

October 1, 2024

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**Reconnaissance Observations and Recommendations Report  
3<sup>rd</sup> Avenue and Copper Ridge Landslide Assessments  
Ketchikan, AK**

Dear Mr. Brakke,

As requested, we have prepared this report to document our site reconnaissance observations and provide recommendations for additional tasks. This report provides interpretations of the 3<sup>rd</sup> Avenue and Copper Ridge landslides and describes the potential for mobilization of additional material from within the failure areas and adjacent slopes. Recommendations are also provided for additional investigations if risk reduction strategies are pursued.

**BACKGROUND**

On August 25, 2024, two landslides occurred in the City of Ketchikan, Alaska (City). One slide occurred above the 3<sup>rd</sup> Avenue Bypass and another on Copper Ridge near Copper Ridge Lane (Figure 1). The 3<sup>rd</sup> Avenue landslide resulted in a fatality, multiple injuries, and property damage. The Copper Ridge landslide resulted in property damage. Following these events an emergency operations center (EOC) was established in cooperation with local fire and police departments, the City, and the Ketchikan Gateway Borough (KGB). As part of the EOC response, the Alaska Department of Transportation & Public Facilities (DOT&PF) and Alaska Department of Geology and Geophysical Survey (DGGs) mobilized to Ketchikan to assist with assessment of slope conditions, monitoring of landslide activity, and evaluation of near-term weather forecasts. Landslide Technology (LT) was contracted by the City to conduct a site reconnaissance to characterize slope conditions within the failure areas and directly adjacent to the slides.

**Available Information**

Numerous historical documents were available for the 3<sup>rd</sup> Avenue Extension project that was constructed between 1999 and 2004 by DOT&PF. These documents were reviewed for relevant information as part of a desktop study. The following reports were reviewed:



- Phase I Geotechnical Investigation for Proposed Third Avenue Extension (R&M Consultants, Inc. (R&M), November 1993)
- Phase II Geotechnical Investigation for Proposed Third Avenue Extension, Volume I (DOT&PF, April 1999)
- Phase II Geotechnical Investigation for Proposed Third Avenue Extension, Volume II (DOT&PF, August 1998)
- Phase II Geotechnical Investigation for Proposed Third Avenue Extension, Volume III (DOT&PF, August 1998)
- Third Avenue Extension Data Review and Site Visit (LT, March. 2000)
- Evaluation of Road Embankment Options Station 38+00 to Station 43+00 (LT, June 2000)
- Subsurface Investigation and Laboratory Testing Program (LT, August 2000)
- Debris Flow Area – Stations 41+00 to 44+00 (LT, May 2001)
- Design Report Stations 40+00 to 52+50 (LT, January 2002)
- White Cliff Blasting Evaluation (LT, August 2001)
- White Cliff Rock Cuts Stations 48+00 to 52+50 (LT, May 2001)
- Third Avenue Bypass As-Built Plans, (DOT&PF, 2001 and 2006)
- Third Avenue Extension Debris Flow Area – Stations 41+00 to 44+00 (LT, May 2001)
- Rock Slope Stability Assessment Report (R&M, November 2023)
- Ketchikan Landslide Weather Report (NOAA, September 2024)

### Base Maps

Field maps used during reconnaissance activities were developed based on several data sets. Orthophotography at the two landslides were collected by DOT&PF drone operators on August 26<sup>th</sup> and 27<sup>th</sup>, 2024. Lidar data used to generate hillshade maps and contours was collected in 2021 by the National Oceanic Atmospheric Administration (NOAA). The NOAA 2021 data is a first return lidar dataset. Additional lidar data is available for a portion of the 3<sup>rd</sup> Avenue Landslide that was collected in 2014 by the Federal Emergency Management Agency (FEMA). However, it only covers approximately half of the landslide area and adjacent slopes. Therefore, it was not used for our reconnaissance or terrain analyses.

### Regional Geology

Ketchikan is located on Revillagigedo Island within the western Coast Mountain Range of Southeast Alaska. Vertical relief from the Tongass Narrows exceeds 2,500 feet in moderate to steep terrain. Bedrock conditions in the region consist of Paleozoic and Mesozoic metamorphic rocks that have been intruded by granitic and ultramafic dikes. Metamorphic rocks of the region consist of phyllites and schists, with minor exposures of metamorphosed igneous rocks. Regionally, the area has been affected by faulting that generally trends northwest to southeast. The nearest fault system to Ketchikan is the inferred Queen Charlotte-Fairweather fault system approximately 110 miles away ([USGS Interactive Fault Map](#)).



During the Pleistocene era, thick ice sheets blanketed the region causing land subsidence. As the glaciers retreated approximately 10,000 years ago, land has uplifted regionally (i.e., isostatic rebound) on the order of tens to hundreds of feet. Sediments deposited by advancing and retreating glaciers are called glacial till, which is regionally found in exposures above bedrock and below colluvium. Commonly, these sediments are overconsolidated due to the weight of the glaciers and are composed of mostly fine-grained sediments with varying amounts of coarse-grained material.

Accumulations of soil and rock debris known as colluvium overlie bedrock and glacial till deposits across the region. Colluvium is defined as material experiencing down slope movement by force of gravity. The slow movement of colluvium is known as creep and is also common across moderate to steep terrain of southeast Alaska.

### Regional Precipitation

Ketchikan’s climate is characterized as Oceanic with cold to moderate temperatures and high precipitation. Relevant climate data for the Ketchikan International Airport (PAKT) spanning 106 years from the Western Regional Climate Center (Station 504590) is summarized in Table 1.

*Table 1: Summary of Ketchikan International Airport Climate Data from 1910-2016*

Characteristic	Value*
Mean Annual Air Temperature, °F	45.5
Mean Monthly Temperature, °F (Min / Max)	28.6 (Jan) / 65.2 (Aug)
Mean Annual Precipitation, inches	153.73
Mean Monthly Precipitation, inches (Min / Max)	7.33 (June) / 22.2 (October)
Mean July / August Precipitation, inches	7.53 (July) / 10.83 (August)
Mean Total Snowfall, inches (Annual / Max Monthly)	36.9 / 13.3 (January)

\* [KETCHIKAN INTL AP, ALASKA - Climate Summary \(dri.edu\)](https://dri.edu/ketchikan-intl-ap-alaska-climate-summary)

Preceding the weather event on August 25<sup>th</sup>, which was the largest recorded in 2024, Ketchikan was experiencing a drier and warmer than average July and August. Locations of rain gauges in the Ketchikan area and a comparison of precipitation data at PAKT, Ketchikan Powerhouse (KPHA2), and Silvis Powerhouse (SLVA2) are provided on Figure 2 and Figure 3, respectively. KPHA2 is discussed due to its proximity to the slides. SLVA2 is discussed to illustrate the variability of weather in the Ketchikan area during the August 25<sup>th</sup> event. PAKT is discussed as it is commonly referred to for general weather conditions in the City.

During July 2024, KPHA2 recorded a total of 8.8 inches with 1.8 inches on July 15<sup>th</sup> and 2.8 inches on July 17<sup>th</sup>. In August 2024, KPHA2 saw a total of 11.7 inches with 1.1 inches occurring on August 20<sup>th</sup> and 5.7 inches occurring on August 25<sup>th</sup>. Other than those four dates with over 1-inch of rain, KPHA2 was relatively dry in July and August 2024, with an average of 0.1 inches of rain for 38 days preceding the weather event on August 25<sup>th</sup>.



The Whiteman Lake Powerhouse (WLDA2), Beaver Powerhouse (KTNA2), and SLVA2 also showed drier July and August precipitation preceding the August 25<sup>th</sup> weather event. Each of these locations recorded a daily average of 0.1 inches of rain for 38 days preceding the slides. On August 25<sup>th</sup>, SLVA2 recorded a regional high with 10.4 inches of rain. PAKT and WLDA2 recorded regional lows at 2.5 and 2.6 inches, respectively, and KTNA2 registered 4.1 inches of rain. This illustrates the spatial variability of precipitation in Ketchikan and southeast Alaska. The amount of rainfall each slide area experienced during the August 25<sup>th</sup> weather event is unknown but could be on the order of 2 to 10 inches.

On September 17, 2024, the National Weather Service Alaska Region division of NOAA released a report<sup>1</sup> detailing weather conditions leading up to and during the low-pressure system and moderate atmospheric river event that occurred on August 25<sup>th</sup>. The report provides precipitation accumulations at six local weather stations for 1-hour up to 24-hour durations. NOAA estimated annual recurrence intervals (ARIs) for each duration at the respective weather stations. At the time of the slide events the weather system was estimated to be at or below a 1-year ARI for all analyzed durations. However, SLVA2 recorded as high as a 10-year ARI for a 12-hour duration. The general ARI of 1-year appears to indicate the weather event was not out of the ordinary for Ketchikan. However, the ARI does not appear to capture localized rain accumulations. Based on the data, it is reasonable to conclude that the slide areas may have experienced rainfall intensities higher than the more regional amounts calculated by statistical methods.

Sustained wind speeds of 24 miles per hour (mph) with peak speeds of 41 mph were recorded the day of the landslides at PAKT. The NOAA report detailed sustained winds ranging between 55 and 69 mph 12 hours before the slides occurred at Annette Island. Wind jacking of trees can be a contributing factor to initiation of landsliding.

## **OBSERVATIONS**

Two LT personnel accessed the slide areas on September 3 and 4, 2024. LT personnel were accompanied by two DOT&PF personnel. The failure areas and adjacent slopes were traversed on foot to observe conditions of the remaining slide debris, characterize exposures of soils and bedrock, and to document current conditions of adjacent slopes. Observations of each slide are summarized below. Stationing developed as part of the Third Avenue Extension project between 1998 and 2001 has been approximately located for reference on Figure 4 through Figure 7.

### **3<sup>rd</sup> Avenue Landslide**

The 3<sup>rd</sup> Avenue landslide occurred between approximate stations 30+50 and 33+30 (Figure 4 and Figure 5). The residential homes impacted by the landslide were situated downslope of 3<sup>rd</sup> Avenue at the toe of a 25° slope. City property was also impacted on 2<sup>nd</sup> Avenue, 3<sup>rd</sup> Avenue, and the 3<sup>rd</sup> Avenue Bypass. The vertical change in elevation from the landslide toe to the top of the landslide (i.e., headscarp) is approximately 560 feet, with the toe located at approximate elevation 80 feet and the headscarp at approximate elevation 640 feet. Prior to the slide event, the slope was densely vegetated

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<sup>1</sup> *Ketchikan Landslide Weather Report*, NOAA, September 17, 2024



with large trees and forest undergrowth. Slopes in the slide area ranged from 28° near the toe to 37° near the headscarp as based on pre-slide topography.

### Geologic Interpretations

Four geologic materials were observed at the 3<sup>rd</sup> Avenue landslide, including organic overburden, colluvium, glacial till, and phyllite bedrock. These deposits have variable character across the site. Observation locations correlating to the photo exhibits are illustrated on Figure 4 and Figure 5.

Overburden (i.e., topsoil) is generally 0 to 2 feet thick and is an organic rich soil that is accumulating due to breakdown of vegetation. Colluvium at the slide area ranges in thickness from 5 to 30 feet. It was observed to be very loose to loose, brown, silty sand with varying amounts of subangular gravel, cobbles and boulders. Photo Exhibits 1 and 2 show exposures of overburden and colluvium across the slide.

An approximate 1- to 3-foot layer of glacial till was observed at numerous freshly scoured locations. It consists of gray to orange (i.e., iron stained), very dense, sandy clayey silt with approximately 30% subrounded gravel sized fragments. The fines (i.e., silt and clay) portion of the glacial till is moderately plastic and over consolidated. Photo Exhibits 3 through 4A show exposures of glacial till across the slide.

Phyllite bedrock was observed at several locations across the site. It is typically highly jointed, thinly foliated, medium hard (R3) to hard (R4), gray, slightly weathered to visually fresh. Areas close to the headscarp, expose phyllite that is extremely soft (R0) to soft (R2), highly weathered to decomposed, and very highly jointed. Foliation dips steeply (i.e., 70-80°) to the northeast (into the slope). Photo Exhibits 4B through 5 show exposures of phyllite at various locations on the slide.

Two joint sets were measured with one dipping moderately (i.e., 50-60°) to the south-southeast and a second with a shallow dip (i.e., 20-30°) to the south-southwest. The headscarp has a southeast orientation and dips at approximately 40-50° (Photo Exhibits 6 to 7). Slickensides<sup>2</sup> are present in the decomposed phyllite outcrops at the headscarp (Photo Exhibit 8). The slope is generally oriented to the south at an approximate angle of 40-50° above horizontal. It appears the slope is controlled by jointing in the phyllite.

A northwest-southeast trending lineation is present approximately 60 feet above the headscarp at approximate elevation 700 feet. The lineation can be seen in the lidar hillshade as it creates a consistent feature that bisects otherwise hummocky terrain<sup>3</sup>. The slopes between the headscarp and the linear feature show evidence of perennial water flow. However, no surface water flow was observed at the time of our site reconnaissance. It is our understanding DOT&PF personnel observed a gaining and losing surface flow<sup>4</sup> from the lineation feature to the headscarp on August 26, 2024. While no ponded

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<sup>2</sup> Slickensides are defined herein as smooth striated surfaces (i.e., long, thin parallel streaks) that form on rock or within soil when one mass moves across another.

<sup>3</sup> Hummocky terrain is defined herein as a landform of an irregular pattern of hills and hollows (i.e., low points). This type of terrain is commonly indicative of slopes that have experienced landslide movement.

<sup>4</sup> Gaining flow is fed by surface water runoff and groundwater recharge. Losing flow indicates surface water infiltration.



water was observed above the lineation feature, wetland vegetation (i.e., skunk cabbage, muskeg) was observed indicating an upslope source of water (Photo Exhibit 9).

Erosion channels observed within the landslide failure area have scoured through the remaining colluvium (i.e., slide debris) exposing glacial till and in some instances phyllite bedrock. Based on interpretations of 2021 lidar data acquired from the NOAA, distinct drainage paths were not present in the landslide area prior to the recent slope movement. It appears drainage within the slide area was more diffuse as opposed to concentrated into a distinct path(s). In contrast, two distinct established drainages are observable to the west and east of the slide area (Figure 4 and Figure 5, Photo Exhibit 10 and 12A).

Ground conditions adjacent to the failure area and above the headscarp did not show evidence of active ground cracking.

#### Possible Slide Causation

It appears that elevated pore pressures in colluvium within the slide area rose to a point that decreased the available shear strength of the underlying glacial till that was necessary to remain standing at its previous inclination. The loss of shear strength allowed debris mobilization downslope. This resulted in the debris flow deposits that impacted the 3<sup>rd</sup> Avenue Bypass and the homes along 3<sup>rd</sup> and 2<sup>nd</sup> Avenues.

Since it appears no distinct drainage existed in the failure area of the 3<sup>rd</sup> Avenue landslide, water was likely moving slowly through the geologic materials which would result in elevated pore pressure in the slope. This buildup likely occurred in the colluvium due to the glacial till acting as an aquitard<sup>5</sup> not allowing water infiltration into bedrock. Buildup of hydrostatic pressures appears to have had less impact in the slopes to the west or east of the slide due to “flashy” drainage paths allowed rain water to flow off the slope more readily. These drainages have been described as “flashy”, meaning they allow water to move quickly off the slope.

Prior to the August 25, 2024 weather event there was an approximate four-week dry period in Ketchikan. It has been anecdotally reported that slope instability tends to be more prevalent when a period of dry weather is followed by a storm with intense rainfall. While these reports may have merit, based on the currently available data set it is unclear how, or if, these changes in weather conditions contributed to the recent failure.

In summary, we conclude that the following factors contributed to the initiation the 3<sup>rd</sup> Avenue Landslide:

- Steep slopes with thick accumulations (i.e., 20-30 feet) of loose colluvial materials.
- Poorly established drainage paths resulting in buildup of hydrostatic pressures.
- High precipitation intensity following a preceding relatively dry month.

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<sup>5</sup> An aquitard is defined herein as a layer of soil or rock that has low permeability thereby restricting water flow through the material.



- Adversely dipping jointing in the phyllite promoting movement to the south.

### Potential for Future Movement

At the time of our visit, the remaining slide debris was saturated and loose. These materials will likely continue to mobilize downslope especially in locations where the debris is thicker (i.e., 10-15 feet) and where surficial water is flowing in the newly established drainage paths. How much material will re-mobilize and from which locations is not known. The slope is in a process of finding equilibrium (i.e., stable configuration). The debris fan becomes more stable as it achieves a lower overall slope inclination and pore pressures within the debris drain out. It is our understanding the City has hydroseeded the slopes between the 3<sup>rd</sup> Avenue Bypass and 2<sup>nd</sup> Avenue as well as a portion of the slopes above the 3<sup>rd</sup> Avenue Bypass. The application of hydroseed should accelerate vegetation growth, which will help with shallow slope stabilization.

The potential for additional movement on slopes to the west and east of the slide area would likely be controlled by the degree to which the conditions summarized above are similar to those underlying the failure area. Many of the slopes to the west and east of the failure area exhibit similar topographic character (i.e., slope aspect, slope angle, lack of distinct drainage paths) as that of the 3<sup>rd</sup> Avenue Landslide. While the terrain appears similar to that of the 3<sup>rd</sup> Avenue Landslide area, there may not be all of the contributing factors that previously combined to result in slope movement. Additional investigations would be necessary to more accurately characterize the stability of specific slopes and the potential consequences of slope failure. Considerations for additional work are below.

### Copper Ridge Landslide

The Copper Ridge Landslide impacted several properties including privately owned lots adjacent to property owned by the City and United States Forest Service (USFS). The slide area is shown on Figure 6 and Figure 7. The slide appears to have initiated on USFS land, moved across KGB property, then private property with an access driveway, next through City property, and deposited debris on private property. The vertical elevation change from the landslide toe to the headscarp is approximately 870 feet, with the toe located at approximate elevation 250 feet and the headscarp at approximate elevation 1,120 feet. Slopes in the slide area ranged from 15° near the toe to 36° near the headscarp as based on pre-slide topography.

### Geologic Interpretations

Based on field observations and our understanding of the underlying geology, we divided the Copper Ridge Landslide site into three zones; upper, middle, and lower, which have unique geomorphic features<sup>6</sup> (Figure 6 and Figure 7).

#### *Upper Zone*

The upper zone is a broad bowl with variable colluvial accumulations, minimal deposits of glacial till, and exposures of schist bedrock. The base of the upper zone is at approximate elevation 660 feet. At this elevation the colluvium is on the order of 30 feet thick (Photo Exhibit 12B), whereas at the

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<sup>6</sup> Geomorphology is defined herein as the study of the Earth's landforms and the processes that shape them.



headscarp (i.e., approximate elevation 1,120 feet) colluvial exposures are on the order of 3 to 5 feet thick (Photo Exhibit 13). Colluvium in the upper zone is composed of brown, very loose to loose, silty sand with approximately 30% gravel, cobbles, and boulders. Newly formed drainage channels scoured colluvial deposits and exposed bedrock (Photo Exhibit 14).

Schist exposures were observed in scoured drainage channels that consist of gray to light brown, highly jointed, thinly foliated, soft (R2) to moderately hard (R3), and moderately to highly weathered (Photo Exhibit 15A). At elevations higher than approximately 1,000 feet, a transition to phyllite bedrock was observed. The phyllite has overall a poor rock quality consisting of brown, highly jointed, thinly to very thinly foliated, very soft (R1) to moderately hard (R3), and moderately to highly weathered rock mass (Photo Exhibit 15B).

Bedrock in the upper zone outcrops in a unique pattern, creating several “steps” from the boundary with the upper and middle zones. These steps appear to have been created by a low angle jointing (i.e., 30-40°) that dips generally to the south and high angle foliation (i.e., 70-80°) that dips into the slope generally to the north. These steps may have contributed to sequential failure of colluvial materials (Photo Exhibit 16 to 17A).

#### *Middle Zone*

The middle zone is an incised drainage channel cut through colluvium that is 15 to 30 feet thick. The colluvial side slopes are inclined up to 55° on either side of the channel. The channel ranges between 12 and 25 feet wide (Photo Exhibit 17B to 18). It appears a partially scoured channel was present prior to the slide event as evidenced by moss growth in the center of the channel near elevation 460 feet. This appears to indicate only margins of the channel were scoured during the debris flow event.

The channel follows a potential fault feature. This is based on interpretations of linear terrain features observed in the 2021 lidar and observations of material described as fault gouge near approximate elevation 620 feet (Photo Exhibit 19). At the location of Photo Exhibit 19, a linear exposure of light brown, very soft (R1) to soft (R2) and moderately to highly weathered was observed trending along the alignment of the linear feature (i.e., potential fault).

Colluvium in the middle zone is composed of brown, very loose to loose silty sand with approximately 30% gravel, cobbles and boulders. Evidence of recent smaller shallow slope failures were observed along the drainage channel (Photo Exhibit 20A). Exposed schist in the middle zone is highly jointed and moderately to thinly foliated, commonly hard (R4), gray and visually fresh to slightly weathered (Photo Exhibit 20B).

Three drainage paths converge near the boundary of the upper and middle zones (Photo Exhibit 21A). At the time of our visit, water flow was highest in the eastern drainage with decreasing flow to the west. This location has been estimated to be the initiation point of the slide due to the high level of water that likely was being directed to this location.

#### *Lower Zone*

The lower zone includes several locations where deposition occurred and a steep slope between depositional areas. The first depositional area is the roadway switchback (Photo Exhibit 21B). This



broad area was covered during the slide event, but the character of the slide debris was not observed as the property owner had cleared the debris prior to our site visit. There is a steep slope (i.e., 41°) between the switchback and the toe of the slide debris (Photo Exhibit 22A). This area was scoured similar to that of the middle zone and had debris from the roadway clearing activities. At the toe of the slide debris fan, debris and mud was deposited near and against a warehouse (Photo Exhibit 22B to 23A). No apparent damage occurred to the structure.

It is our understanding that water flowing from the channel in the middle zone originally flowed towards the private property at the toe of the slide. This drainage path has been diverted in two locations. Near the boundary between the middle and lower zones a ditch has been excavated to divert water toward the east (Photos Exhibit 23B and 24A). Likewise, a small earthen berm has been constructed at the bottom of the steep slope in the lower zone in effort to divert drainage away from private landowners (Photo Exhibit 24B).

The relatively flat nature of the topography in the lower zone suggests this to be a historic area of deposition resulting from historic scouring and slumping of the upper slopes.

#### Possible Slide Causation

We estimate slide initiation occurred near elevation 660 feet at the boundary between the upper and middle zones. As precipitation rate and surface flow increased, erosion of the thick, loose colluvial materials was likely initiated at the drainage confluence. The erosional forces head cut upward in elevation mobilizing additional loose colluvial material (i.e., slumping action). As colluvium mobilized, the underlying bedrock “steps” were exposed. Exposure of the bedrock rock surface promoted additional downslope movement due to the unfavorable joint orientations. The mobilized colluvial materials and other debris appear to have been sluiced through the middle zone channel and were eventually deposited in the lower zone.

In summary, we conclude that the following factors contributed to the initiation the Copper Ridge Landslide:

- Steep slopes with thick accumulations (i.e., 15-30 feet) of loose colluvial materials.
- Confluence of three drainage paths at the boundary between the upper and middle zones.
- High precipitation intensity following a preceding relatively dry month.
- Scouring at the confluence leading to cascading upslope failures (i.e., slumps).

#### Potential for Future Movement

Similar to the 3<sup>rd</sup> Avenue Landslide, slide debris at the Copper Ridge Landslide was loose and, in many locations, saturated. These materials will likely be subject to continued localized movement as the slope finds equilibrium. Exposed colluvial materials in the middle zone will likely slough into the channel and result in mobilization of material towards the lower zone.

The temporary drainage diversions constructed in the lower zone may be effective with current water flow rates but would likely be compromised in larger precipitation events. If these were to be



compromised, water and mobilized debris would be directed over the roadway towards the toe of the slide and adjacent private property.

## CONCLUSIONS

Risk from a debris flow is the product of probability of failure and the consequences of failure. Risk can be reduced by implementing measures that reduce the probability of failure or by reducing the consequences of failure. In general terms, reducing the probability of failure would involve measures that improve the stability of the slope while reducing the consequences would involve reducing the population and/or property at risk if a failure were to occur.

The slopes in the vicinity of the two slides are considered marginally stable, which can become unstable when subjected to high rainfall intensities. These conditions have existed for thousands of years (based on mapping and geologic conditions), and slides will continue to occur. Both landslide events were a result of steep terrain being exposed to intense rainfall. The initiation and movement mechanisms are unique to each site, but the likelihood of future debris flow events are very similar. Likelihood of future occurrence and potential consequences are described below and summarized in Table 2.

The slopes above 3<sup>rd</sup> Avenue Bypass are interpreted to be marginally stable colluvial slopes. The portion of the slope that failed in August will experience erosion and movement of loose materials remaining on the slope. Slopes adjacent to the slide are also marginally stable. Failure of slopes adjacent to the slide scar would likely result in debris impacting the roadway and may result in damage to the pavement, sidewalks, and drainage systems (i.e., gutters, culverts). This damage may cause stormwater and/or debris to move across the road and onto downslope properties. Consequences of a slope failure impacting the roadway could be reduced by management and maintenance methods and/or early warning systems. The probability of a future debris flow impacting downslope properties could be reduced by installing a barrier. Residents may want to consider localized risk reduction measures to deflect stormwater and debris flows to reduce impacts to their homes to the practical extent possible. In addition, residents could reduce potential consequences (and risk) by temporarily relocating during severe rainfall events.

The Copper Ridge Landslide impacted downslope properties and local access. Failure of slopes adjacent to the slide scar would likely result in debris impacting downslope properties and the local access road that may result in damage to the private property and drainage systems (i.e., ditches). Stormwater drainage systems could be improved to accommodate high water flows and to reduce impacts to roads and property. Potential consequences of future debris flow events could be reduced by implementing improvements to manage stormwater and reduce the likelihood of debris flows from impacting facilities and operations. Consequences of future debris flows could also be reduced by installing a berm or barrier and/or early warning systems.



*Table 2: Summary of Potential Failure Scenarios and Consequences*

Location	Potential Failure Scenario	Potential Consequence
3 <sup>rd</sup> Avenue Bypass	1. Landslides occur, impacting the roadway and drainage system on the inboard side causing stormwater and/or debris materials to cover and travel across the roadway.	A. Roadway drainage system function. B. Pavement damage. C. Stormwater and/or debris crossing the roadway.
	2. Stormwater and debris materials travel across the roadway and onto downslope properties causing impacts to property, structures, and residents.	A. Damage to property and structures. B. Bodily harm of residents in the path of debris materials. C. Bodily harm to residents if stormwater and/or debris materials enter structures and basements.
Copper Ridge	1. Landslides occur, causing stormwater and/or debris materials to discharge from upslope impacting developed property, structures, and human life.	A. Scour of local access roadway. B. Damage to ditches and culverts causing wider deposition of debris onto private property. C. Damage to structures, equipment, and stockpiles of personal property D. Bodily harm to residents in the path of debris materials.

**POTENTIAL RISK REDUCTION STRATEGIES**

Stabilization measures do not appear feasible for these two areas due to the large extents of marginally stable slopes and associated costs that would be required for design and construction. However, there are risk reduction strategies that could be pursued by the City, private property owners, and/or in a cooperative approach as discussed below and summarized in Table 3. These risk reduction concepts focus on reducing the potential consequences of a future debris flow rather than reducing the probability of an event occurring.



*Table 3: Summary of Potential Risk Reduction Strategies*

Location	Potential Failure Scenario	Potential Risk Reduction Strategy
3 <sup>rd</sup> Avenue Bypass	1. Landslides occur, impacting the roadway and drainage system on the inboard side causing stormwater and/or debris materials to cover and travel across the roadway.	A. Road closures. B. Hazard signage to improve public awareness. C. Educational outreach. D. Restrict area usage during weather events. E. Increased maintenance patrols during weather events. F. Warning systems to detect stormwater and debris materials. Alarms sent to Public Works and audible horns onsite. G. Maintenance preparedness to remove debris materials and restore road to traffic.
	2. Stormwater and debris materials travels across the roadway and onto downslope properties causing impacts to property, structures, and human life.	A. Restrict area usage during weather events. B. Increased maintenance patrols during weather events. C. Warning systems to detect stormwater and debris materials. Alarms sent to Public Works and audible horns onsite. D. Maintenance preparedness to remove debris materials and restore road to traffic prior to reaching the outboard side. E. Property mitigations to direct debris away from critical structures. Consider reinforcing upslope side of structures. F. Flexible debris flow barrier on outside edge of road to capture debris materials.
Copper Ridge	1. Landslides occur, causing stormwater and/or debris materials to discharge from upslope impacting developed property, structures, and human life.	A. Warning systems to detect stormwater and debris materials. Alarms sent to Public Works and audible horns onsite. B. Owner and occupant preparedness training. C. Barrier mitigations to deflect debris materials away from structures. Combine with supplemental stormwater management systems. D. Scour mitigation, consisting of riprap infilling of middle zone channel and buttressing at the boundary of the middle and upper zones.



## Avoidance

Avoidance is a consequence reduction strategy commonly used with geologic hazards that involves moving population and/or property away from the hazard permanently or temporarily. Avoidance could be implemented by the City during extreme rain events. Depending on the forecasted weather the City could issue warnings of upcoming precipitation. If the forecast is of high concern the City could close the 3<sup>rd</sup> Avenue Bypass through the duration of the precipitation event. The City could also issue evacuation guidance for the properties below the Copper Ridge Landslide. Limiting property development below the two landslides could also be considered by the City but would have impacts to property owners.

## Management and Maintenance

Management of activities in the vicinity of the two landslides can be performed to reduce potential consequences of debris flow to the public. Improving public understanding of the hazard is a common measure implemented by public agencies to mitigate risk. Signage that informs users that landsliding has occurred at the two sites previously. Educational outreach could also be conducted to inform the public of landslides and other geohazard (i.e., rockfall) potential in connection with weather events.

Management could also be used to limit or restrict use of the slide areas during high precipitation when the risk of geohazards increases. In their September 17, 2024 report, NOAA provided a quick reference guide that relates precipitation ARI to anticipated flooding and landslide potential (Figure 8). A similar informative reference guide could be prepared directly related to geohazards. LT assisted the Haines Borough with a similar guide as part of responses to the Beach Road Landslide in 2021-2022.

Understanding the conditions of each area and any changes that may be occurring is critical for the determining response actions that may be undertaken by the City and/or property owners. City maintenance personnel could increase the frequency of patrols during extreme rain events to observe conditions of the slopes, surface drainage, and infrastructure (i.e., ditches, gutters, culverts, catchment ponds). Property owners could observe the conditions of their parcels to note if and where changes are occurring. Conditions to note include:

- High stormwater flows
- Turbid (i.e., dirty, muddy water) surface water flows
- New seepage or surface water flow locations
- Artesian <sup>7</sup>water pressures at downslope locations
- Slumped ground or leaning trees
- Slide debris in ditches and/or across pavement
- Blocked culverts impeding stormwater discharge

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<sup>7</sup> Artesian pressure is the pressure that builds up in underground aquifers, causing water to rise to the surface without the need for a pump.



If concerning conditions are observed, maintenance activities could be implemented. The City could be prepared to:

- Control high stormwater flow in ditches and through cross-culverts
- Remove debris from roadside ditches, culverts, and roadways
- Inform the public of conditions and potential changes
- Restrict access into and through areas of concern
- Close areas of concern until conditions normalize

Property owners could be prepared to:

- Deploy stormwater control measures (i.e., sandbags)
- Evacuate to outside locations

### **Warning System**

Warning systems address risk by alerting population at risk so that they can choose to remove themselves from the area of potential impact. Detection systems may be considered to alert the City of high stormwater flows and/or debris at areas of concern. For the 3<sup>rd</sup> Avenue Bypass identifying the occurrence of high flows in the ditches and/or accumulation of debris in the ditches, on the road, or at the outboard shoulder would be beneficial for active response by City crews and residents. At Copper Ridge understanding the flow rate of surface water and if debris is accumulating in the middle and lower zones could inform the City and property owners when slope failure potential is increasing. If these conditions are identified through instrumentation (i.e., weirs, trip lines, cameras) then the City, KGB, residents, and property owners can respond appropriately.

### **Scour Mitigation**

The City and property owners could consider scour mitigation at the Copper Ridge Landslide. By preventing additional scour in the Middle Zone, the likelihood of oversteepened colluvial slopes would be reduced. This strategy could include placement of riprap infilling in the middle zone channel near the local access road and/or at the toe of the slope in the lower zone. These riprapped areas could serve as stormwater control measures and act as attenuator structures for debris that may be mobilized. However, there would be opportunity for the riprap materials to mobilize and become part of the debris flow material under more extreme events.

Another option that could reduce the potential for slope failure is placement of buttressing material against the colluvium deposits. This could be constructed at the boundary between the middle and upper zones and/or as a channel liner along the middle zone channel.

For either scenario, construction would start at the bottom of the lower zone and work upslope to the extents identified by the City and property owners. Additional investigations would be necessary for the development of designs and preparation of construction documents.



## **Berms**

Berms can be constructed in locations below landslide paths to either contain or direct debris away from population and/or infrastructure. Berms can also serve as stormwater control measures. These types of consequence reduction measures require adequate space to allow for collection of debris where it can be temporarily stored and eventually disposed. Berms are often constructed using earthen materials but can be constructed with other engineered systems such as gabion baskets, mechanically stabilized earth (MSE), reinforced soil slopes (RSS), cast-in-place concrete structures, pre-cast concrete structures, or ecology blocks. A berm system could be considered at the Copper Ridge Landslide area for both debris flow and stormwater control. Berms are not feasible for the 3<sup>rd</sup> Avenue slopes. If a berm is pursued, additional investigations would be required to design the system and develop construction documents.

## **Flexible Debris Flow Barriers**

Debris flow barriers are a consequence reduction measure that can be used to protect downslope assets. These systems are constructed with flexible steel mesh supported by wire ropes and steel posts. In a debris flow event, slide debris is intercepted by the barrier. The barrier is designed to elongate to catch and stop debris movement. While the system is elongating, water is allowed to drain from the saturated material, which reduces the material's ability to flow. Once the event is over, debris is cleared from the system and the infrastructure (i.e., mesh, wire ropes, posts, anchors) is repaired or replaced. Debris flow barriers are feasible for both the slide areas. Additional investigations would be required to develop designs and prepare construction documents for these systems.

## **Risk Reduction Measure Design**

If the City elects to pursue risk reduction measures at either landslide area, additional investigations and geotechnical design work will be required. This could include detailed site reconnaissance, subsurface investigations, laboratory testing, slope stability modeling, risk reduction measure design development, and construction document preparation. We recommend the City conduct an economic feasibility study of pursuing risk reduction measures prior to selecting specific measures. An economic feasibility study could include development of conceptual risk reduction measures so that costs associated with completing engineering designs and developing construction documents can be estimated.

## **ADDITIONAL CONSIDERATIONS**

The following items do not directly address consequence reduction at either site, but could help the City formulate a better understanding of the risk so that future risk reduction measures can be implemented in a more informed manner for the two sites as well as the City at large.

### **Slope Monitoring for Change Detection**

Monitoring for changes in slope conditions (i.e., slumps, rockfalls, new drainage paths) could be conducted using remote technology and other data collection techniques such as cameras, drones,



lidar, and possibly InSAR<sup>8</sup>. The City is already utilizing cameras at the 3<sup>rd</sup> Avenue Landslide. Drone photogrammetry and lidar data collection has been undertaken at both sites by the DOT&PF and DGGS, respectively. InSAR data could be available for the sites but has not yet been pursued. Temporal series of these data sets can be compared visually or analyzed with change detection software. This could inform the City of real-time or long-term changes to slope conditions. Small changes and change trends are often an indicator of impending slope failure.

Collection of the temporal data sets could be conducted at various time intervals. Initially it could be collected more often (i.e., monthly or quarterly) to develop baseline conditions and slope change trends. As slope morphology is better understood data collection frequency could be reduced (i.e., annually, every 5 years). Collection and processing of data may be supported by DOT&PF and/or DGGS. Options for data collection and processing could be discussed in more detail if the City selects slope monitoring as part of their preferred risk reduction strategy.

### **Weather Monitoring**

The variability of weather patterns in Ketchikan is evident in precipitation records discussed above. Measurement of site-specific weather conditions would help with estimating the effects of precipitation and other weather (i.e., wind) on slope conditions. If site-specific weather conditions are better understood, it may be possible to correlate slope changes to weather events and intensities. It is our understanding, the Sitka Sound Science Center (<https://sitkascience.org/research-projects/landslide-research/>) is conducting research to collect weather and slope condition data to achieve this goal. Likewise, the DOT&PF has some data that showed trends between weather intensity and slope movements on the recent Wrangell Landslide event.

During emergency response activities, a tipping bucket weather station was installed by the NOAA near the Rainbird trailhead along the 3<sup>rd</sup> Avenue Bypass. This information has been beneficial for understanding site-specific precipitation accumulations. The City could consider installing permanent stations along the 3<sup>rd</sup> Avenue Bypass and near the Copper Ridge Landslide in addition to other targeted areas of interest. This could possibly be conducted in collaboration with NOAA, KGB, and DGGS.

### **Historical Data Analysis**

Existing data could be reviewed in light of the recent failure in an attempt to draw conclusions about surrounding slopes. Geotechnical data (i.e., borehole locations, subsurface characterization, geologic discontinuity measurements, hazard rock/tree locations, debris flow maps) collected between 1993 and 2001 as part of the 3<sup>rd</sup> Avenue Extension project could be used to characterize slopes and subsurface materials outside of the recent failure area. We recommend these data be digitized so that additional slope stability interpretations can be made to inform the need and locations for additional investigations.

Slope inclinometer and groundwater instrumentation was installed in the early 2000's as part of the 3<sup>rd</sup> Avenue Extension project. This instrumentation could be located in the field to record additional

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<sup>8</sup> InSAR (Interferometric Synthetic Aperture Radar) is a remote sensing technique that measures ground displacement by comparing radar signals from multiple satellite images taken over time.



measurements. These measurements could be used to better understand if slope movements have occurred since they were installed. Current groundwater elevations could also be measured to better understand if slope conditions have changed since active monitoring of the instruments was discontinued. We recommend conducting field work to locate the instrumentation and collect additional measurements as possible.

### **2024 Data Analysis**

It is our understanding DGGS collected lidar data for the two slide areas. Once this data has been processed, change detection analyses could be conducted to identify potential areas of marginal stability. It should be noted that the historical lidar data available for the area is either not extensive (i.e., the 2014 lidar data set) or is of lower quality (i.e., 2021 lidar data set). As such, interpretation of the change detection analyses should consider the limitations of historical data sets. If marginally stable areas are identified, these areas could be targeted for additional periodic lidar data collection, processing, and analysis.

The availability of historical and opportunity for collection of new InSAR data is not known. If InSAR is a desired component of the City's overall risk reduction strategy, we recommend engaging with a consultant that specializes in collection and analysis of InSAR data. The consultant will be able to review available historic data to determine if the slide areas are oriented in a manner appropriate for movement trend analysis. If the slides are beneficially oriented, the historical data could be analyzed along with periodic collection of new data for more long-term analysis.

### **Landslide Susceptibility Study**

We recommend that the City engage KGB and DGGS to pursue funding options for conducting a landslide susceptibility study of the City and portions of KGB. Completing a landslide susceptibility study will inform the City, KGB, and the public of current slope conditions. Areas of interest could be identified for further investigation, monitoring, and/or installation of risk reduction measures (i.e., berms, barriers, scour mitigation). A similar study has recently been conducted by DGGS for the Haines Borough. It is our understanding that the Haines Borough study was completed over a two-year period.



## CLOSING

We appreciate the opportunity to assist the City of Ketchikan with this challenging and important project. As the City evaluates these risks and risk reduction strategies, we are available to provide additional technical guidance during the decision-making process for implementation of preferred strategies. If you have any questions, please call us at (503) 452-1200.

Sincerely,

## LANDSLIDE TECHNOLOGY

A Division of Cornforth Consultants, Inc.

Benjamin George, P.E. C.E.G, P.G.  
Senior Associate Engineer

Sebastian Durringer, C.E.G.  
Associate Engineering Geologist



10/1/2024



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## LIMITATIONS IN THE USE AND INTERPRETATION OF THIS GEOTECHNICAL REPORT

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Our professional services were performed, our findings obtained, and our recommendations prepared in accordance with generally accepted engineering principles and practices. This warranty is in lieu of all other warranties, either expressed or implied.

The geotechnical report was prepared for the use of the Owner in the design of the subject facility and should be made available to potential contractors and/or the Contractor for information on factual data only. This report should not be used for contractual purposes as a warranty of interpreted subsurface conditions such as those indicated by the interpretive boring and test pit logs, cross-sections, or discussion of subsurface conditions contained herein.

The analyses, conclusions and recommendations contained in the report are based on site conditions as they presently exist and assume that the exploratory borings, test pits, and/or probes are representative of the subsurface conditions of the site. If, during construction, subsurface conditions are found which are significantly different from those observed in the exploratory borings and test pits, or assumed to exist in the excavations, we should be advised at once so that we can review these conditions and reconsider our recommendations where necessary. If there is a substantial lapse of time between the submission of this report and the start of work at the site, or if conditions have changed due to natural causes or construction operations at or adjacent to the site, this report should be reviewed to determine the applicability of the conclusions and recommendations considering the changed conditions and time lapse.

The Summary Boring Logs are our opinion of the subsurface conditions revealed by periodic sampling of the ground as the borings progressed. The soil descriptions and interfaces between strata are interpretive and actual changes may be gradual.

The boring logs and related information depict subsurface conditions only at these specific locations and at the particular time designated on the logs. Soil conditions at other locations may differ from conditions occurring at these boring locations. Also, the passage of time may result in a change in the soil conditions at these boring locations.

Groundwater levels often vary seasonally. Groundwater levels reported on the boring logs or in the body of the report are factual data only for the dates shown.

Unanticipated soil conditions are commonly encountered on construction sites and cannot be fully anticipated by merely taking soil samples, borings or test pits. Such unexpected conditions frequently require that additional expenditures be made to attain a properly constructed project. It is recommended that the Owner consider providing a contingency fund to accommodate such potential extra costs.

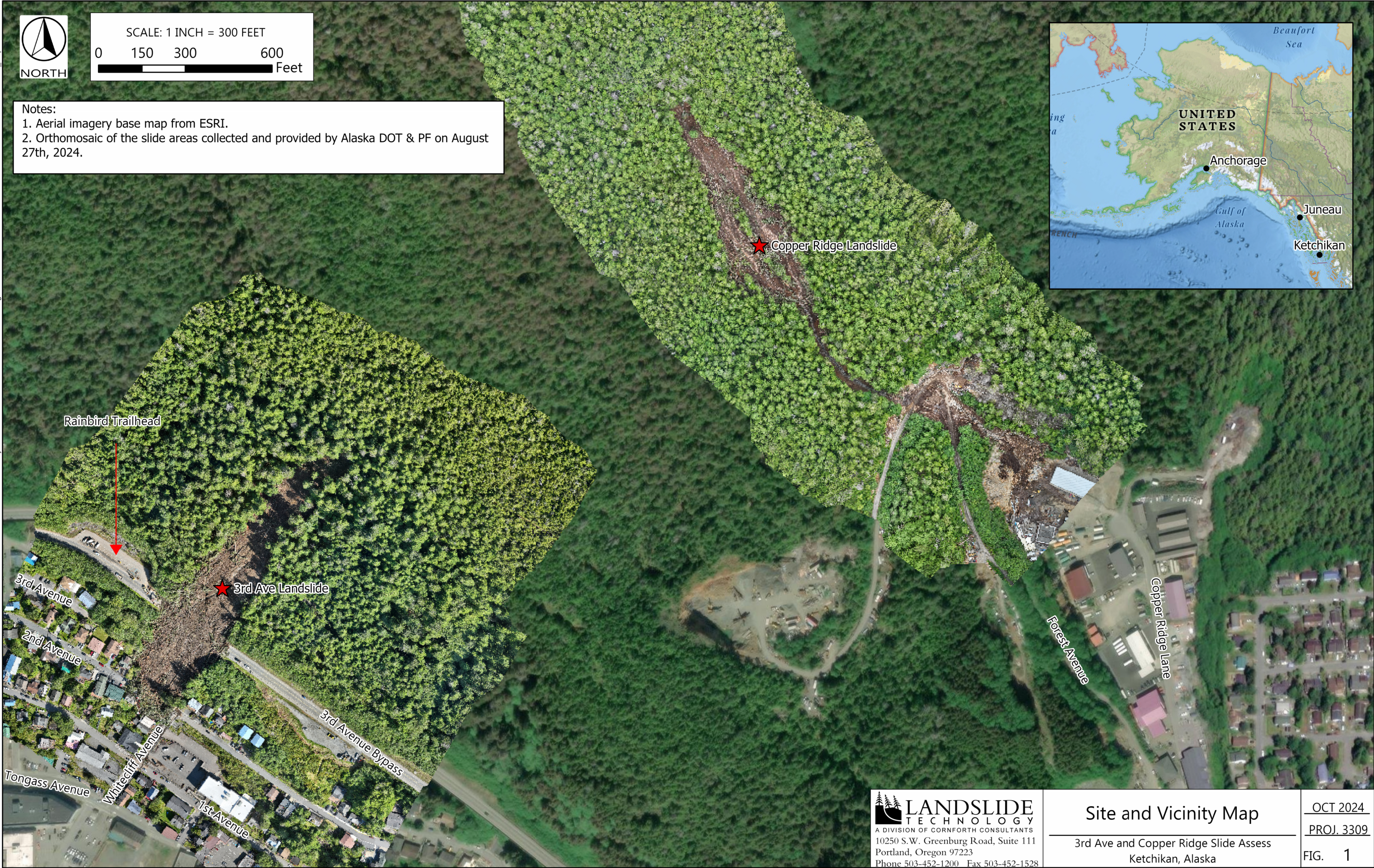
This firm cannot be responsible for any deviation from the intent of this report including, but not restricted to, any changes to the scheduled time of construction, the nature of the project or the specific construction methods or means indicated in this report; nor can our firm be responsible for any construction activity on sites other than the specific site referred to in this report.

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SCALE: 1 INCH = 300 FEET  
0 150 300 600 Feet

Notes:  
1. Aerial imagery base map from ESRI.  
2. Orthomosaic of the slide areas collected and provided by Alaska DOT & PF on August 27th, 2024.

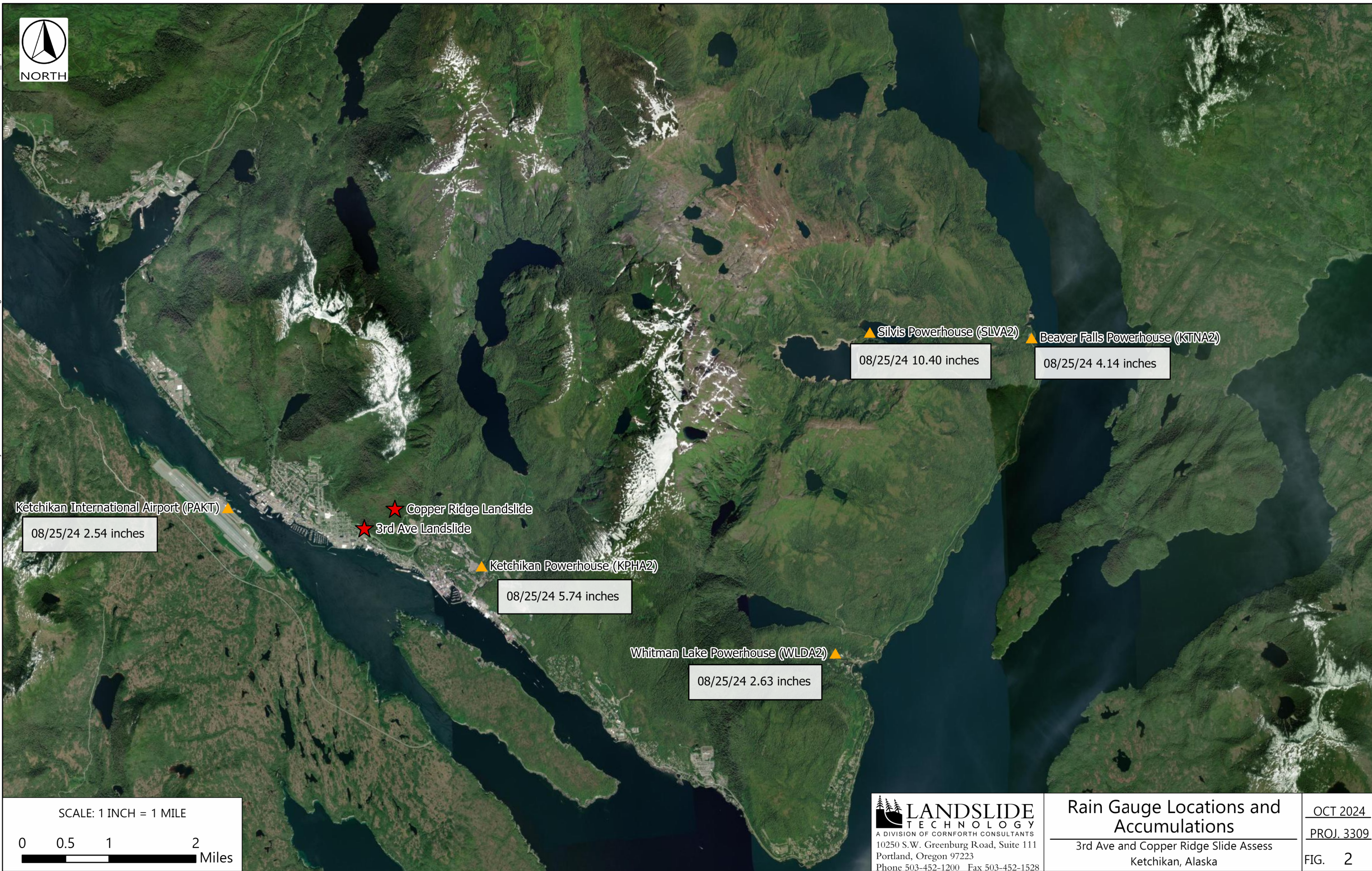


**LANDSLIDE TECHNOLOGY**  
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Portland, Oregon 97223  
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**Site and Vicinity Map**  
3rd Ave and Copper Ridge Slide Assess  
Ketchikan, Alaska

OCT 2024  
PROJ. 3309  
FIG. 1

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Ketchikan International Airport (PAKT)

08/25/24 2.54 inches

Copper Ridge Landslide

3rd Ave Landslide

Ketchikan Powerhouse (KPHA2)

08/25/24 5.74 inches

Whitman Lake Powerhouse (WLDA2)

08/25/24 2.63 inches

Silvis Powerhouse (SLVA2)

08/25/24 10.40 inches

Beaver Falls Powerhouse (KTNA2)

08/25/24 4.14 inches

SCALE: 1 INCH = 1 MILE

0 0.5 1 2 Miles

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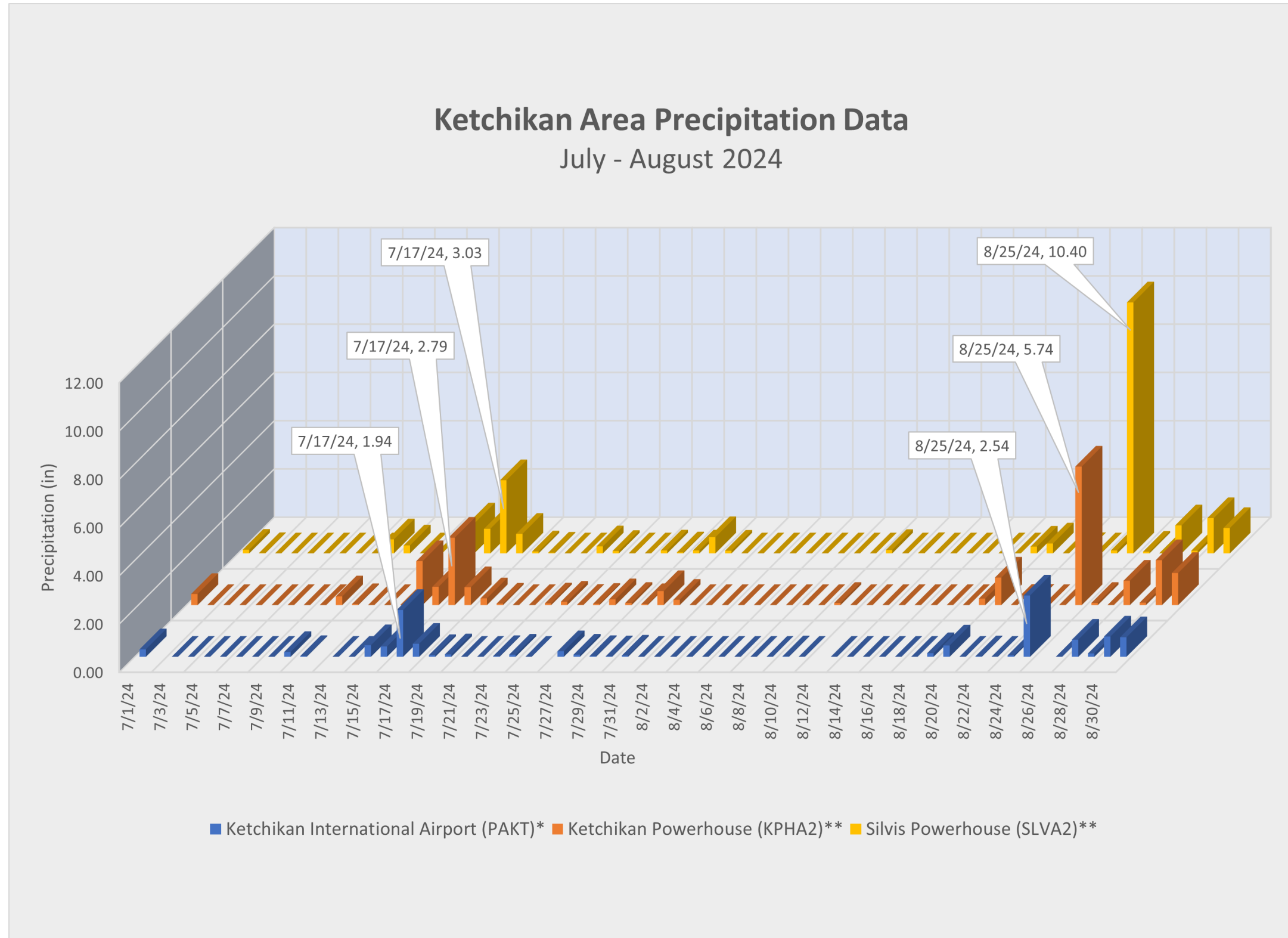
### Rain Gauge Locations and Accumulations

3rd Ave and Copper Ridge Slide Assess  
Ketchikan, Alaska

OCT 2024

PROJ. 3309

FIG. 2



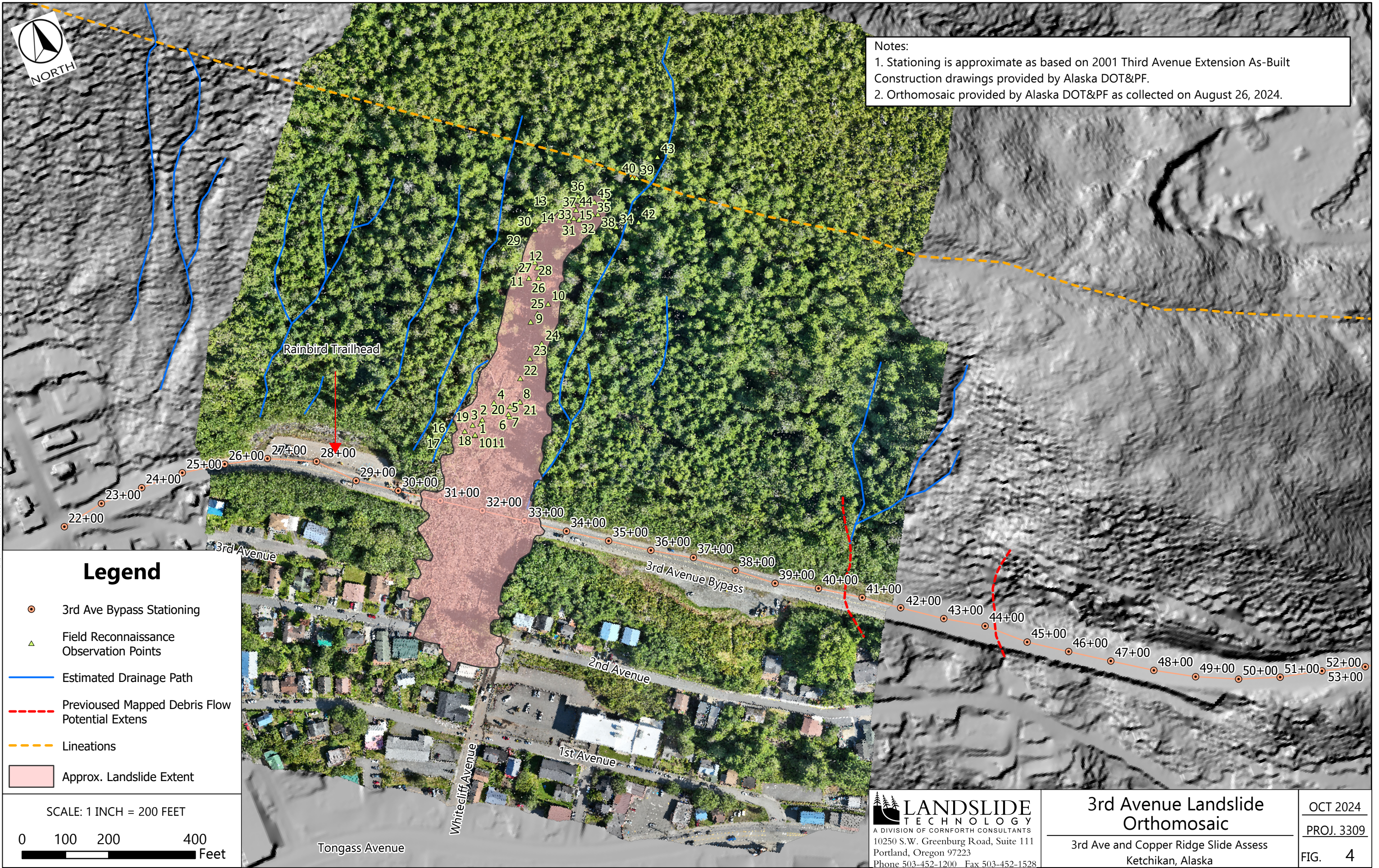
**Notes:**

1. Weather data for PAKT acquired from Alaska Climate Research Center (<https://akclimate.org>).
2. Weather data for KPHA2 and SLVA2 provided by Ketchikan Public Utilities.







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Notes:  
1. Stationing is approximate as based on 2001 Third Avenue Extension As-Built Construction drawings provided by Alaska DOT&PF.  
2. Orthomosaic provided by Alaska DOT&PF as collected on August 26, 2024.



### Legend

-  3rd Ave Bypass Stationing
-  Field Reconnaissance Observation Points
-  Estimated Drainage Path
-  Previous Mapped Debris Flow Potential Extens
-  Lineations
-  Approx. Landslide Extent

SCALE: 1 INCH = 200 FEET



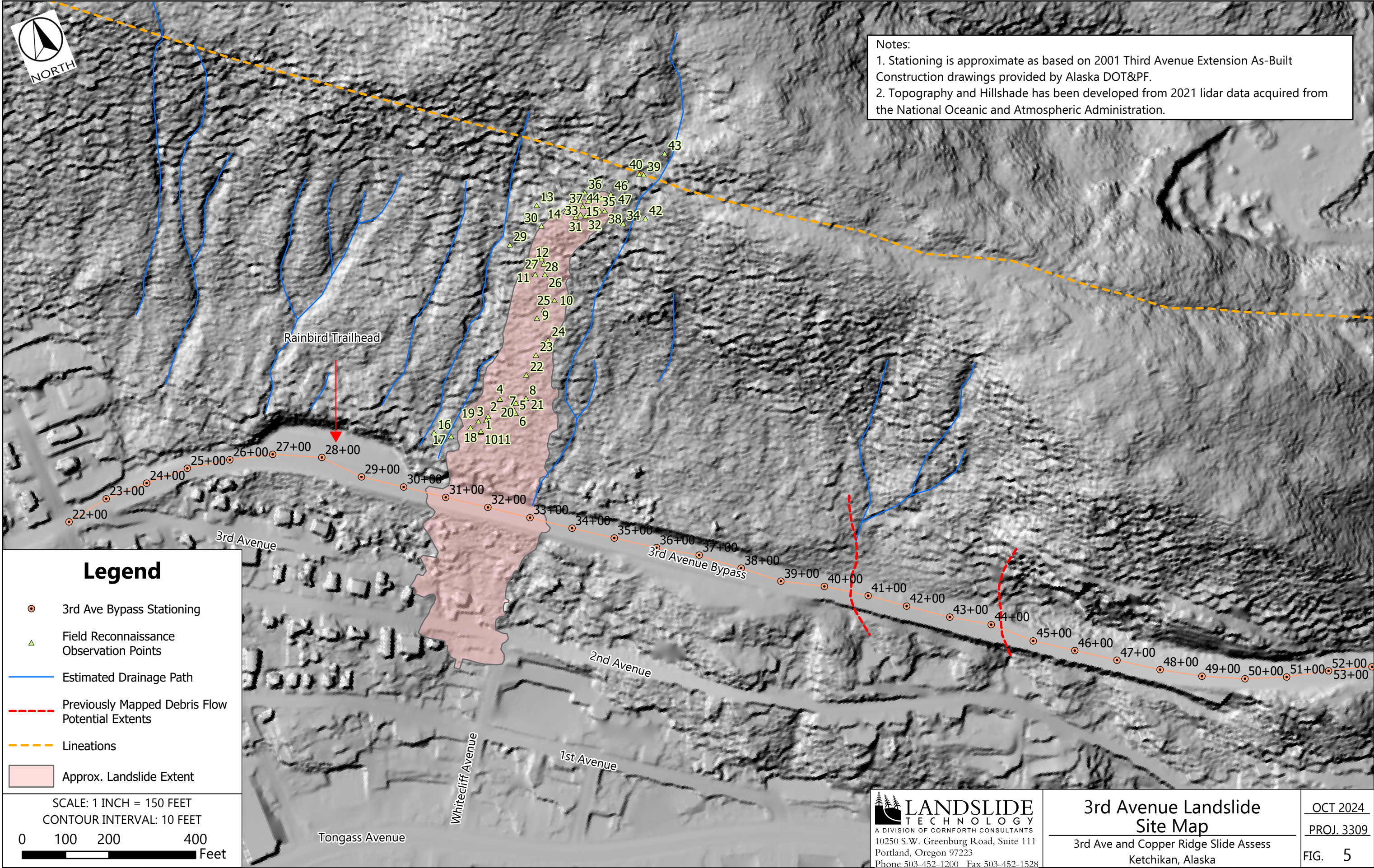
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 Portland, Oregon 97223  
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**3rd Avenue Landslide Orthomosaic**  
 3rd Ave and Copper Ridge Slide Assess  
 Ketchikan, Alaska

OCT 2024  
 PROJ. 3309  
 FIG. 4



Notes:  
1. Stationing is approximate as based on 2001 Third Avenue Extension As-Built Construction drawings provided by Alaska DOT&PF.  
2. Topography and Hillshade has been developed from 2021 lidar data acquired from the National Oceanic and Atmospheric Administration.



### Legend

- 3rd Ave Bypass Stationing
- Field Reconnaissance Observation Points
- Estimated Drainage Path
- Previously Mapped Debris Flow Potential Extents
- Lineations
- Approx. Landslide Extent

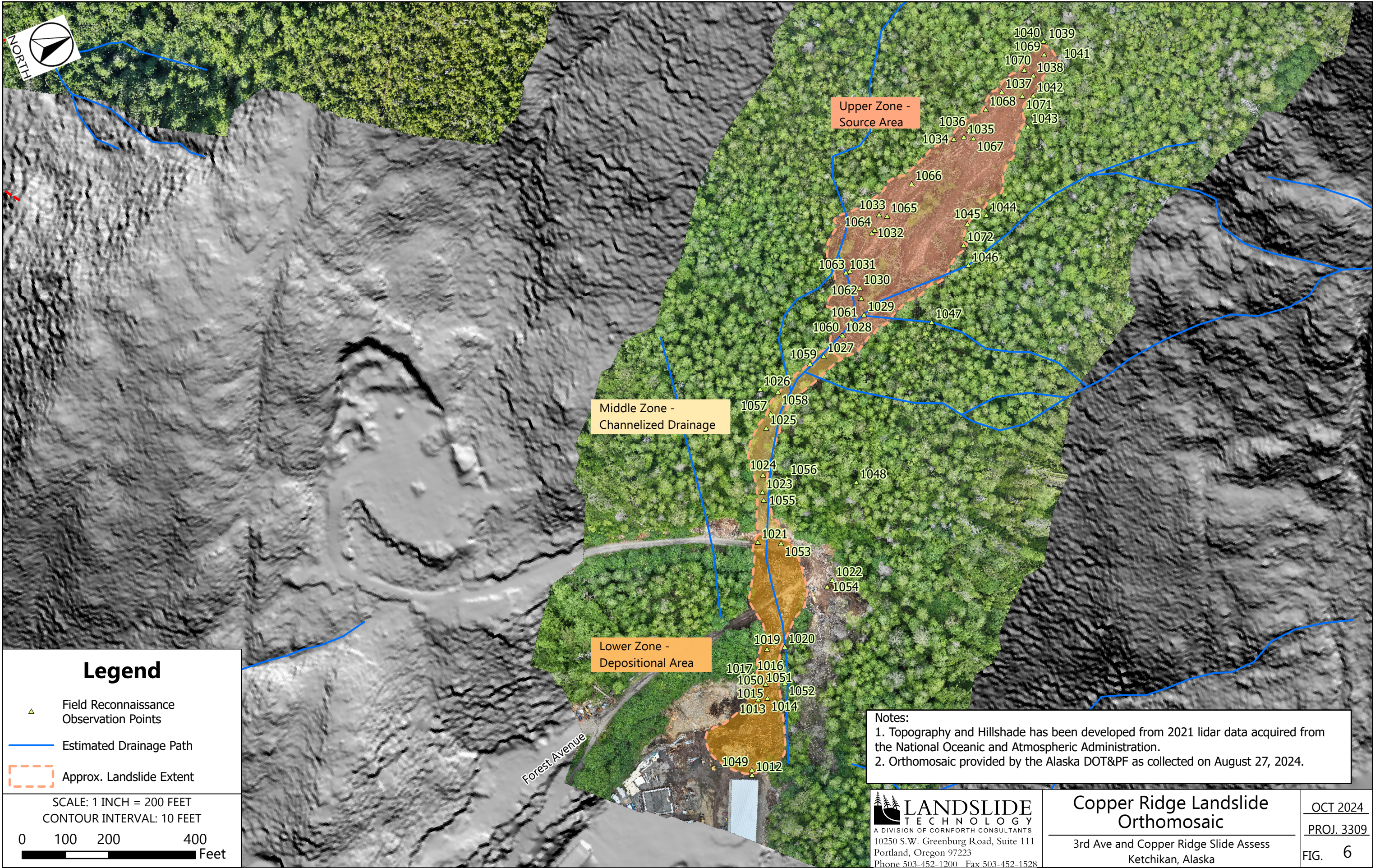
SCALE: 1 INCH = 150 FEET  
 CONTOUR INTERVAL: 10 FEET

0 100 200 400 Feet




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**3rd Avenue Landslide Site Map**  
 3rd Ave and Copper Ridge Slide Assess  
 Ketchikan, Alaska

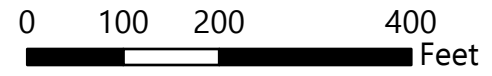
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 PROJ. 3309  
 FIG. 5



### Legend

-  Field Reconnaissance Observation Points
-  Estimated Drainage Path
-  Approx. Landslide Extent

SCALE: 1 INCH = 200 FEET  
 CONTOUR INTERVAL: 10 FEET



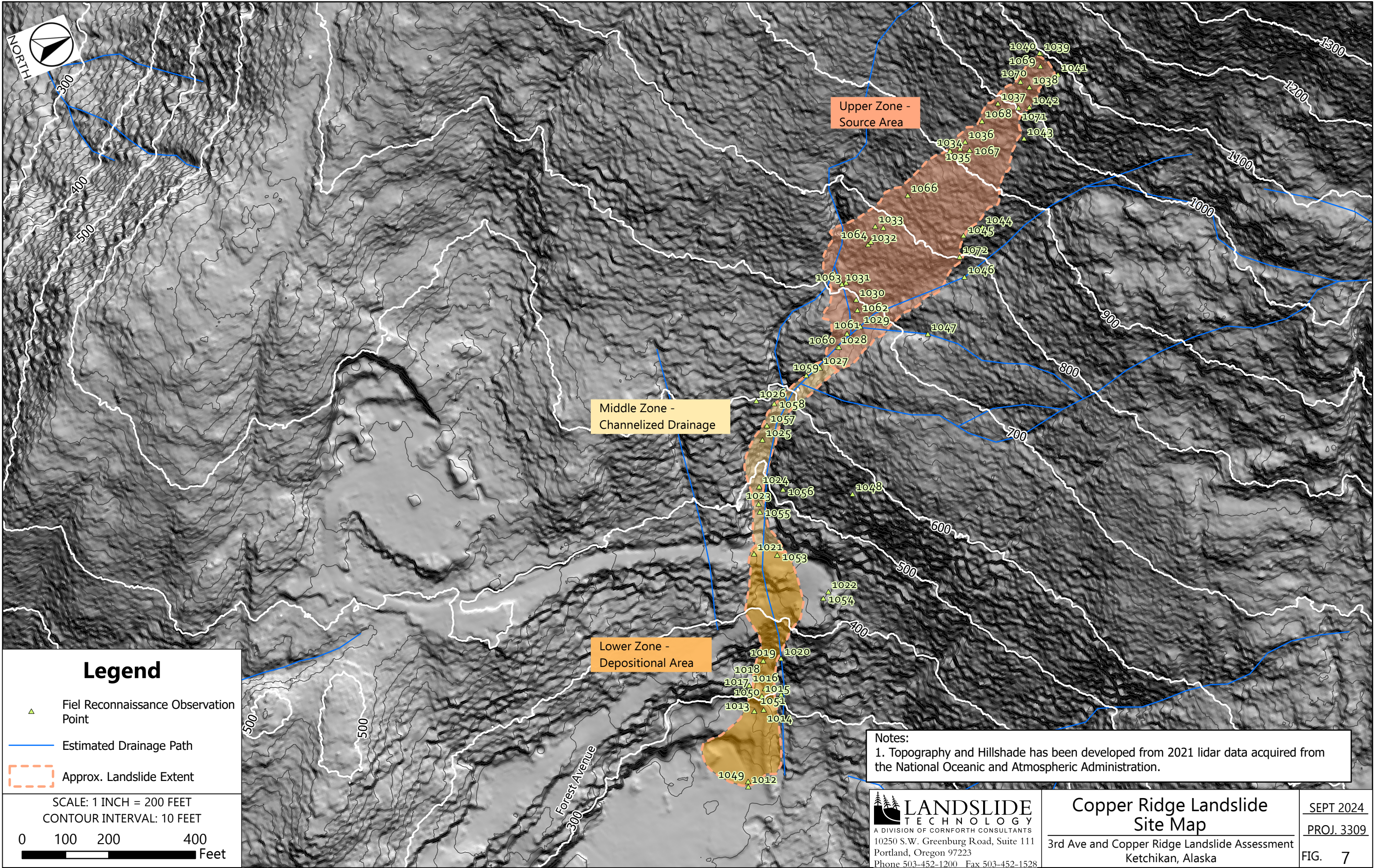
Notes:  
 1. Topography and Hillshade has been developed from 2021 lidar data acquired from the National Oceanic and Atmospheric Administration.  
 2. Orthomosaic provided by the Alaska DOT&PF as collected on August 27, 2024.

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**Copper Ridge Landslide Orthomosaic**  
 3rd Ave and Copper Ridge Slide Assess  
 Ketchikan, Alaska

OCT 2024  
 PROJ. 3309  
 FIG. 6

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**Legend**

- Field Reconnaissance Observation Point
- Estimated Drainage Path
- Approx. Landslide Extent

SCALE: 1 INCH = 200 FEET  
 CONTOUR INTERVAL: 10 FEET

0 100 200 400  
 Feet

**Notes:**  
 1. Topography and Hillshade has been developed from 2021 lidar data acquired from the National Oceanic and Atmospheric Administration.

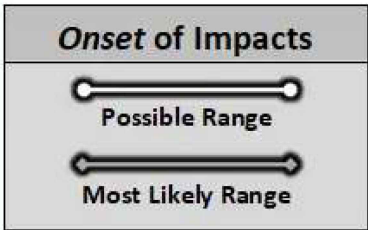
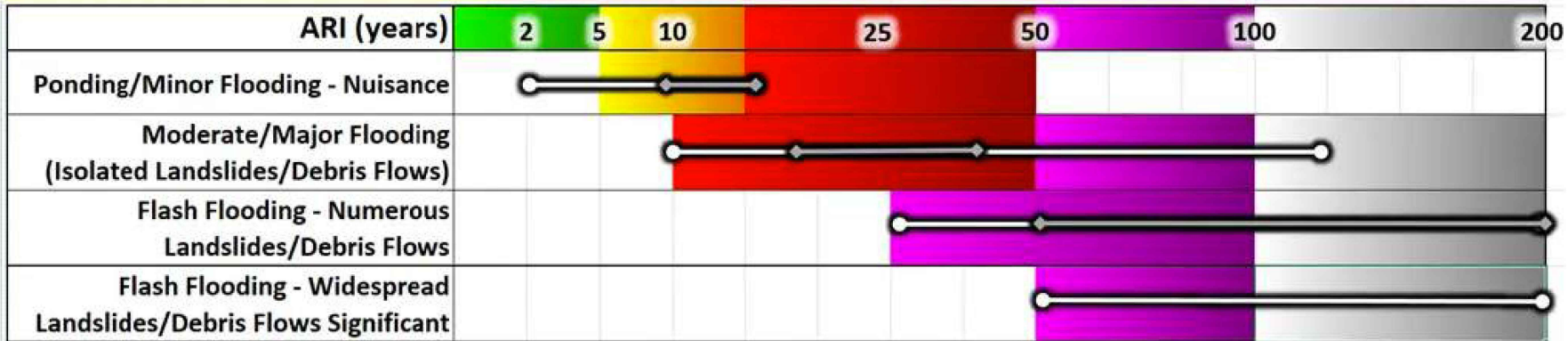
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**Copper Ridge Landslide Site Map**  
 3rd Ave and Copper Ridge Landslide Assessment  
 Ketchikan, Alaska

SEPT 2024  
 PROJ. 3309  
 FIG. 7

# Alaska Flash Flood/ Flood Product Quick Reference Guide

<b>Ponding/Minor Flooding - Nuisance</b>	<b>Moderate/Major Flood-</b>	<b>Flash Flooding - Debris Flows</b>
Minimal or no property damage, but possibly some public threat. Advise the public of flood events that are expected to exceed the minor flood category but not moderate flood category	Uncommon flooding of usually dry areas that is a threat to life and property because it may impact roads/structures. Exceeding moderate flood category is expected with isolated landslides/debris flows.	Numerous to widespread debris flow along with very rare flooding of areas one would not reasonably expect to flood. A serious threat to life and property.
<b>Flood Advisory</b>	<b>Flood Warning</b>	<b>Flash Flood Watch/Warning</b> with "considerable" or "catastrophic" damage tag



**Other Tips**

- Different time durations 3,6,12,24hrs will help assess the threat of flooding.

**Other Tips**

- Antecedent soil conditions.
- Rain on snow event
- Rising freezing levels from 2k to >6k
- Look for spatial consistency on EFPT rather than single pixels.

Note: Alaska flash flood guidance produced by the NOAA Juneau Weather Forecast Office relating annual precipitation recurrence intervals to expected impacts. Taken from NOAA NWS Alaska Region *Ketchikan Landslide August 25, 2024* report dated September 17, 2024.

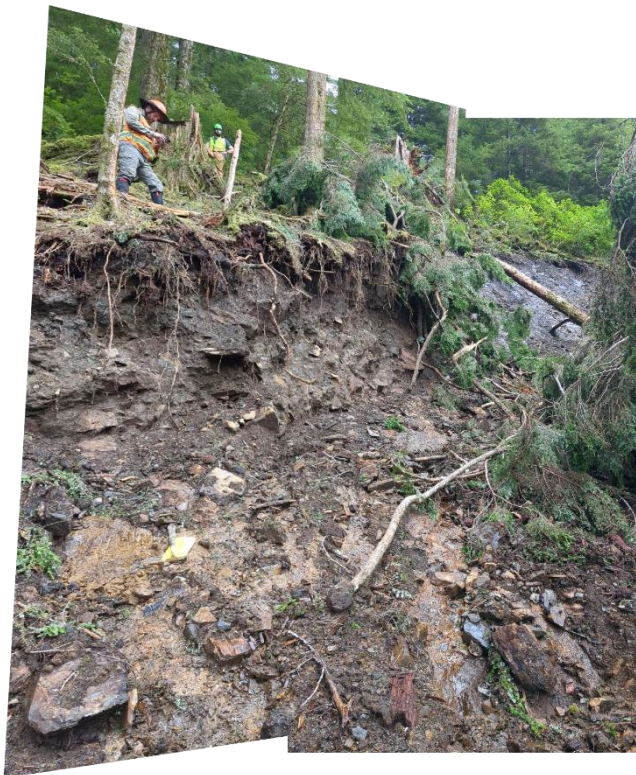
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**Alaska Flash Flood Quick Reference Guide**  
3<sup>rd</sup> Ave and Copper Ridge Slide Assess  
Ketchikan, Alaska

OCT 2024  
PROJ. 3309  
FIG. 8



A: 3rd Avenue Landslide, Point 1, slide debris.



B: 3rd Avenue Landslide, Point 33, colluvium exposures.



A: 3rd Avenue Landslide, Point 37, colluvium deposits.



B: 3rd Avenue Landslide, Point 30, colluvium deposits under an isolated tree within slide mass.



A: 3rd Avenue Landslide, Point 35, glacial till exposure in recently developed drainage channel.



B: 3rd Avenue Landslide, Point 10, glacial till exposure in recently developed drainage channel.



A: 3rd Avenue Landslide, Point 26, glacial till exposure.



B: 3rd Avenue Landslide, Point 5, phyllite exposure.



A: 3rd Avenue Landslide, Point 5, phyllite exposure in recently developed drainage channel.



B: 3rd Avenue Landslide, Point 5, phyllite exposure in recently developed drainage channel.



A: 3rd Avenue Landslide, Point 5, phyllite exposure below headscarp with unfavorable jointing.



B: 3rd Avenue Landslide, Point 15, west side of headscarp looking southeast.



A: 3rd Avenue Landslide, Point 15, middle portion of headscarp looking upslope to northeast.



B: 3rd Avenue Landslide, Point 15, east side of headscarp looking north.



A: 3rd Avenue Landslide, Point 46, exposure of decomposed phyllite with slickensides.



B: 3rd Avenue Landslide, Point 47, exposure of decomposed phyllite with slickensides.



A: 3rd Avenue Landslide, Point 43, wet area upslope of landslide headscarp. Note skunk cabbage growth.



B: 3rd Avenue Landslide, Point 43, wet area upslope of landslide headscarp.



A: 3rd Avenue Landslide, Point 13, western drainage adjacent to landslide looking down slope (~south).



B: 3rd Avenue Landslide, Point 13, western drainage adjacent to landslide showing water flowing on phyllite exposure.



A: 3rd Avenue Landslide, Point 13, western drainage adjacent to landslide looking upslope (~north).



B: 3rd Avenue Landslide, Point 42, eastern drainage adjacent to landslide looking downslope (~south).



A: 3rd Avenue Landslide, Point 42, eastern drainage adjacent to landslide looking upslope (~north).



B: Copper Ridge Landslide, Point 1028, Upper Zone, colluvium deposits, looking northwest.



A: Copper Ridge Landslide, Point 1068, Upper Zone, thin colluvial deposits, looking southeast.



B: Copper Ridge Landslide, Point 1068, Upper Zone, thin colluvial deposits, looking northwest.



A: Copper Ridge Landslide, Point 1065, Upper Zone, bedrock exposures in newly formed stream channels looking southeast.



B: Copper Ridge Landslide, Point 1065, Upper Zone, bedrock exposures in newly formed stream channels, looking northwest.



A: Copper Ridge Landslide, Point 1064, Upper Zone, schist outcropping in recently scoured stream channel.



B: Copper Ridge Landslide, Point 1037, Upper Zone, phyllite bedrock exposure.



A: Copper Ridge Landslide, Point 1069, Upper Zone, headscarp conditions looking north.



B: Copper Ridge Landslide, Point 1038, Upper Zone, headscarp conditions with phyllite bedrock exposures, looking northwest.



A: Copper Ridge Landslide, Point 1041, Upper Zone, headscarp conditions looking northwest.



B: Copper Ridge Landslide, Point 1021, Middle Zone conditions with steep colluvial slopes.



A: Copper Ridge Landslide, Point 1023, Middle Zone conditions with scoured bedrock exposures.



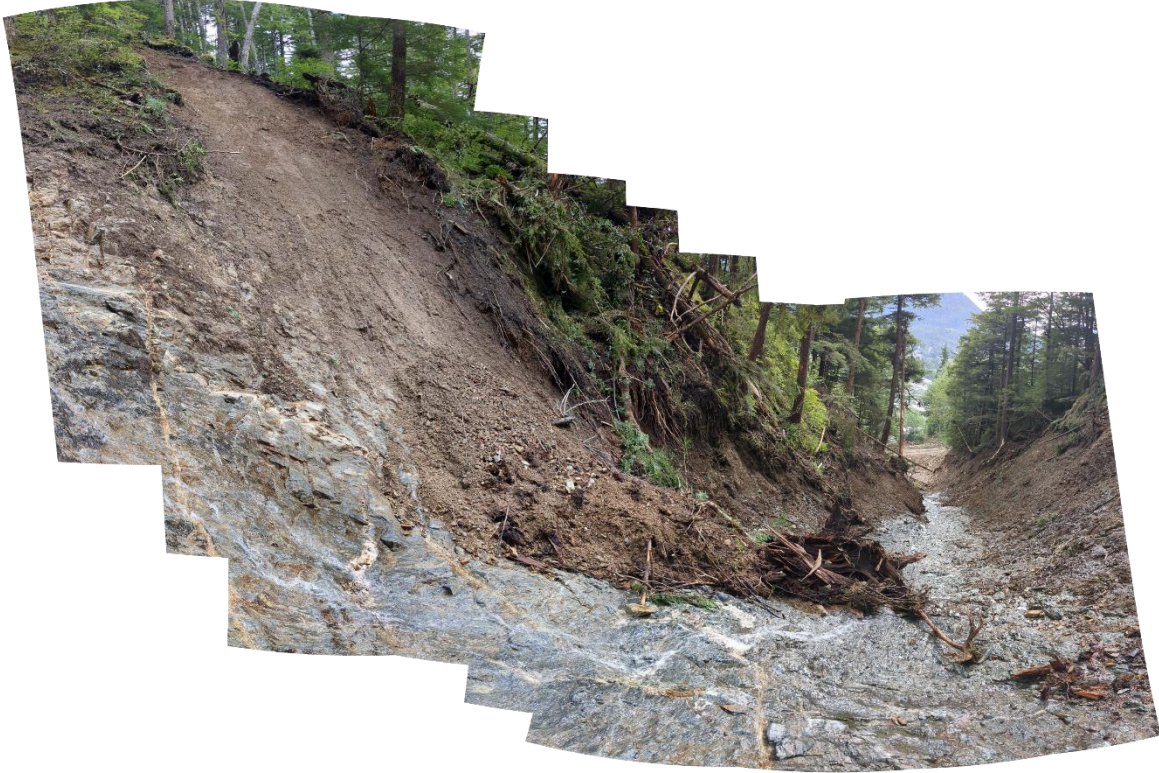
B: Copper Ridge Landslide, Point 1024, Middle Zone conditions with colluvium exposures.



A: Copper Ridge Landslide, Point 1059, Middle Zone fault gouge in upper scoured stream channel.



B: Copper Ridge Landslide, Point 1059, Middle Zone fault gouge in upper scoured stream channel looking southeast.



A: Copper Ridge Landslide, Point 1025, Middle Zone conditions with recent shallow failures.



B: Copper Ridge Landslide, Point 1025, Middle Zone schist exposures surrounded by overhung topsoil exposures.



A: Copper Ridge Landslide, Point 1028, Upper and Middle Zone Transition, base of source area at topographic convergence, looking northwest.



B: Copper Ridge Landslide, Point 1022, Lower Zone, debris accumulation at access driveway switchback.



A: Copper Ridge Landslide, Point 1050, Lower Zone, steep slope below access driveway switchback.



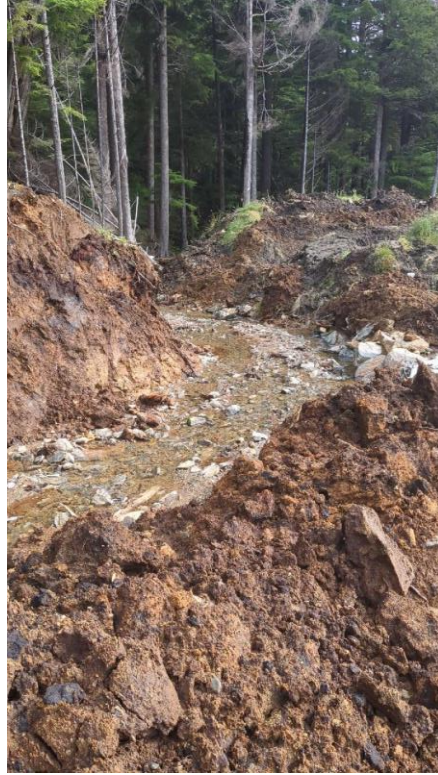
B: Copper Ridge Landslide, Point 1049, Lower Zone, debris accumulation at landslide toe.



A: Copper Ridge Landslide, Point 1049, Lower Zone, debris accumulation at landslide toe.



B: Copper Ridge Landslide, Point 1022, Lower Zone, stream channel diversion adjacent to access driveway switchback looking southwest.



A: Copper Ridge Landslide, Point 1022, Lower Zone, drainage channel diversion adjacent to access driveway switchback looking northeast.



B: Copper Ridge Landslide, Point 1018, Lower Zone, drainage channel diversion at base of steep slope near landslide toe.