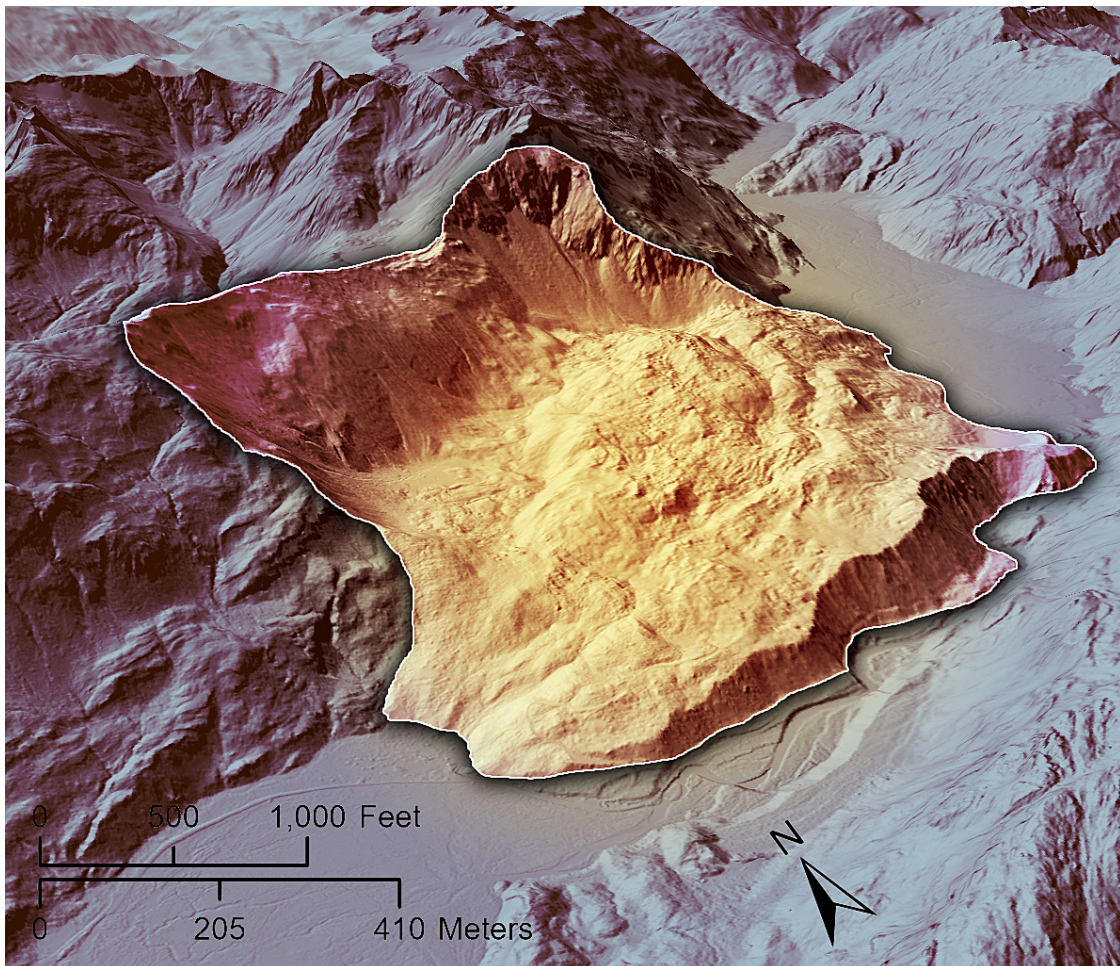


Landslide mapping and susceptibility modeling near Cordova, Alaska

Jillian A. Nicolazzo



Large, deep-seated paleolandslide northeast of Cordova, Alaska. Image is a digital terrain model-derived hillshade raster overlain with blended color layers.



Landslide mapping and susceptibility modeling near Cordova, Alaska

Jillian A. Nicolazzo

Report of Investigation 2026-7

State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys

State of Alaska

Mike Dunleavy, Governor

Department of Natural Resources

John Crowther, Commissioner

Division of Geological & Geophysical Surveys

Erin A. Campbell, State Geologist & Director

Publications produced by the Division of Geological & Geophysical Surveys (DGGs) are available for free download from the DGGs website (dgg.alaska.gov). Publications on hard-copy or digital media can be examined or purchased in the Fairbanks office:

Alaska Division of Geological & Geophysical Surveys
3354 College Rd., Fairbanks, Alaska 99709-3707
Phone: (907) 451-5010 Fax (907) 451-5050
dggspubs@alaska.gov

DGGs publications are also available at:

Alaska State Library
Historical Collections & Talking Book Center
395 Whittier Street
Juneau, Alaska 99801

Alaska Resource Library and Information Services (ARLIS)
Library Building, Suite 111
3211 Providence Drive
Anchorage, AK 99508

Suggested citation: Nicolazzo, J.A. 2026, Landslide mapping and susceptibility modeling near Cordova, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2026-7, 15 p., 3 sheets. <https://doi.org/10.14509/32148>



Contents

Abstract	1
Introduction	1
Existing Information.....	2
Lidar Acquisition	2
Methods	2
Landslide Inventory Geodatabase and Map	2
Shallow-Landslide Susceptibility Modeling	3
Channelized Debris Flow Inundation Modeling	5
Results and Discussion	8
Landslide Inventory and Database.....	8
Susceptibility Maps	8
Intended Use and Limitations	9
Mapping limitations.....	9
Shallow landslide susceptibility model limitations.....	9
Debris flow model limitations.....	9
Intended use.....	9
Conclusion.....	9
Acknowledgments	10
References	10

Figures

1. Figure showing this project's study area and major infrastructure displayed over Esri's World Terrain basemap.....	2
2. Landslides mapped by Winkler and Plafker (1981) and extent of an existing lidar dataset in the Cordova area.....	3

Tables

Table 1. Factor of safety input parameters. See equation 1 for explanation of variables.....	6
Table 2. Critical slope values per soil unit designating areas moderately (FOS < 1.50) and highly (FOS < 1.25) susceptible to failure.	6
Table 3. Summary of values for debris flow initiation potential.	8
Table 4. Final debris flow initiation susceptibility scores.	8
Table 5. Summary of values for channel transport potential (Burns and others, 2022).	9
Table 6. Final channel transport susceptibility scores (Burns and others, 2022).....	9
Table 7. Summary of values for watershed potential (Burns and others, 2022).....	10
Table 8. Final watershed susceptibility score (Burns and others, 2022).	10

Landslide mapping and susceptibility modeling near Cordova, Alaska

Jillian A. Nicolazzo¹

Abstract

Slope failures pose significant risks to people and infrastructure in many Alaska communities, including the City of Cordova. To improve understanding of these hazards and support community resilience, the Alaska Division of Geological & Geophysical Surveys (DGGS) developed maps of historical and prehistorical slope failures, modeled shallow landslide susceptibility, and modeled debris flow initiation and runout for approximately 245 km² (94 mi²) surrounding the City of Cordova. Analyses relied exclusively on remote sensing and existing datasets without field verification.

The landslide inventory integrates previously mapped landslides with additional slope failures identified through interpretation of high-resolution light detection and ranging (lidar) data and aerial imagery. Shallow landslide susceptibility was modeled using calculated factors of safety derived from slope angle, surficial mapping, and estimated soil engineering properties. Because detailed soil data are limited, the resulting susceptibility map represents a conservative estimate. Channelized debris flow hazards were modeled using a lidar-based approach that identifies initiation, transport, and inundation areas for both common and rare events.

Together, these products provide a regional assessment of landslide hazards that can inform land-use planning, infrastructure management, emergency preparedness, and future site-specific investigations.

Introduction

Slope failures are common throughout Alaska. Their impacts range from minor (e.g. causing little or no damage to infrastructure, transportation networks, or the economy) to catastrophic (e.g. resulting in destroyed buildings, severed utilities and lifelines, and loss of life). In recent years, Alaska has experienced several severe storms that triggered destructive and deadly landslides, while retreating glaciers have also revealed new areas where large slope failures are possible. These events highlight the importance of identifying areas susceptible to future slope failures before they affect communities and infrastructure.

Cordova is located near the mouth of the Copper River in eastern Prince William Sound, an area with numerous documented landslides,

including the actively monitored Barry Arm landslide (Schaefer and others, 2024, Alaska Division of Geological & Geophysical Surveys, 2026). Cordova is not connected to Alaska's highway system and is accessible by air and sea.

As part of the Federal Emergency Management Agency (FEMA) Cooperating Technical Partners (CTP) Program, the Alaska Division of Geological & Geophysical Surveys (DGGS) developed a landslide inventory and maps of shallow landslide susceptibility and debris flow inundation for a selected study area surrounding the City of Cordova. These products provide baseline information on landslide hazards that can support future planning and risk reduction. The City of Cordova Planning Commission voted in support of this project on February 18, 2021. This study area includes the

¹Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, Alaska 99709-3707.

Heney Range south of Cordova and the Power Creek valley to the north (fig. 1), an area of approximately 245 km² (94 mi²). The project area includes portions of the Cordova B-5, B-6, C-4, and C-5 quadrangles.

This study relied on existing datasets and remote sensing analyses and did not include field verification. This report describes the datasets and methods used in this study and discusses the mapping and modeling results. Three 1:25,000 scale map sheets accompany this report:

- Map Sheet 1. Landslide Inventory
- Map Sheet 2. Shallow Landslide Susceptibility
- Map Sheet 3. Channelized Debris Flow Susceptibility and Inundation

Existing Information

A 1:250,000 scale geologic map identified one landslide within this project's study area located along Power Creek north of Cordova (Winkler and Plafker, 1993; fig. 2). The map also shows a landslide approximately 21 kilometers (13 miles) northwest of Cordova, a cluster of six landslides approximately 35 kilometers (21.7 miles) east of Cordova, at least one of which was attributed to the 1964 Good Friday earthquake, and several more in the mountains and glacial valleys north and northwest of Cordova (Winkler and Plafker, 1993; fig. 2). The Cordova Local Hazards Mitigation Plan Update (HMP) mentions one landslide in 1985 that destroyed water lines south of the city (LeMay Engineering & Consulting, Inc, 2018) but states the overall

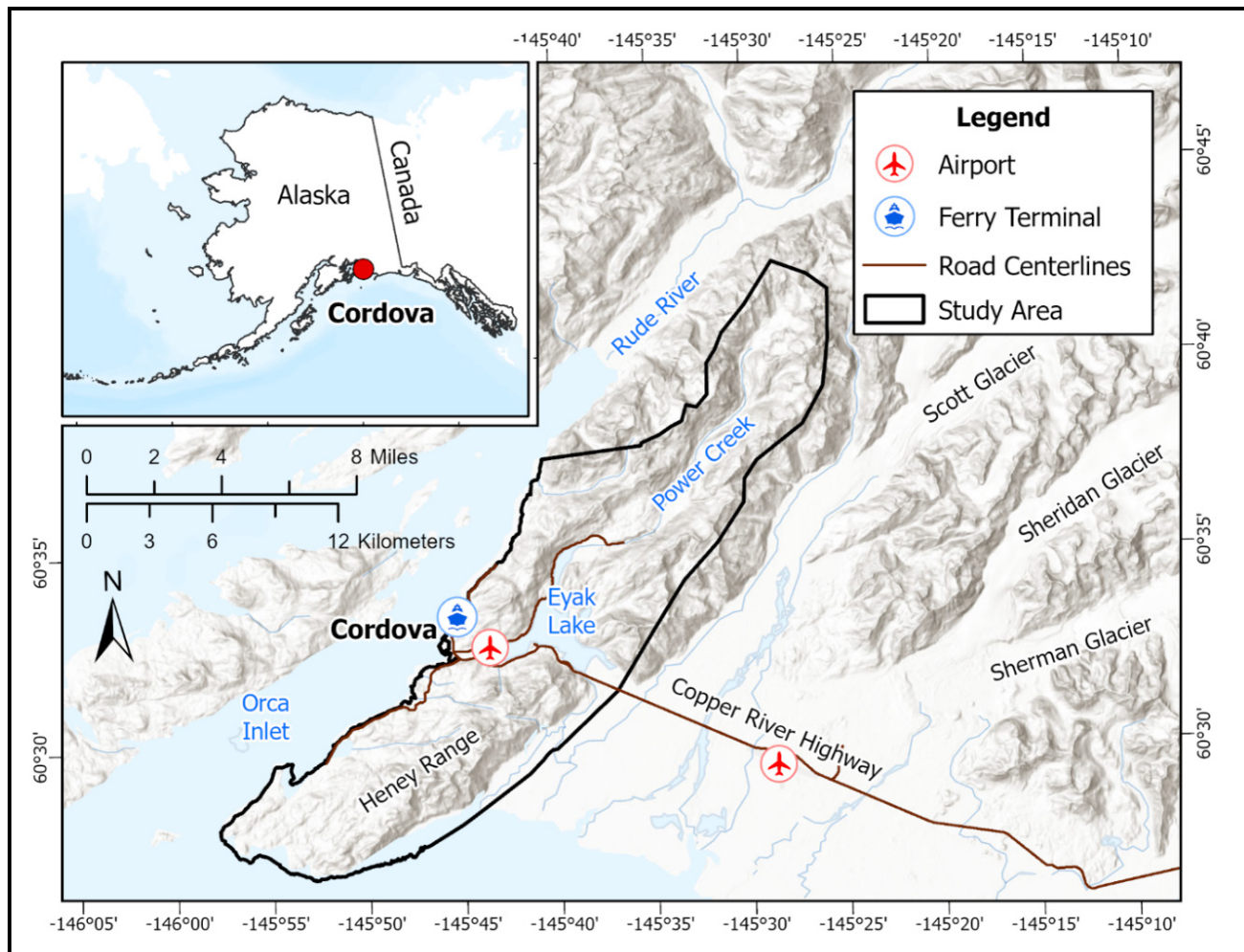


Figure 1. Figure showing this project's study area and major infrastructure displayed over Esri's World Terrain basemap.

landslide risk is low and did not identify any mapped landslide hazard zones. We did not find mention of other landslides or debris flows in news reports. News articles mention a fatality and an injury from a snow avalanche in 2000 (Fesler and Fredston, 2000). The FEMA grant that funded this landslide hazard assessment also funded a snow avalanche hazard assessment (Wolken and others, unpub. data).

We compiled surficial soils information from the U.S. Fish & Wildlife Service wetlands dataset (U.S. Fish & Wildlife Service, 2024), the Eyak Lake Area Meriting Special Attention Cooperative Management Plan (Professional Fishery Consultants, 1985), and the USDA STATGO2 soils database (U.S. Department of Agriculture, 2017). We also reviewed the Alaska Department

of Transportation & Public Facilities (DOT&PF) Geologic Event Tracker dataset for recorded landslides that impacted roads in and around Cordova (Alaska Department of Transportation & Public Facilities, 2022).

Prior to this study, one light detection and ranging (lidar) dataset was collected in 2011 covering the City of Cordova and narrow strips along the coastline (OCM Partners, 2024; fig. 2).

Lidar Acquisition

For this project, DGGS conducted a new lidar survey in August and September of 2023 (Zechmann and others, 2024). DGGS processed the data in-house and produced a 50-cm (1.6-ft) resolution digital terrain model (DTM), which we used for all the analyses described in this report. This DTM is a single-band, 32-bit GeoTIFF.

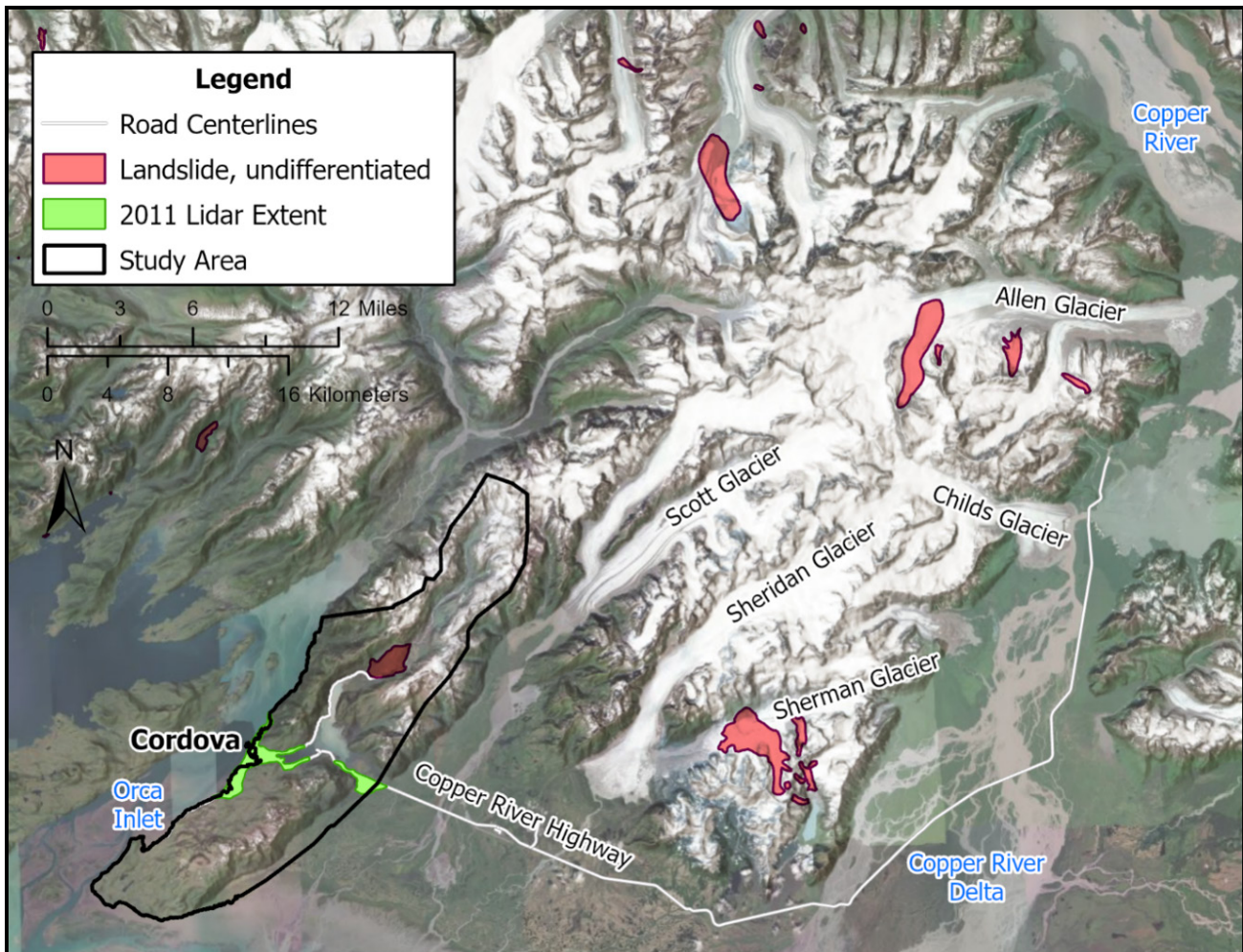


Figure 2. Landslides mapped by Winkler and Plafker (1981) and extent of an existing lidar dataset in the Cordova area.

Methods

Landslide Inventory Geodatabase and Map

In this section we use the word “landslide” generically to include all types of slope failures identified in the area, including landslides, debris flows, and rockfall. We followed the landslide inventory mapping protocols described in Burns and Madin (2009) and Slaughter and others (2017) to identify landslide deposits, flanks, and scarps. We used the same database feature layers, attributes, and data dictionary as Nicolazzo and Larsen (2025a).

Using ArcGIS Pro, we created three feature classes for the inventory: deposit polygons, flank polygons, and scarp polylines; however, not all slope instabilities have all these features. The “ideal” translational or rotational landslide includes a head scarp, possible internal scarps, flanks, and a deposit, but we rarely identified all these features. Additionally, debris flows that are confined to drainage channels generally lack a well-defined source area and do not originate at a scarp, so these deposit polygons do not have associated scarps or flanks. Rockfall deposits might have an associated scarp polyline but no flank polygon. Erosional deposits such as colluvium and talus were not classified as landslides, but we mapped scarp polylines for some because their presence indicates the bedrock is unstable in these areas and falling rock could pose a hazard.

We identified slope instabilities through interpretation of hillshade and slope rasters derived from the 2024 lidar DTM (Zechmann and others, 2024). Review of aerial imagery from publicly available sources, including DGGS’ 50-centimeter Maxar, Esri Wayback, and Google Earth supplemented the lidar data. The large landslide along Power Creek and a large alluvial fan/debris flow deposit on the Copper River Highway were quickly identified and their geomorphology was used as a calibration for identifying other instabilities. We then identified landslide scarps, flanks, and deposits throughout the study area. Each of the mapped landslides may represent a single occurrence, or multiple events.

The resultant inventory map is shown on map sheet 1.

Shallow-Landslide Susceptibility Modeling

Shallow landslides are downslope movements of soil or rock that occur within the uppermost layers, typically within surficial soils. Shallow landslides are generally defined as having a failure plane less than 3 to 4.5 m (10 to 15 ft) deep. This modeling does not include deep-seated bedrock failures or ground failures triggered by seismic shaking, such as liquefaction or lateral spread, which require site-specific information and are outside the scope of this project. Additionally, shallow landslide susceptibility does not include channelized debris flow inundation, which is discussed in the next section.

We based our shallow landslide susceptibility analysis on the methodology of Burns and others (2012). This method combines mapped shallow landslides with calculated factors of safety (FOS) based on surficial soil strengths and slope angles. To better represent conditions in the Cordova area, we modified the method to account for vegetation, and the resulting susceptibility map is shown on map sheet 2.

Factor of Safety

The FOS is the ratio of forces resisting slope movement (e.g., soil cohesion) to forces driving movement (e.g., gravity; Burns and others, 2012; eq. 1). A slope is theoretically stable when resisting forces exceed driving forces, $FOS > 1.0$, and is theoretically unstable when driving forces exceed resisting forces, $FOS < 1.0$. Because of natural variability and uncertainty in soil composition and properties, engineering practice typically takes a conservative approach. Slopes with an FOS less than 1.50 are generally considered to have an inadequate safety margin. Following Burns and others (2012), we classified slopes with an $FOS < 1.25$ as highly susceptible to failure, slopes with a FOS between 1.25 and 1.50 as moderately susceptible, and slopes with an FOS equal to 1.50 or greater as having low to no susceptibility to failure.

Equation 1. Factor of safety (FOS)

$$\text{FOS} = \frac{c'}{\gamma t \sin \alpha} + \frac{\tan \phi'}{\tan \alpha} + \frac{m \gamma_w \tan \phi'}{\gamma \tan \alpha}$$

Where:

c' = effective cohesion

ϕ' = effective angle of internal friction

γ = saturated soil density (unit weight)

γ_w = groundwater density (unit weight)

t = depth to failure surface

m = groundwater depth ratio

α = slope angle

The existing surficial soils mapping and soils data we located during the research phase of this project were not detailed enough for our purposes and sometimes conflicted with each other. We used these resources as a guide, combining their information, and where necessary, adjusting soil unit contacts and digitizing additional contacts based on interpretation of aerial imagery and the lidar DTM to improve the accuracy and detail of this analysis. Because this work did not include field investigations or laboratory testing, we estimated soil engineering properties from published values (Burns and others, 2012; Filz, 1982; Geotechnical Info, 2012). We assigned conservative estimates of effective cohesion, effective angle of internal friction, and saturated unit weight for each soil unit (table 1). Larger cohesion values result in higher calculated FOS values, so the more conservative approach is to select lower or no cohesion. We assigned a value of 1.0 to the groundwater depth ratio for all soils, which represents fully saturated conditions.

We calculated FOS for each soil unit for the full range of possible slopes, from 1.0 to 90.0 degrees, in 0.5-degree increments, and identified slope angles corresponding to FOS values of 1.25 and 1.50 (table 2). During model calibration we found that shallow soils over bedrock did not match what we expected from the FOS calculations. Two inventoried landslides in these units occurred on slopes averaging approximately 33 degrees, which was nearly twice the slope predicted by the initial calculations. Because the slopes are heavily vegetated, we concluded that

vegetation is providing additional shear strength that was not represented in the initial model. We then revised the surficial soils mapping to distinguish vegetated from non-vegetated soils, and also to differentiate older, stable landslide deposits from recent, active failures.

Research in Southeast Alaska has documented a correlation between vegetation loss and increased landslide activity (Bishop and Stevens, 1964) and attempted to test or estimate the shear strength of tree roots as a stabilizing element for a soil (Wu, 1976, Ziemer and Swanson, 1977). Although vegetation is not specifically included in the FOS equation, it can be considered to contribute to soil cohesion (Turner and Schuster, 1996). This cohesion component varies with vegetation type and the underlying soils, but values between 1.0 to 5.9 kPa (20 to 125 lb/ft²; Turner and Schuster, 1996) may be appropriate for tree-covered slopes in the Cordova area. Some of the cohesion values for vegetated soil units presented in table 1 include this additional vegetation-related component.

Using ArcGIS Pro, we applied the threshold values in table 2 to classify each soil unit into areas of high, moderate, and low susceptibility based on slope angle. We then mosaicked the rasters into a single raster.

Buffers and Smoothing

Numerous small, low-relief features such as ditches, retaining walls, and road cuts appear to have moderate or high susceptibility due to their steep elevation changes in the high-resolution slope raster. These man-made features do not pose a significant hazard, and their inclusion may be misleading. To reduce this, we applied the ArcGIS Pro Focal Statistics tool using a 3-meter (9.8-foot) square neighborhood and 3-meter (9.8-foot) vertical height to remove these structures from the mosaicked raster. We evaluated several combinations of the smoothing parameters and selected values that removed many of the man-made structures without compromising the accuracy of the analyses. Mostly, this smoothing process reduced the number of small, isolated susceptibility “islands” within a larger area of

Table 1. Factor of safety input parameters. See equation 1 for explanation of variables.

Soil Unit	Effective angle of internal friction ϕ'	Effective cohesion c'		Saturated unit weight of soil γ		Depth to failure		Groundwater depth ratio
		lb/ft ²	kPa	lb/ft ³	kN/m ³	ft	m	
Alluvial fan	27	0.0	0.0	125.0	19.6	5.0	1.5	1.0
Artificial fill	38	0.0	2.4	130.0	20.4	4.0	1.2	1.0
Bedrock	30	210.0	10.1	120.0	18.9	2.0	0.6	1.0
Colluvium w/vegetation	30	235.0	11.3	103.0	16.2	5.0	1.5	1.0
Colluvium-alluvium	36	100.0	4.8	102.0	16.0	5.0	1.5	1.0
Floodplain, active	24	0.0	0.0	105.0	16.5	5.0	1.5	1.0
Floodplain, inactive	27	50.0	2.4	120.0	18.9	5.0	1.5	1.0
Glacial moraine	37	50.0	2.4	120.0	18.9	5.0	1.5	1.0
Glacial outwash	36	140.0	6.7	114.0	17.9	5.0	1.5	1.0
Landslide, active	28	0.0	0.0	110.0	17.3	5.0	1.5	1.0
Landslide, stable	36	135.0	6.5	130.0	20.4	5.0	1.5	1.0
Muskeg	22	0.0	0.0	115.0	18.1	5.0	1.5	1.0
Rock glacier	32	50.0	2.4	110.0	17.3	5.0	1.5	1.0
Talus	35	0.0	0.0	130.0	20.4	5.0	1.5	1.0

Table 2. Critical slope values per soil unit designating areas moderately (FOS < 1.50) and highly (FOS < 1.25) susceptible to failure.

Soil Unit	Slope angle threshold for FOS < 1.50	Slope angle threshold for FOS < 1.25
	Degrees	Degrees
Alluvial fan	10.0	12.0
Artificial fill	15.5	18.0
Bedrock	45.5	56.0
Colluvium w/vegetation	26.5	31.5
Colluvium-alluvium	18.5	22.0
Floodplain, active	7.0	8.5
Floodplain, inactive	12.5	15.0
Glacial moraine	17.0	20.0

Soil Unit	Slope angle threshold for FOS < 1.50	Slope angle threshold for FOS < 1.25
	Degrees	Degrees
Glacial outwash	22.0	26.0
Landslide, active	9.0	10.5
Landslide, stable	22.0	26.0
Muskeg	7.5	8.5
Rock glacier	14.0	16.5
Talus	14.0	16.5

consistent susceptibility (e.g. a single cell or a few cells of moderate susceptibility within a low susceptibility flat area in town were reclassified as low). Manually identifying and removing all man-made features from the DTM was not practical.

Landslides tend to have a steep head scarp that may fail retrogressively, meaning a new landslide may form above the head scarp due to the removal of resisting material directly below and adjacent to the head scarp; therefore, flat areas near a head scarp may have a higher risk of failure than the FOS calculations indicate. To account for this increased hazard, Burns and others (2012) recommend adding a buffer equal to 2 horizontal to 1 vertical (2H:1V) around head scarps. Due to the large number of scarps identified during this project, we did not differentiate head scarps from internal scarps so we applied the 2H:1V buffer to all scarps and assumed the vertical distance (V) was equal to 1.5 meters (5 feet), which is the maximum depth to failure for all soils (table 1). The horizontal distance (H) is 2x this depth, or 3 meters (10 feet). These buffer areas were assigned a high susceptibility rating because of their proximity to a mapped scarp, regardless of the calculated FOS. By buffering all scarps, bedrock faces that produce talus or colluvium, which might otherwise have been excluded, also show a high susceptibility to failure.

Because landslides that originate on a steep slope can extend back into a flatter area above the slope or may have a toe that extends over a flat area at the bottom, Burns and others (2012) recommend applying a similar 2H:1V buffer to all areas with a calculated FOS ≤ 1.5 and assigning a moderate susceptibility rating to the areas within these buffers, effectively creating a halo of moderate susceptibility around areas of moderate or high susceptibility. We used the ArcGIS Pro Expand tool to create this buffer.

The final shallow landslide susceptibility map combines the extracted landslide inventory, FOS calculations, buffers, and surface smoothing (map sheet 2).

Channelized Debris Flow Inundation Modeling

Debris flows are a form of mass movement characterized by a slurry of water, soils, rocks, trees, and other debris quickly moving down slope under the influence of gravity. They are often associated with large rain events and are among the most destructive and expensive geohazards that occur in Alaska (Alaska Division of Homeland Security & Emergency Management, 2023). Channelized debris flows often initiate as a shallow landslide entering a channel, or erosion within or directly adjacent to a channel, that then flows down the channel eroding and entraining additional material as it flows until it reaches a flatter or less confined ground, where the flow then slows and material is deposited (Burns and others, 2022).

Laharz is a computer model developed for the U.S. Geological Survey (USGS) that simulates the behavior of volcanic mudflows, known as lahars, and was modified to include channelized debris flows (Schilling, 1998). Burns and others (2022) extended the Laharz model to include the ability for volumes to expand as they flow down the channel. Burns and others (2022) produced custom ArcGIS geoprocessing tools to simplify the process. The method models debris flow initiation (deposition) to produce a map that displays debris flow initiation and transport susceptibility as watersheds having high, moderate, or low susceptibility, and the inundation extent for each level of modelled event severity (map sheet 3).

Initiation

Nicolazzo and Larsen (2025b) evaluated whether the debris flow modeling parameters proposed by Burns and others (2022) are appropriate for southeast Alaska. Using the database of landslide initiation points for the Tongass National Forest (U.S. Forest Service, 2024) and the Wrangell Island elevation data (Zechmann and others, 2023), Nicolazzo and Larsen (2025b) found that the average slope closely matches that reported by Burns and others (2022), but curvature values differ, suggesting that the curvature value should be adjusted for Alaska.

The protocol developed by Burns and others (2022) identifies drainage channels using a curvature-based method. They used a concavity threshold of -2.0 but this value split Cordova's glacial basins into numerous smaller watersheds, which resulted in debris flow deposition in areas where we do not have evidence of debris accumulation. We tested various combinations of input parameters and visually compared the resulting modeled channels and watersheds with features visible in the lidar data and aerial imagery. We selected a concavity threshold of -2.2 because it appeared to provide a better representation of the observed drainage network in the Cordova area. When multiple iterations were run, the minimum concavity size and contributing concave area inputs did not appear to change the output significantly, so we retained the values of 10 m² (107.6 ft²) and 200 m² (2,152.8 ft²), respectively, recommended by Burns and others (2022). We also used these values to model deposition, described in the Inundation/Deposition section of this report. We retained the category values suggested by Burns and others (2022) throughout the analysis, because the categories were developed as part of the method and they appeared to produce reasonable results for the Cordova area.

Using values suggested by Burns and others (2022), we assigned values of 1 to 4, corresponding to no, low, moderate, and high susceptibility, respectively, to a range of slope and curvature raster values. Slopes 55 degrees and greater were not included in the analysis because they are less likely to accumulate the colluvium (loose, unconsolidated sediment) necessary for channelized debris flow initiation (Burns and others, 2022). The curvature raster identifies topography that is concave or convex and indicates where water and colluvium might collect or be dispersed. Debris flows tend to initiate in or near an existing drainage channel, so the distance to a channel was also included in the initiation potential (Burns and others, 2012; table 3).

The final initiation potential score is the sum of the slope, curvature, and distance values, culminating in a single value, which we then classified as high, moderate, low, or very low/no susceptibility (table 4).

Transport

Once a debris flow begins to travel down a channel, certain conditions must exist for it to continue to flow. Burns and others (2022) use channel gradient and confinement as the two primary criteria to define the transportation

Table 3. Summary of values for debris flow initiation potential.

Assigned Value	Category	Slope angle	Curvature	Distance to drainage	
		Degrees	0.0035 m (1/100 ft)	ft	m
4	High	35 to < 55	≤ -0.4	≤ 100	≤ 30.5
3	Moderate	25 to ≤ 35	-0.4 to ≤ 0.3	100 to ≤ 200	30.5 to ≤ 61
2	Low	15 to ≤ 25	0.3 to ≤ 1.1	200 to ≤ 300	61 to ≤ 91.4
1	Very low to none	≤ 15	> 1.1	> 300	> 91.4

Table 4. Final debris flow initiation susceptibility scores.

Score (Slope + Curvature + Distance)	Susceptibility Class
11 and 12	High
8 to 10	Moderate
5 to 7	Low
4 or less	Very low to none

potential of a flowing channelized debris flow. Their tool divides the drainage network created in an earlier step (see Initiation) into 30.5-meter (100-foot) segments, which are used as the flow paths for transportation potential.

Channel gradient is the downhill slope of the channel, defined by the number of meters (feet) the channel drops per kilometer (mile) along its length. Steeper channel gradients are more likely to transport debris flows than shallower gradients, and debris is more likely to deposit where the gradient becomes shallower (Burns and others, 2022).

Channel confinement describes the degree to which lateral movement within a channel is restricted and reflects the relationship between channel width and the surrounding landscape, floodplain, or valley. The tool created by Burns and others (2022) transects the channel segments perpendicularly at 8-meter (25-foot) intervals that extend 30.5 meters (100 feet) to either side of the channel line, creating five transect lines per segment. It places points at 3-meter (9-foot) intervals along the transect lines and extracts the elevation at each point from the DTM. The tool

calculates the difference between the highest and lowest elevation values for each transect line, then calculates the average of the differences for the five transect lines for each channel segment and assigns the average to that channel segment. This value defines the amount of confinement for that segment. A difference of 3 m (10 ft) along the 30.5-meter (100-foot) segment indicates low confinement (i.e. the channel can more easily shift side to side), whereas a difference of 23 m (75 ft) along the 30.5-meter (100-foot) segment indicates high confinement (i.e. the channel cannot easily shift laterally).

We used the values suggested by Burns and others (2022) for this project (table 5). The final channel transport susceptibility score is the sum of the confinement value of each segment and the channel gradient value (table 6).

Table 5. Summary of values for channel transport potential (Burns and others, 2022).

Assigned Value	Category	Confinement		Gradient
		Vertical Feet Per 100-Foot Increment	Vertical Meters Per 30.5-Meter Increment	Degrees
4	High	≥ 40	≥ 12	≥ 15
3	Moderate	20 to < 40	6 to < 12	7.5 to < 15
2	Low	10 to < 20	3 to < 6	5 to < 7.5
1	Very low to none	≤ 10	≤ 3	≤ 5

Table 6. Final channel transport susceptibility scores (Burns and others, 2022).

Score (Confinement + Gradient)	Susceptibility Class
8	High
6 and 7	Moderate
4 and 5	Low
Less than 4	Very low to none

Watershed Susceptibility to Debris Flow

A watershed is the upslope area that contributes flow to a common outlet. The tool created by Burns and others (2022) generates watersheds using standard hydrography tools in ArcGIS Pro and applies user-defined pour points (i.e. outlets) and the transport channels created in an earlier step (see Transport). Watershed susceptibility combines initiation and transportation potentials and is based on the estimated number of initiation sites per area and the percent of transport channels with high and moderate susceptibility (Burns and others, 2022; table 7). The tool joins initiation and transport susceptibility scores to each watershed polygon and sums the values to create a final susceptibility score for that watershed (Burns and others, 2022; table 8). This score does not take into account how long it might take for debris to accumulate after an event or how much water is flowing; it assumes a sufficient volume of material that can be transported is always available and that there is always water flowing fast enough to transport it. Susceptibility zones are shown on map sheet 3.

Inundation/Deposition

Burns and others (2022) recommend modeling debris flows for three hazard scenarios: typical, intermediate, and extreme. The typical scenario is a relatively common event that has a small to medium impact and might occur every few years or decades. The extreme scenario is less common, has a much larger impact, and might occur only once per 1,000 years or less frequently. Characteristics of an intermediate scenario fall between typical and extreme. Two input values are required for modeling each scenario: growth factor and maximum volume. Growth factor defines the erosion and entrainment of debris that increases the volume of a moving debris flow. The maximum volume limits how large the debris flow can grow. Input values for the typical scenario are selected and adjusted until the modeled inundation area closely matches observed debris flow extents in the area. These values are then scaled up to obtain corresponding values for the intermediate and extreme scenarios (Burns and others, 2022).

We evaluated multiple combinations of growth factor and maximum volume inputs, ran

Table 7. Summary of values for watershed potential (Burns and others, 2022).

Assigned Value	Category	Number of Estimated Potential Initiation Sites per Watershed	Percent of High and Moderate Channels in Watershed
4	High	≥ 5	≥ 50
3	Moderate	1 to < 5	25 to < 50
2	Low	0.5 to < 1	10 to < 25
1	Very low to none	< 0.5	< 10

Table 8. Final watershed susceptibility score (Burns and others, 2022).

Score (initiation site + susceptible channels)	Susceptibility Class
8	High
6 and 7	Moderate
4 and 5	Low
Less than 4	Very low to none

the model for each combination, and visually compared the results with observed debris flow deposits. This evaluation indicated that growth factor had a greater influence on inundation extent than maximum volume, which rarely limited the output. We modeled the typical scenario with a growth factor of $0.10 \text{ m}^3/\text{m}^2$ ($0.30 \text{ ft}^3/\text{ft}^2$) and a maximum volume of $100,000 \text{ m}^3$ ($3,531,467 \text{ ft}^3$), and the extreme scenario with a growth factor of $1.0 \text{ m}^3/\text{m}^2$ ($3.3 \text{ ft}^3/\text{ft}^2$) and a maximum volume of $250,000 \text{ m}^3$ ($8,828,667 \text{ ft}^3$). We did not model the intermediate scenario since it falls between the other two and would not add any significant value to the map.

For both scenarios, we used the same values for concavity threshold, minimum concavity size, and minimum contributing concave area that we used in Initiation, described above, and defined by Burns and others (2022). We manually selected the locations where debris flows would slow, and deposit material based on a decrease in slope gradient and where the potential for upslope initiation and transport decreased to “low” or “very low to none,” as defined by Burns and others (2022).

We used Esri’s Boundary Clean tool to smooth the final inundation rasters and then converted them to polygons to further smooth the edges and to remove unrealistic deposition spikes where the DTM appeared flat, such as across water surfaces. We also adjusted the edges of some polygons to remove areas that were likely incorrectly classified due to interpolation during production of the DTM.

Results and Discussion

Landslide Inventory and Database

Through interpretation of lidar data and aerial imagery, we identified debris flow, landslide, and rockfall deposits within our study area (map sheet 1). This project did not include field verification; therefore, many features could not be confidently assigned to a specific movement type and are classified as undifferentiated. The final database includes 85 deposits: 33 rockfalls, 28 landslides, and 24 debris flows.

The rockfall category may include debris fall,

rockfall, and rock topple. We identified rockfall along road cuts, specifically Point Whitshed Road, Cannery Road, and Eyak Lake Road. Colluvium and talus deposits below steep bedrock slopes might also include rockfall.

The most prominent landslide in the study area is a large deep-seated landslide on Power Creek, about 9.6 kilometers (6 miles) northeast of Cordova. This landslide is about 2,000 m (1.35 mi) wide and, at the time of failure, appears to have completely blocked the Power Creek valley with a deposit up to about 150 meters (500 feet) thick. The earliest map to include the landslide is a 1951 report regarding a proposed dam and reservoir site (Miller, 1951). Miller interpreted the failure to have resulted from glacial oversteepening of the valley walls and noted the deposit was already vegetated and appeared stable. A report from 1915 described Power Creek as cutting a narrow gorge through the eastern side of a 95 to 122-meter (300 to 400-foot) high ridge and then falling 53 meters (175 feet) over a horizontal distance of about 152 m (500 ft) (Ellsworth and others, 1915). This description closely matches the morphology of the landslide deposit at the existing dam, and the site investigated in 1951. This suggests the landslide occurred at least several decades before 1915.

We initially hypothesized that the landslide occurred shortly after retreat of the Little Ice Age glaciers when removal of glacial ice may have debutressed the valley walls. Barclay and others (2013) studied tree rings at four glaciers that terminate in the Copper River Delta and found that Sheridan Glacier (located approximately 24 km [15 mi] east of Cordova) experienced four distinct advances during the Little Ice Age, occurring approximately during the 1510s to 1700s and 1810s to 1860s. Scott, Sherman, and Saddlebag glaciers, also east of Cordova, showed the same final two advances as Sheridan Glacier. Based on the Barclay study alone we were not able to determine when the Power Creek landslide occurred, but the study suggests that it may be more recent than shortly after the Little Ice Age, and a targeted tree ring analysis may be able to determine it.

We identified debris flow deposits in several drainage channels, but we did not find historical reports or news articles documenting debris flows in the Cordova area. Some of the mapped deposits may represent alluvial processes, instead. Debris flows deposits are more poorly sorted than alluvial deposits, but this distinction cannot be reliably interpreted from lidar data or aerial images; therefore, we assumed all streams draining steep slopes and terminating in alluvial fans have the potential to generate debris flows. We mapped these deposits with approximate or inferred confidence levels. Additional site-specific investigation should be conducted before development in these areas.

Susceptibility Maps

In general, steeper slopes and those comprised of loose, non-cohesive soils are more susceptible to shallow landslides than gentler slopes and those with dense or cohesive soils. Our conservative analysis indicates that slopes steeper than about 14 degrees may be susceptible to shallow landslides; however, this is influenced by assumptions regarding soil engineering properties, and depth to failure that could be refined in future studies. Although we attempted to consider vegetation impacts to slope stabilization, we used published values without site-specific information, and this could also be refined by a future study. The shallow landslide susceptibility map identifies areas that may warrant further investigation before development (map sheet 2).

Most drainages within the study area have the potential to produce channelized debris flows. Debris flows account for about 28 percent of our inventory; however, we did not find reports or news articles documenting a history of debris flows in the Cordova area. The debris flow model assumes a static amount of material within each watershed is always available, and does not account for changing hydrologic conditions such as rainfall intensity or streamflow velocity. The channelized debris flow map identifies watersheds with greater potential to initiate and transport debris flows, and where debris might deposit (map sheet 3).

Intended Use and Limitations

The intended use of this report and associated maps is to help identify areas that may be susceptible to slope failure, to provide a basis for regional planning and increased resiliency, and to help identify areas where more detailed landslide mapping is warranted. Limitations of the input data and modeling methods are such that the maps are not suitable to answer site-specific or legal questions. The maps should be used only for regional- or community-scale purposes and should not be viewed at scales other than the published map scale (1:25,000). They are not suitable for land-use regulation, building-code development, or to answer legal questions.

Mapping limitations

- This project was desktop-based, did not include field verification, and relied on available datasets.
- Lidar provides a snapshot view of the landscape at the time of data collection; therefore, maps based on lidar data interpretation may become less accurate as new landslides occur or improved technology becomes available.
- Lidar data interpretation may also change as new mapping techniques are developed.
- While every reasonable effort was made to identify all slope failures, limitations in lidar data, available imagery, vegetation cover, and the lack of field verification mean that some slope failures were likely missed, overlooked, or misinterpreted.
- Lidar-based analysis cannot always distinguish between natural elevation changes (e.g. landslide scour and deposition) and man-made structures (e.g. buildings and other structures).

Shallow landslide susceptibility model limitations

- The FOS calculations were done per soil unit and are strongly influenced by the accuracy and resolution of the input data for soil unit extents, material properties, depth to failure,

depth to groundwater, and slope angle. Material properties were estimated based on generalized soils data and are conservative estimates.

- FOS calculations were done per individual cell, without regard for the adjacent cells. We resampled slopes to 3-meter (~10-foot) resolution and applied focal statistics to reduce the “noise” of processing interpolation and local overestimation in areas of steep slopes with low relief; however, some localized overestimations are still possible.

Debris flow model limitations

- Debris flow modeling is based on estimated growth factors and volumes. Actual debris flow behavior may differ from the modeled results.
- Buildings, bridges, culverts, changes in topography, and mitigation measures can alter debris flow paths.
- The modeling does not account for differences in material composition. For example, woody debris entrained within the debris flow slurry can affect flow behavior and runout length and width.

Intended use

- DGGS is not a regulatory agency; therefore, this report and maps are non-regulatory.

Conclusions

DGGS completed this landslide hazard assessment for the City of Cordova by developing a landslide inventory and database, a map of modeled shallow landslide susceptibility, and a map of modeled debris-flow initiation and runout. Together these products provide a regional assessment of slope failure hazards that can support community planning, emergency preparedness, and the identification of areas where more detailed investigations may be warranted. The maps identify areas that are relatively more susceptible to slope failure but do not predict the timing, probability, or recurrence intervals of future landslides. Site-specific geologic and geotechnical investigations should be completed prior to development in potentially hazard-prone

areas. The results presented herein are for informational purposes only and are not suitable for legal, engineering, or surveying uses.

Acknowledgments

DGGS collected and processed lidar and conducted landslide susceptibility mapping for this project using funds provided by the Federal Emergency Management Agency (FEMA) Cooperative Technical Partnership (CTP) Program grant number CTP EMS-2021-CA-00014-01.

We thank our reviewers Dennis Staley with the U.S. Geological Survey and Nealey Sims with DGGS for their thoughtful comments and suggestions that helped improve the quality of this product. We also thank Bretwood Higman for sharing his unpublished landslide mapping in the Cordova area, which we incorporated into our inventory.

References

- Alaska Department of Transportation & Public Facilities, 2022, Geo Event Tracker-download event data, <https://akdot.maps.arcgis.com/sharing/rest/content/items/44a003d1b33945b0ba5284ca9abddd14/data>
- Alaska Division of Geological & Geophysical Surveys, 2026, Barry Arm landslide and tsunami hazard: Alaska Department of Natural Resources website, <https://dggs.alaska.gov/hazards/barry-arm-landslide.html>
- Alaska Division of Homeland Security and Emergency Management, 2023, State of Alaska state hazard mitigation plan, p. 465. <https://ready.alaska.gov/Mitigation/SHMP>
- Barclay, D.J., Yager, E.M., Graves, Jason, Kloczko, Michael, Calkin, P.E., 2013, Late Holocene glacial history of the Copper River Delta, coastal south-central Alaska, and controls on valley glacier fluctuations: Quaternary Science Reviews, Vol 81, p. 74-89, <https://doi.org/10.1016/j.quascirev.2013.10.001>
- Bishop, D.M. and Stevens, M.E., 1964, Landslides on logged areas in southeast Alaska:

- U.S. Department of Agriculture, U.S. Forest Service Research Paper NOR-1, 18 p., <https://archive.org/details/CAT31292080>
- Burns, W.J., Franczyk, J.J., and Calhoun, N.C., 2022, Protocol for channelized debris flow susceptibility mapping: Oregon Department of Geology and Mineral Industries Special Paper 53, 89 p., <https://pubs.oregon.gov/dogami/sp/SP-53/p-SP-53.htm>
- Burns W.J., and Madin I.P., 2009, Protocol for inventory mapping of landslide deposits from light detection and ranging (lidar) imagery: Oregon Department of Geology and Mineral Industries Special Paper 42, 30 p., <https://www.oregongeology.org/pubs/sp/p-SP-42.htm>
- Burns W.J., Madin I.P., and Mickelson, K.A., 2012, Protocol for shallow landslide susceptibility mapping: Oregon Department of Geology and Mineral Industries Special Paper 45, 32 p., <https://www.oregongeology.org/pubs/sp/p-SP-45.htm>
- Ellsworth, C.E., Davenport, R.W., and Hoyt, J.C., 1915, A water-power reconnaissance in south-central Alaska, with a section on southeastern Alaska: U.S. Geological Survey Water Supply Paper 372, 173 p., <https://pubs.usgs.gov/wsp/0372/report.pdf>
- Fesler, Doug, and Fredston, Jill, 2000, Lessons learned: Cordova Alaska's residential avalanche accident, Jan. 26, 2000: Proceedings of the 2000 International Snow Science Workshop, Big Sky, Montana, October 1-6, 2000, p. 486, accessed September 17, 2026, <https://arc.lib.montana.edu/snow-science/item/780>
- Filz, George, 1982, Engineering properties of southeast Alaskan forest soils: Oregon State University, M.S. thesis, 51 p., <https://ir.library.oregonstate.edu/downloads/mw22v9355>
- Geotechnical Info, 2012, Technical guidance, http://www.geotechnicalinfo.com/technical_guidance.html
- LeMay Engineering & Consulting, Inc., 2018, City of Cordova, Alaska, Local hazards mitigation plan update, 161 p., <https://www.cityofcordova.net/wp-content/uploads/2022/06/2018-FINAL-Cordova-HMP-Update.pdf>
- Miller, D.J., 1951, Geology at the site of a proposed dam and reservoir on Power Creek near Cordova, Alaska: U.S. Geological Survey Circular 136, 8 p., 2 sheets, <https://dggs.alaska.gov/pubs/id/13498>
- Nicolazzo, J.A., and Larsen, M.C., 2025a, Alaska landslide inventory database: Alaska Division of Geological & Geophysical Surveys Digital Data Series 23, 14 p., <https://doi.org/10.14509/31697>
- Nicolazzo, J.A., and Larsen, M.C., 2025b, Landslide hazard susceptibility mapping in Haines, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2024-8, 16 p., 3 sheets, scale 1:25,000, <https://doi.org/10.14509/31309>
- OCM Partners, 2024, 2011 FEMA Lidar: Cordova, Alaska: National Oceanic and Atmospheric Administration National Centers for Environmental Information, <https://www.fisheries.noaa.gov/inport/item/67815>
- Professional Fishery Consultants, 1985, Eyak lake AMSA cooperative management plan, 168 p., <https://copperriver.org/wp-content/uploads/2016/03/AMSA-Cooperative-Report.pdf>
- Schaefer, L.N., Kim, J., Staley, D.M., Lu, Z., and Barnhart, K.R., 2024, Satellite interferometry landslide detection and preliminary tsunamigenic plausibility assessment in Prince William Sound, southcentral Alaska: U.S. Geological Survey Open-File Report 2023-1099, 22 p., <https://pubs.usgs.gov/of/2023/1099/ofr20231099.pdf>
- Schilling, S.P., 1998, LAHARZ; GIS programs for automated mapping of lahar-inundation hazard zones: U.S. Geological Survey Open-File Report 98-638, 80 p., <https://doi.org/10.3133/ofr98638>
- Slaughter, S. L., Burns, W. J., Mickelson, K. A., Jacobacci, K. E., Biel, Alyssa, and Contreras, T. A., 2017, Protocol for landslide inventory mapping from lidar data in Washington State:

- Washington Geological Survey Bulletin 82, 27 p. text, with 2 accompanying ESRI file geodatabases and 1 Microsoft Excel file, http://www.dnr.wa.gov/Publications/ger_b82_landslide_inventory_mapping_protocol.zip
- Turner, A.K., and Schuster, R.L., eds., 1996, Landslide investigation and mitigation; National Academy Press, Transportation Research Board Special Report 247, 678 p., <https://onlinepubs.trb.org/Onlinepubs/sr/sr247/sr247.pdf>
- U.S. Department of Agriculture, 2017, U.S. General Soil Map (STATSGO2) by State, [accessed September 23, 2024], <https://nrcs.app.box.com/v/soils/folder/18247487156>
- U.S. Fish and Wildlife Service, 2024, Wetlands data by state, [accessed October 25, 2024], <https://www.fws.gov/program/national-wetlands-inventory/download-state-wetlands-data>
- U.S. Forest Service, 2024, Tongass National Forest: Tongass Landslide Initiation: U.S. Department of Agriculture Forest Service. [accessed April 2024], <https://data.fs.usda.gov/geodata/edw/datasets.php?xmlKeyword=tongass>
- Winkler, G.R., and Plafker, George, 1993, Geologic map of the Cordova and Middleton Island quadrangles, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map 1984, 1 sheet, scale 1:250,000, <https://dggs.alaska.gov/pubs/id/12911>
- Wu, T.H., 1976, Investigation on landslides on Prince of Wales Island, Alaska: Ohio State University, Geotechnical Engineering Report No. 5, 106 p., <https://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub501.pdf>
- Zechmann, J.M., Wikstrom Jones, K.M., and Wolken, G.J., 2023, Lidar-derived elevation data for Wrangell Island, Southeast Alaska, collected July 2023: Alaska Division of Geological & Geophysical Surveys Raw Data File 2023-28 v. 1.1, 14 p., <https://doi.org/10.14509/31098>
- Zechmann, J.M., Wikstrom Jones, K.M., and Wolken, G.J., 2024, Lidar-derived elevation data for Cordova, southcentral Alaska, collected August 18-19, 2023, and September 19 and 22, 2023: Alaska Division of Geological & Geophysical Surveys Raw Data File 2024-6, 11 p., <https://dggs.alaska.gov/pubs/id/31159>
- Ziemer, R.R, Swanston, D.N., 1977, Root strength changes after logging in southeast Alaska: U.S. Department of Agriculture, Forest Service Research Note PWN-306, 10 p., <https://research.fs.usda.gov/treearch/8667>