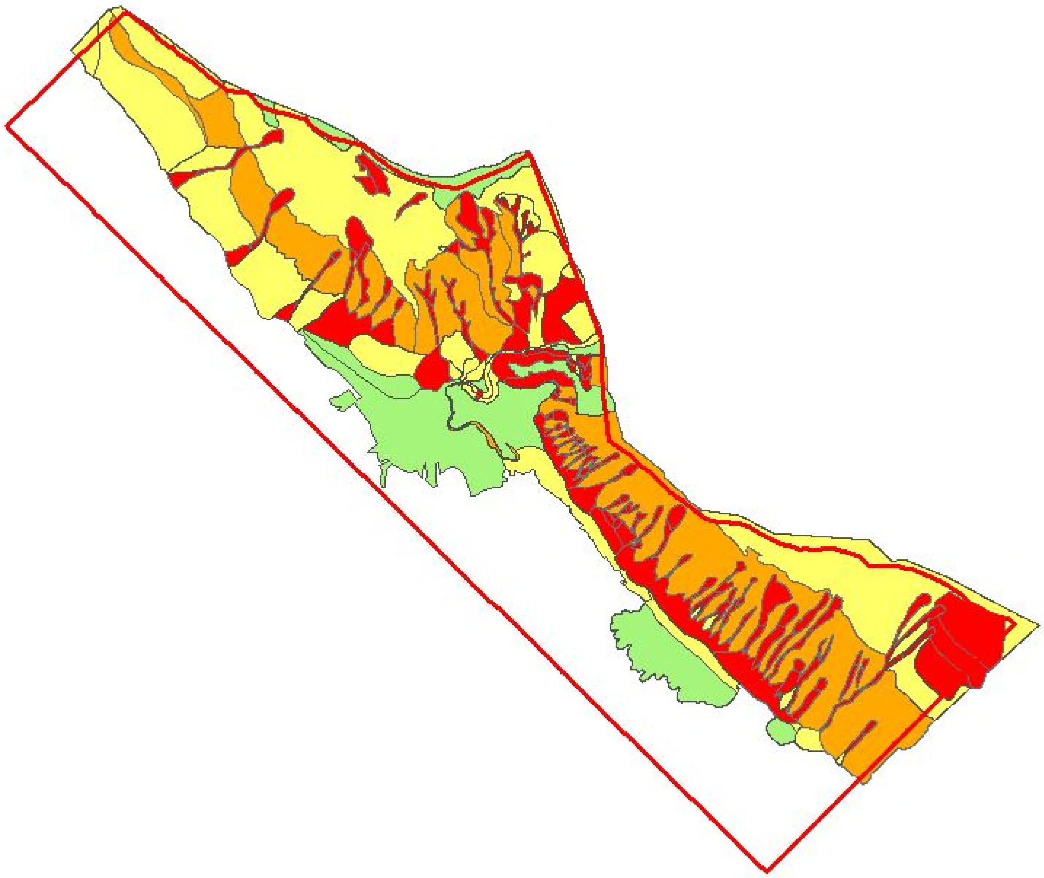

Figure B.6: Revised Landslide Hazard Designation Map.

(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

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