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DEBRIS FLOW HAZARD EVALUATION IN SITKA, ALASKA

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INTRODUCTION & METHODS

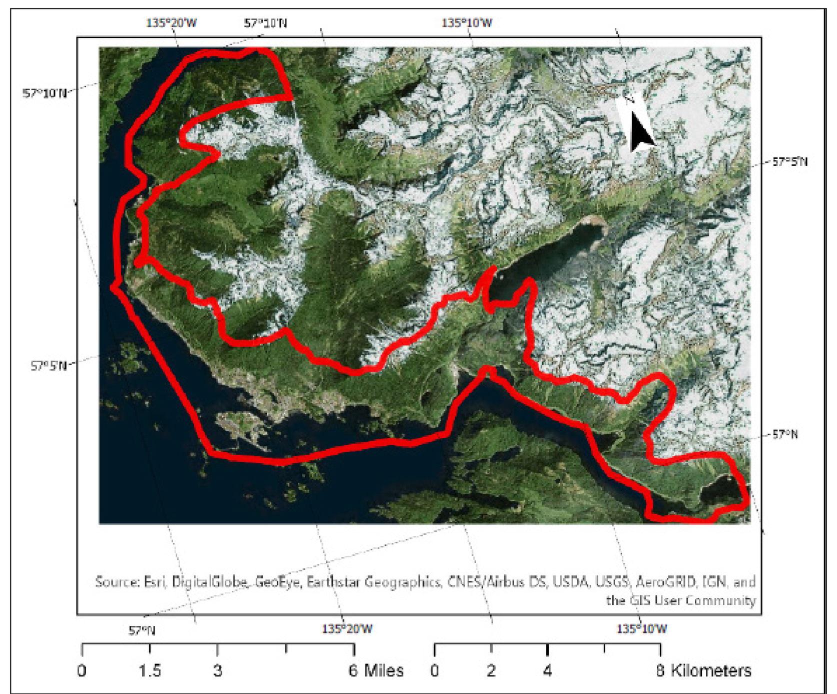


Figure 1. Area of investigation near Sitka, Alaska.

INTRODUCTION

On August 18, 2015, heavy rainfall and wind resulted in numerous debris flows in and around Sitka, Alaska (fig. 1).

- Over 45 debris flows were documented on Chichagof and Baranof islands.
- Four debris flows impacted roads and infrastructure in Sitka.
- These events highlight the importance of understanding debris flow risk to inform mitigation efforts, guide future development activities, and promote public safety.

PROJECT OBJECTIVES

To produce:

- Landslide Inventory Maps
- Landslide Susceptibility Factor of Safety (FOS) Maps
- Modeled Debris Flow Runout Maps

LANDSLIDE INVENTORY & DEBRIS FLOW SUSCEPTIBILITY

LANDSLIDE INVENTORY

Methodology

- Collect and evaluate existing landslide information, including geospatial and nongeospatial data.
- Collect available imagery and new lidar elevation data (Daanen and others, 2020).
- Conduct desktop studies to map landslides and create geospatial data with appropriate attribute information (Varnes, 1978; Burns and Madin, 2009; Burns and others, 2012).

Landslide Susceptibility (FOS)

$$FOS = \frac{\text{Forces resisting downslope movement}}{\text{Forces acting to move material downslope}}$$

In general, the lower the FOS, the greater the likelihood of debris flow failure

Classification

- FOS >1.5: little or no debris flow susceptibility
- FOS 1.25- 1.5: Moderate debris flow susceptibility
- FOS <1.25: High debris flow susceptibility

In general, the lower the FOS the greater the likelihood of debris flow failure.

FOS approximates landslide susceptibility.

FOS CALCULATION

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

c' = cohesion (effective)
Φ = angle of internal friction (effective)
γ = soil density (unit weight)
γ_w = groundwater density (unit weight)
t = depth to failure surface
m = groundwater depth ratio
α = slope angle

For our geologic units, we used "parent material" designations from the U.S. Department of Agriculture (USDA, 2018).

We approximated geotechnical data for each geologic unit based on published information (Yehle, 1974; Filz, 1982; Schroeder, 1983; Harp and others, 2006; Golder Associates, 2008; Shannon & Wilson, Inc., 2016; USDA, 2018; Table 1).

Table 1. Geotechnical properties used to calculate FOS for each geologic unit.

Map ID	Geologic unit	Effective cohesion		Effective angle of internal friction	Unit weight of soil		Unit weight of water		Depth to failure		Ground-water depth ratio
		lb/ft²	kPa	Degrees	lb/ft³	kN/m³	lb/ft³	kN/m³	ft	m	
1	Alluvium	140.0	6.7	36	101.1	15.9	64.0	10.1	6.6	2.0	1
2	Bedrock	280.0	13.4	35	103.6	16.3	64.0	10.1	1.0	0.3	1
3	Colluvium	50.0	2.4	22	102.3	16.1	64.0	10.1	1.4	0.4	1
4	Colluvium and/or glaciofluvial deposits	90.0	4.3	29	106.7	16.8	64.0	10.1	2.7	0.8	1
5	Colluvium and/or residuum	50.0	2.4	22	103.6	16.3	64.0	10.1	2.6	0.8	1
6	Colluvium derived from sandstone and/or residuum weathered from sandstone	50.0	2.4	22	108.6	17.1	64.0	10.1	1.7	0.5	1
7	Glaciofluvial deposits	140.0	6.7	36	113.6	17.8	64.0	10.1	5.3	1.6	1
8	Gravelly alluvium	50.0	2.4	36	101.1	15.9	64.0	10.1	0.8	0.2	1
9	Organic material	80.0	3.8	23	123.6	19.4	64.0	10.1	5.9	1.8	1
10	Organic material over residuum	80.0	3.8	23	82.4	12.9	64.0	10.1	1.4	0.4	1
11	Volcanic ash	140.0	6.7	20	126.0	19.8	64.0	10.1	2.7	0.8	1

SIMULATING DEBRIS FLOW RUNOUT-LAHARZ

LAHARZ

A model for simulating behavior of volcanic mudflows suitable for many debris flows because of their fluidity (Schilling, 1998).

$$A = cV^{2/3}$$

V= mass-flow volume

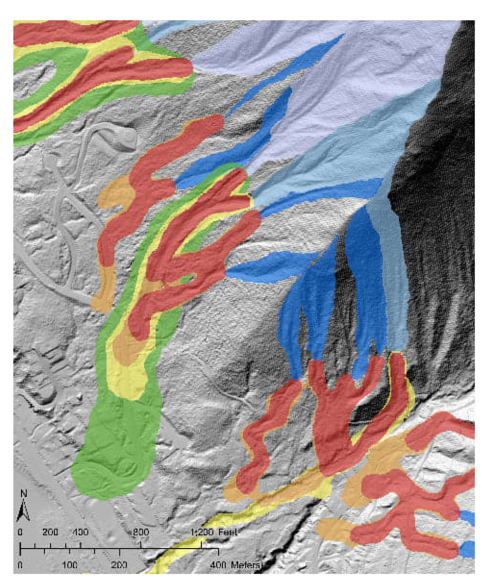
A= planimetric or cross-sectional areas inundated by an average flow as it descends a given drainage.

PARAMETERS

1. A starting point of debris accumulation
2. Total debris volume (V)
3. Two constants (C and c, cross-sectional and planimetric, respectively) describing flow characteristics.

We calibrated the LaharZ parameters for flow characteristic constants C and c with the known size and volume of the August 2015 South Kramer debris flow in Sitka, Alaska (fig. 2).

The Silver Bay and Starrigavin debris flows fit well with the calibrated South Kramer debris flow parameters (C=0.1; c=55), but the North Kramer debris flow did not.



We also conducted additional runout models based on the North Kramer Debris flow parameters to illustrate how surface roughness can affect runout distance.

Figure 2. South Kramer debris flow simulated with LaharZ after calibration. Green–yellow–orange–red polygons indicate extreme–high–medium–low volumes for medium-size catchments, respectively; flow boundaries are smoothened.

CATCHMENT-SCALED MODELING

CATCHMENT SIZE

Smaller debris flows occur more often than larger ones and larger catchments produce debris flows more often than smaller ones, so we scaled the modeled debris flows by catchment size and related characteristics. None of the catchments were scaled individually for debris volume.

CATCHMENT VOLUME SCALING PARAMETERS

- Catchment area (40,000 m²)
- Catchment mean slope (35 degrees)
- Catchment maximum elevation range (250 m)

For each of the three parameters, cutoffs were chosen to divide the catchments into two groups of roughly the same number. See values in parentheses above.

Scores of one or zero were assigned to each parameter based on greater or lesser values.

Parameter scores were summed to determine catchment size categories: large (3), medium (2), and small (0 or 1).

CATCHMENT VOLUME

Volumes for debris flow runout models were based on known values of debris flows in the area, which were calculated through elevation differencing of surface models.

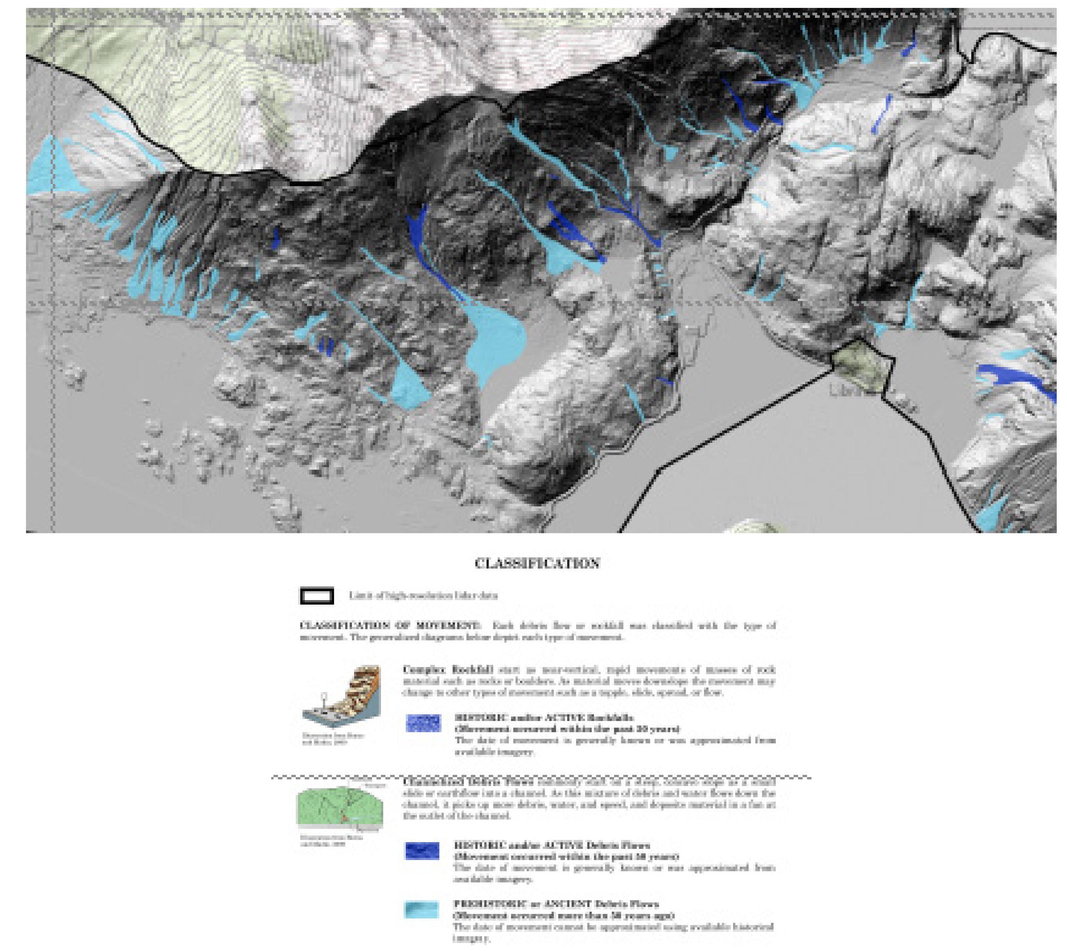
Table 2. Debris flow volume ranges per simulated flow.

Catchment Size	Volume: Low Flow Volume	Medium Flow Volume	High Flow Volume	Extreme Flow Volume
Large	900 m³ (31,783 ft³)	2,500 m³ (88,287 ft³)	11,000 m³ (388,461 ft³)	48,000 m³ (1,695,104 ft³)
Medium	900 m³ (31,783 ft³)	2,500 m³ (88,287 ft³)	11,000 m³ (388,461 ft³)	N/A*
Small	900 m³ (31,783 ft³)	2,500 m³ (88,287 ft³)	N/A*	N/A*

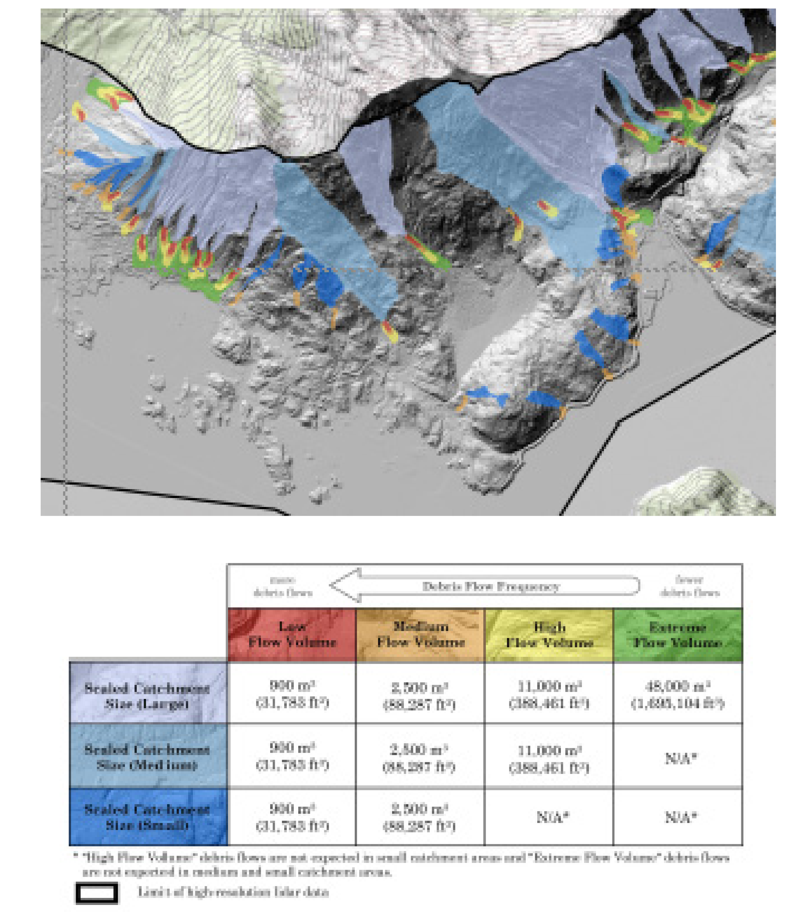
* "High Flow Volume" debris flows are not expected in small catchment areas and "Extreme Flow Volume" debris flows are not expected in medium and small catchment areas.

SIMULATING DEBRIS FLOW RUNOUT- CATCHMENT-SCALED MODELS

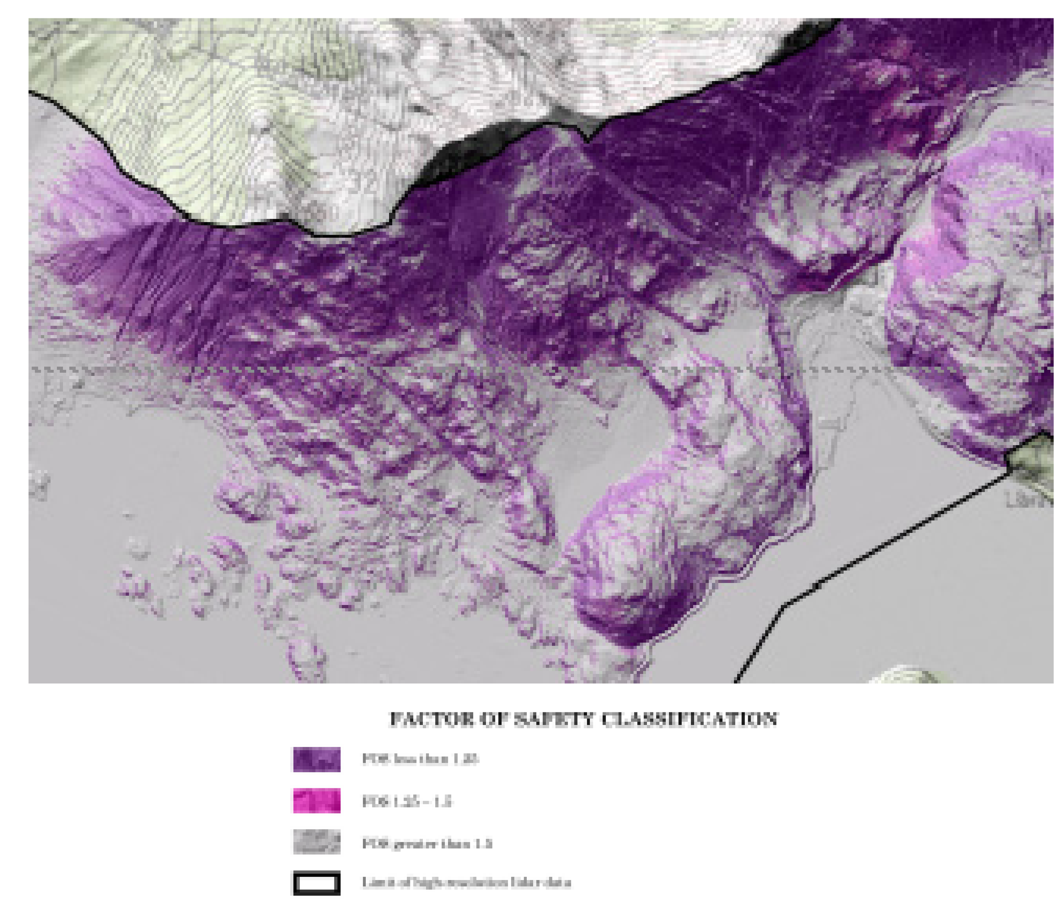
LANDSLIDE INVENTORY MAP



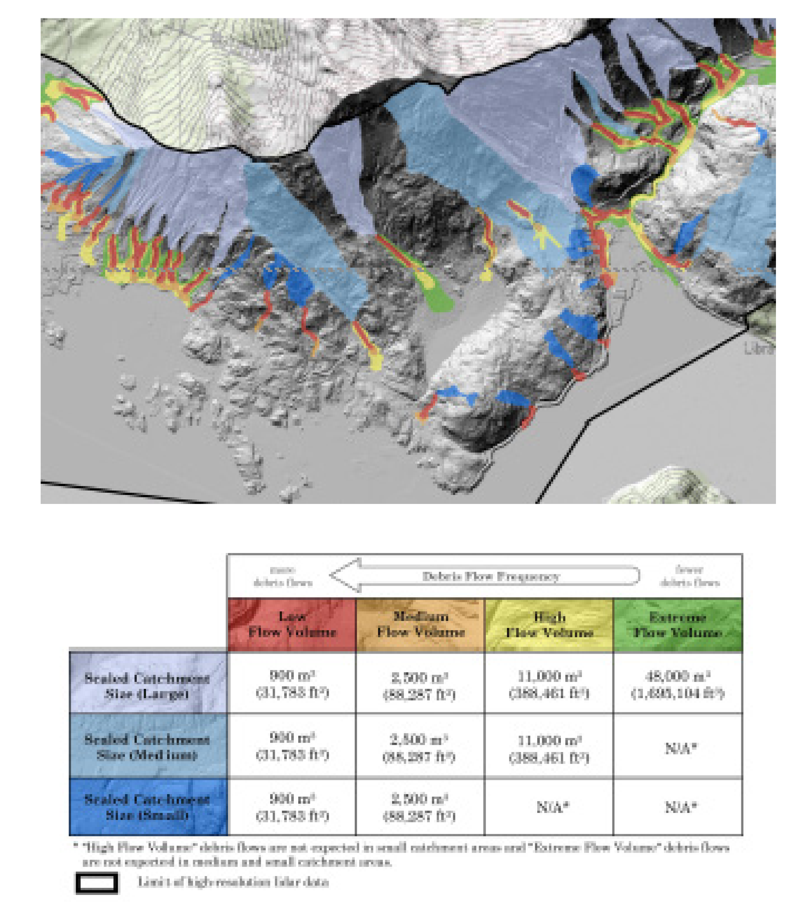
MODELED RUNOUT, BASED ON SOUTH KRAMER DEBRIS FLOW



LANDSLIDE SUSCEPTIBILITY MAP



MODELED RUNOUT, BASED ON NORTH KRAMER DEBRIS FLOW



ABSTRACT & REFERENCES

ABSTRACT

The threat of debris flows poses a great safety and financial risk to people and infrastructure in many communities throughout Alaska, including Sitka. To better understand potential debris flow hazards and increase hazard resiliency, the Alaska Division of Geological & Geophysical Surveys created maps of historical debris flows, factor of safety, and simulated debris flow runout to assess geohazards in and around the community. The historical debris flow inventory map integrates existing mapped debris flows with additional debris flows identified using high-resolution lidar. A map showing factor of safety was created following protocols similar to those developed by the Oregon Department of Geology and Mineral Industries, incorporating geotechnical data and lidar-derived slope data. Two debris flow runout maps were generated using the computer model LaharZ, which simulates runout extent based on physical parameters derived from documented debris flows in the Sitka area. One model was based on physical parameters from the South Kramer debris flow, and the other was based on physical parameters from the North Kramer debris flow. We used catchment size and slope derived from lidar to scale each catchment to the estimated volume of debris. Data from the historical debris flow inventory, the factor of safety map, and the runout model based on physical parameters of the South Kramer debris flow were combined to produce an integrated map of study results showing worst-case credible debris flow scenarios. A separate, integrated map using the runout model based on the North Kramer debris flow's physical parameters illustrates a debris flow scenario where greater surface roughness due to trees and other features in the flow path slows the downslope movement of debris. While not intended to predict debris flows, the results provide important information about the geohazard that can help guide planning and future investigations.

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