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FINAL REPORT

LYNN CANAL HIGHWAY
PHASE I
ZONE 4 GEOTECHNICAL INVESTIGATION

STATE PROJECT NUMBER: 71100

Submitted to:

Alaska Department of Transportation and Public Facilities
Southeast Region, Design and Engineering Services
6860 Glacier Highway
Juneau, Alaska 99801-7999

Submitted by:

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Distribution:

10 Copies - ADOT&PF-SE (Ralph Swedell)
3 Copies - Golder Associates Inc.

December 2006

Job No. 063-5782

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December 29, 2006

Our Ref.: 063-5782

Alaska Department of Transportation and Public Facilities
6860 Glacier Highway
Juneau, AK 99801-7999

Attention: Ralph Swedell, Regional Geologist

RE: FINAL REPORT
LYNN CANAL HIGHWAY PHASE I
ZONE 4 GEOTECHNICAL INVESTIGATION

Dear Ralph:

Golder Associates Inc. Is pleased to present 10 copies of our Final Report for the Lynn Canal Highway Phase I – Zone 4 Geotechnical Investigation. The material presented in this report covers the proposed highway alignment from Independence Creek to the Katzehin River.

Please call if you have any questions.

Sincerely,

GOLDER ASSOCIATES INC.

Robert G. Dugan, C.P.G.
Principal Engineering Geologist

RGD/lcm

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LIST OF ABREVIATIONS

ADOT&PF-SE	Alaska Department of Transportation and Public Facilities – Southeast Region
ASTM	American Society for Testing and Materials
C.E.	Common Era, year given
CSV	Comma separated value file
CY	Cubic yard(s)
ELC	East Lynn Canal, from Glude and others (2004) snow avalanche report
°F	Degrees Fahrenheit
ft	Foot, feet
g	Acceleration due to gravity, approximately 32 ft/second^2
GHRS	Geologic Hazard Rating System
Golder	Golder Associates Inc.
GPS	Global Positioning System
HIN	Hazard Index Number
IRP 2006	Inertial Reference Point 2006 alignment
in	Inch(es)
km	Kilometer(s)
lb	Pound(s)
LIDAR	Light detection and ranging
m	Meter(s)
MPa	Megapascal
PDOP	Position Dilution of Precision, GPS term for position uncertainty
psi	Pounds per square inch
WAAS	Wide Area Augmentation System, GPS location correction system
WGS 84	World Geodetic System 84, GPS datum
yr	Year(s)
yr B.P.	Radiocarbon years before present with respect to the year 1950 C.E.

1.0 INTRODUCTION

The Alaska Department of Transportation and Public Facilities (ADOT&PF-SE) is conducting studies of a highway corridor linking the community of Juneau, Alaska to a ferry terminal on the north side of the Katzehin River near Haines, Alaska. As part of this project, Golder Associates Inc. (Golder) conducted Phase I of a multi-phase geotechnical investigation for Zone 4, which is a 22.2 mile segment extending along the east side of Lynn Canal from Independence Creek to the Katzehin River. This segment traverses a steep side-slope near tidewater. The slopes above the proposed corridor are typically mountainous and extend to elevations that are typically 3,000 ft to 6,000 ft above the proposed highway. The ADOT&PF-SE staked the proposed Inertial Reference Point 2006 (IRP 2006) alignment in the spring of 2006 which was the working alignment for Golder during Phase I field work. After completion of fieldwork, some segments of the alignment were realigned. However, for this report, all alignment locations are referred to in terms of the staked alignment in spring of 2006, the IRP 2006 alignment.

The Golder work was conducted for ADOT&PF-SE Project No. 71100 under Agreement No. 36863003.

1.1 Purpose

The purpose of the Phase I investigation was to more precisely characterize the in situ soil and rock conditions and geologic hazards, and to make recommendations for Phase II design level geotechnical investigations.

1.2 Scope

The Phase I scope of work included the development of surficial soils maps of the route corridor, identification of geologic and slope hazards, and recommendations for design level geotechnical investigations. The scope of work for Phase II will include the collection and evaluation of subsurface information along centerline plus engineering evaluations and geotechnical recommendations relevant to the design and construction of the project. Phase III would include geotechnical assistance as necessary when geotechnical issues arise during construction.

The specific scope of work for Phase I included the following tasks:

- Conduct office review, data and air photo acquisition, and field plan development.

- Conduct surficial geologic mapping of the route corridor extending from tidewater to 1,000 ft right of the proposed centerline at a scale of 1 inch = 200 ft. The mapping was to include delineation of soil and bedrock units and discontinuity orientations of the bedrock. Mega-boulders, defined as boulders greater than 10 ft in diameter for the smallest dimension, were to be identified and catalogued. Preliminary structural rock mapping was to be carried out on relevant outcrops.

- Develop an area map showing the limits of geologic hazards that could impact the proposed highway. Hazard mapping was to extend beyond the road corridor cut and fill limits. The hazard mapping results were to be presented as 1 inch = 500 ft scale maps.

- Evaluate the IRP 2006 alignment in concert with the ADOT&PF-SE to develop a design level geotechnical investigation to include centerline and foundation test drilling.

1.3 Project Team

The project was managed and carried out by personnel from the Golder office in Anchorage, Alaska with assistance from staff in our office in Redmond, Washington. Norm Norrish of Wyllie & Norrish Rock Engineers made field inspections of selected rock slopes, provided input on data gathering, and provided other insights relevant to the design. Helicopter support was provided by Temsco Helicopters out of Juneau, Alaska. Golder established a field office in Haines, Alaska as a base to carry out the field operations.

1.4 Project Location

The proposed Lynn Canal Highway is located in southeast Alaska (Figure 1) and extends from Echo Cove near Juneau to the mouth of the Katzehin River near the communities of Haines and Skagway (Figure 2). Zone 4 of the proposed highway begins on the east side of Lynn Canal, approximately 40 miles north of Juneau (20 miles north of the end of the existing road at Echo Cove) and extends approximately 22.2 miles to the Katzehin River delta opposite the community of Haines (Figure 3). The IRP 2006 alignment closely follows the coastline at the base of steep mountain slopes and intersects several steep side valleys. The terrain is roadless and mantled by old-growth forest that typically extends from tidewater to elevations exceeding 1500 ft. As there are no trails or developed access to the area, boat or helicopter transportation is required.

Lynn Canal is a prominent fjord and marine highway corridor with a northerly trend. It is approximately 40 miles long, three to five miles wide, and up to 1,000 ft deep. It is bound to the west by the Chilkat Range and to the east by the Coast Mountains. The northern reaches of Lynn Canal are divided by the Chilkat Peninsula, with Chilkat Inlet to the west and Chilkoot Inlet to the east (Figure 3). Chilkoot Inlet, approximately 3 miles wide, extends northward to its junction with Taiya Inlet and Lutak Inlet a few miles north of Haines. Taiya Inlet extends 15 miles northward to Skagway and Dyea. The southern part of Lynn Canal extends southward to the junction of Chatham and Icy Straits (Figure 1).

2.0 PROJECT DESCRIPTION AND SETTING

2.1 Site Conditions

2.1.1 Regional Geology

The project area spans the east Lynn Canal region from Independence Creek, at the south end, to the mouth of the Katzehin River at the north end. The east side of Lynn Canal comprises the western margin of the Coast Range, with mountains exceeding elevations of 6,000 ft. The topography is characterized by steep, glaciated, mountainous terrain and U-shaped side valleys. Rock knobs, colluvial aprons, and rock cliffs are common. The mountainous slopes generally extend steeply into the waters of Lynn Canal to depths exceeding 600 ft. Relatively broad flat deltas have built up at the mouths of large rivers such as the Katzehin River.

The northern part of Southeast Alaska lies within the active tectonic belt that rims the Pacific Basin (Lemke, 1974). Tectonic activity has resulted in northwesterly trending arcuate bands of faults and folded sedimentary, volcanic, and metamorphic rocks. Lynn Canal occupies the Chatham Strait fault, a right-lateral fault which is a southerly extension of the Denali Fault system that arcs northward across interior Alaska. There are also northwest/southeast trending faults that are sub-parallel to Lynn Canal and typically occupied by linear stream courses.

The Katzehin River valley was carved by the Meade Glacier, a large piedmont glacial system that covers more than a hundred square miles. The glacier has been retreating and currently terminates 8 miles east of Chilkoot Inlet. The river has a heavy sediment load and has created a large sandy delta where it enters Lynn Canal.

The steep, high slopes and high precipitation rates have created conditions for snow avalanches. Numerous avalanche zones intersecting the Zone 4 alignment have been mapped (Glude and others, 2004). Other types of geologic hazards, particularly related to slope stability, are also present and these are addressed in subsequent sections.

Permafrost is not likely to be present in the vicinity of the proposed highway alignment.

2.1.1.1 Bedrock

The bedrock on the east side of Lynn Canal consists of several rock lithologies within the immediate vicinity of the study area (Figure 4) (Gehrels and Berg, 1992). The bedrock on the west side of Lynn Canal consists primarily of Paleozoic sedimentary and volcanic rocks. The rock lithologies encountered within the project area are predominantly Cretaceous to Permian basalt, metasedimentary rock, and weakly to strongly foliated Cretaceous to Tertiary gneissic rocks, apparently derived from a granitic parent rock. The basalt, typically massive and vesicular, underlies the southern end of Zone 4. The metasedimentary bedrock, which is strongly foliated and contains gneissic elements, underlies much of the middle portion of Zone 4. The gneiss is generally massive and typically underlies the northern part of Zone 4. Detailed descriptions of these rock types can be found in Section 3.2.5. The occurences and extents of units can be seen on the surficial geologic maps presented in Appendix E as well as in Section 4.1.

The bedrock is prominently exposed over much of the alignment in the intertidal area, and on the many cliffs, despite the heavy forest cover.

2.1.1.2 Unconsolidated Deposits

Upland areas are generally characterized by shallow, glacially-scoured bedrock overlain by glacially-derived deposits, except at the base of steep slopes where there are predominantly colluvial/alluvial deposits and talus that can include mega-talus fields. The extremely coarse talus is present over much of the alignment and includes some clasts with diameters greater than 40 ft. Many unconsolidated deposits, up to elevations of over 200 ft, have been re-worked by wave action and uplifted through isostatic rebound following de-glaciation. Detailed descriptions of the unconsolidated deposits can be found in Section 3.2.4. The occurences and extents of units can be seen on the surficial geologic maps presented in Appendix E as well as in Section 4.1.

2.1.1.3 Glaciation and Isostatic Rebound

During the last Ice Age (70,000–12,000 yr B.P.), much of southeast Alaska was covered in ice several thousand ft thick. Lynn Canal was filled with ice that flowed southward from the valleys north of Haines and Skagway, and from the side valleys along Lynn Canal. Following the Last Glacial Maximum (12,000 yr B.P.), the Earth's climate reached a thermal maximum (6,000-7,000 yr B.P.), at which point glacial coverage was slightly less than modern day glaciers (Connor and O'Haire, 1988). More recently, during the period 1200-1770 C.E., a global cooling known as the Little Ice Age produced regional glacial advances throughout southeast Alaska including the Juneau Icefield, Glacier Bay, and tributaries to Lynn Canal.

As these large ice sheets melted, weight was removed and the Earth's crust began to rebound slowly. Rebound following the Last Glacial Maximum has raised the shorelines 300 ft in upper Lynn Canal (Larsen and others, 2005). Glacial rebound may have stalled during the Little Ice Age. Following the Little Ice Age, however, isostatic rebound resumed and the upper Lynn Canal coast has risen by 18.7 ft, at a rate of 0.95 in/yr. Other modern rebound rates in the region include 0.51 in/yr (Juneau), 0.67 in/yr (Skagway), and 1.05 in/yr (Glacier Bay) (Larsen and others, 2004).

Crustal uplift has produced frequent elevated, wave cut terraces throughout southeast Alaska and Lynn Canal. Elevated beaches are common where beach deposits worked by wave action have been uplifted out of the intertidal zone.

Rapid retreat of ice sheets may have generated pervasive joint sets in Lynn Canal bedrock by removing overburden pressure and stress on the Earth's crust. While bedrock at depth remained under pressure and deformed plastically, near-surface bedrock responded with brittle deformation. This resulted in an exfoliation joint set typically observed in the field as joint planes parallel to the local hill slope. Other regional joint sets exist with more consistent orientation and may result from tectonic forces such as faulting and terrane accretion. The exfoliation joint set likely originated prior to the Little Ice Age during post-Last Glacial Maximum uplift or prior interglacial periods. Persistence and aperture of exfoliation jointing may vary with elevation, as deglaciation relieved varying amounts of stress at different elevations and times (Motyka, 2006).

2.2 Climate

The Lynn Canal region of southeast Alaska is located in a maritime climate zone with cool to moderate temperatures and high amounts of precipitation falling in the coastal mountains (WRCC, 2006). Average annual maximum and minimum temperatures show similar values for stations along Lynn Canal, mid-to upper-40's °F and mid-30's °F, respectively (Table 1). Lynn Canal has temperatures in the range of 45 to 65 °F in the summer and 18 to 37 °F in the winter (Glude and others, 2004).

Upper Lynn Canal near Haines and Skagway receives less precipitation than Juneau with the heaviest precipitation falling from November through January (Glude and others, 2004). Average annual total precipitation ranges from about 48 inches/year in Haines, 46 inches/year at Eldred Rock, and 57 inches/year at the Juneau Airport (Table 1). Glude and others (2004) estimate snowfall for east Lynn Canal at 147 inches/year. Average annual total snowfall ranges from about 123 inches/year in Haines, 71 inches/year at Eldred Rock, and 94 inches/year at the Juneau Airport (WRCC, 2006).

2.3 Seismicity

Lynn Canal is situated on the circum-Pacific earthquake belt, one of the most tectonically active areas in the world. Several major and minor north and northwest-trending lineaments interpreted to represent potential faults transect the region. Along the east shore of Lynn Canal, creeks and debris flow paths occupy many lineaments. In addition to crustal uplift caused by isostatic rebound, Lemke and Yehle (1972) note that large earthquakes could potentially cause land uplift or subsidence on the order of several ft or tens of ft.

Seismicity of the area is characterized by right-lateral strike-slip motion along several faults of the Chatham Strait and the Queen Charlotte-Fairweather fault systems. The Chatham Strait fault system is approximately 190 miles (300 km) long with displacements up to 90 miles (150 km). The fault system extends the length of Chatham Strait, up Lynn Canal and into Chilkat Inlet, continuing northwest as the Denali fault (see Fogleman and others, 1993). There is no recent onshore or submarine evidence of displacement along the fault system (Connor and O'Haire, 1988).

The Queen Charlotte-Fairweather fault system is currently active and presents the greatest earthquake hazard to the area (Wesson and others, 1999a; Haeussler and Plafker, 2003). The fault is several hundred miles long, paralleling the southeast Alaskan coast, approximately 75 miles (120 km) west of Lynn Canal. Earthquakes with a Richter magnitude of up to 8.1 have occurred on the fault system. The most recent rupture on the fault system occurred in 1958. The March 9, 1952 magnitude 6.0 earthquake located approximately 30 miles northwest of Haines represents the closest and most recent magnitude ≥ 6.0 earthquake relative to Zone 4 (Lemke and Yehle, 1972).

Wesson and others (1999b) estimate 15-20% g peak horizontal acceleration with 10% probability of exceedance in 50 years for the Zone 4 region from Berners Bay to the Katzehin River delta.

3.0 METHODOLOGY

3.1 Mapping Equipment & Tools

3.1.1 Light Detection and Ranging (LIDAR) & Topographic Maps

Light Detection and Ranging (LIDAR) was used extensively by the field staff. A LIDAR image is created by transmitting a light at an object (in this case the eastern side of Lynn Canal), and timing the reflection and refraction of that light to return to the transmitting vessel. The measured time of that light to return to the transmitter is used to determine that object's range (Kavaya, 1999). The data are collected as point data, processed to remove the effects of vegetation, and a digital surface is created from the "bare earth model" (Figure 5). The data used in the 2006 field season had a density of 1 LIDAR data point per 1.5 square m. These models were used to create the topographic maps that the field staff used daily for the duration of the field work. The models were also used by the field staff to view the surrounding topography in a 3-dimensional image. QT Modeler (Version 5.1) was used to view and manipulate the LIDAR data.

The LIDAR data and images that were used for the Zone 4 mapping effort did have some inconsistencies with field observations. Processing of coastal wave artifacts produced offshore contours that indicated landforms at 10 ft or 20 ft elevation, whereas field observations clearly indicated an offshore environment. Also noted was the inability of LIDAR to correctly map overhanging or vertical cliffs, possibly due to poor ray paths between the transmitter and terrain. In these rare cases, the slopes may appear to be much shallower than in reality because of these data artifacts. In other cases, the ground surface was smoothed and did not accurately reflect the ground conditions. This was possibly due to poor coverage of the area or interference from the surrounding vegetation.

3.1.2 Thales MobileMapper™

During the field season, Thales MobileMapper™ GPS units were utilized for data collection and GPS navigation.

All point data collected with the MobileMapper™ were geo-referenced using WGS 84 in the field during data collection and then converted to the local Eldred Grid 2003 coordinate system (easting, northing, altitude) developed by ADOT in the office for the final product. The MobileMapper™ utilized the Wide Area Augmentation System (WAAS) for real time position correction in the field, when satellite coverage was available. Horizontal position accuracy is generally considered to be 2-3 m under optimal conditions (MobileMapper™ Office Users Manual, 2005).

The MobileMapper™ was often used as a GPS unit in order to locate the field staff in relation to the proposed IRP 2006 alignment for the purposes of field documentation and route finding. Sections of the IRP 2006 alignment were loaded into the MobileMapper™ daily. These sections were determined by field staff prior to the field day and were representative of the areas of interest for that day. The information loaded daily consisted of the IRP 2006 alignment with stationing every 100 ft, the mapping boundary, and any eagle nests, landing zone locations, or waypoints of interest.

3.1.3 Data Collection

Data collection in the field utilized two data dictionaries that work like flow charts, one for surficial mapping (Figure 6) and one for hazard mapping (Figure 7). The data dictionaries were used by scrolling through the menus to enter the appropriate data for a particular data point. The data dictionaries were constructed by the field staff prior to any data collection and covered all of the features expected to be encountered while in the field. The data dictionary allowed the field staff to scroll through a list of features and choose one that was applicable to the location (e.g., soil, bedrock, hazard, mega-boulder, and photo). The user was then prompted to enter all of the applicable data concerning that point. For example, when making a soil point, the field staff would choose "soil" from the main menu. A secondary menu would then appear that would allow the field staff to choose which type of soil was encountered, where it was located (e.g., upslope, downslope, up alignment, down alignment, or if it was a mid point), any underlying unit associated with the point, and enter a photo number if a photo was taken. The reason for this particular method of data collection was flexibility in downloading points to an AutoCAD® drawing, and to easily create a Microsoft Access™ database.

In order to create the Access™ database and point files to import into AutoCAD®, the data collected in each MobileMapper™ were downloaded at the end of each working day and processed by a technician. Shape files were made of the points to import into AutoCAD®. The Access™ database was updated daily by exporting the data as comma separated value (CSV) files. A quality control check was done at this time in order to determine if any data was lost or corrupted. There were instances where data was lost and a site had to be revisited at a later date.

3.2 Surface Geologic Mapping

Surface geology maps were produced at the 1 inch = 200 ft scale throughout the Zone 4 IRP 2006 alignment from shoreline to 1,000 ft east of the IRP 2006 alignment. Geologic contacts were drawn on field maps and later digitized, in-house, using AutoCAD® software. Surface material, bedrock type, structure, and orientation were recorded where observable. Where stream channels intersected the IRP 2006 alignment, qualitative size and bedload data was collected. Overburden material thickness was noted wherever possible, commonly where incised by streams, avalanche chutes, or debris flows.

3.2.1 Corridor of Study

The 1,000 ft wide corridor presented a larger area than could be mapped in high detail by the available field staff. To accomplish complete coverage, two teams were used. A low elevation team mapped the area between tidewater up to 100-200 ft upslope (east) of the IRP 2006 alignment with high detail. This team was responsible for collecting all hydrologic and mega-boulder data relevant to the IRP 2006 alignment. The second team mapped the remaining corridor area at greater distances upslope and at and higher elevations than the lower team. This team was also responsible for mapping geologic hazards. Because of rugged terrain and the greater area covered by this team, map detail and accuracy decrease at greater distances from the IRP 2006 alignment.

3.2.2 Site Access

Access to East Lynn Canal was difficult due to its remote nature without road access. Field crews were stationed in Haines the nearest town, and transported to the field daily by a Hughes 500 helicopter. Field team drop-off and pick-up locations were largely limited to beach landing zones, requiring crews to cover the mapping area on foot over rugged, densely vegetated terrain. In two locations, helicopter traffic was restricted for a 3,000 ft radius surrounding sea lion haul outs at Met Point (IRP 2006 1606) and Gran Point (IRP 2006 2361). Access to these areas typically required long approaches on foot. On one occasion, access was provided by a local boat with beach landing capabilities.

3.2.3 Map Completion and Validation

Field mapping had two stages: preliminary map production and revision/map validation. First, the entire corridor was mapped from Independence Creek to the Katzehin River delta. Second, mapping teams revisited key sites throughout the corridor to validate map accuracy and ensure complete coverage. 45 days were spent mapping in the field (June 15 to August 6). During the first five weeks, field mapping teams worked to complete initial drafts of both the surficial geology and hazard maps. Daily mapping rates averaged 4,300 ft/day and varied greatly depending on rugged terrain and complexity of the geology. This initial pass left 13 field days for field teams to revisit select sites and review previous mapping techniques, interpretation and data collection. As teams initially mapped northward, understanding of local and regional geology improved, as did interpretations and descriptions of geologic units. Returning to the southern part of the IRP 2006 alignment was a key step in establishing consistency in geologic interpretation, unit identification, nomenclature, and hazard mapping accuracy.

3.2.4 Surficial Geologic Units

Prior to field work, definitions for expected materials were created for guidance and to assure consistent data collection for all staff for the extent of the project. The soil and bedrock units created are as follows, presented in such order to imply possible age relationships from youngest to oldest. However, absolute and definitive relative ages were not determined. Appendix A presents photographs of each soil type and rock type.

Colluvium (Qc): Material deposited through gravity and/or overland water flow on moderately-angled slopes (Appendix A-1). In Zone 4, colluvium typically varies in size from sand to boulder, and typically is angular to sub rounded especially at lower elevations. Colluvium may be intermixed with talus or elevated beach deposits. Generally, colluvium has a density ranging from loose to dense.

Talus (Qct): Gravity-transported rock material that has been deposited by falling, rolling, or sliding off of nearby cliffs (Appendix A-2). Typically angular to sub angular but in some areas may also be sub rounded. The degree of roundness and the size of vegetation (e.g., trees) growing on top of the talus provide a rough indicator of the relative age of the talus, with the most recent talus typically very angular and absent of vegetation. The talus ranges in size from gravel to boulders, with boulders greater than 10 ft in diameter often encountered near the source cliffs. In many instances, the talus extends to the shoreline. In rare occasions, boulders greater than 40 ft in diameter were encountered. Especially in areas dominated by larger boulders, the talus will often contain voids exceeding several ft in width and depth. Thickness of the talus varies greatly, from a few ft of talus over bedrock to 40 ft or more. Talus, especially at lower elevations, may have been partially reworked by wave action, and may be intermixed with other soil types, such as colluvium or beach deposits. Typically, talus forms steep slopes at around 20 to 40 degrees. In some instances talus slopes will exceed 40 degrees, especially near the base of cliffs and in areas dominated by very large clasts greater than 10 ft diameter. The talus may have been deposited as individual clasts over time, or as large, infrequent events totaling 1,000 CY or more per event.

Modern Beach Deposits (Qb): Soil worked by wave action within the intertidal zone. Modern beach deposits consist of sub rounded to rounded sand- to cobble-size clasts (Appendix A-3). Modern beach deposits may be intermixed with other soil types, such as colluvium or talus. The source for beach deposits is often glacial outwash or debris flow deposits. Modern beach deposits may contain minor amounts of organic matter, such as shells and driftwood. Typically beach deposits are well sorted (i.e., poorly graded) and loose to compact.

Elevated Beach Deposits (Qeb): Beach deposits that have been raised above the intertidal zone by isostatic rebound and/or tectonic uplift (Appendix A-4, A-5). Typically forms low-angle slopes (i.e., less than 10 degrees). Linear ridges and valleys trending roughly parallel to the modern shoreline typically represent elevated wave cut platforms of elevated beach deposits. Elevated beach deposits consist of sub rounded to rounded sand- to cobble-size clasts and minor amounts of organic matter, such as shells and driftwood. Elevated beach deposits may be intermixed with other soil types, such as colluvium or talus. Elevated beach deposits generally have a density of loose to compact and may be weakly cemented.

Debris Flow Deposits (Qdf): Typically an unsorted mix of sand- to boulder-size clasts, often mixed with splintered and broken trees, and other vegetation (Appendix A-6). Deposited in narrow channels or spread out on low-angle surfaces as a mix of water and debris during periods of high run-off, such as during heavy precipitation, snowmelt, or rain-on-snow events. Debris flow material is often multi-lithic, with sub angular to rounded clasts ranging in size from less than 1 ft to more than 5 ft in diameter.

Alluvial Fan Deposits (Qaf): Sediment deposited where a high-energy stream encounters a relatively flat slope (Appendix A-7). Alluvial fan deposits are typically triangular in map view, and have been sorted by flowing water. Alluvial fan clasts typically range in size from sand to boulders, and may provide a good source of borrow material where thick enough. In the project area, the alluvial fan deposits are usually derived from glacial deposits, and consist of sub rounded to rounded clasts.

Landslide Deposits (Qls): Historically recent (i.e., within the last few hundred years) mass wasting deposits from one or few events (Appendix A-8). These areas are generally vegetated by deciduous trees and brush, or smaller coniferous trees in contrast to the adjacent old growth forest. Landslide materials are typically unsorted masses of coarse soil and rock and may include trees and other organic materials.

River Deposits (Qr): Sediments deposited at the mouth of the Katzehin River at the north end of the IRP 2006 alignment (Appendix A-9). The sediments are influenced both by the flow of the Katzehin River and daily tidal changes. These deposits primarily consist of silt and sand, with gravel present. The river deposits may contain organic material such as logs, seaweed, shells, or other organic matter washed down the Katzehin River or floated in during high tide/storm events. They generally have densities ranging from loose to compact.

Glacial Outwash (Qgo): Sediment deposited by meltwater streams originating from glaciers (Appendix A-10, A-11). Glacial outwash consists of poorly to well-sorted sand, gravel, cobbles, and boulders with silt interbeds. Glacial outwash typically forms low-angle deposits. In areas where the slope has been over steepened, such as by wave erosion, glacial outwash is prone to scallop-shaped slope failures on steeper slopes. May be overlain or intermixed with talus or colluvium, especially near steep cliffs. Glacial outwash is typically encountered at the mouth of “U”-shaped glacial valleys. These deposits generally have densities ranging from compact to very dense and may be weakly cemented in areas. Can be an excellent source of borrow material.

3.2.5 Bedrock Units

Basalt Bedrock (Bxv): Lightly to moderately metamorphosed massive vesicular basalt, typically phaneritic with fine to medium grains (Appendix A-12). Typically has a compressive strength of R4 to R5 based on field assessment (Table 2). An exfoliation joint set can form parallel to the local hillside slope. The basalt displays multiple joint sets ranging from tightly spaced to extremely wide. In localized zones, the basalt appears to have been hydrothermally altered, resulting in a significant reduction of rock strength (to approximately R2). Many outcrops have been smoothed and rounded, by glacial processes, wave action, and erosion by flowing water.

Metasedimentary Bedrock (Bxms): Metamorphic bedrock with a sedimentary parent rock (Appendix A-13). Typically consists of a mix of biotite-rich schist, quartzite, marble, with intrusions of metamorphosed diorite (gneiss). Usually forms strongly defined, tightly spaced foliations steeply dipping to the northeast. Outcrops may contain several pervasive joint sets. Typically has a compressive strength of R4 to R5 based on field assessment (Table 2). May display original cross-bedding and typically has a tabular fabric. The metasedimentary bedrock is typically intermixed with gneiss near the gneiss contact.

Gneiss Bedrock (Bxmg): Metamorphic bedrock that appears to have originated as a dioritic or granodioritic pluton (Appendix A-14, A-15). The gneiss has weak to strong foliation. The foliation typically dips steeply to the northeast. Typically forms large vertical cliffs (100+ ft high), and is a common source for mega-talus. The gneiss tends to form more massive cliffs than the metasedimentary bedrock. Typically has a compressive strength of R5 to R6 based on field assessment (Table 2). An exfoliation joint set typically forms parallel to the cliffs. The gneiss may be massive or may display several joint sets (some pervasive). Many outcrops have been smoothed and rounded by glacial processes, wave action, and erosion by flowing water. The gneiss is sporadically intermixed with the metasedimentary bedrock, particularly in transition zones between the gneissic and metasedimentary bedrock.

Undifferentiated Metamorphic Bedrock (Bxm): Metamorphic bedrock that shares characteristics of both the metasedimentary and gneissic bedrock, or consists of intermixed metasedimentary and gneissic bedrock either observed or inferred at a scale too small to be resolved on the surficial geology maps (Appendix A-16, A-17).

3.2.6 Surface Hydrology

Per the direction of the Regional Hydraulics Engineer, streams encountered in the field were classified as Type I, II, III, or IV. Guidelines for assigning these classifications were provided by ADOT&PF and outlined below. The purpose of qualitative characterizations was to identify potential design challenges and priorities at stream crossings along the alignment. These classifications were not to be interpreted as design recommendations. Final engineering design and pipe size selection is the responsibility of ADOT&PF.

Streams were characterized at locations crossing the IRP 2006 alignment centerline. Four features (described below) were collected at a stream crossing using the MobileMapper™: type, bed, width, and photo. Sometimes ephemeral streams were encountered. Ephemeral streams with evidence of water flow (e.g., aligned tree needles, vegetation and duff pushed up against tree roots and rock) were categorized. These observations represent one-time visits to streams. The weather varied greatly during the summer field season, from clear and warm, to moderate rain lasting several days. Hydrologic observations could change if the streams were visited in a different season.

Type is based on visual or audible stream detection.

- Type 1 – Stream channel is easy to step over, typically up to 2 ft wide.
- Type 2 –Stream channel is more difficult to step over, typically 2 to 3 ft wide.
- Type 3 – Stream channel is typically greater than 3 ft wide.
- Type 4 – A Type 3 stream with an additional complicating factor – bridge sites, multiple stream channels, meandering channel, debris flow channel or avalanche path, unconfined flow down bedrock slope or cliff.
- Audible – Water flow not visible but flow is audible in the subsurface (e.g., water flowing through coarse talus).

Bed refers to the stream channel material observed or inferred in the stream bed:

- Fine
- Sand
- Gravel
- Cobble
- Boulder
- Bedrock

Width is based on visual estimates of stream width:

- 0-3 ft
- 3-6 ft

- >6 ft

Photo documentation of the streams was conducted, with field personnel or field gear used for scale. A photo number of #1000 means that no photo was taken.

3.2.7 Rock Structure Mapping

Detailed rock structure mapping data was collected at 117 locations representing roughly one site per 1,000 ft of the IRP 2006 alignment (Appendix B). Rock mass and discontinuity descriptions and measurements were typically taken at sites proposed for large rock cuts, fills, bridge abutments, or where mitigation is likely needed for rockfall hazard. Effort was made to select outcrops that are representative of the local bedrock conditions. For all relevant and accessible rock discontinuity sets, the orientation of dip and dip direction were measured using Brunton™ Geo Transit structural compasses set to 23.5° east magnetic declination for “true north” measurements. Additionally, data concerning discontinuity persistence, aperture, shape, surface roughness, number, and spacing were collected. Data were collected using a uniform template (Figures 8 & 9) and locations were noted on the surficial geology maps. The results of the rock structure mapping is presented as a separate addendum.

3.2.8 Mega-Boulders

Extremely large boulders and talus are widespread along east Lynn Canal and may present unique challenges to excavation, road construction and hazard management. In this project, clasts greater than 10 ft diameter for the smallest dimension are referred to as *mega-boulders*. Typical mega-boulders range from 10 ft to 20 ft diameter with some boulders reaching 50 ft diameter. In particular areas, mega-boulders are so common that they form entire talus fields, often interlocked on steep slopes. Removal of mega-boulders may present challenges to mechanical excavation by earth moving equipment and may require blasting. Large voids (up to 6 ft wide and 15 ft deep) are common between mega-boulders and mega-talus, which may complicate fill and compaction for road grading. The size and location of mega-boulders were routinely recorded using MobileMapper™ units and noted on maps. Because mega-boulders are so frequent and widespread in some areas, their appearance on geologic maps simply indicates their presence, not necessarily their number.

3.2.9 Alternative Mapping Methods

In many locations, particularly at higher elevations, rugged terrain was impassible or too hazardous to be mapped directly on the ground. Where walking was not possible, completion of map coverage depended on alternative or supplementary mapping methods listed below.

- Airborne/helicopter flights allowed visual mapping of otherwise impassible areas, such as cliff-dominated sites or steep shorelines.
- High altitude and low angle/oblique aerial photography gave insight into regional and local bedrock structures affecting surface processes. Appendix C presents a sequence of aerial photographs along the alignment from IRP 2006 1445+00 to 2620+00.
- LIDAR bare earth images were frequently used to interpret slope morphology or spatial extent of surface deposits.

3.2.10 Geologic Map Nomenclature

Surficial geologic maps were drawn as an outline of areas in which an observed bedrock or soil type persists at the surface. These areas are outlined on topographic maps and labeled with symbols specific to the observed conditions. In areas where a combination of more than one material or condition persists, the area may be labeled with more than one symbol type. For example, an area in which shallow talus (Qct) overlies basalt bedrock (Bxv), the label used is $\frac{Qct}{Bxv}$. The upper term is the material seen on the surface and the lower term is the underlying material. “Shallow” is interpreted to be between approximately 3 ft and 10 ft depth. In the example above, basalt bedrock is estimated to be not more than 10 ft below the talus surface. This is an approximation and localized exceptions certainly exist. In areas characterized by both deposits and bedrock at the surface, for example talus and basalt bedrock, the two terms can be combined, as in “Qct + Bxv”. The first term indicates the dominant or primary surface material, followed by the secondary or less common material.

Geologic mapping was based on direct field observation, in addition to LIDAR and aerial photograph interpretation in the field and office. Even with direct field observation, thick vegetation often obscured deposits or bedrock exposures. Thus, in an area mapped as a soil deposit, some bedrock may be encountered, and vice versa. Vegetation removal is required for positive identification of geologic materials.

3.3 Geologic Hazard Identification

Geologic hazard maps were produced at the 1 inch = 500 ft scale throughout Zone 4 from tidewater to 3,000 ft east of the IRP 2006 alignment. Geologic contacts were drawn on field maps and later digitized, in-house, using AutoCAD® software. At frequent points, data was digitally recorded using the MobileMapper™ to document surface and underlying materials, in addition to data being entered into field notebooks.

Identifying geologic hazards in Zone 4 of the Lynn Canal Highway area required a multifaceted approach since many of the hazards were observed on a regional scale. The required mapping limits often led into terrain that was impassable or otherwise too difficult to attempt. The large area designated for geologic hazard mapping was too large for the team to walk in the time allowed. As a result of the immense study area, the hazard mapping team often employed means other than walking and physically observing the terrain in order to create the geologic hazard map.

Topographic maps produced from LIDAR, as well as bare earth LIDAR were used to identify geologic features and assist in mapping the geologic hazards encountered. Topographic maps and LIDAR imagery were employed to identify the extent of some hazards and the bounds of those hazards were then interpolated when possible. LIDAR was particularly useful for seeing large features such as bedrock cliffs, massive talus fields, and gullies that were potential debris flow paths. In LIDAR images, certain hazard conditions present relatively consistent patterns, often allowing hazards to be interpreted by the texture of their digital image (Figure 5). Both of these tools, coupled with helicopter reconnaissance of the corridor, allowed the hazard investigation team to target areas for further investigation that posed a threat to the proposed IRP 2006 alignment.

Another crucial element in completing the hazard map was coordination with the centerline mapping team. Radio communication between the two teams was often used to resolve questions about potential hazard conditions encountered by each team. The teams would often communicate site conditions to one another in order to determine spatial continuity of a potential hazard and its severity.

The hazard investigation team used two MobileMapper™ units as well as two digital cameras to document and collect data about all hazards encountered. The type of data collected is listed and described below and was used to create the hazard database. The method of digitally collecting point data is described in the MobileMapper™ Section 3.1.2.

3.3.1 Definitions of Hazards

The definitions of each geologic hazard type encountered are as follows.

Rock Slide: Characterized by large volume events that fail from bedrock outcrops. These events create talus deposits described in Section 3.2.4.

Debris Flow: Episodic, channelized, gravity driven events that are mixtures of sediment and water. These events can produce a wide range of particle sizes, and create debris flow deposits described in Section 3.2.4. These deposits also have the potential to create thick organic deposits at the beach line.

Rockfall: Detachment of individual rocks or relatively small groups of rocks from a steep rock face. There is generally little or no shear displacement. These events create talus soils described in Section 3.2.4.

Hazard Rock: Perched boulders that could become dislodged either during or after construction of the road. These rocks are often mega-boulders.

Soil Raveling: Particle by particle failure over time from steep soil slopes. This type of event is common in glacial outwash deposits described in Section 3.2.4.

Translational Sliding: Slope failure via planar sliding of soils that can include trees and other debris. This type of event is seen in glacial outwash deposits described in Section 3.2.4.

Avalanche: Evidence of avalanche activity. Avalanches have the potential to transport logs and soil which can result in thick organic deposits at the beach line. Avalanche paths are frequently associated with debris flow paths.

A comprehensive study of snow avalanches was carried out by Glude and others (2004) prior to Golder's work on the project, and the identification and assessment of avalanche hazards are outside the scope of this report.

3.3.2 Hazard Characteristics

At each point where hazard data was collected, a value was recorded for each of the following characteristics. A definition of each characteristic and the possible values follows.

IRP 2006 Location represents the unique 4-digit numerical identifier for each hazard. The value is based on assigning one IRP 2006 value to the hazard (e.g., 1493), and was primarily used when entering data into the MobileMapper™ during the field season. However, the value does not provide information on the scale of the hazard, only the general location of the hazard.

IRP 2006 South and North Margin refers to the beginning and ending IRP 2006 stationing at centerline that the hazard is considered to impact or potentially impact, for example 1498+90 and 1492+90, respectively. The values were often determined after field mapping of the hazard and map revisions were completed. Thus, the values provide information on locations of the hazard boundaries.

Bounds refers to the location of the hazard relative to the observation point. For example, "up alignment" indicates that the hazard occurs up (north) the IRP 2006 alignment from the perspective of the observer.

- Up alignment
- Down alignment
- Upslope
- Downslope
- Mid

Impacts alignment refers to whether or not the hazard being observed has impacted the proposed IRP 2006 alignment in the past.

- Yes
- No

Frequency is divided into five different time frames which approximate the recurrence interval of the hazard in years. The category is estimated from field observations of vegetation disturbance, degree and type of revegetation, and freshness of rockfall and talus in terms of weathering and moss/lichen growth on rock face and talus. For some hazards, frequency is unknown, possibly due to loss of MobileMapper™ data or hazard identification after fieldwork was completed. In these cases, frequency was estimated based on field notes, photographs, and information on site specific factors, and labeled as *Unk([frequency]?*) with the frequency estimate noted in the brackets.

The frequency values presented should be considered preliminary estimates. The accuracy and precision of frequency values have not been established. Frequency values could change based on a more complete time series of direct observations, weather and climate factors, and absolute age dating of vegetation and lichen.

- >25 yrs
- 5 to 25 yrs
- 1 to 5 yrs
- 0 to 1 yr
- Unk([frequency value]?)

Quantity is measured in cubic yards (CY) and reflects the approximate volume of material during the most recent event.

- 1000+ yds
- 100 to 1000 yds
- 10 to 100 yds
- < 10 yds

Source Elevation refers to the vertical height in ft above the proposed IRP 2006 alignment that the hazard originates from. Note: this is not elevation.

- >3000 ft
- 2000 to 3000 ft
- 1000 to 2000 ft
- 500 to 1000 ft
- 100 to 500 ft
- <100 ft

Alignment Exposure is the total length in ft of the highway estimated to be at risk from the hazard.

- 500+ ft
- 200 to 500 ft
- 50 to 200 ft
- <50 ft

Predictability refers to how predictable a hazard is. For example, if a debris flow is often catalyzed by heavy rain events, then the predictability may be "high". By contrast, rockfalls can occur at any time and are relatively unpredictable.

- High
- Moderate
- Low
- Unpredictable

Source Material is the material type supplying, or moved by, the hazard event. The definitions for each material type can be found in Sections 3.2.4 for deposits and Section 3.2.5 for bedrock.

Qc	Colluvium deposits
Qct	Talus deposits
Qb	Modern beach deposits
Qeb	Elevated beach deposits
Qdf	Debris flow deposits
Qaf	Alluvial fan deposits
Qls	Landslide deposits
Qr	River deposits
Qgo	Glacial outwash
Qm	Glacial moraine deposits
Bxv	Basalt bedrock
Bxms	Metasedimentary bedrock
Bxmg	Gneiss bedrock
Bxm	Metamorphic bedrock

Centerline Slope identifies the terrain characteristics on centerline for each hazard. This characteristic is specific to the IRP 2006 alignment. Note that the terrain characteristics at the source, along the path, or in the deposition zone could be different than the terrain characteristics at centerline.

- Open soil slope
- Open bedrock slope

- Single channel
- Multi-channel
- Fan
- Deciduous trees
- Other

Clast Size indicates the typical or mean clast diameter in ft that has been transported.

- >4 ft
- 3 to 4 ft
- 2 to 3 ft
- 1 to 2 ft
- 0 to 1 ft

Alignment Location describes the location of the proposed IRP 2006 alignment with respect to the observed hazard.

- Below deposition zone
- Deposition zone
- Path

Slope Angle is the slope angle of the hazard at its origin. This number was often estimated using topographic maps and measured in degrees.

- >60
- 50 to 60
- 40 to 50

- 30 to 40
- 20 to 30
- 10 to 20

Slope Drainage refers to how water is moving in relation to the hazard deposits.

- Into slide
- Off of slide
- Unknown

Vegetation is a generalized characterization of the vegetation type within the hazard area.

- Denuded
- Disturbed
- Undisturbed
- Deciduous Trees

The following categories all have *yes/no* answers and refer to whether or not specific characteristics are present within the hazard limits.

- Tension Cracks
- Seeps
- Tilting Trees
- Curving Trunks
- Deciduous Trees

3.3.3 Geologic Hazard Rating Systems

Two independent systems were developed to rate the geologic hazards encountered in Zone 4. The Geologic Hazard Rating System (GHRS) and Hazard Index Number (HIN) scale (Table 3) were created to assign preliminary, estimated relative and absolute rankings to geologic hazards. The GHRS was created by Golder staff in conjunction with Norm Norrish. The GHRS is a relative scale with each hazard being assigned an *"A"*, *"B"*, or *"C"* rating. The ratings are defined as follows:

- "A": Field evidence that the hazard condition has affected the proposed IRP 2006 alignment within the past 25 years, and that the conditions of hazard origin still exist OR failure would generally be of sufficient volume to close the highway for several days to weeks and could result is loss of the roadway prism.

- "B": Field evidence that the hazard condition has affected the proposed IRP 2006 alignment more than 25 years ago, and the hazard condition persists OR failure would be of sufficient volume to close the highway for several hours to a few days.

- "C": No field evidence that the hazard condition has ever affected the proposed IRP 2006 alignment but the potential is judged to be present. Failure would generally not close the highway but could pose a significant hazard to vehicular traffic.

The HIN scale (Table 3) was adapted from the United States Department of Transportation, Federal Highway Administration Rockfall Hazard Rating System (Pierson and Van Vickle, 1993). Ascending HIN values indicate a greater estimated geologic hazard. The HIN for each hazard represents the weighted sum of five hazard characteristics: frequency, quantity, source elevation, alignment exposure, and predictability. Each hazard characteristic has four attributes. Each attribute is assigned a weighted value of 3, 9, 27, or 81, with higher values indicating a greater estimated geologic hazard. The HIN scale has minimum and maximum values of 15 and 405, respectively. These values are estimates based on preliminary coverage of Zone 4.

The GHRS and HIN scale values for Zone 4 presented in this report are preliminary and subject to revision. No estimates of accuracy or uncertainty have been provided for the GHRS or HIN scale. Since values are dependent on the location of the proposed IRP 2006 alignment, any future shifts in the alignment will require additional GHRS and HIN scale calculations. Sepecifically, alignment shifts will change the source elevation and alignment exposure characteristics of the HIN value for a given hazard. Additional work to constrain hazard characteristics, weather and climate change, and absolute age dating of vegetation and lichen will further constrain GHRS and HIN scale values.

Table 4 lists all hazards sorted by ascending IRP 2006 location while Table 5 lists all hazards by hazard type and ascending HIN value. The HIN weighting scheme for all hazards sorted by ascending HIN and IRP 2006 location is presented in Table 6. HIN scale values for Zone 4 range from 33 to 279.

3.4 Geophysical Surveying

Geophysical surveys were carried out in an effort to determine the depth to bedrock. Electromagnetic methods (e.g., EM-31, Time Domain) were attempted but were not effective in determining depth to bedrock. Seismic reflection profiling provided the best results. These data are presented in a separate addendum. The locations where the seismic profiles were conducted are shown on the surficial geologic maps (Appendix E).

3.5 Helicopter Landing Zones

As described in Section 3.2.2 regarding site access, helicopter transport was essential for the successful completion of this project. The helicopter landing zone database (Appendix D) served several purposes, including documenting the location and ground conditions of the landing zones, updating ADOT&PF-SE on newly identified landing zones used, and providing crews in the field with landing zone positions to decrease travel over extremely rugged terrain.

4.0 RESULTS

The following section provides a general station by station review of surficial geology, including geologic materials and geomorphology, found along the IRP 2006 alignment.

4.1 IRP 2006 Alignment Surficial Geologic Map Descriptions

The descriptions begin at Independence Creek (IRP 2006 1454+30) to the south and end at the Katzehin River (IRP 2006 2626+20) in the north. The descriptions represent a condensed, written summary of the preliminary surficial geologic map (Appendix E). Descriptions for IRP 2006 alignment segments are provided to the nearest 10 ft on centerline where possible (e.g. IRP 2006 1525+60). 100 ft identifiers (e.g., IRP 2006 1525) are used to provide general position information in some cases.

4.1.1 IRP 2006 Segment 1454+30 to 1483+70

Beginning on the north bank of Independence Creek, the IRP 2006 alignment traverses a wide band (up to several hundred ft wide) of low-angle elevated beach deposits. A steep slope of basalt bedrock, with some talus cover, rises several thousand ft above the elevated beach deposits. The base of the slope is more than 100 ft from the proposed centerline.

4.1.2 IRP 2006 Segment 1483+70 to 1501+90

The IRP 2006 alignment crosses mostly alluvial fan and debris flow deposits that originate from a avalanche chute upslope. The IRP 2006 alignment also crosses modern beach deposits with some mega-boulders. The avalanche chute descends and broadens into a wide, low-angle alluvial fan at the IRP 2006 alignment. Along the shoreline, wave action has reworked the alluvial fan, modern beach, and debris flow deposits.

4.1.3 IRP 2006 Segment 1501+90 to 1557+80

The IRP 2006 alignment traverses low-angle to moderate slopes of basalt bedrock and talus with mega-boulders, plus several debris flows. A large rockslide centered above IRP 2006 1524 released approximately five years ago. The slide stopped approximately 150 ft upslope of the IRP 2006 alignment. The slide debris included basalt slabs more than 40 ft across. The IRP 2006 alignment traverses beneath basalt bedrock cliffs at IRP 2006 segment 1525 to 1537.

4.1.4 IRP 2006 Segment 1557+80 to 1574+20

The IRP 2006 alignment crosses a side valley, traversing low-angle to moderate slopes of alluvial fan and some beach deposits, and basalt bedrock. Alluvial fan deposits 5 ft to 15 ft thick and approximately 30 ft thick were observed along with mega-boulders. Several hundred feet upslope of the IRP 2006 alignment, basalt bedrock cliffs are present on the north and south valley walls.

4.1.5 IRP 2006 Segment 1574+20 to 1695+00

The IRP 2006 alignment traverses colluvium, talus, and debris flow deposits beneath basalt bedrock cliffs covered intermittently with talus, mega-talus, and landslide deposits. Numerous mega-boulders appear in some regions. The Met Point sea lion haulout is located at approximately IRP 2006 1606. The IRP 2006 alignment traverses beneath cliffs in the following regions:

- IRP 2006 segment 1603 to 1606
- IRP 2006 segment 1609 to 1611
- IRP 2006 segment 1622 to 1628
- IRP 2006 segment 1650 to 1661
- IRP 2006 segment 1690 to 1692

4.1.6 IRP 2006 Segment 1695+00 to 1725+30

The IRP 2006 alignment continues to traverse talus, debris flows, mega-boulders, and basalt bedrock beneath steep bedrock slopes covered intermittently by talus. The inferred bedrock contact between gneiss bedrock (upslope) and basalt bedrock (downslope) trends obliquely north-northwest down the slope above the IRP 2006 alignment. Basalt bedrock cliffs exist above the IRP 2006 alignment at IRP 2006 segment 1697 to 1703, and IRP 2006 segment 1705 to 1716.

4.1.7 IRP 2006 Segment 1725+30 to 1748+30

Bedrock along centerline changes from basalt to gneiss. The IRP 2006 alignment traverses gneiss, talus, mega-boulders, and debris flow deposits beneath gneiss and metasedimentary bedrock cliffs, with some slopes intermittently overlain by talus. Upslope, an additional north-northwest-trending bedrock contact is inferred between gneiss and metasedimentary bedrock. The IRP 2006 alignment traverses beneath cliffs in the following regions:

- IRP 2006 segment 1725 to 1730
- IRP 2006 segment 1729 to 1739 – Steep to overhanging cliffs are upwards of 350 ft high. The slopes drop off steeply into the water.
- IRP 2006 segment 1745 to 1746

4.1.8 IRP 2006 Segment 1748+30 to 1766+70

The IRP 2006 alignment traverses talus, mega-boulder zones, debris flow deposits, and metasedimentary bedrock beneath steep metasedimentary bedrock slopes intermittently covered by talus. Several steep, narrow gullies descend down the slope with debris flow deposits found in deposition zones across centerline. The IRP 2006 alignment traverses beneath cliffs in the following regions:

- IRP 2006 segment 1748 to 1751
- IRP 2006 segment 1755 to 1758
- IRP 2006 segment 1759 to 1767

4.1.9 IRP 2006 Segment 1766+70 to 1797+20

The IRP 2006 alignment traverses low-angle to moderate slopes of mostly talus, with some debris flow deposits, and metasedimentary bedrock. Talus deposits greater than 10 ft thick and 15-30 ft thick were observed in places. The moderate to steep slopes upslope of the IRP 2006 alignment are composed of talus and colluvium, in addition to metasedimentary bedrock intermittently covered by talus.

4.1.10 IRP 2006 Segment 1797+20 to 1935+00

The IRP 2006 alignment traverses talus and colluvium, glacial outwash, elevated beach, debris flow, and alluvial fan deposits, and metasedimentary bedrock. Upslope of the IRP 2006 alignment, moderate slopes are composed of glacial outwash, and metasedimentary bedrock and talus covering bedrock. The IRP 2006 alignment crosses three side valleys. Several landslide deposits found in the glacial outwash scarp at IRP 2006 segment 1857 to 1863 encroach as close as ~20 ft but do not cross the IRP 2006 alignment.

4.1.11 IRP 2006 Segment 1935+00 to 1950+40

The IRP 2006 alignment traverses moderate slopes of bouldery talus and mega-boulders, and some metasedimentary bedrock, beneath gneiss and metamorphic bedrock cliffs up to ~250 ft high.

4.1.12 IRP 2006 Segment 1950+40 to 1995+00

The IRP 2006 alignment traverses moderate slopes of glacial outwash and talus, crossing the debris flow of a side valley deeply incised into gneiss bedrock. 25 to 30 ft thick thick glacial outwash and talus deposits were observed. Upslope, cliffs composed of gneiss, metasedimentary, and metamorphic bedrock are covered intermittently with talus. Cliffs begin at IRP 2006 1935 and continue northward up to approximately IRP 2006 1953. Cliffs above the IRP 2006 alignment are found beginning at approximately IRP 2006 1993 and continue northward to IRP 2006 1999.

4.1.13 IRP 2006 Segment 1995+00 to 2182+20

The IRP 2006 alignment traverses mostly moderate and some low-angle slopes of talus, mega-boulders and mega-talus colluvium, and beach deposits, along with gneiss, metasedimentary, and metamorphic bedrock. Upslope of the IRP 2006 alignment, metasedimentary, gneiss, and metamorphic bedrock are intermittently overlain by talus. Several steep, narrow gullies descend down the slope with debris flow deposits found in deposition zones across centerline. The IRP 2006 alignment traverses beneath cliffs in the following regions:

- IRP 2006 segment 1993 to 1999
- IRP 2006 segment 2015 to 2019
- IRP 2006 segment 2064 to 2069
- IRP 2006 segment 2074 to 2088
- IRP 2006 segment 2103 to 2108
- IRP 2006 segment 2112 to 2115

- IRP 2006 segment 2124 to 2125
- IRP 2006 segment 2160 to 2174 – Gneiss bedrock cliffs are up to ~250 ft high.
- IRP 2006 segment 2179 to 2182

4.1.14 IRP 2006 Segment 2182+20 to 2225+00

The IRP 2006 alignment traverses mostly low-angle and some moderate slopes of colluvium and talus. Upslope of the IRP 2006 alignment, gneiss bedrock cliffs descend covered intermittently with talus extend northward at IRP 2006 segment 2200 to 2236.

4.1.15 IRP 2006 Segment 2225+00 to 2301+50

The IRP 2006 alignment traverses moderate to steep slopes of talus, mega-talus, colluvium, and landslide deposits, in addition to metasedimentary and gneiss bedrock. The steep slopes above the IRP 2006 alignment are composed of gneiss bedrock intermittently overlain by talus. Several steep, narrow gullies, including Yeldagalga Creek, are incised into gneiss bedrock. Some gullies have debris flow deposits found in deposition zones across centerline. The IRP 2006 alignment traverses beneath cliffs in the following regions:

- IRP 2006 segment 2236 to 2240
- IRP 2006 segment 2250 to 2280 – Cliffs exist above and below the IRP 2006 alignment.
- IRP 2006 segment 2290 to 2292
- IRP 2006 segment 2296 to 2302

4.1.16 IRP 2006 Segment 2301+50 to 2401+70

The IRP 2006 alignment traverses steep slopes of gneiss bedrock, talus, mega-talus, and mega-boulders. Upslope, cliffs of gneiss bedrock are intermittently covered by talus. Maximum cliff heights in some regions reach approximately 400 ft. Two steep gullies with debris flow deposits across centerline were identified. The Gran Point sea lion haulout is located at approximately IRP 2006 2361. The IRP 2006 alignment traverses beneath, and sometimes above cliffs in the following regions:

- IRP 2006 segment 2301 to 2308

- IRP 2006 segment 2321 to 2330 – A structural lineament and possible left-lateral fault is located at bridge site 14E at IRP 2006 2322.

- IRP 2006 segment 2344 to 2360

- IRP 2006 segment 2360 to 2372 – Considerable megatalus is present. Rockfall from the cliff above is embedded in trees on centerline.

- IRP 2006 segment 2372 to 2390 – Cliffs of gneiss slope into Lynn Canal.

- IRP 2006 segment 2390 to 2404

4.1.17 IRP 2006 Segment 2401+70 to 2445+40

The IRP 2006 alignment crosses a side valley, traversing mainly low-angle slopes with glacial outwash, some talus and alluvial fan deposits, and gneiss bedrock. Located on the north side of the creek, four landslide deposits cross the centerline, originating from the steep glacial outwash scarp. The glacial outwash deposits are probably at least 50 ft thick. Upslope, moderate slopes of glacial outwash deposits are inferred up to ~350 ft elevation. Steep gneiss bedrock cliffs crop out on the north and south sides of the valley, with cliffs immediately above the IRP 2006 alignment at IRP 2006 segment 2401+70 to 2405+00.

4.1.18 IRP 2006 Segment 2445+40 to 2571+30

The IRP 2006 alignment traverses steep slopes of talus, mega-talus, and debris flow deposits, along with predominantly gneiss and some metasedimentary and metamorphic bedrock. Talus in some locations is estimated to be 50 ft thick. Slopes above the IRP 2006 alignment have gneiss, metasedimentary, and metamorphic bedrock cliffs, intermittently overlain with talus.

4.1.19 IRP 2006 Segment 2571+30 to 2603+80

The IRP 2006 alignment crosses a side valley, traversing mainly low-angle slopes of glacial outwash, talus, and metasedimentary bedrock. Upslope of the IRP 2006 alignment, low-angle to moderate glacial outwash with gneiss bedrock cliffs crop out. Cliffs above the IRP 2006 alignment are located at IRP 2006 segment 2317 to 2583.

4.1.20 IRP 2006 Segment 2603+80 to 2626+20

The IRP 2006 alignment traverses low-angle and moderate slopes of talus, mega-talus and mega-boulders, and gneiss, metasedimentary, and metamorphic bedrock. Gneiss, metasedimentary, and metamorphic bedrock cliffs above the IRP 2006 alignment occur at IRP 2006 segment 2604 to 2615, and IRP 2006 segment 2620 to 2626.

4.1.21 Up alignment of IRP 2006 2626+20

The IRP 2006 alignment begins to cross river deposits composed primarily of silt and sand, with gravel present, of the Katzehin River delta and intertidal zone. The IRP 2006 alignment trends northwest away from gneiss bedrock cliffs, up to 450 ft high, located on the left bank of the river.

4.2 Geologic Hazards

Numerous hazards were encountered during Phase I of the Zone 4 Geotechnical Investigation and are presented on the Preliminary Geologic Hazard Maps (Appendix F). The most common of these hazards were rockfalls. Over the approximately 22.2 miles of proposed road, there were 52 catalogued rockfall hazard areas, 42 debris flow hazards, 5 hazard rocks, 4 soil raveling hazard areas, 4 translational sliding hazards, 3 landslide hazards, and 2 rockslide hazards. Each hazard was given a Hazard Index Number (HIN), as well as an ‘A’, ‘B’, or ‘C’ GHRS ranking, as described previously. Individual hazards are presented in Appendix G, with photographs and pertinent data for determining the HIN of each hazard.

5.0 PRELIMINARY RECOMMENDATIONS FOR PHASE II INVESTIGATIONS

Based on the work completed in Phase 1 of the geotechnical investigations, preliminary recommendations have been developed for Phase II investigations and are presented here for consideration.

The most significant design issue for the alignment is the overburden materials. The overburden is relatively coarse, and over much of the alignment, is extremely coarse, including mega-talus (clast size greater than 10 ft in the smallest diameter). Cuts in talus pose the greatest potential construction and operational hazards and therefore they require more attention. Based on the observed fragment sizes of the talus, there does not appear to be practical methods of retaining the talus without resorting to structural methods, such as retaining walls. Therefore cut heights in talus must be minimized by either putting the road in prism or removing the talus from above the cut slope. Both approaches will have environmental, right-of-way, and material quantity impacts.

The large talus also presents a significant challenge during investigation and construction as many clasts are too large to be moved with conventional earthmoving equipment, and the clasts create a ground surface that is too irregular to be trafficable. Contraction in these segments will require special measures, such as blasting large boulders to a manageable size and filling voids.

For the most part, the bedrock on the alignment is widely jointed, very strong, and competent. However, it appears that the jointing in the bedrock units is not conducive to 0.1H:1V cuts as depicted in the pre-design documents. A lower cut angle will result in a greater cut height, larger material volume, and a larger overall construction footprint. Because the bedrock surface is difficult to define with the borehole spacing typical of most highway projects, we anticipate that final design will have to depend on observations and investigations made in the field by geologists or engineers during construction as the subsurface conditions are revealed.

Except for investigations at bridge sites, most of the subsurface investigations are oriented to determining depth to bedrock and confirming the character of overburden so that appropriate excavations, retaining walls, and slope stabilization measures can be designed. Preliminary recommendations for the Phase II investigations are outlined below.

5.1 Alignment Optimization Collaboration

ADOT&PF is currently modifying portions of the IRP 2006 alignment used during summer 2006 field investigations. An alignment termed the “A” line was available by October 2006. The Golder geotechnical team should meet with the ADOT&PF design team in early January 2007 to begin to collaborate on optimization of the latest alignment. This initial collaboration should be carried out in a large room with multiple computer screens so the AutoCAD® maps, LIDAR, geologic maps, photos, and other data can be rapidly displayed. The team would go through the entire alignment and make appropriate changes based on all the geologic, hazard, and topographic information. This will be an iterative process and follow-up sessions will likely be necessary. Optimization of the alignment will consider the following:

- Establishing stream crossing locations to take advantage of terrain features.
- Avoiding deep cuts in talus because of the difficulty and expense of cut stabilization.
- Minimizing the potential impacts of geologic hazards and avalanches.
- Assessing terrain for potential major re-alignments.

Many realignments have already been discussed with ADOT&PF during summer and fall 2006, and incorporated into later versions of the alignment. Based on summer 2006 field work and observations, segments of the IRP 2006 alignment that should be considered for realignment are shown below. This list is by no means final but represents impressions from the initial field mapping effort.

IRP 2006 Segment 1727 to 1740

Gneiss and metasedimentary cliffs, steep to overhanging, rise from tidewater to greater than 500 ft elevation. Talus accumulations and debris flows will threaten any cut. This segment needs further evaluation for a possible tunnel or elevated highway closer to tidewater.

IRP 2006 Segment 1855 to 1885

The proposed alignment crosses a major creek and traverses along the base of the glacial outwash scarp which is cut by numerous landslide deposits. Moving the alignment upslope onto the glacial outwash surface would avoid the scallop-shaped landslide deposits and difficulties resulting from cutting into the unconsolidated glacial outwash scarp.

IRP 2006 Segment 1950 to 1995

The proposed alignment crosses a stream and traverses along the base of the glacial outwash scarp displaying numerous incised channels and scalloped topography. Moving the alignment upslope onto the glacial outwash surface would avoid a high cut in the outwash scarp.

IRP 2006 Segment 2250 to 2270

North of Yeldagalga Creek, the proposed alignment traverses steep gneiss bedrock with a maximum cut depth of approximately 150 ft. A more favorable alignment should be considered at a slightly higher elevation.

IRP 2006 Segment 2301 to 2317

The proposed alignment traverses mid-slope across gneiss bedrock cliffs found from tidewater to approximately 350 ft elevation. A cut would likely need to be at least 100 ft deep with a steep drop-off to tidewater on the downslope side. Exfoliated gneiss slabs upslope of the cut may produce rockfall hazards. The alignment design in this area should be revisited, including tunnel evaluation.

IRP 2006 Segment 2321 to 2323

The proposed alignment crosses a deep gneiss gorge interpreted as a structural lineament. The alignment design at this site should be revisited, considering a bridge and change in grade.

IRP 2006 Segment 2360 to 2372

The proposed alignment, opposite the Gran Point sea lion haulout, crosses above a gneiss gorge that descends steeply to tidewater. A bench cut would probably need to be at least 190 ft high. Exfoliated gneiss slabs upslope of the cut may produce rockfall hazards. The alignment design at this site should be revisited.

IRP 2006 Segment 2388 to 2391

The proposed alignment traverses the base of gneiss bedrock cliffs approximately 300 ft high from tidewater. A cut would probably need to be at least 120 ft high. Exfoliated gneiss slabs upslope of the cut may produce rockfall hazards. The alignment at this site should be revisited. A tunnel may be warranted if a higher elevation alignment is not feasible.

IRP 2006 Segment 2415 to 2440

The proposed alignment crosses a stream and to the north, traverses along the base of a glacial outwash scarp which is cut by numerous landslide deposits. Moving the alignment either downslope onto shallower glacial outwash deposits, or significantly upslope, may reduce slope stability problems associated with cutting into the unconsolidated glacial outwash deposits.

IRP 2006 Segment 2540 to 2585

The proposed alignment traverses gneiss bedrock and talus to the north bank of a side valley and stream, with very steep cliffs both above and below the alignment, and a maximum pre-design cut depth of approximately 165 ft. Moving the alignment upslope several hundred ft to a less steep slope of gneiss bedrock with talus over bedrock would result in the alignment avoiding the steep cliffs.

IRP 2006 Range 2623 to 2626

At the northern end of Zone 4, the proposed alignment has an approximately 300-ft-long bench cut before trending northwest across the Katzehin River delta. The cut may not be necessary if the alignment begins to cross the river at IRP 2006 2620+00.

5.2 Preliminary Stability Analyses

Preliminary global stability analyses need to be conducted for prospective walls on talus and mega-talus to determine if the required global factors of safety can be attained. The surficial geology cross-sections (as discussed in Section 5.3.1) in large talus will be used as the basis for the analyses. In addition, some limited provisional analyses and designs for proposed rock cuts should be undertaken, using the previously collected field data, in order to determine optimal slope angles and possible support requirements.

Some limited provisional analyses and designs should also be undertaken for possible tunnel locations. Provisional portal designs in mega-talus and the effects of side slopes and shallow cover should be considered in these provisional analyses.

5.3 Centerline Investigations

5.3.1 Mapping Geologic Cross-Sections

An effort has been made to develop cross-sections of the surficial geology between IRP 2006 1520+00 and 1603+00. The focus of this mapping was to confirm bedrock contacts, describe talus characteristics, measure void widths and depths, and estimate depth to bedrock. It is recommended that this type of work should be extended to cover the entire Zone 4 segment at approximate intervals of 100 ft, although the initial effort should be concentrated on IRP 2006 segment 1500+00 to 1660+00 (Met Point segment). The spacing of these cross-sections can be adjusted to cover specific structures or cuts, as required. The cross-section widths generally span about 600 ft horizontally. Quick sections, based on visual check of the geologic mapping, are recommended in regions of exposed bedrock. More detailed sections, based on taped measurements on brushed lines, should be carried out where upslope and downslope bedrock/talus contacts need to be identified for design purposes, particularly where slope stability could be an issue.

These cross-sections will provide useful and cost effective information in the most expedient manner.

5.3.2 Cuts

Golder has collected rock structure data at 117 locations, but the datasets have not been analyzed. Stereonet analyses of these data should be carried out so that kinematic failure modes can be identified and appropriate cut angles determined. Additional and more detailed rock structure mapping will be necessary and will depend on the location of the final alignment. Drilling at some prospective cuts may be warrranted if the surficial data is deemed inadequate.

The typical investigation standard for the higher cuts (say +80 ft) would be to have at least one core hole that penetrates the slope template in the toe region of the cut. While a single hole is somewhat limiting, the intent is to confirm that a low shear strength layer (fault) is not present near the toe. If the first exploratory hole encounters such a layer, a provision in the investigation should be made to drill a second hole to develop a cross-section. The above recommendation assumes that low angle faulting cannot be precluded on the basis of geologic interpretation.

5.3.3 Embankments

ADOT&PF geotechnical guidelines recommend boreholes on spacings of approximately 200 ft (cuts) and 400 ft (fills), to a minimum depth of 10 ft below proposed grade or refusal. Prior to the development of a pioneer road, these types of investigations are relatively impractical on Zone 4 from a cost standpoint because of the access difficulties and coarseness of the materials. Therefore, testpits are recommended on 400 ft centers from Independence Creek at IRP 2006 1454+30 to IRP 2006 1500+00. These investigations should be combined with material site explorations. Subsurface investigations north of IRP 2006 1500+00 should be limited to specific critical areas once the alignment is defined. Additional investigations can be conducted as deemed appropriate once a pioneer road is in place, or during construction.

5.3.4 Material Sites

Material sites are likely to be established on elevated beach, alluvial fan, and glacial outwash deposits, and debris flow accumulations. Boreholes and testpits are the primary methods for subsurface investigations. Because the unconsolidated materials are very difficult to drill and sample, testpits are recommended where the terrain is accessible to a tracked backhoe/excavator. Boreholes are recommended on all other terrain.

A preliminary list of potential areas for material sites is provided below:

IRP 2006 Segment 1455 to 1484

Elevated beach deposits were found on centerline and on shallow slopes up to several hundred ft right of centerline.

IRP 2006 Segment 1560 to 1570

Heavily-forested, bouldery alluvial fan deposits extend several hundred ft right of centerline.

IRP 2006 Segment 1797 to 1827

Glacial outwash deposits were found on centerline and up to several hundred ft upslope of the alignment. The alignment also traverses talus, elevated beach, and debris flow deposits, and metasedimentary bedrock.

IRP 2006 Segment 1856 to 1923

Glacial outwash deposits were found on centerline and up to several hundred ft upslope of the alignment at a creek. Glacial outwash thicknesses greater than 15 ft and 20 ft were noted. The alignment traverses additional elevated beach and debris flow deposits, and metasedimentary bedrock.

IRP 2006 Segment 1950 to 1985

Glacial outwash and talus deposits were found on centerline and up to several hundred ft upslope of the alignment, south of a stream. Glacial outwash and talus deposits 25-30 ft thick were noted.

IRP 2006 Segment 2404 to 2435

Glacial outwash deposits were found on centerline and up to several hundred ft upslope of the alignment at a glacially-carved side valley and creek. Glacial outwash thicknesses greater than 20 ft and 25 ft were noted. The alignment also locally traverses gneiss bedrock, landslide, and alluvial fan deposits.

IRP 2006 Segment 2435 to 2445

Talus over glacial outwash deposits were found on centerline and up to several hundred ft upslope of the alignment. One debris flow deposit was noted as close as 80 ft upslope of the alignment.

IRP 2006 Segment 2571 to 2604

Glacial outwash and talus deposits were found on centerline and up to several hundred ft upslope of the alignment at a glacially-carved side valley and creek. The alignment traverses additional beach deposits and metasedimentary bedrock. Gneiss bedrock cliffs several hundred ft high crop out south of the creek.

5.3.5 Materials Testing

The preliminary IRP 2006 alignment indicates that segments of the highway will be on the coast and need to be protected from wave attack. Although the bedrock and large talus in the intertidal zone appears to be very durable and would perform well as armor and riprap, there are no laboratory test results to confirm this assumption. Therefore, the basalt, metasedimentary, and gneiss should be bulk sampled and tested for parameters typically required for shore protection. These include but may not be limited to: petrographic analysis (no fatal flaws), freeze-thaw (ASTM D-5312), accelerated expansion by ethylene glycol immersion (CRD-C 148-69), wet-dry (ASTM D-1513), specific gravity/absorption (ASTM 127), LA abrasion (ASTM 131), sulfate soundness (ASTM C88), and degradation (Alaska T-13). Many of these tests take months to conduct due to the number of cycles; therefore, testing should be carried out relatively early on in the project to confirm that the different rock types are suitable. The rock quality is considered to be relatively uniform within a given rock type and the test results will generally confirm their suitability regardless of where the rock is obtained along the alignment.

In addition to the above tests, other testing will be necessary when material sites are investigated, for example to confirm material suitability as structural fill for embankments.

5.4 Foundation Investigations

5.4.1 Bridges and Elevated Structures

Once the location of bridges and elevated structures are determined, diamond drilling with core retrieval should then be undertaken at abutment and pier locations. In some locations where bedrock is exposed on the surface, it may be sufficient to undertake surface mapping rather than drilling. This will, however, depend on a number of factors including anticipated loads and the rock mass structure.

5.4.2 Walls

If the depth to bedrock proves to be critical to the global stability of walls on mega-talus, then subsurface investigations will be needed to determine depth to bedrock in critical sections. If ADOT&PF proceeds with construction of a pioneer road, then these investigations could be done at substantially less cost using a lightweight truck-mounted Odex or equivalent drilling system. Otherwise they will have to be heli-drilled.

5.4.3 Tunnels

Once tunnel locations are identified, detailed geologic mapping will need to be carried out to assess overburden depths and rock structure. Depending on tunnel length and the amount of bedrock that is exposed for detailed mapping, drilling plans will need to be formulated to collect adequate rock mass characterization for design. Drilling of portal locations will likely be a requirement once we better understand the potential locations for these structures.

5.4.4 Snow Sheds

There are a number of avalanche zones intersecting the alignment. Some of these zones may require construction of snow sheds to protect the highway. Once these locations are identified, detailed geologic mapping will need to be carried out to assess overburden depths and rock structure. Depending on snow shed length and the amount of bedrock that is exposed for detailed mapping, drilling plans will need to be formulated to collect adequate site characterization for design. Drilling of portal and intermediate locations will likely be a required.

6.0 LIMITATIONS

This report has been prepared exclusively for the use of ADOT&PF and their representatives for use in design of the proposed Lynn Canal Highway. The work program followed the standard of care expected of professionals undertaking similar work in the State of Alaska under similar conditions. No warranty expressed or implied is made.

7.0 CLOSING

Golder Associates, Inc. appreciates this opportunity to work with you on this project. Please call if you have any questions or comments.

Sincerely,

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8.0 REFERENCES

Brown, 1981, Suggested Methods for Rock Characterization Testing and Monitoring, International Society for Rock Mechanics.

Connor, C. L., and O'Haire, D., 1988, Roadside geology of Alaska: Missoula, Mountain Press Publishing Company, 250 p.

Fogleman, K. A., Lahr, J. C., Stephens, C. D., and Page, R. A., 1993, Earthquake locations determined by the Southern Alaska seismograph network for October 1971 through May 1989: U.S. Geological Survey Open-File Report 93-309, 54 p.

Gehrels, G. E., and Berg, H. C., 1992, Geologic map of southeastern Alaska: U.S. Geological Survey Miscellaneous Investigation Series I-1867, 24 p., 1 sheet, 1:600,000 scale.

Glude, B., Braun, R., Erickson, J., Kanan, R., and Mears, A. I., 2004, Juneau Access Improvements Environmental Impact Statement Appendix J. Snow Avalanche Report: Alaska Department of Transportation and Public Facilities, 339 p.

Haeussler, P. J., and Plafker, G., 2003, Earthquakes in Alaska, version 1.1: U.S. Geological Survey Open-File Report 95-624, 1 map, 1:4,200,000 scale.

Kavaya, M. J., 1999, LIDAR Tutorial: NASA. ONLINE. Available at http://www.ghcc.msfc.nasa.gov/sparcle/sparcle_tutorial.html [Accessed Nov. 13, 2006].

Larsen, C. F., Motyka, R. J., Freymueller, J. T., Echelmeyer, K. A., and Ivins, E. R., 2004, Rapid uplift of southern Alaska caused by recent ice loss: Geophysical Journal International, v. 158, p. 1,118–1,133.

Larsen, C. F., Motyka, R. J., Freymueller, J.T., Echelmeyer, K.A., and Ivins, E.R., 2005, Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat: Earth and Planetary Science Letters, v. 237, p. 548– 560.

Lemke, R. W., and Yehle, L. A., 1972, Reconnaissance engineering geology of the Haines area, Alaska, with emphasis on evaluation of earthquake and other geologic hazards: U.S. Geological Survey Open File Report 72-229, 109 p., 2 sheets, 1:24,000 scale.

MobileMapper™ Office Users Manual, Thales Navigation, Part No. 631514-01B, 141 p. ONLINE. Available at http://professional.magellangps.com [Accessed Nov. 27, 2006].

Motyka, R., 2006, Professor of Geology and Geophysics, University of Alaska Fairbanks, personal communication regarding glacial geology of Lynn Canal, Sept. 5, 2006.

Pierson, L. A., Van Vickle, R., 1993, Rockfall Hazard Rating System Participants Manual, U. S. Department of Transportation, Federal Highway Administration, Publication No. FHWA SA-93-057.

Wesson, R. L., Frankel, A. D., Mueller, C. S., and Harmsen, S. C., 1999a, Probabilistic seismic hazard maps of Alaska: U.S. Geological Survey Geologic Open-File Report 99-36, 43 p.

Wesson, R. L., Frankel, A. D., Mueller, C.S., and Harmsen, S.C., 1999b, Seismic-hazard maps for Alaska and the Aleutian Islands: U.S. Geological Survey Miscellaneous Investigations Series I-2679, 2 sheets, 1:7,500,000 scale.

WRCC, 2006, Western Regional Climate Center, Desert Research Institute, Reno, NV, Western U.S. historical summaries (individual stations) and Climate of Alaska. ONLINE. Available at http://www.wrcc.dri.edu [Accessed Nov. 13, 2006].