Personnel

Geo-Personnel (On-site)	Title	Arrived in Haines	Departed Haines
Ronald Daanen	Geohydrologist	12/4/2020	12/13/2020
Katreen Wikstrom Jones	Natural Resource Specialist	12/4/2020	12/13/2020
Trent Hubbard	Geologist	12/6/2020	12/13/2020
Amanda Willingham	Geologist	12/6/2020	12/13/2020

Off-site DGGS geologists: De Anne Stevens, Gabriel Wolken, Barrett Salisbury, and Simone Montayne; and DGGS GIS specialists Andrew Herbst and Michael Hendricks.

We also received assistance from Haines Avalanche Center and local Haines residents; USGS geologists Jonathan Godt, Stephen Slaughter, and Jeffrey Coe; Alaska Geospatial Information Officer Leslie Jones; Alaska Division of Mining, Land, and Water Chief Surveyor Gwen Gervalis and surveyor Kevin Bow; University of Alaska tsunami modelers and seismologists Elena Suleimani, Dmitry Nicolsky, and Michael West; and University of Southern California tsunami modeler Patrick Lynett.

Field Activities

- Conducted ground- and boat-based assessments of geologic hazards on Lutak Spur, Lutak Road, Haines Highway, Mud Bay Road, the Cathedral/Piedad Road area, Beach Road, “Slump” Area of Concern (AOC), and several other AOCs. During the assessments, we took field notes, photographs, and videos to compare over time. At many locations, we observed:
    - Areas where slope movement (or suspected slope movement) had occurred, particularly near residences, and on repeat visits noted any changes or lack thereof.
    - Streamflow (and any changes). We noted many areas where streams had deposited sediments during the heavy rains but saw no imminent threats to homes or roads.
    - Outcrops to determine their composition while noting materials that are more susceptible to failure (e.g., clays, very fine silt). We evaluated these during subsequent aerial and ground-based assessments and downgraded areas that caused no concern.
- Performed helicopter-based aerial geologic reconnaissance surveys for geohazards at the following locations:
    - Haines Highway near Haines
    - Lutak Road to Lutak Spur
    - East side of Lutak Inlet potential tsunamigenic rock slope
    - West slope of Mount Villard (“Santa Claus Mountain”) potential tsunamigenic slope
    - South and west slopes of Mount Ripinski
    - Beach Road and Beach Road slide
    - Mud Bay Road to Mud Bay
    - Chilkat Lake
- Collected high-resolution lidar-derived topographic data over Haines AOCs to document recently mobile and potentially unstable slopes.

- Utilized DOT-installed pressure transducers in groundwater monitoring wells on Oceanview Street and Lutak Road to assess groundwater conditions at “Slump” AOC, and existing well monitoring system on community artesian well to monitor groundwater conditions in Piedad Road area.
- Conducted multiple residential site visits to assess and monitor ground failure indicators.
- Monitored ground water pressures and surface water flow in numerous AOCs.
- Collaborated with tsunami modelers at University of Alaska Fairbanks’ Geophysical Institute and University of Southern California to explore tsunami dynamics (e.g., potential wave heights and travel times) resulting from hypothetical bedrock slope failures along Lutak Inlet.
- Focused specifically on the Beach Road slide headscarp, lateral margins, debris body, and runout zone to assess likelihood of potential movement.
    - Hired UAV contractor to collect reconnaissance video and orthomosaic imagery of affected area
    - Visited the headscarp to ground-truth cracks observed in new lidar-derived elevation models. We documented the size of the crack extending from the headscarp to the southeast while looking for evidence of any additional instabilities that were not imaged by the lidar scan. None were observed, although snow impeded our ability to make observations on the ground.
    - Repeated daily theodolite measurements to identifying markers distributed throughout the slide body
    - Performed residential site visits for homes southeast of the Beach Road slide looking for additional imminent dangers. We noted no indicators of additional imminent danger to the homes.

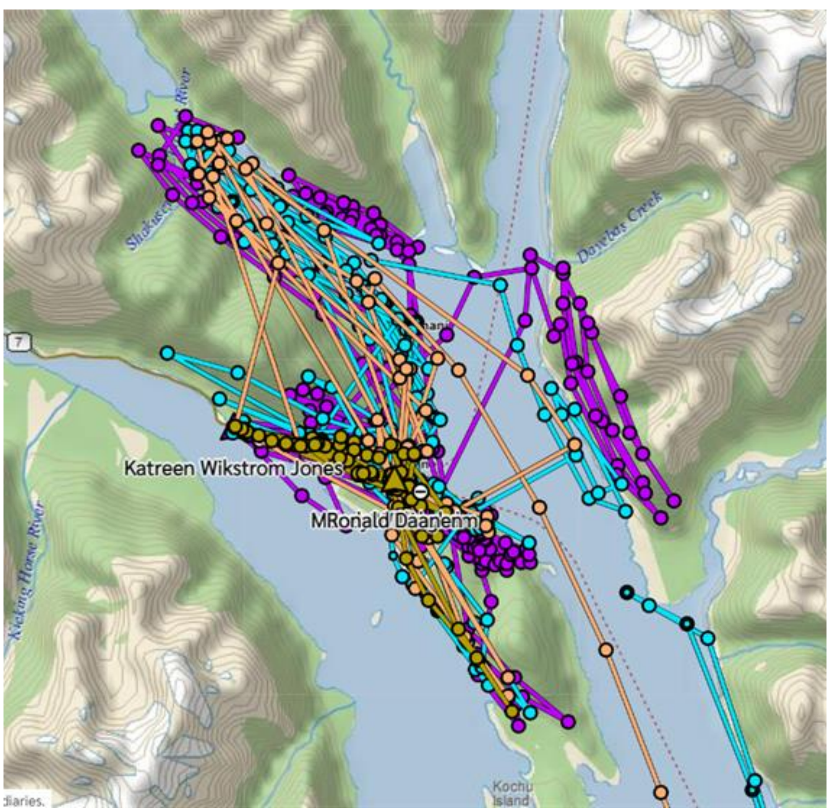

Figure 1. Track logs of DGGS field crews showing areas covered by aerial and ground-based activities.

FINDINGS

Contributing Factors

Unusually high intensity rainfall fell on a deep snowpack, resulting in quick saturation of soil and surface overflow. The precipitation event began on December 1, 2020, and started out cold with snow accumulation of up to approximately 60” in higher elevations. The rain/snow line rose, and precipitation type was predominantly rain by December 2 up to 2,500 ft of elevation. At Haines airport, 7.12” of rain was recorded within 24 hours on December 1–2 (100–150 year return interval [RI]) and 10.26” in 48 hours (500 year RI).

Beach Road Landslide

The Beach Road landslide measured approximately 500 ft wide and 2,500 ft long (measured from head scarp to shoreline), with additional deposition in the water. The release was likely triggered by a combination of bedrock failure and oversaturated soils that allowed the entire soil mass to become liquified and move downhill. The failed material was primarily bedrock in the upper portion of the slide, which then incorporated saturated soils and other surface materials as it traveled downslope in a debris flow. Based on lidar differencing (comparing lidar elevation data from 2014 with the newly-acquired 2020 data) there is a lot of material accumulated in the upper part of the landslide path that is likely rock debris that did not mobilize to the bottom of the slide. Very little scouring of the original land surface was observed in the lower part of the landslide path, suggesting a highly saturated debris flow.

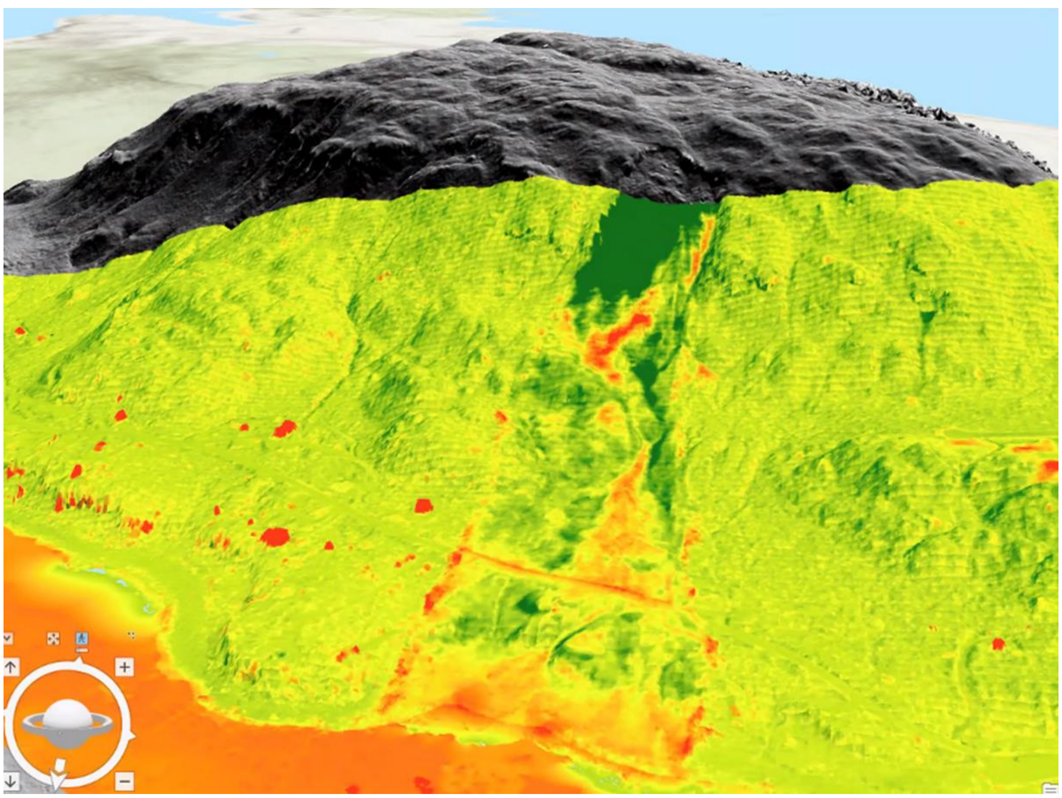

Figure 2. Preliminary lidar differencing product showing areas of erosion in green and deposition in orange. The 2014 lidar does not extend to the top of the ridge so change analysis could not be done for the headscarp area.

A linear feature was observed in the forest extending from the beach to the top of Mount Riley, running close to the head scarp failure. This feature may be an inactive fault that allowed water to infiltrate over a much longer time period, saturating the fractured bedrock and, during the main extreme weather event, providing a large amount of water pressure on those fractures and leading to failure in the bedrock. Because we do not have lidar coverage of the head scarp area prior to the landslide, we cannot determine if the bedrock had open fractures exposed at the surface or if they were covered with a vegetation layer. Our hypothesis is that the fractures had widened over time due to freeze-thaw processes and the rocks were thus already unstable to the degree that intense rainfall was enough to trigger complete failure.

Rainfall was observed to be extreme just three hours prior to landslide movement by the residents of the Beach Road neighborhood as unusual runoff in areas where there normally is no visible running surface water. At least one groundwater well was observed to become artesian during the extreme rain event and remained artesian months after that event. This unusual groundwater well behavior indicates unusual amounts of infiltration into the deeper groundwater aquifers beneath Beach Road, providing water pressure from within bedrock fractures onto the overburden soils. Our team observed water flowing off the north side of the head scarp, as well as flushing water and foaming in a culvert on Beach Road north of the landslide for several days after the event. Water flow returned to normal and water flow off the head scarp had diminished by December 12.

In the days following the event, the landslide deposit in the middle and lower reaches was water saturated and had very little bearing strength. This material behaved much like “quicksand,” resulting in sinking in up to one’s knees for several days after the release; this inhibited our ability to make ground observations. The slide path also contains abundant rocky debris, including numerous large bedrock boulders and blocks. Thanks to dry and cool weather that moved into the area by December 9, and consequent dewatering of the sediments, the mud-like debris had dried and stiffened considerably by December 12, though it was still soft in thicker accumulation areas. Spotters noted that debris was 10 feet above road surface the day of the slide, and by December 9 it was about 5 feet thick in the same spot.

Our aerial observations and lidar data collected during December 5–10 revealed that there is an open fracture that continues south from the head scarp and is possibly part of the same fracture set that initiated the main landslide. We estimate its length to be about 160 ft. This fracture, and the potential consequences should it fail and trigger a landslide, remain a concern to our team because there are properties located in the potential runout zone. We consider freeze/thaw activity, heavy rain, snow load, seismicity, high winds shaking trees, and other factors as potentially capable of triggering a new slide with no advance warning. Landslide simulations of potential failure of the fractured rock mass associated with the large crack at the head of the Beach Road slide helped refine the Beach Road area of concern (AOC), but DGGS does not have the data or expertise to evaluate the stability of the fractured rock mass. We recommend a focused assessment by geotechnical experts to fully evaluate the stability of the rock mass and understand the risk going forward.

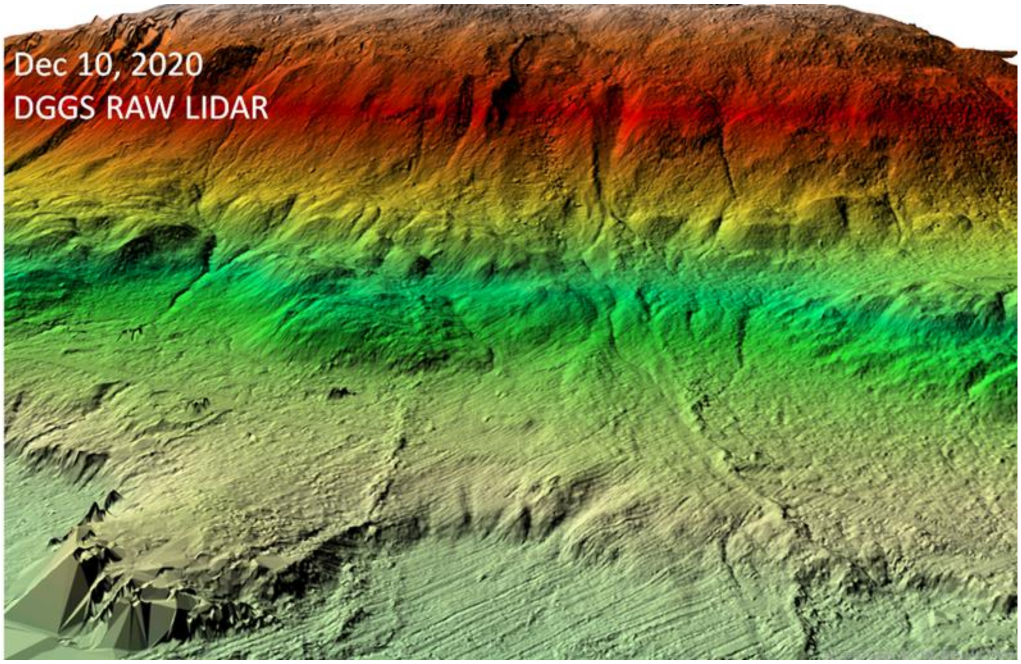

Figure 3. December 10 raw lidar elevation product showing Beach Road slide. View is looking west.

On December 11 and 12, a group visited the head scarp to observe the open fracture directly and map out its visible extent on the ground, as well as to characterize the head scarp area. Recent snow cover since the slide partially obscured direct observation of the fracture, but we were able to follow it about the same distance as is readily apparent on the lidar (~160 ft); beyond that there is no observable evidence of recent cracking or shifting. There were no readily apparent open fractures extending from the other (northwestern) side of the head scarp. Within the head scarp area itself, bedrock structurally above the failure plane on either side (the southern and northern walls of the scar near the head scarp) is highly fractured and crumbly, and the soil cover is thin (maximum ~8 in. including vegetative mat). Relatively small fractures are open, and chunks of this rock will topple into the slide area as the scar stabilizes itself over time. The biggest block, measuring approximately 20 ft tall by 50 ft long by 10 ft wide, appears to be separating from the sidewall. This could be a potential hazard for SAR crews below, but it seems likely that the material would stop short of the active search area. The fractures in side walls roughly parallel the slide surface at the head area, with a strike and dip (S°/D°) of ~110/44 on the slide surface compared to 118/52 on the fracture set. There is a creek that drains from above into the northern corner of the head scarp—this is the waterfall seen from below earlier in the event. During the visits on December 11–12, water was still flowing but was a trickle rather than a jet.

At the request of Beach Road residents, DGGS developed several topographic cross sections using the 2014 and 2020 lidar data to show how the land surface changed.

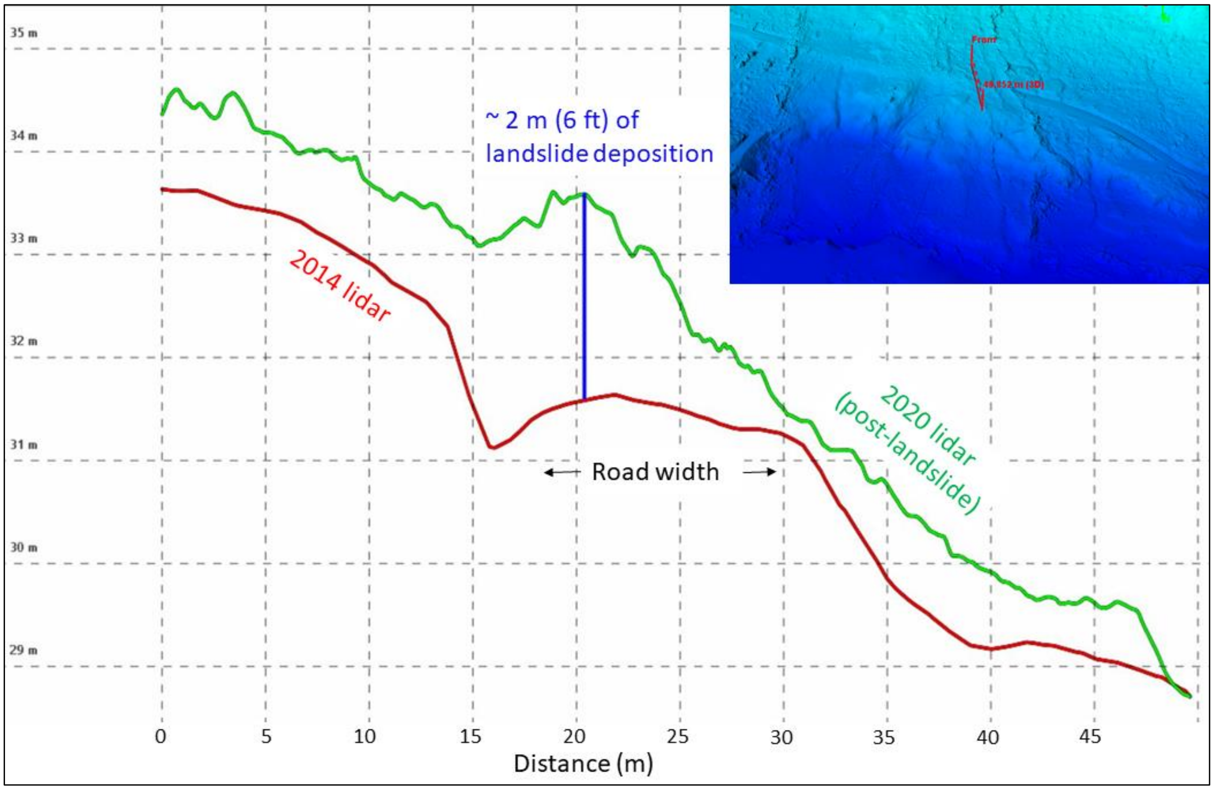

Figure 4. Cross section extending from above the road to below the road comparing land surfaces before and after the Beach Road landslide. Inset map shows location of cross section on 2020 lidar hillshade image.

Lutak Road

A variety of mass movements were triggered along Lutak Road on December 1–3, including small landslides on convex slopes and debris flows in more constrained channels. Although small relative to the Beach Road landslide, many of these events generated deposits that were large enough to cover the road and damage infrastructure. In addition to the steep slope angles, these mass movements initiated in an unconsolidated mix of fluvial, glacial, and marine deposits (varying proportions of unconsolidated sand, silt, gravel, and clay).

There was little observed damage to structures along this corridor due to low building density, but we did visit a home south of the Ferry terminal on Lutak Road that had a substantial slide that pushed a shed 4–6 feet downhill and packed debris behind it. The failed material in this location was glacial outwash, composed of coarse sand with pebbles and cobbles. The head scarp was about 40–50 feet wide, about 15 feet tall, and located on a moderately steep hillside.

Along this path, we encountered a group of residents who were regularly visiting culverts in the area and reporting water conditions through Mountain Hub, a mobile phone data crowd-sourcing app (https://app.mountainhub.com/explore). Many citizen-science observations from the days following the main Beach Road slide event are captured on Mountain Hub for areas all over town.

We worked with residents, looking at reported damage, and informing them of things to look for that might indicate additional movement and cause for concern.

Lutak Spur Mass Wasting

Lutak Spur is located on a glacial moraine consisting of glacial till with beach deposits along the shoreline. Mass wasting occurred along the steep slope of the moraine front and mainly involved medium to coarse sand, with gravel and subrounded to rounded pebbles, and contained no observable clay. These slope failures were relatively small compared to the Beach Rd slide, but large enough to severely damage single-family homes that were backed up to the steep slope, and they occurred along the entire length of the spur east of the bridge over the Chilkoot Lake outlet. At the west end of the Lutak Spur area, we could see a failure scarp uphill and up-gully of one of the larger releases. The exposed face was approximately 50 ft tall and consisted of loose gravelly material capped by better-consolidated sediments. There was some minor groundwater seepage at the very end of Lutak Spur Road the day of our ground observations on December 8, 2020.

At the end of Lutak Spur road we observed larger slope movements along steeper valley side walls.

While we were making observations, residents had already begun to remove the deposited material with heavy equipment, including digging away at the toes of the slides. We provided photos and video to the Haines EOC. We informed the EOC that residents should use caution in removing materials to avoid reactivating the slopes.

Mount Ripinski

During the December 1–2 rainfall event there was significant erosion, deposition, and rerouting of the creek that flows down Mount Ripinski and through the Cathedral Road neighborhood, resulting in several damaged homes and roads, as well as evacuations. A debris flow occurred at the lower elevations of Mount Ripinski and deposited debris into the 4th Ave Quarry. Lidar indicates the debris from this event came from a steep rocky slope just above Cathedral Road and was released by the stream in the quarry owned by “Little Jack.” The equipment owner attempted to maintain the creek channel but was not able to handle the large volume of debris being deposited on his property by the creek.

We noted high groundwater pressure, pooling water, ditches full to bank level, and overflow in the forest in this area for several days after the main rainfall event. Based on our ground observations, surface water flow normalized by December 12. The owner of the quarry above Cathedral Road did manual work to channelize the creek and divert water flow away from built structures.

Our airborne observations and lidar data did not reveal any further concern for this area. The soils are shallow on the town side of Mount Ripinski and consist primarily of glacial till. These types of soils on steep slopes typically respond rapidly to intense rainfall, and stabilize relatively quickly afterwards. We observed only a few very isolated and very small (short runout) landslides/debris flows in the middle and upper elevations on Mount Ripinski.

The “Slump”

This area was visited on multiple days by ground crews to follow up on reports of property damage.

The “Slump” is a previously known area of ground instability in town, and DOT completed a geotechnical study of the area in 2012 in response to observed slow ground movement (i.e., creep). This instability was re-activated during the December 2020 event, resulting in minor house shifting (e.g., drywall and grout cracking, shifted door jambs, un-level floors), most dramatically for one house located at the very bottom of the hill. We also observed some fresh cracking on the downhill side of the road surface very close to the location of the previously mentioned home. This sub-area was isolated from the rest of the original "Slump" AOC as a higher level of concern due to the more extreme ground deformation there.

The rest of the original AOC was separated into the Highland AOC (further uphill), which also sustained some home damage in the form of drywall cracking and shifting, as well as flooding, erosion, and sediment redeposition during the heavy rains.

Just north of the more severely damaged home in the Slump area, we found a slope failure in a gully below the end of Oceanview Street, which allowed us to see the material underlying the Slump area. We observed a recently-slid 30-ft-high scarp of massive gray clay that is probably marine (based on published mapping), with some subrounded cobbles at the very top of the clay layer, overlain by a thin soil cap.

We provided damage observations and photos to Haines EOC. Residents also documented observed damage using the Mountain Hub app. This area remained at a higher level of concern due to potential delayed groundwater response and continued deformation after the main precipitation event. One home was visited by the team several times to observe growing cracks in drywall, and residents decided to evacuate.

DOT had installed several groundwater wells during the 2012 investigation of the slump. Water pressure sensors were installed in those wells after we requested them to be installed by DOT. The pressure in those wells showed that they were elevated, but slowly decreasing over time. We also observed that installed drains were producing water. We therefore concluded that the installed drains were performing as needed to prevent the slump from reactivating during this event.

Mud Bay Road to Mud Bay

Mud Bay Road was initially identified as an area of concern because a geologic contact may extend from the Beach Road slide across the peninsula to the southwest. Early speculation suggested that this contact may have been a factor in the development of the Beach Road slide.

This area was visited by ground crews and observed aerially, and no major concerns were identified. We did not observe the expected geologic contact in the area, and it is a different rock type entirely from the rocks in the Beach Road slide. This area has a spring as a local water source, and bedrock is highly fractured here.

Intense water flow was reported during the main precipitation event, and waterfalls were still gushing and culvert water discolored when visited on December 7. Jeff Moskowitz of the Haines Avalanche Center mentioned that other waterfalls that generally flowed strong here had slowed considerably, while others had picked up and were gushing much more than normal. Surface water channels were reported to have shifted, but this was not observed by the DGGS team.

On the north end of the road, we visited a home that reported heavy water flow in a nearby creek, but no shifting or debris movement was observed. This home is underlain by glacial gravels on glaciomarine (likely) clay. Roadcuts southeast of this area show predominantly bedrock.

This AOC was quickly downgraded because we observed no major damage or instability beyond intense water movement during the event.

Between Mud Bay Road and Beach Road

This area was never identified as a separate area of concern, but ground crews visited Lily Lake access road and the Small Tracts neighborhood in response to Mountain Hub reports. Aerial crews observed a medium-sized shallow slope failure in the steep area above the dump.

Lily Lake access road sustained heavy flooding and erosion during the main event and continued to have high water flow incising the roadbed when visited on December 7. The water was turbid (i.e., dirty). The home visited in the Small Tracts neighborhood had a large volume of sediment-laden water flowing past on the day of the event (chocolate milk), and a subsequent pulse of high-volume sediment-laden water several days later.

A small landslide was identified in the lidar elevation model just upslope of Riley Road cul-de-sac.

Potentially Tsunamigenic Slopes

Slopes on the east side of Lutak Inlet (directly opposite the ferry terminal) and Chilkoot Inlet (the southwest flank of Mt. Villard) were initially flagged during the late 2020 weather event with the concern being that they could potentially fail and generate a local tsunami. DGGS evaluated these slopes from the air during lidar scans, and the combined remote observations (aerial photographs and lidar-derived elevation models) suggest that major, deep-seated tsunamigenic slope failures in this type of bedrock are less likely to be triggered by weather events than are the debris flows observed in the Beach Road area. Existing, regional-scale geologic mapping shows stronger crystalline rocks across the water, and small-scale shallow soil slips that occurred in December 2020 corroborate the existing regional-scale Quaternary and bedrock geologic maps. While it is not possible to say that these slopes are unaffected by prolonged rainfall, we think the shallow soils slides are far more likely during rainfall events than deep-seated, mass wasting of bedrock.

The potential for a major landslide and tsunami to be triggered by a significant seismic event has not changed. Were such a large-scale slope failure to occur, the deep water and shape of the inlet would allow for destructive waves to resonate back and forth many times before dissipating. It is a natural hazard that exists across much of Southeast Alaska and we should all be aware of its potential, but it is not a new concern for Haines.