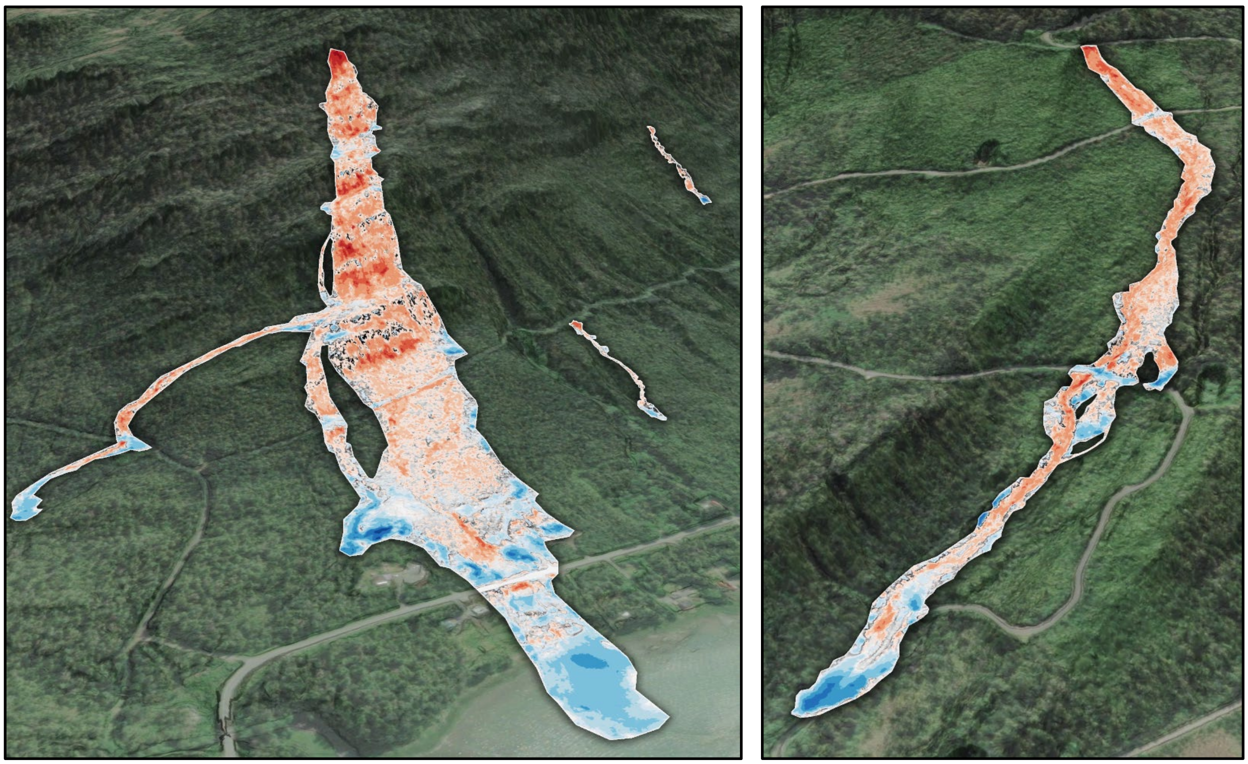
POST-LANDSLIDE ELEVATION CHANGES DETECTED FROM MULTI-TEMPORAL LIDAR SURVEYS OF THE NOVEMBER 2023 WRANGELL, ALASKA, LANDSLIDES

Jillian A. Nicolazzo, Katreen M. Wikstrom Jones, J. Barrett Salisbury, and Keith C. Horen

Preliminary Interpretive Report 2024-2



Landslides identified by lidar data after the November 20, 2023, precipitation event in Wrangell, Alaska.

This report was updated on February 29, 2024. We edited the precipitation discussion and replaced figure 2. This edit did not affect the lidar analyses or overall interpretations in the report.

2024
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POST-LANDSLIDE ELEVATION CHANGES DETECTED FROM MULTI-TEMPORAL LIDAR SURVEYS OF THE NOVEMBER 2023 WRANGELL, ALASKA, LANDSLIDES

Jillian A. Nicolazzo[1], Katreen M. Wikstrom Jones[1], J. Barrett Salisbury[1], and Keith C. Horen[1]

INTRODUCTION

Two large rain-induced landslides occurred late in the evening on November 20, 2023, in Wrangell, Alaska. The first recorded landslide covered Zimovia Highway near milepost 11.2 (MP11.2, fig. 1), destroyed three homes, and resulted in six fatalities and one survivor. The event cut off residents south of the landslide from Wrangell, as the sole access road was covered, and electric and communication lines were downed. Boats shuttled generators, fuel, water, food, and other goods around the landslide to the stranded residents. The second landslide occurred nearby on Middle Ridge Road (fig. 1), crossed the switchback forestry road in three places, and stranded one person between the two upper crossings. Geologists from the Division of Geological & Geophysical Surveys (DGGS) conducted a field visit to Wrangell in the days after the event to assist with slope-stability assessments. The following week (November 28–29), DGGS staff collected aerial lidar data over the two landslides and other areas of concern (Zechmann and others, 2024). One of these areas is located near milepost 3 of the Zimovia Highway, upslope of Nugget Trailer Court; a debris flow occurred here in recent years, and residents observed water flowing out of the hillside on the evening of November 20, 2023, scouring the trail connecting the powerline right-of-way and the trailer court. Other areas of concern for the community included water reservoir dams and the steep hillside of Mount Dewey (fig. 1).

We compared the November 2023 post-landslide lidar dataset to lidar data collected in July of the same year (Zechmann and others, 2023) to determine the extents and volumes of the two known landslides, as well as to identify other recent landslide activity that occurred between these collection dates, some of which may be attributable to the November rain event. We also examined rainfall and wind data to characterize the weather conditions during the 24-hours preceding the event. The purpose of this preliminary interpretative report is to describe DGGS' field investigations in the days immediately after the event, our methodology, and our preliminary interpretation of the pre- and post-landslide lidar datasets.

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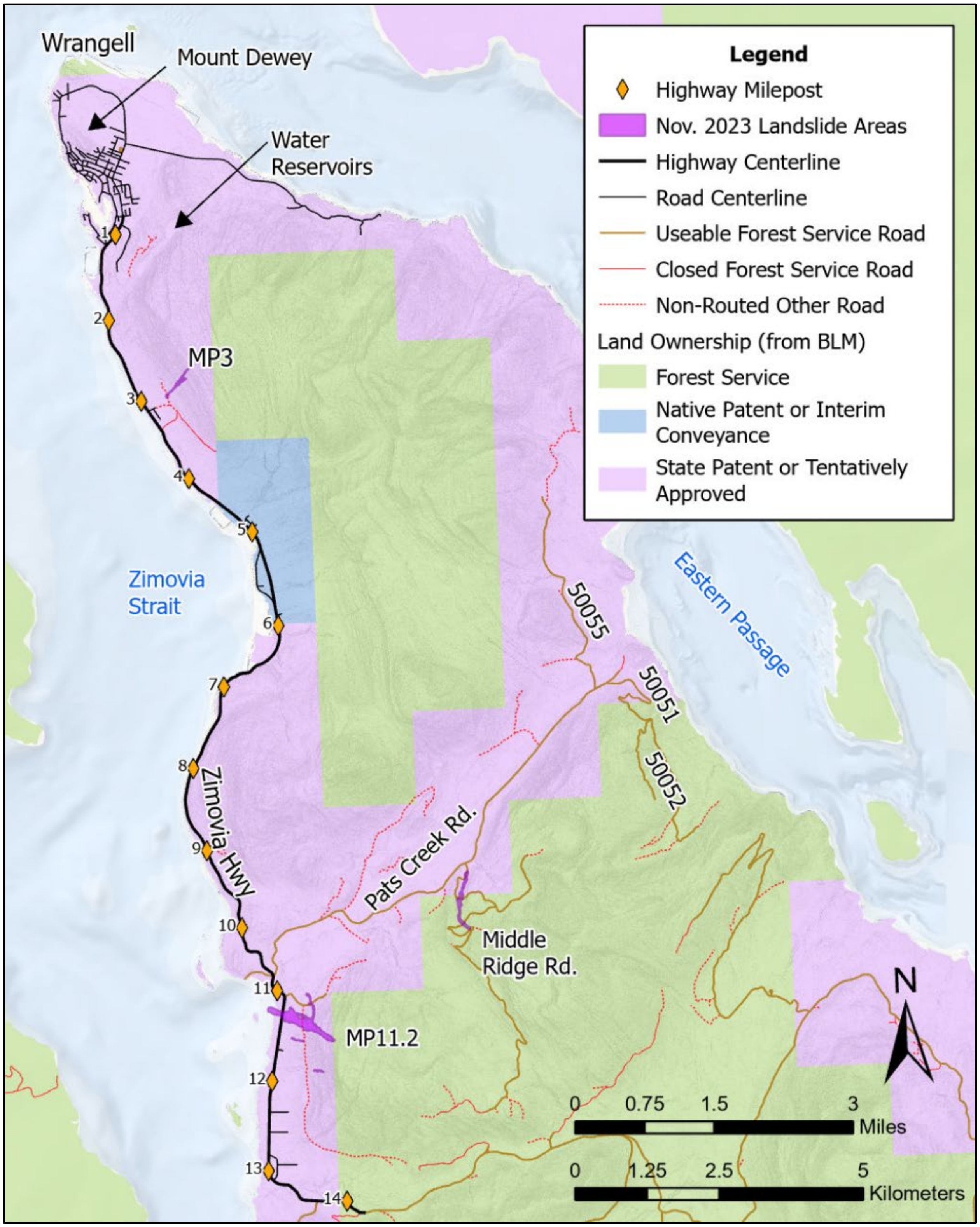

Figure 1. Location map showing the three main areas of concern: Milepost (MP) 11.2, Middle Ridge Road, and MP3.

WEATHER

Wrangell has a maritime climatic zone characterized by cool summers, mild winters, and heavy precipitation. Average high summer temperatures are in the 60s °F (16 °C) and winter lows are in the 20s °F (-7 °C). Average rainfall exceeds 85 inches (2.2 meters) per year. September, October, and November are the three rainiest months on average. Climate data for Wrangell, Alaska, from 1981 to 2010 were obtained from the Western Region Climate Center (WRCC, 2024; table 1).

Table 1. Climate data summary for Wrangell, Alaska (1981–2010; WRCC, 2024).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature °F (°C)	36.6 (2.6)	38.5 (3.6)	43.2 (6.2)	50.1 (10.0)	57.2 (14.0)	62.0 (16.7)	64.4 (18.0)	63.6 (17.6)	57.6 (14.2)	49.2 (9.6)	39.9 (4.4)	37.3 (2.9)	50.1 (10.0)
Average Min. Temperature °F (°C)	28.5 (-1.9)	29.4 (-1.4)	32.7 (0.4)	36.8 (2.7)	42.7 (5.9)	48.0 (8.9)	51.2 (10.7)	50.9 (10.5)	47.0 (8.3)	40.8 (4.9)	32.4 (0.2)	29.5 (-1.4)	39.3 (4.1)
Average Total Precipitation in (cm)	8.0 (20.3)	5.8 (14.7)	6.0 (15.2)	4.7 (11.9)	4.2 (10.7)	4.0 (10.1)	4.9 (12.4)	6.2 (15.7)	10.4 (26.4)	13.3 (33.8)	9.9 (25.1)	8.2 (20.8)	85.6 (217.4)

The National Weather Service (NWS) reported 2.23 in (5.6 cm) of rain at the Wrangell Airport between 9:00 PM AKST on November 19 and 9:00 PM AKST on November 20, with 1.13 in (2.9 cm) of that occurring within the six hours immediately preceding the landslide event (A. Jacobs, NWS Juneau, personal commun., November 22, 2023). More than 4 in (10 cm) of rain was recorded in Petersburg (NOAA, 2023), located approximately 30 miles (48 km) northwest of Wrangell, during this same 24-hour period. Winds gusted up to 40 mph (17.9 m/s) at the Wrangell Downtown Harbor at 4:00 PM but were less than 25 mph (11.2 m/s) at the time of the event. Wind gusts on Zarembo Island, west of Wrangell at 900 ft (274 m) above sea level (asl), reached 70 mph (31.3 m/s) at 7:00 PM and decreased to 34 mph (15.1 m/s) at the time of the event (A. Jacobs, NWS Juneau, personal commun., November 22, 2023). According to NWS Juneau, the November 19–20 precipitation event in Wrangell was not out of ordinary for the area, except for the six hours preceding the MP11.2 landslide event, which included more than the average amount of rain (A. Jacobs, personal commun., November 22, 2023).

Rainfall data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) for the Wrangell Airport for the period of September 1, 2023, through November 30, 2023 (NOAA, 2024). On November 20, the day of the landslides, 2.65 in (6.7 cm) of rain was recorded (fig.2). These numbers differ slightly from the numbers reported in table 1 because NOAA data are reported from midnight to midnight.

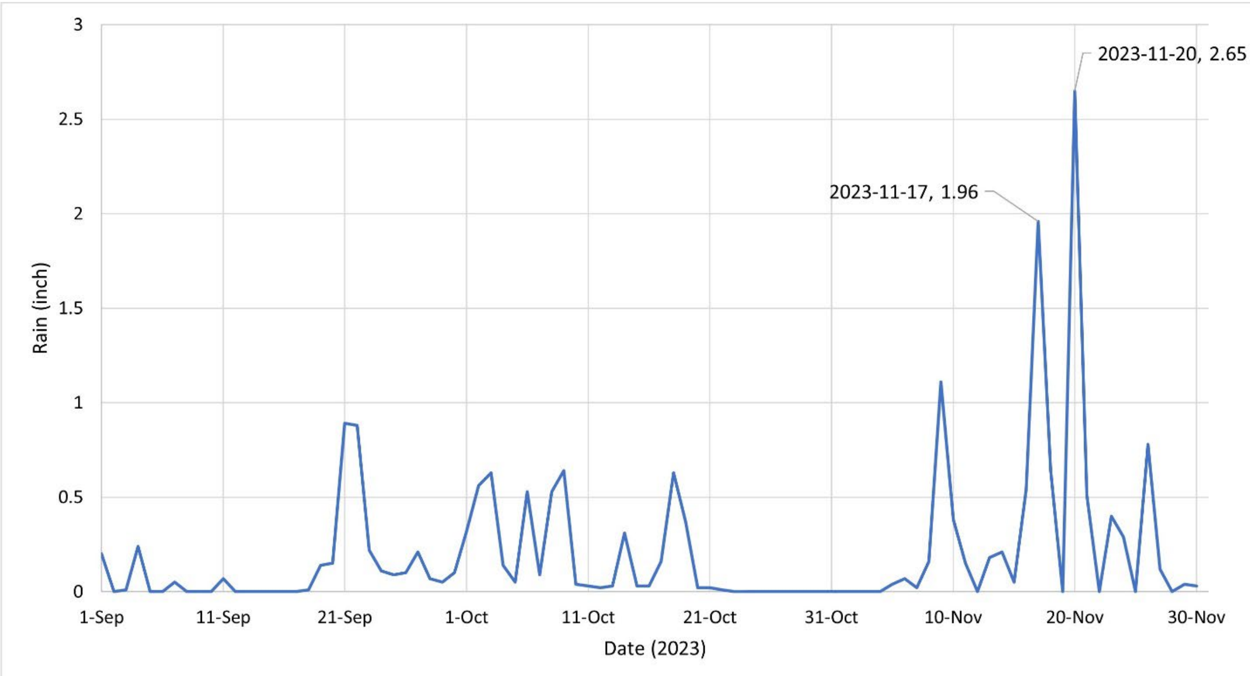

Figure 2. Daily rainfall recorded at Wrangell Airport, September 1, 2023, to November 30, 2023 (NOAA, 2024).

Local variabilities in weather are prevalent on Wrangell Island due to its mountainous topography; mountains force moist air and clouds to rise, which can result in increased rainfall at higher elevations. Funneling of winds and orographic-driven precipitation rates can cause significant differences in observed rain accumulation and wind gusts; weather recorded at the Wrangell Airport, located at sea level, may not accurately represent conditions at other sites on the island. While onsite, we observed comparatively more cloud cover and rainfall at the landslide sites approximately 10 miles (16 km) outside of town than we observed at the airport. The Alaska Department of Transportation & Public Facilities (DOT&PF) installed a simple rain gauge at MP11.2 to monitor rainfall during post-landslide road clearance and construction. This unofficial account often measured up to twice the accumulated rain compared to what was recorded at the airport—an indication that four or more inches (10 cm) of rain could have fallen at MP11.2 during the 24 hours preceding the landslide events. DOT&PF plans to install a more-permanent weather station near MP11.2 that will provide more accurate weather information for future considerations.

We investigated average wind speeds and direction for Wrangell Island and compared these to conditions during the 24 hours preceding the landslides to determine if changes in wind speed or direction may have contributed to landslide initiation. Data from Automated Weather Observation System (AWOS) station PAWG (NCEI, 2024) located at the Wrangell Airport and data from the National Data Buoy Center (NDBC) station LCNA2 (NDBC, 2024) located on Lincoln Island off the western shore of Etolin Island (about 32 mi [51 km] southwest of Wrangell

Airport) were downloaded and used for this analysis. The weather station data were analyzed to identify the historical prevailing wind direction; calculate the minimum, maximum, and average sustained wind and gust speeds; and generate direction and speed wind roses. Wind roses are graphical charts that show wind speed and direction at a particular location. Presented in a circular format, the length of each "spoke" around the circle indicates the frequency of winds blowing from that particular direction. Colors along the spokes indicate categories of wind speed.

Table 2 summarizes weather station PAWG's average historical wind data and the data covering the 24 hours preceding the landslides; the data are visually depicted in wind roses in figures 3 and 4. Table 3 summarizes weather station LCNA2's average historical wind data and the data covering the 24-hour period prior to the landslides. Although wind may have been a factor, it is not interpreted as having a meaningful impact on landslide initiation during this event.

Table 2. Wind data summary at weather station PAWG.

Period of Record	Jan. 1, 1973, to Nov. 16, 2023	9:00 PM Nov. 19 to 9:00 PM Nov.20, 2023
Prevailing wind direction	111.5 degrees	96.5 degrees
Maximum sustained wind speed	70.0 mph (31.3 m/s)	19.7 mph (8.8 m/s)
Average sustained wind speed	6.6 mph (2.9 m/s)	9.0 mph (4.0 m/s)
Maximum wind gust speed	90.8 mph (40.6 m/s)	30.0 mph (13.4 m/s)
Average wind gust speed	23.1 mph (10.3 m/s)	22.0 mph (9.9 m/s)

Table 3. Wind data summary at weather station LCNA2.

Period of Record	Aug. 20, 2007, to Nov. 30, 2023	9:00 PM Nov. 19 to 9:00 PM Nov.20, 2023
Prevailing wind direction	143.5 degrees	112.5 degrees
Maximum sustained wind speed	95.5 mph (42.7 m/s)	39.1 mph (17.5 m/s)
Average sustained wind speed	13.3 mph (5.9 m/s)	17.7 mph (7.9 m/s)
Maximum wind gust speed	114.1 mph (51.0 m/s)	56.4 mph (25.2 m/s)
Average wind gust speed	19.6 mph (8.7 m/s)	28.9 mph (12.9 m/s)

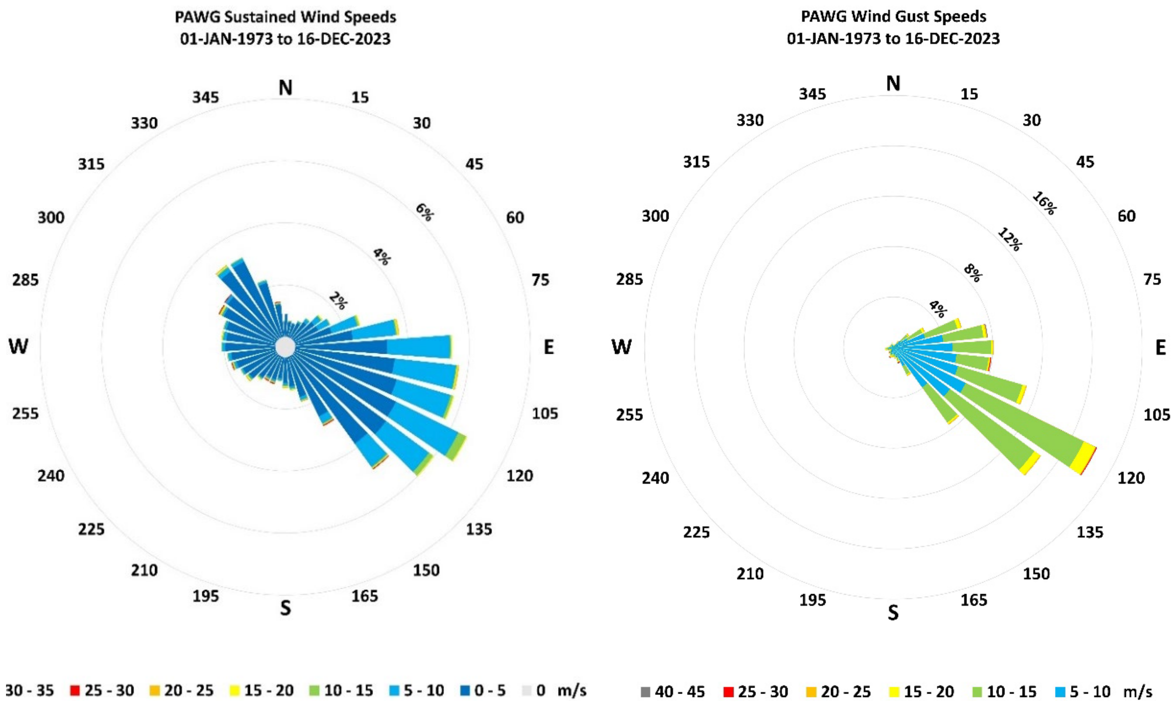

Figure 3. Weather station PAWG historical wind data: direction and sustained speeds (left) and direction and gust speeds (right).

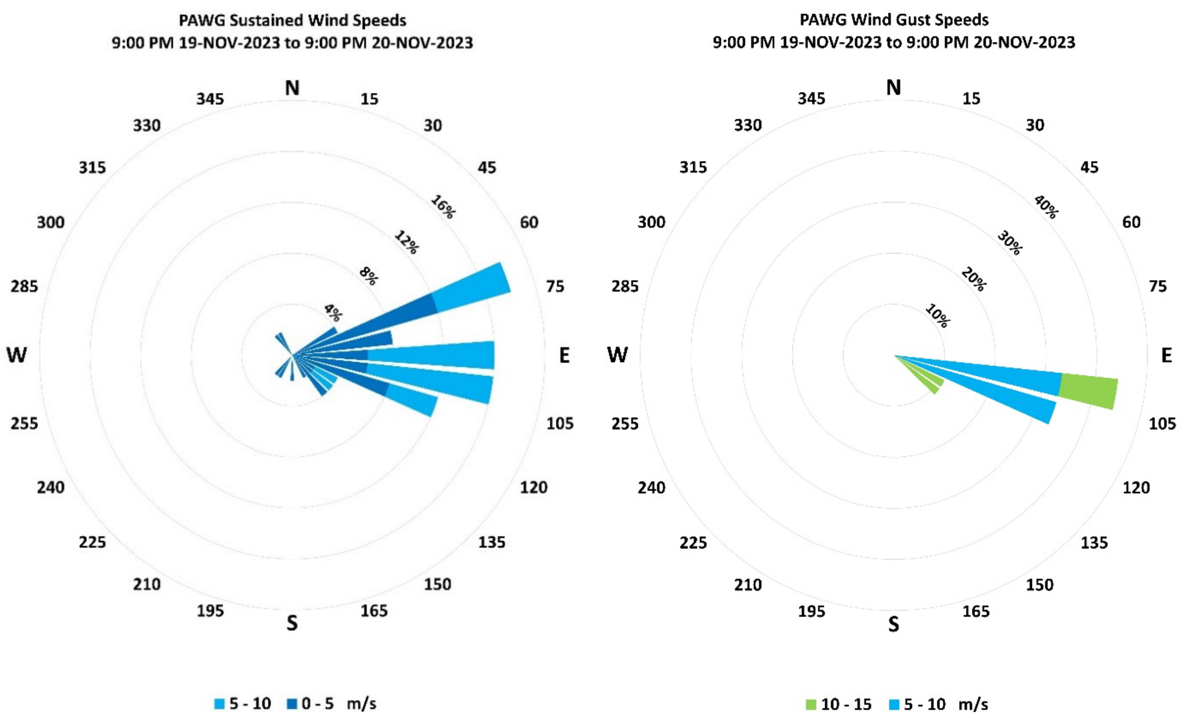

Figure 4. Weather station PAWG November 19–20, 2023, wind data: direction and sustained speeds (left), and direction and gust speeds (right).

FIELD INVESTIGATION

The State Emergency Operations Center (SEOC) at the Alaska Division of Homeland Security & Emergency Management (DHS&EM) contacted DGGS late on the night of November 20 requesting DGGS involvement in the Wrangell landslide response. The Governor issued a state disaster declaration on November 21. Three DGGS geologists mobilized to Wrangell on November 21 and 22 and stayed through November 26. At the time of our arrival, the main concern for the City of Wrangell was the MP11.2 landslide. Search and rescue (SAR) operations were active in the area, and DOT&PF was flying drone reconnaissance missions to assist SAR efforts and assess landslide stability. DGGS geologists focused on assessments of the wider Wrangell area and identifying additional landslide activity.

Zimovia Highway milepost 11.2 Landslide

DGGS geologists flew helicopter reconnaissance over the MP11.2 landslide on November 22 and 26 to document and assess the landslide source area and flow path. There is a distinct head scarp at 1,490 ft (450 m) asl and several bedrock benches at various elevations that trend roughly perpendicular to the path of the landslide. The soil cover in the steep source area is thin, with potential for thicker soil development in the flat areas above the bedrock benches. The landslide debris is primarily comprised of saturated soils and large wood debris, with minimal rock material. The landslide spanned approximately 3,750 ft (1,140 m) from head scarp to shoreline, with roughly an additional 500 ft (152 m) extending into Zimovia Straight (fig. 5). The landslide was approximately 350 ft (106 m) wide where it crossed the highway, wider in other sections further upslope, and it tapered to about 100 ft (30 m) at the head scarp.

Figure 5. Zimovia Highway milepost 11.2 landslide (photo taken looking east by Barrett Salisbury, November 22, 2023).

Middle Ridge Road Landslide

The Middle Ridge Road landslide occurred within one to two hours after the MP11.2 landslide, based on information given by the resident who was temporarily trapped by this landslide. DGGS geologists accessed the toe of the landslide to document and assess the debris composition. This lower section of the landslide was estimated to be approximately 150 ft (50 m) wide and covered approximately 600 ft (180 m) of Middle Ridge Road (fig. 6). The Southeast Power Authority flew a drone survey over the landslide on November 24, 2023, which helped determine the location of the source area and the flow path downhill. The landslide crossed Middle Ridge Road in three places and followed an already established stream channel resulting in significant erosion and entrainment of material in the V-shaped channel. From head scarp to toe, the landslide was approximately 3,600 ft (1,100 m) long and more than 100 ft (30 m) wide, with similar composition to the MP11.2 landslide: primarily large wood debris and saturated soils with very little rock.

Figure 6. Toe of the Middle Ridge Road landslide where it covers the road (photo looking south by Barrett Salisbury, November 24, 2023).

Nugget Trailer Court (Zimovia Highway milepost 3, "MP3") Landslide

On November 21, 2023, residents of the Nugget Trailer Court, located at approximately MP3 of the Zimovia Highway, reported an unusually large volume of water flowing through the neighborhood drainages and down Phillips Street, as well as sediment accumulation in an unusual location. According to several residents, a landslide that occurred upslope of the neighborhood in 2021 or 2022 (date undetermined) deposited rocks and sediment onto the powerline right-of-way (confirmed with Google Earth historical imagery). On November 23, DGGS geologists flew helicopter reconnaissance over the area, took aerial photographs (fig. 7), and visited the MP3 slide area on foot with the City of Wrangell Public Works Director and a local resident. We observed new mass wasting material in the channel and on the powerline right-of-way, which we associated with the November 20 precipitation event, and identified potential stream channels directing water flow toward the trailer court.

Figure 7. Aerial image of the landslide deposition zone, looking southeast, located upslope from the Nugget Trailer Court (photo by Barrett Salisbury, November 23, 2023).

Other Areas of Concern

We investigated other sites of concern, including the town of Wrangell's water reservoirs, which have two aging dams that are in poor condition and receive regular inspections (US Army Corps of Engineers, 2006), and the steep slopes of Mount Dewey, for which Shannon & Wilson was contracted to perform a geotechnical investigation in 2022. We visited these locations by foot and flew aerial reconnaissance in a helicopter over the water reservoirs. We did not see any recent signs of unstable slope material at either location.

We hiked along the logging road and powerline right-of-way that parallels Zimovia Highway near MP3 to ground-truth existing mapped landslides and historical landslide scars visible in aerial images, and to look for signs of recent mass wasting activity in established drainages or on exposed hillsides. No new landslides were identified and only the MP3 flow channel appeared to have reactivated during the November 20 rain event.

We joined a U.S. Forest Service officer to investigate additional landslide activity along the logging road network accessible north of the MP11.2 landslide road closure (forestry roads 50051, 50052, and 50055). The higher elevations were cloud-covered so visibility was limited, but no new landslides were identified near the roads. An existing landslide originating at forestry road 50052 and crossing forestry road 50051 was visited to investigate for possible reactivation (fig. 8).

Figure 8. Existing landslide on forestry road 50052 (photo by Jillian Nicolazzo, November 25, 2023).

TONGASS NATIONAL FOREST LANDSLIDE AREAS

The U.S. Forest Service previously mapped landslides within the Tongass National Forest (U.S. Forest Service, continuously updated). This publicly available inventory includes landslides, rockfalls, debris flows, talus slopes, and snow avalanches. Most of the polygons were digitized from orthophotos taken between 1998 and 2010, and the occurrence dates reflect an age bracket of when the landslides were first visible in the images. The inventory became available online in 2017 and was last updated in 2020.

The inventory includes 327 entries on Wrangell Island, which have been combined here into two categories: debris flows and snow avalanches (table 4). Although in this report we use the word "landslide" generically, the Tongass National Forest inventory defines the word "landslide" specifically as rotational landslides. There are no identified rotational landslides on Wrangell Island in the inventory. All "landslide" events in the inventory on Wrangell Island are categorized as debris torrents or debris avalanches, which we combined here as debris flows. Mapped locations in the general vicinity of MP3 are shown in figure 9, and those near MP11.2 and Middle Ridge Road landslides are shown in figure 10. During our visit to Wrangell in November 2023, we verified a few of these mapped landslides by ground-truth visits. We also observed mass wasting activities that were not in the U.S. Forest Service's inventory. For example, the MP3 slide occurred after the most-recent inventory update and is therefore not included.

Table 4. Tongass National Forest mapped landslides by failure type (U.S. Forest Service, continuously updated).

Failure Type	Count
Debris flows and deposition areas	252
Snow avalanche chutes and deposition areas	75

LIDAR DATASETS

Light detection and ranging (lidar) is a remote sensing technique that uses timed laser pulses to measure distances to the earth's surface. Each measurement, of which there are hundreds of thousands made per second, is represented by a point in 3D space. The collection of individual measurements is known as a "point cloud" and contains information about the surface of the earth as well as trees, structures, and other objects on the ground. A digital surface model (DSM) represents the tops of trees and structures; a digital terrain model (DTM) represents the bare earth, where trees, structures, and other objects have been removed. When assessing and mapping landslides, DTMs are typically used to detect changes in earth material underneath the tree canopy. DSMs are used for assessing the ages and health of trees and changes in the built environment that may have contributed to or resulted from landslide activity. The combined use of DTMs and DSMs reveals changes in vegetation and soils, which provides a complete picture of landslide activity.

In partnership with the U.S. Forest Service, DGGS collected lidar data for Wrangell Island in July 2023 (Zechmann and others, 2023). As part of the landslide emergency response, DGGS collected new aerial lidar data over selected areas November 28–29, 2023 (Zechmann and others, 2024). Poor weather conditions limited data collection to only the areas of highest concern: the steep slopes between MP1 and MP6.5, MP11–13 of the Zimovia Highway, and the area around the Middle Ridge Road landslide.

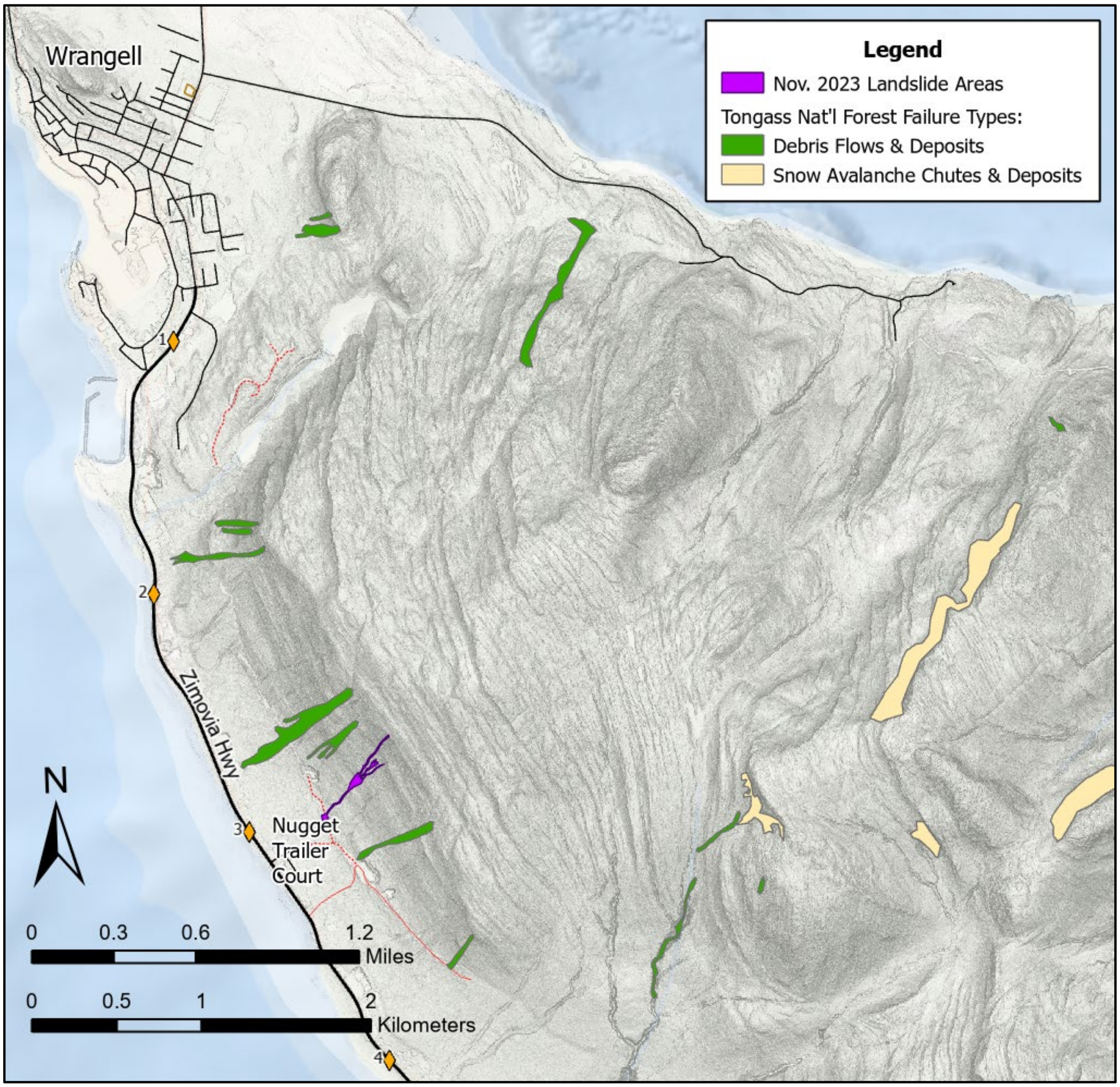

Figure 9. Tongass National Forest mapped landslides, Zimovia Highway MP1–4; basemap is a hillshade raster derived from Zechmann and others, 2023.

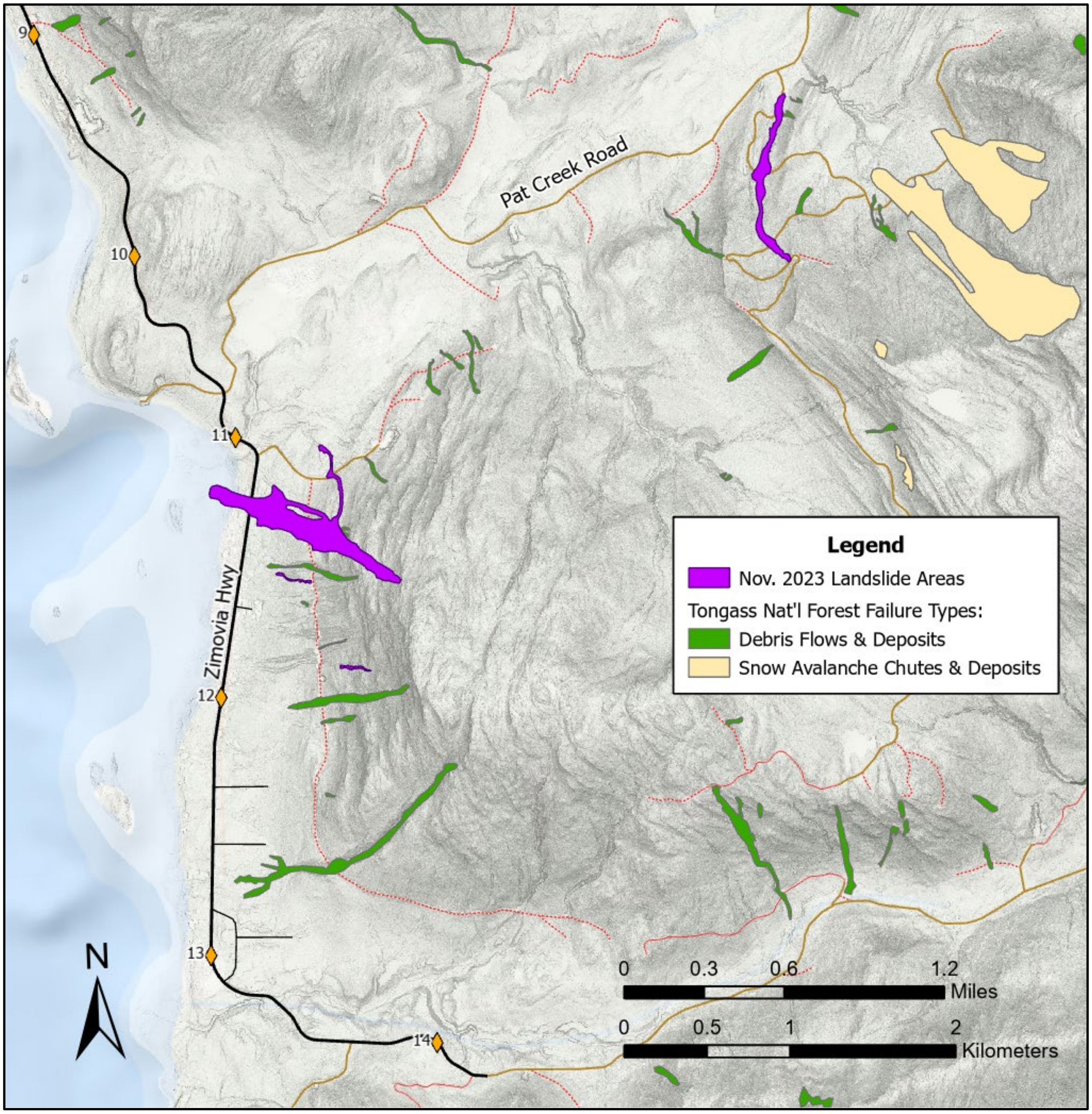

Figure 10. Tongass National Forest mapped landslides, Zimovia Highway MP10–14, basemap is a hillshade raster derived from Zechmann and others, 2023.

LIDAR DIFFERENCING METHODS

We assessed topographic changes that occurred between July and November 2023 by comparing the DTMs of the two lidar datasets (Zechman and others 2023; 2024). First, the November DTM was aligned with the July DTM by applying horizontal and vertical shifts. Second, we subtracted the July DTM from the November DTM to detect any positive or negative changes in topography between the two acquisitions. It is important to note that the two lidar surveys were flown with different specifications due to different requirements of their derived products. The November lidar dataset was acquired with a higher laser-pulse rate compared to the July dataset, resulting in a denser point cloud and more accurate, higher-detail bare earth surface (DTM). When directly compared to the July DTM there are areas in the terrain that appear to have an elevation change; however, this is due to interpolation over areas that suffer from sparser ground coverage in the July point cloud (fig. 11). These discrepancies required in-depth interpretation of the change layer to confidently depict features related to recent landslide activity.

We reviewed the new "change" layer for areas of surface elevation change that could represent landslide erosion and deposition and digitized their extents. We calculated eroded (negative volume change) and deposited (positive volume change) materials for each identified landslide polygon using the Volume Calculation tool in QT Modeler and the Cut Fill tool in ArcGIS Pro. The volumes presented below are an average of the two methods. As explained above, note that the November elevation surface had higher resolution than the July elevation surface, which affected the volume estimates.

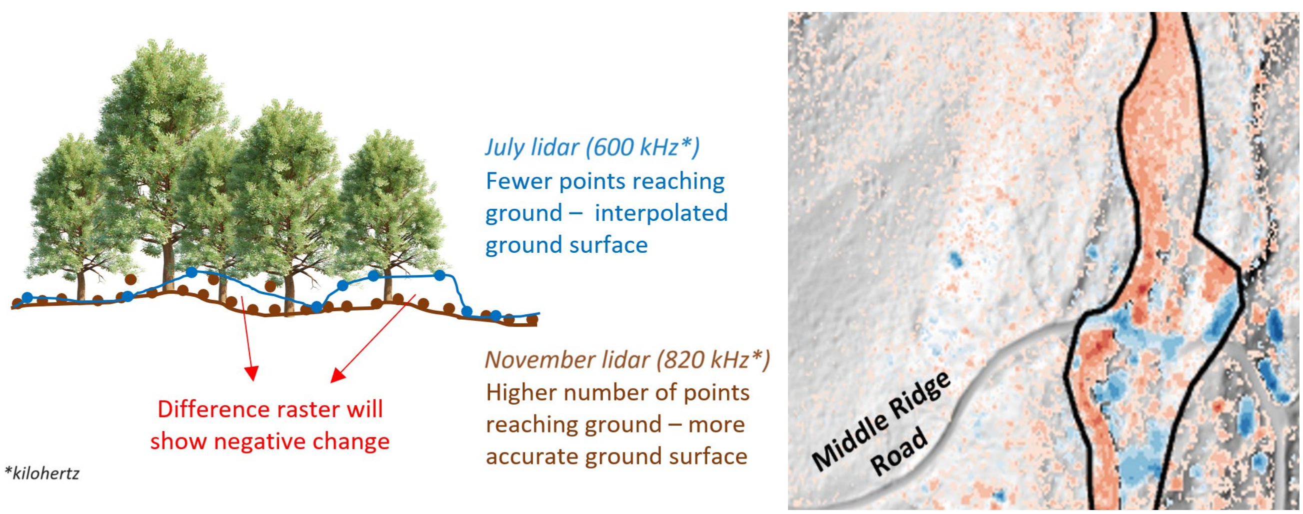

Figure 11. Lidar examples. (Left) Schematic demonstrating the issue of differencing two lidar-derived surfaces with different ground sampling. (Right) Red and blue colored dots outside of the landslide outline (black polygon) show areas of erratic change that are due to ground sampling differences between the two lidar datasets, and do not indicate landslide activity.

INTERPRETATION & DISCUSSION

Zimovia Highway MP11.2 landslide and slide activity between MP11 and MP13

A 150-ft- (45-m-) long head scarp shaped like an inverted "U" is visible at the top of the MP11.2 landslide (fig. 12) at approximately 1,500 ft (455 m) asl. The lidar differencing suggests that roughly 2.8 million ft^3 (80,000 m^3) of material was released/eroded and approximately 1.7 million ft^3 (48,000 m^3) was deposited by the landslide (fig. 13). The DOT&PF had already removed debris from the road at the time of the November lidar survey and that removed volume is not part of the deposited volume stated here. In addition, this landslide ran into the ocean and deposited sediment in the water. Additional bathymetric lidar or sonar is necessary to calculate this deposition volume (not currently planned).

Figure 12. MP11.2 landslide head scarp (photo by Barrett Salisbury, November 23, 2023).

Based on the lidar differencing analysis, we identified two additional (much smaller) landslides on the hillside south of MP11.2, referred to here as MP11.5 and MP11.8 (fig. 13). MP11.5 released at an old logging road approximately 500 ft (150 m) asl. A new head scarp is visible in the November lidar cutting into the road edge, with the slide material following an existing stream channel before stopping where the slope flattens. This small slide had a release/erosion volume of roughly 31,800 ft^3 (900 m^3) and deposition volume of approximately 31,000 ft^3 (880 m^3). The slide at MP11.8 released higher on the slope, near 1,030 ft (315 m) asl, and may have also followed an existing stream channel, although this channel is less distinct. The landslide stopped before reaching the logging road. It had a release/erosion volume of approximately 53,000 ft^3 (1,500 m^3) and deposition volume of roughly 21,000 ft^3 (600 m^3). We note that the release/erosion volumes are larger than the deposition volumes. This is common for landslides that run into water and lose material, but for on-land landslides, the numbers are typically more equal. Some volume may have been lost as a thin layer of mud that spread across the ground; however, this volume discrepancy is likely due to the interpolation differences described above, since this hillside has numerous narrow gullies with thick vegetation that are smoothed over in the July DTM compared to the November DTM. In the July DTM, there was greater interpolation during data processing and the gullies appear filled-in or flattened, while the gullies appear as V-shaped channels, truer to reality, in the November DTM. It is likely that those inaccuracies in the July DTM contributed to exaggerated release/erosion volumes.

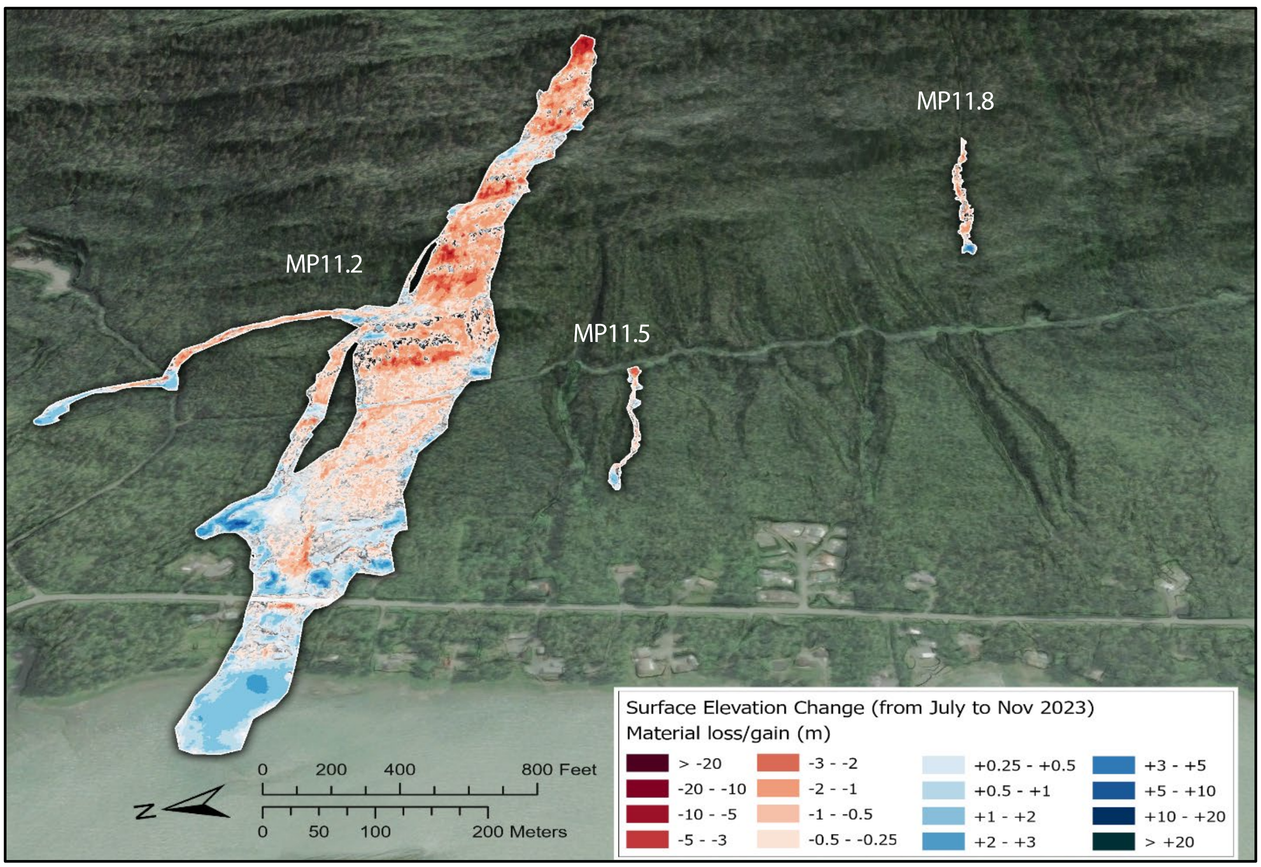

Figure 13. Landslides identified on the hillside between MP11–MP12 on the Zimovia Highway associated with November 20, 2023, precipitation event. Color range depicts erosion and deposition based on surface elevation change in the lidar datasets.

Middle Ridge Road Landslide

The Middle Ridge Road landslide originated at the outer edge of the road on a hairpin curve at roughly 1,230 ft (375 m) asl. An 85-ft- (26-mr-) wide head scarp cutting into the road edge is visible in the November 2023 lidar. The landslide crossed the road and then followed an existing stream channel downslope, crossed the road a second time, and finally encountered the road a third time. The toe of the debris flow (definition USGS, 2004) completely covered the road for about 450 ft (135 m) near the intersection with Pat Creek Road (fig. 14). The lidar differencing suggests that approximately 895,000 ft^3 (25,000 m^3) of material was released/eroded and roughly 385,000 ft^3 (11,000 m^3) of material was deposited by this landslide. Here again, differences between the lidar acquisition methods likely contributed to this discrepancy in volumes, though we observed during our field visit that a thin layer of mud had spread across the forest floor, material which would be missed in this volume calculation.

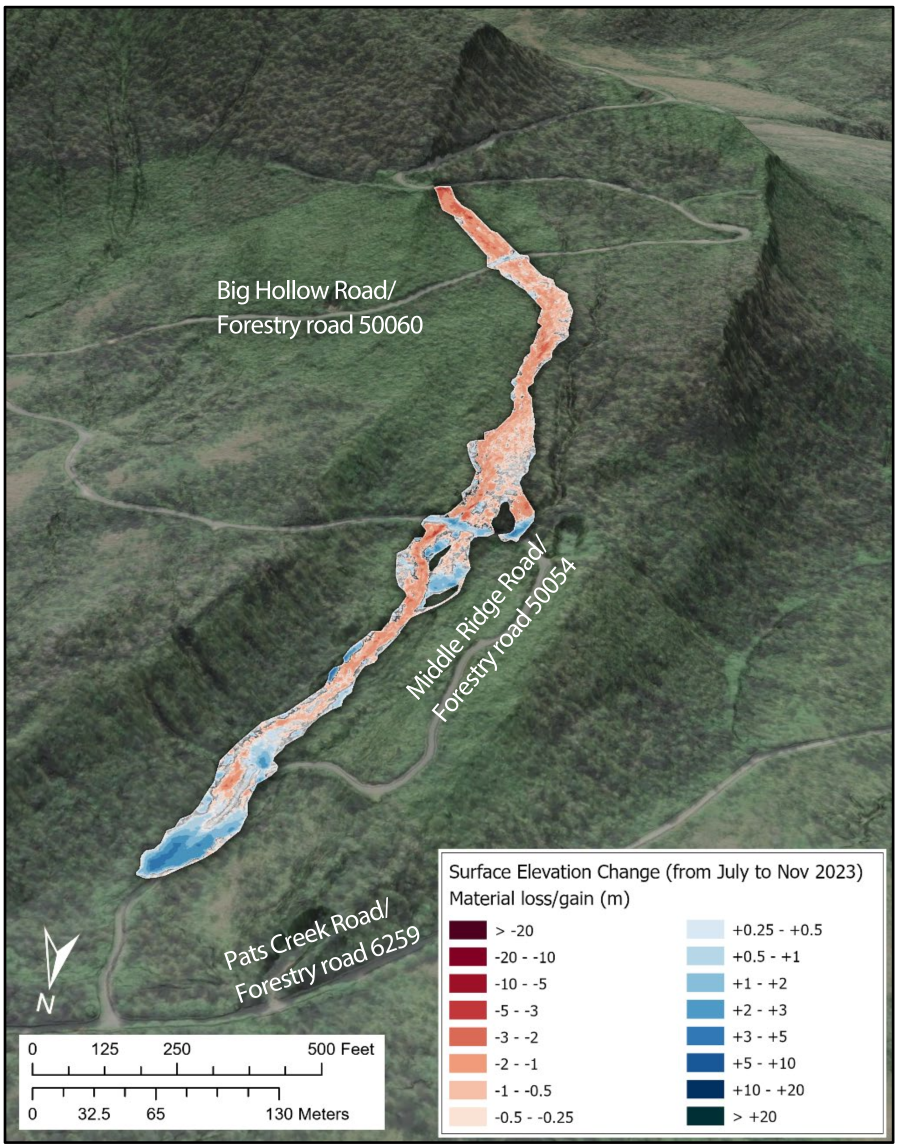

Figure 14. Erosion and deposition of the Middle Ridge Road landslide.

Nugget Trailer Court (MP3) Landslide

The 2021 or 2022 landslide upslope of Nugget Trailer Court (MP3) likely initiated in at least one of three existing drainages that converge just upslope from the debris fan on the powerline right-of-way/old logging road (fig. 15). During our field visit, we noted a log pile on the downhill side of the logging road that functions as a natural levee and helps divert water and debris onto the logging road, rather than straight downhill toward the trailer court (fig. 7). This log pile may be accumulated debris from previous landslide activity. It is common for debris flows (definition USGS, 2004) to create levees where the slope changes and the water flow is no longer confined to a well-defined channel.

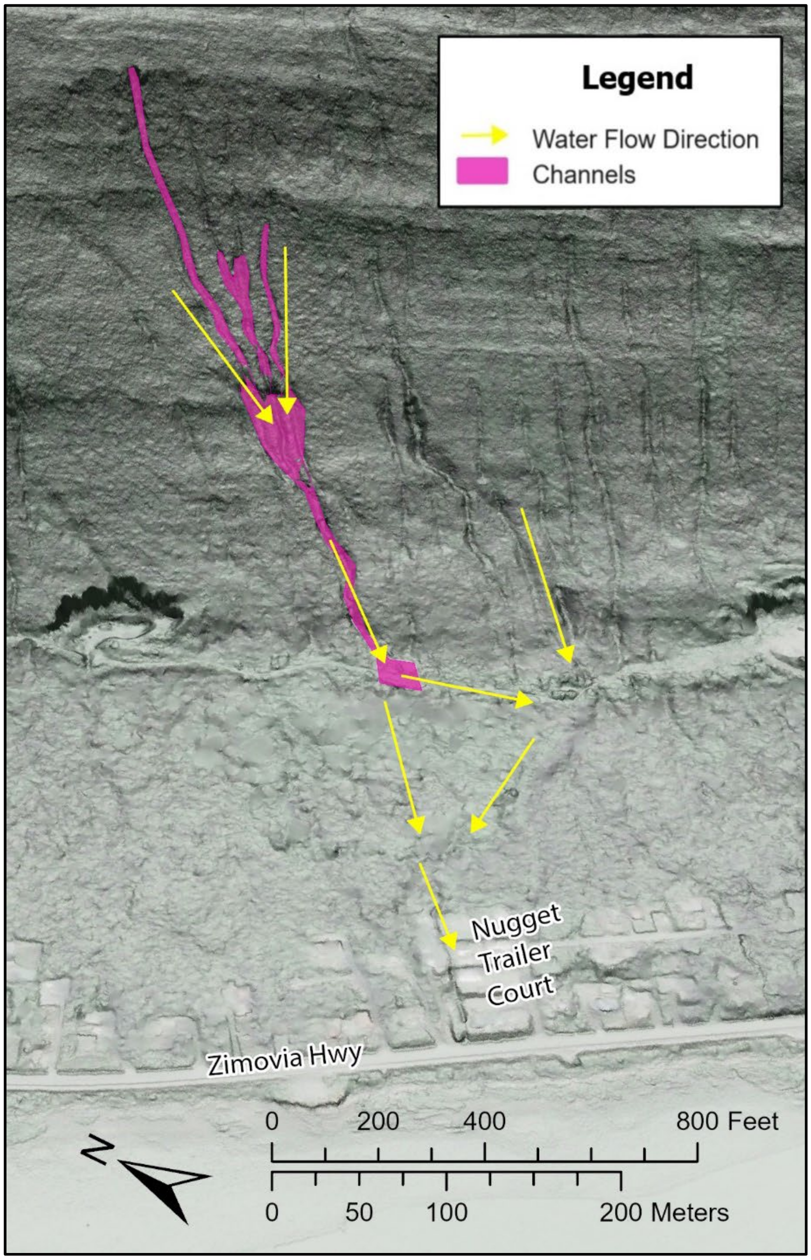

Figure 15. Nugget Trailer Court, MP3 landslide area, basemap is a hillshade raster derived from Zechmann and others, 2023.

Loose rock occupies the drainages in the upper elevations on the hillside (fig. 16) and is mobilized during heavy rains. Smaller sands and gravels are more easily transported by flowing water than larger gravels and cobbles, which require a heavier and faster flow. Recent sand deposits were noticed in several areas along this section of the logging road; it is likely this will continue. Differencing of the two lidar datasets did not show any significant volume change between acquisition dates.

Figure 16. Angular bedrock debris in stream channel that feeds into the debris fan upslope from Nugget Trailer Court (photo by Tom Wetor, City & Borough of Wrangell, December 7, 2023).

Water Reservoirs

Based on our lidar differencing analysis, we did not identify any recent mass movement on slopes adjacent to the water reservoirs or at the dams. A debris fan at the upper reservoir is clearly visible in the lidar (orange polygon in fig. 17) but it is not a recent deposit. Wrangell residents mentioned this landslide occurred around 2001, but it appears to be vegetated in aerial images dating back to August 8, 1948 (USGS EarthExplorer, 2024), indicating the original deposit pre-dates 1948. However, these images have large time gaps between them; smaller events might have occurred within these data gaps. There is a large drainage feeding into the reservoir here, and it is possible that debris accumulates over time and may be flushed downstream to the reservoir, given the right conditions.

The lidar shows hummocky terrain in the spillway between the reservoirs and downslope from the lower reservoir (purple polygons in fig. 17). This topography is indicative of talus piles or other slumped material. Loose soils and rocks erode from the steep hillside and collect at the base of the slope.

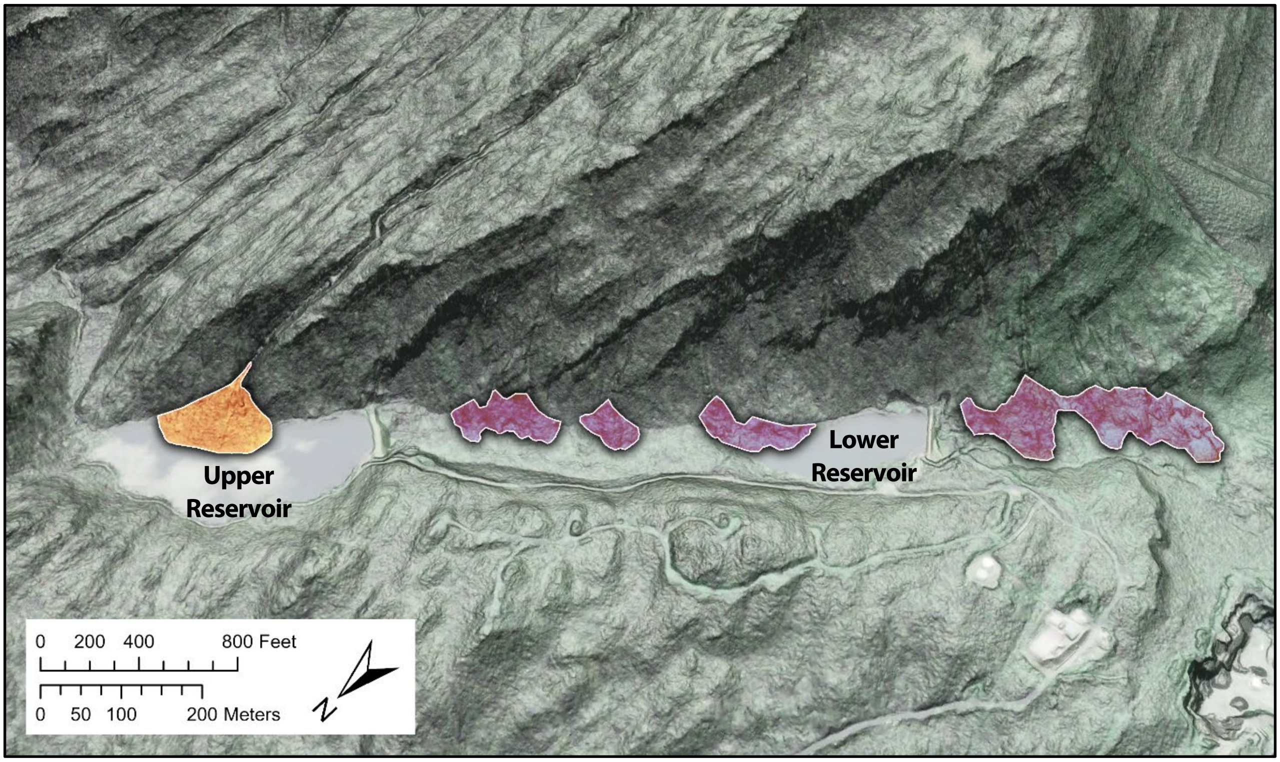

Figure 17. Debris fan (orange polygon) and colluvium deposits (purple polygons) at the water reservoirs.

INTENDED USE AND LIMITATIONS

This is a preliminary lidar differencing assessment to determine the extents and volumes of the MP11.2 and Middle Ridge Road landslides, as well as to identify other unknown landslides that have occurred since the July 2023 lidar data collection, some of which may be attributable to the November 20, 2023, rain event. Differences in lidar data collection methods and thick vegetation make a direct comparison difficult; interpretations involve subjectivity. Small landslides may have been misinterpreted or missed. Lidar-based change detection captures differences over a discrete period of time; therefore, landscape changes, such as those due to construction activities, more recent rainfall, and general settling of landslide materials, that may have occurred since the latest lidar dataset was collected are not represented here.

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