Juneau Access Improvements Project
Final Supplemental
Environmental Impact Statement

2017 Update to Appendix J
Snow Avalanche Report

Prepared for:

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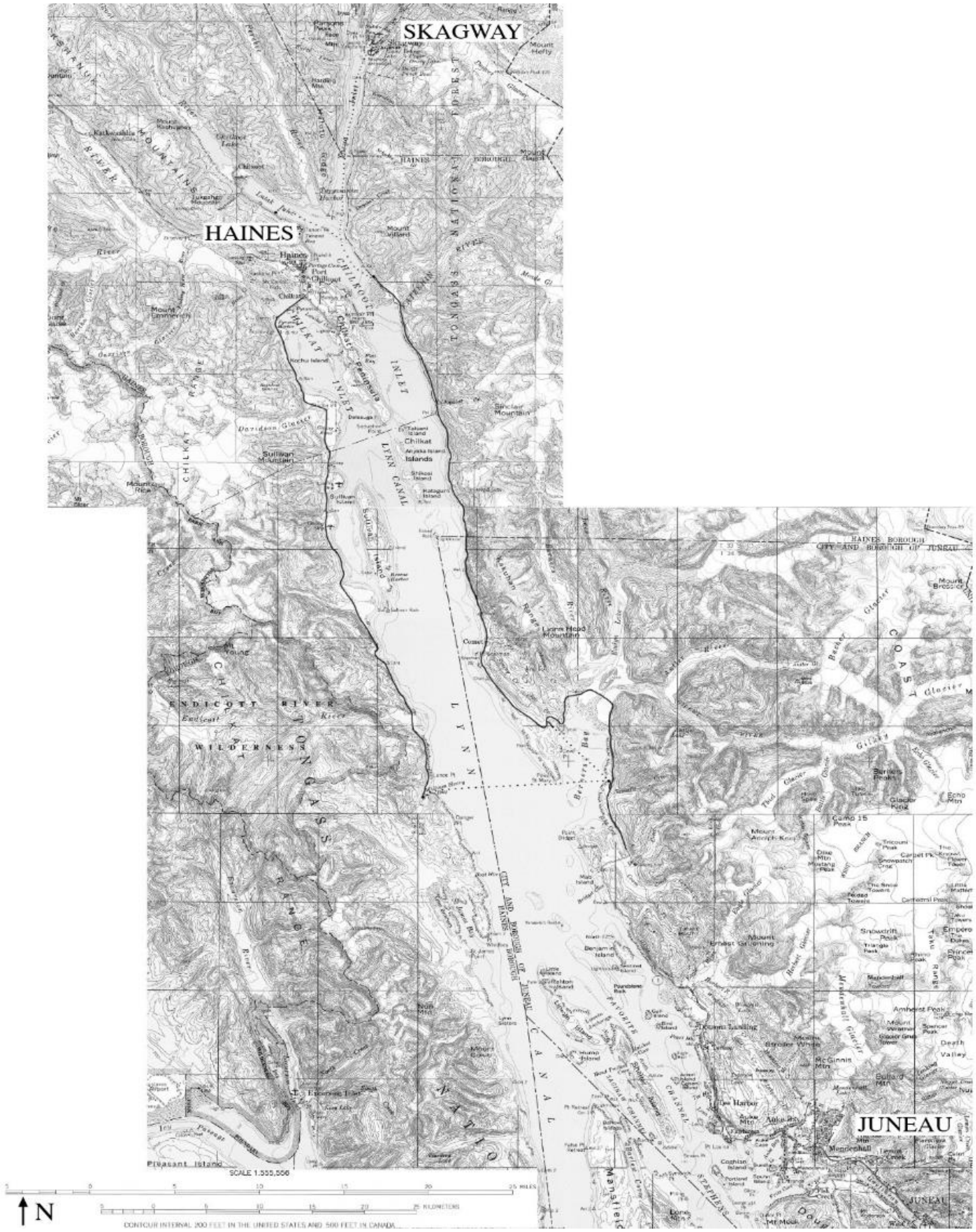


2. Executive Summary

2.1. *Introduction*

One of the major challenges in designing and operating a highway on either of the two proposed routes out of Juneau is the snow avalanche paths along Lynn Canal. The avalanche hazard and mitigation alternatives were evaluated for the proposed West Lynn Canal and East Lynn Canal highway alignments, with the goal of finding the most cost-effective way to reduce avalanche risk to an acceptable level by minimizing the physical hazards and managing the remaining, or residual, risk.

The current East Lynn Canal alignment is affected by 43 avalanche paths, and the West Lynn Canal alignment is affected by 19 paths.

2.2. *2017 Update*

This report updates the 2004 SDEIS Appendix J, Snow Avalanche Technical Report, the 2005 FEIS Addendum to Appendix J, and the 2013 SDEIS Appendix J, *Snow Avalanche Technical Report*. Except for the updates, the information in the earlier documents is still valid. New information in this report includes revised traffic projections, new cost estimates, debris volumes, additional information in response to public comments, and new mitigation options.

2.3. *Avalanche Hazard Index*

Because avalanche paths vary widely in the size, frequency, and consequences of the slides they produce, the Avalanche Hazard Index (AHI) is preferred as a more accurate measure of risk than the total number of paths.

The AHI calculations have been updated from earlier studies to reflect the results of additional geotechnical and environmental work. Mitigation alternatives and cost figures are also updated. The unmitigated AHI figure for the current East Lynn Canal alignment is now 291, and for the West Lynn Canal alignment it is 102.

The unmitigated AHI figures for both alignments fall in the high or very high category, but are within the range for highways operated with good safety records in avalanche terrain.

While it can be useful to compare unmitigated avalanche hazard figures, residual AHI is the most accurate measure of risk. In North America, a residual AHI of 30 to 40 or less, i.e. the moderate range after mitigation measures are applied, is considered acceptable.

Mitigation measures such as adjusting highway alignment, building bridges, using elevated fills, constructing snowsheds, forecasting avalanche cycles, implementing preventive closures, and using explosives could reduce the residual AHI to acceptable levels for all the practical options listed here.

2.4. *Avalanche Mitigation: Hazard Reduction and Risk Management*

Hazard reduction methods are physical changes such as constructing barriers, using snowsheds, or adjusting the alignment of the highway. *Risk management methods* include avalanche forecasting, warnings, highway closures, and explosives delivery, including remote exploders, which are used to release unstable snow during temporary highway closures. Both methods would be used for the East and West Lynn Canal routes.

In addition, shuttle ferries would be used to cross Lynn Canal and serve Taiya Inlet. Those ferries could carry northbound and southbound traffic between Haines, Skagway, and Juneau when the highway is closed. Very few highways in avalanche terrain have alternative transportation so readily available.

The East Lynn Canal route would require three snowsheds. The remaining top three high-AHI paths would have mitigation by bridges or elevated fills. The West Lynn Canal route would not require additional mitigation to meet the AHI target of 30 to 40 or less, but could use elevated fills and bridges to further reduce the AHI.

2.5. *Results*

The avalanche study shows that all the practical options for combined hazard reduction and risk management for both the East and West Lynn Canal routes would achieve the North American standard residual AHI of less than or equal to 30 to 40. The hazard reduction and risk management options selected for both alignments would include elevated fills and bridges that reduce the avalanche hazard, and a standard risk management program requiring avalanche forecasting, explosives delivery, including remote exploders, and preventive closures. The East Lynn Canal alignment would include snowsheds as well.

Figure 1: Comparison of Selected Options

Explosive Delivery Option	Capital Budget	Operating Budget	Average Closure Time/yr (days)	Average Number of Closures/yr	Range of Closure Length (days)	Residual AHI
D E Lynn, DOTPF, Blaster Boxes, plus Helicopter	$11,185,325	$1,458,719	12.1	9.9	0.8-2.2	28.2
H W Lynn, DOTPF, Howitzer On Most Paths; Blaster Boxes on Path WLC009	$6,199,259	$1,257,483	6.4	10.8	0.4-0.9	18.0

3. Findings

The Alaska Department of Transportation and Public Facilities (DOT&PF) is conducting environmental impact studies to examine the feasibility of constructing a highway north from Juneau toward Haines and Skagway, both of which are connected to the North American highway system. Practical travel between Juneau and either Haines or Skagway is currently by ferry, other boats, or air.

Lynn Canal is a fjord stretching between Juneau and Haines and Skagway. Haines is on the west side of northern Lynn Canal, at the mouth of Chilkat Inlet, and Skagway is situated on the east side near the northern end of Lynn Canal, up Taiya Inlet north and east of Haines.

As part of this Final SEIS update process, this report updates the 2004 SDEIS Appendix J, Snow Avalanche Technical Report, the 2005 FEIS Addendum to Appendix J, and the 2013 SDEIS Appendix J, Snow Avalanche Technical Report. Except for the updates, the information in the earlier documents is still valid. New information in this report includes revised traffic projections, new costs, debris volumes, additional information in response to public comments, and new mitigation options.

Two alternative highway alignments are being considered for avalanche analysis. The proposed East Lynn Canal alignment would begin at the northern end of Juneau's current road system on the south side of Berners Bay, and would extend about 47 miles (76 km) along the east side of Lynn Canal to a ferry terminal at the north edge of the Katzehin River delta, with shuttle ferries connecting to Haines and Skagway.

The other alternative is the West Lynn Canal alignment from William Henry Bay north, extending about 36 miles (58 km) to connect with the Mud Bay Road in Haines. The West Lynn Canal alternative would require a ferry crossing of Lynn Canal between Berners Bay and the southern end of the West Lynn Canal alignment at William Henry Bay, and a ferry from Haines to Skagway.

3.1. *Avalanche Hazard*

One of the major challenges to designing and operating either proposed highway route is the snow avalanche paths along Lynn Canal. The proposed alignment along the east side of Lynn Canal is affected by 43 avalanche paths, including subpaths. The proposed alignment along the west side of Lynn Canal is affected by 19 avalanche paths, including subpaths.

The purpose of this document is to assess the extent and nature of the avalanche hazard, and to develop a range of programs for physically reducing that hazard where possible, and managing the residual risk to acceptable levels.

For purposes of assessing the avalanche hazard of the Lynn Canal routes and comparing them to other highways, the avalanche hazard index (AHI) is used. The AHI is an index representing the probability of encounters between avalanches and vehicles on a highway and the likely damage.

The AHI calculation was based on figures revised in 2013 for projected winter average daily traffic of 495 vehicles per day on the East Lynn Canal route and 405 vehicles per day on the West Lynn Canal route.

The following list shows the classification of unmitigated AHI ranges. In North America, a residual AHI of 30 to 40 or less is accepted as an adequate level of mitigation.

Unmitigated AHI	Classification
<1	very low
1 - 10	low
10 - 40	moderate
40 - 100	high
>100	very high

Figure 2: Avalanche Hazard Index (AHI) Comparison

Highway	Unmitigated AHI	Daily Observations & Forecasts	Forecasting, Closure, & Explosives	Structural Mitigation	Special Explosives Methods
Little Cottonwood, UT	**1045**	x	x		x
Rogers Pass, BC	**1004**	x	x	x	x
Red Mtn. Pass, CO	**335**	x	x	x	
* Seward Highway, AK (Anchorage-Seward, old alignment)	**331**	x	x	x	
East Lynn, AK	**288**	x	x	x	
* Seward Highway, AK (Anchorage-Girdwood, old alignment)	**188**	x	x	x	
Coal Bank/Molas, CO	**108**	x	x		
West Lynn, AK	**101**	x	x	x	
Berthoud Pass, CO	**93**	x	x		
Coquihalla, BC	**90**	x	x	x	x
Loveland Pass, CO	**80**	x	x		
Wolf Creek Pass, CO	**54**	x	x	x	
Silverton-Gladstone, CO	**49**	x	x		
Teton Pass, WY	**47**	x	x		x
Lizard Head Pass, CO	**39**	x	x		
I-70 Tunnel Approaches, CO	**27**	x	x	x	
Thane Road, AK	**21**		x	x	

* Historical data for AHI calculation is only available for the pre–1998 Seward Highway alignment.

3.2. *Unmitigated AHI Comparison*

The unmitigated AHI figures for the current Lynn Canal alternatives are 291 for East Lynn Canal and 102 for West Lynn Canal. These are considered high or very high, but are well within the range for highways that have achieved good operational risk management records through appropriate mitigation, as listed in Figure 1.

3.3. *Avalanche Mitigation*

In designing an avalanche mitigation program, managers must combine two basic methods:

1. Hazard Reduction

   Hazard refers to the physical characteristics of the avalanche exposure. *Hazard reduction* encompasses any actions that reduce the hazard from avalanches, such as adjusting the highway alignment to avoid avalanche paths, or constructing physical barriers or snowsheds.

2. Risk Management

   Risk refers to the consequences of exposure to avalanches. *Risk management* practices reduce the avalanche risk to travelers through operational methods such as avalanche forecasting, warnings, highway closures, and explosives work to release unstable snow when the highway is closed. *Residual risk* is the risk that remains after mitigation through both hazard reduction and risk management.

A maximum hazard reduction program requires high initial investment but can minimize highway closures. A program based entirely on operational risk management has low initial costs but higher operating costs and highway closure times.

For example, maximum hazard reduction on the Coquihalla Highway in British Columbia has virtually eliminated the operational avalanche risk management program there. A maximum hazard reduction approach would be much more difficult in the terrain along Lynn Canal, but structural avalanche hazard reduction investments would reduce highway closure times and are likely to reduce operational risk management costs as well.

3.4. *Lynn Canal Mitigation - Options*

The mitigation options evaluated here for the Lynn Canal routes combine both hazard reduction and risk management approaches to provide a range of solutions that balance cost and closure time while managing residual risk to the accepted standard.

The East and West Lynn Canal highway alignments have been adjusted to reduce the avalanche hazard. The routes avoid avalanche paths wherever possible, and cross unavoidable paths at lower hazard locations. Since the 2004 and 2005 reports, other geotechnical issues have required some realignment into higher avalanche hazard locations, requiring increased mitigation measures.

Bridges span above the flow level on some slide paths. Elevated fills that provide a catchment reduce the hazard at several locations. Snowsheds that carry slides over the highway while allowing traffic to flow unimpeded through them are used on three avalanche paths on the East Lynn Canal route.

Avalanche detection and warning systems, were rejected because their performance was judged as unreliable. As warning systems improve, they will still be constrained by the performance requirements of sending a warning in time for traffic to stop, and to not either miss slides or send false alarms. As such systems improve, they could easily be added to the systems already in place. Doppler radar and seismic sensors would already be installed as part of the remote exploder systems, where they detect avalanche release when the system is operated. Those sensors can also be used to detect natural releases and give warning of the onset of an avalanche cycle.

The remaining avalanche hazard is managed through an industry-standard program of risk management using a combination of avalanche forecasting, explosives, and preventive highway closures. Explosives and remote exploders are used to trigger avalanches when the road is closed, rather than waiting for them to release naturally when the public is traveling. The result is an increased frequency of generally smaller avalanches during closures, and a decreased frequency of larger slides when the road is open. Frequency of avalanches when the road is closed affects only snow removal.

The goal is to reduce the residual avalanche risk to levels commonly accepted on highways throughout North America, equivalent to a residual AHI value of 30 to 40 or less.

Both the East and West Lynn Canal routes have a unique safety factor in that both would employ shuttle ferries to cross Lynn Canal and Taiya Inlet. The shuttle ferries could be used to carry north-south traffic when the highway is closed. Few avalanche-prone highways have alternative transportation so readily available. Avalanche closures occur during the lowest traffic season of the year, and even when the highway must be closed, travel would be possible more frequently than it is under the current ferry winter schedule.

The combined hazard reduction and risk management options evaluated here differ primarily in their methods of explosives delivery. *All these mitigation options achieve the target residual AHI of 30 to 40 or less, but the methods have different initial (capital) costs, ongoing (operating) costs, and anticipated highway closure times.*

3.5. *Explosive Delivery*

The following explosive delivery methods were used to develop the mitigation options:

Helicopter placement: Explosive charges are dropped by hand from a low-hovering helicopter with the door removed. The helicopter time is expensive, but the explosive charges are relatively cheap, and helicopter delivery has proven to be an effective, accurate, and flexible method for covering a large area in a short time. The major disadvantage in the stormy climate of northern Southeast Alaska is that helicopter delivery requires calm ridgetop-level winds and good visibility. The lack of such flying weather can result in substantial delays and missed opportunities.

Daisy Bell: The Daisy Bell, a new technology developed since the 2004 and 2005 reports, is a hydrogen-oxygen gas exploder that is slung on a cable under a helicopter. The Daisy Bell is expensive to purchase and requires a helicopter pilot with highly developed sling-load skills; but it reduces the cost per shot, preparation time, and explosive risk to the operating crew. It is subject to the same weather limitations as helicopter explosive delivery, though its rapid mobilization allows use of shorter weather breaks.

105mm howitzer: The 105mm howitzer is the artillery weapon of choice for avalanche work. Its accurate working range is over three miles, and it can be blind-fired in conditions of poor visibility once coordinates are developed for each position. Howitzers can be used in storms with light to moderate winds, but their accuracy suffers when winds are strong. Howitzers can be trailered to sites along the highway, on spur roads to optimal firing locations, or stored in secure enclosures for firing from remote locations.

Blaster boxes: Blaster boxes are secure steel cabinets mounted on a mast in an avalanche-protected location from which they can fire pre-targeted mortar rounds into avalanche starting zones by remote control. Doppler radar and seismic detectors help to verify avalanche release when the system is operated, and can also provide early warnings of natural avalanche cycles. Blaster boxes are one of several potentially-usable explosive delivery methods using a fixed, remotely-operated installation. They are evaluated here as a representative sample of the fixed installation methods currently available. Other exploder systems use hydrogen or propane-oxygen gas explosions, or conventional high explosives. Any of these remote exploder systems may be somewhat limited by such coastal climate factors as rime ice buildup or high winds. Blaster boxes require helicopter flights to nearby landing zones to deliver the rounds, can fire only ten shots before reloading, require time to set up and maintain, and have a high initial installed cost, but they allow explosive delivery by one operator, even under stormy conditions or at night.

This report analyzes combinations of the above methods to develop explosive delivery options.

The residual risk figures for all these mitigation options achieve the target residual AHI of 30 to 40 or less. All mitigation options include some elevated fills and bridges that reduce the hazard, and all are based on a standard risk management program of avalanche forecasting, explosives delivery, and preventive closures.

All East Lynn Canal options require construction of snowsheds on Paths ELC019, 020, and 021, elevated fills on Paths ELC002 and 014, and a protective berm for the ferry approach road at Path ELC035. The West Lynn Canal route does not require structural mitigation to reach the target AHI but the options considered here use elevated fills on Paths WLC006A and B; 009 A, B, and C; and 010 A, B, and C to further lower the residual risk and closure times.

The snowshed and elevated fill costs are considered part of the highway construction and are budgeted separately from those for the avalanche program itself. The discussion here concerns only the direct avalanche program costs.

3.6. *Permits for Avalanche Program*

U.S. Forest Service and any other land use permits for highway alternatives must include provisions for the avalanche program, including access, explosive use, any installations in the avalanche paths, and permits for the weather station sites.

As with any avalanche programs using explosives, permits from the federal Bureau of Alcohol, Tobacco, and Firearms (ATF) are necessary; including special permits allowing storage of explosives in blaster box magazines.

Howitzers, if used for explosive delivery, require lease agreement from the US Army, and their crews must attend Army gunners’ school.

There is no requirement for ATF permits for gas-based alternatives such as MND's GazEx or the O'Bellx, which use propane and hydrogen, respectively, combined with oxygen to produce their explosions.

3.7. *East Lynn Canal Mitigation Options*

3.7.1. Option A, East Lynn Canal, Helicopter Delivery Only

As noted above, helicopter explosive placement is simple, flexible, and economical, but is limited by flying weather that can result in delays and missed opportunities. This option has the lowest East Lynn Canal avalanche program capital cost, with operating costs somewhat higher than the Daisy Bell option, and the most total highway closure time of the various options.

3.7.2. Option B, East Lynn Canal, Daisy Bell Gas Exploder Delivery

This option uses the Daisy Bell hydrogen-oxygen gas exploder slung under a helicopter. Because the explosion has less energy than large explosive charges, conventional explosives would still be used for deep or resistant weak layers.

The exploder has higher initial cost, but lower operating cost than conventional explosives. Setup for the exploder requires less staff time, but closure time does not change because explosives makeup is done before dawn on mission days.

3.7.3. Option C, East Lynn Canal, Howitzer Delivery Supplemented By Blaster Box and Helicopter Delivery

This option uses howitzers in secure enclosures on Eldred Rock, Anyaka Island, and near the end of the Chilkat Peninsula to target the major Eldred Rock and North and South Yeldagalga path groups. Crews would helicopter to the howitzer locations. Storms would limit operations, but flying conditions at sea level are generally more favorable than at starting zone elevations. Paths LC040 A through D would be hit by a howitzer fired from a pad at Tanani Point on the Lutak Road just north of Haines. Major paths LC002, LC049, LC050, and LC051 would have blaster boxes. The remaining paths run infrequently and could be managed with occasional helicopter missions.

This option allows explosive delivery to the major paths under most storm conditions, reducing closure times, but it was dropped early in the evaluation due to very high capital costs, high operating costs, and long shot distances.

Permits for the howitzer sites would be needed from the U.S. Coast Guard for Eldred Rock and from the Alaska Department of Natural Resources for the other sites, which are located in state parks. Howitzers are obtained under lease agreement from the US Army, and crews must attend gunners' school.

3.7.4. Option D, East Lynn Canal, Blaster Box Delivery Supplemented by Helicopter Delivery

This option uses blaster boxes or other remote exploders on all the paths with a mitigated AHI greater than 1.75 that do not have snowsheds, so the highway could be kept open in most storm conditions, and uses helicopter explosive delivery for the paths that require less frequent explosive work. The initial cost of purchasing and installing the blaster boxes is high, giving this option the highest capital costs, also, servicing them and loading their charges requires substantial helicopter time, giving it the highest operating costs as well; but this option, in combination with three snowsheds, has the lowest highway closure times of the East Lynn Canal options, at 53 percent less than Option A.

3.7.5. Option E, East Lynn Canal, Blaster Box Delivery to Highest-Hazard Paths, Supplemented by Helicopter Delivery

This options uses blaster boxes on the paths with a mitigated AHI greater than 4.0, maximizing the AHI reduction with less blaster box investment than under Option D. A number of paths would still require helicopter explosive delivery, so highway closures are not reduced as much as under other options. Avalanche program capital costs are moderately high, avalanche program operating costs are the second highest, and closures are reduced substantially, but not as much as by option D.

3.8. *West Lynn Canal Mitigation Options*

3.8.1. Option F, West Lynn Canal, Howitzer Delivery Only

This option has been dropped from further consideration in favor of Option H, because the shots on Path WLC 009 are both long and at an oblique angle. Option H substitutes blaster boxes or other remote exploders for howitzer use for Path WLC 009.

In this option, a 105 mm howitzer would have hit all the paths on the West Lynn route from a total of five firing locations. One howitzer would be towed to the firing locations. There would be one highway-side pad on the Chilkat River crossing, and four pads on river deltas.

3.8.2. Option G, West Lynn Canal, Blaster Box Delivery, Supplemented by Howitzer Delivery

This option uses blaster boxes on the major South Sullivan River, Sullivan, Rainbow, and Pyramid paths, and uses a howitzer for the infrequently running paths. This option has low closure time but has high initial capital cost and high helicopter costs for reloading the blaster boxes. Howitzers are obtained under lease agreement from the US Army, and crews must attend gunners’ school.

3.8.3. Option H, West Lynn Canal, Howitzer On Most Paths; Blaster Boxes on Path WLC009

A 105 mm howitzer could hit all the paths on the West Lynn route except WLC 009 from a total of five firing locations. One howitzer would be towed to the firing locations. There would be one highway-side pad on the Chilkat River crossing, and four pads on river deltas.

The howitzer operation is simple, reliable, and inexpensive. Firing locations could be reached by highway in most weather conditions, and blind firing is possible, though high winds would sometimes limit operations.

Blaster boxes or other remote exploders would be used instead of the long and oblique howitzer shots that would otherwise be required on Path WLC 009. These systems raise the capital costs, but operating costs are mid-range, and all the West Lynn options have lower closure times and lower residual AHIs than the East Lynn options. Howitzers are obtained under lease agreement from the US Army, and crews must attend gunners' school and reach the required levels of certification and experience to operate them.

3.9. Comparison of Mitigation Options

The mitigation options are compared in terms of cost, total closure days (total hours divided by 24), and residual avalanche hazard index (AHI) figures (see Appendices 10-12) in Figure 3. All options include elevated fills and bridges, and all are based on a standard risk management program of avalanche forecasting, explosives delivery, and highway closures. The capital budgets cover equipment and supplies to start up the avalanche program. They do not include the construction of snowsheds, elevated fills, or protective berms, all of which are accounted for separately as part of the highway construction costs. The operating budget is the annual costs, including replacement costs for capital items.

Figure 3: Option Comparison - Costs, Closure Times, and Residual AHI

Explosive Delivery Option	Capital Budget	Operating Budget	Average Closure Time/yr (days)	Average Number of Closures/yr	Range of Closure Length (days)	Residual AHI
A E Lynn, DOTPF, Helicopter Only,	$5,380,306	$1,178,071	25.9	12.4	0.8-8.0	28.2
B E Lynn, DOTPF, Daisy Bell only	$5,530,306	$1,151,317	22.4	12.4	0.8-8.0	28.2
C E Lynn, DOTPF, Howitzer, plus Blaster Boxes & Helicopter *	$27,751,259	$1,418,160	15.8	11.6	0.6-4.1	28.2
D E Lynn, DOTPF, Blaster Boxes, plus Helicopter	**$11,185,325**	**$1,458,719**	**12.1**	**9.9**	**0.8-2.2**	**28.2**
E E Lynn , DOTPF, Limited Blaster Boxes, plus Helicopter	$9,251,045	$1,370,385	22.4	12.4	0.8-6.1	28.2
F W Lynn, DOTPF, Howitzer Only *	$4,028,381	$1,245,539	6.4	10.8	0.4-0.9	18.0
G W Lynn, DOTPF, Howitzer plus Blaster Boxes	$10,289,903	$1,124,881	5.5	8.4	0.4-1.0	18.0
H W Lynn, DOTPF, Howitzer On Most Paths; Blaster Boxes on Path WLC009	**$6,199,259**	**$1,257,483**	**6.4**	**10.8**	**0.4-0.9**	**18.0**

* Starred options proved impractical from a cost or operational standpoint and were dropped from further consideration. Selected options are in bold.

4. Avalanche Hazard

4.1. *Avalanche Event Variability*

As is customary in a study of this nature, budgets, operational decisions, and expected events are presented as averages and likely ranges. This is a useful convention, and over the long term, averages prove accurate. Avalanche events, however, are by nature given to extremes. Average winters or average cycles rarely occur. DOT&PF budgets already accommodate this variability by means of supplemental budget requests in heavy-snow years.

Alaska avalanche specialist Doug Fesler notes that it is common for heavy snow winters to have about two-and-a-half times as much avalanche activity as quieter winters. In the timeframe of the short-term variability of a ten-year cycle, this is an accurate approximation.

In the timeframe of the 30-year, 100-year, and 300-year events, there will be about 10 to 100 times as much avalanche activity in the big years as in quieter winters, and the size of the avalanches will show a similar range of variability. Operational planning for these rare but large events must maintain risk management standards as the uncompromised first priority.

Other years may have far less than average activity. Budgetary planning should always consider the more severe winters; under-budgeting could result in increases in closure time and risk to workers and to the traveling public.

There is a learning curve in the early years of any avalanche program. Lower efficiency should be anticipated in the first three years, as the program is developed.

Lynn Canal is a dynamic, high-energy environment, subject to constant change. Over the fifteen years of avalanche studies, one new avalanche path was created by landslide activity, and others were substantially expanded. Changes will continue to occur. Avalanches may entrain wet or unstable ground material, and earth movements may influence avalanche activity. The analysis in this report is for the avalanche paths as they are in 2013.

Avalanche paths on highways worldwide are dynamic, and their risk is mitigated to acceptable levels. There is nothing about Lynn Canal that gives reason to expect changes that could not be mitigated acceptably. The programs outlined here have the flexibility to accommodate change, and managers should be prepared to accommodate change as well.

4.2. *Avalanche Hazard Index (AHI) Overview*

The avalanche hazard index (AHI) is a dimensionless numerical expression representing the probability of encounters between avalanches and vehicles on a highway, and the resulting damage. It was developed in 1974 in Canada (Avalanche Task Force, 1974), and published in its current form by Peter Schaerer in 1989.The method takes into account (1) traffic volume, and (2) avalanche size, destructive effect and frequency, and calculates an index (AHI) for each path. This method has been applied widely in the United States and Canada and is useful for comparing the relative severity of avalanche risk at and between various paths.

The application of this method is most reliable when a long, detailed history of avalanche activity is available. In many cases, especially where a new highway such as the Juneau Access is planned, the available historical record is limited. For this study, six winters of aerial observations were supplemented by (1) terrain evaluation, (2) climate, weather and snowpack conditions, and (3) effects of avalanches on forests. Avalanche engineers Mears and Wilbur estimate that this level of available data yields results accurate to the nearest half order-of-magnitude (about a factor of 3).

AHIs were calculated for the proposed East and West Lynn Canal highway alignments, and for the old alignment of the Seward Highway (historical data is not yet available for the new highway) to provide an Alaskan comparison. The other highway AHIs cited for comparison are from other studies.

Following is a conceptual explanation of how AHI is calculated. The formulas and mathematical details of AHI calculations for this study are explained and illustrated in the Technical Appendices at the end of this report.

The chance of a moving vehicle being hit at any given avalanche path, or multiple paths, can be estimated based on the average size and frequency of an avalanche on a given path; the average daily traffic count (ADT) in vehicles per day; the typical vehicle size, and typical driving speeds. For the DOT&PF-estimated winter ADT of 495 for the East Lynn Canal highway route and 405 for the West Lynn Canal route in the year 2038, the encounter probability between a moving vehicle and an avalanche is actually quite low.

The more complicated part develops when a fallen avalanche blocks the highway, bringing traffic flow to a halt. The encounter probability between vehicle and avalanche then increases.

First, in winter driving conditions, a vehicle is more likely to run into the fallen avalanche debris. Among avalanche workers, this is known as Bachman's Law: cars hit avalanches more often than avalanches hit cars.

Second, the stalled vehicle plus those stacking up behind it are more susceptible to another avalanche on the same path or adjacent paths. This is where a major part of the encounter probability and damage risk lies. Calculating this factor involves estimating vehicle spacing response time, and chance of additional avalanches.

The potential damage is taken into account by weighting the calculation by probable avalanche size. Small avalanches (light snow crossing the highway up to one meter deep) may move a light vehicle but not inflict serious damage or injury, provided there is a guardrail or wide shoulder. Such an avalanche gets a numerical weighting of 3. A bigger, faster avalanche that can exceed 1-meter depth and push or seriously damage a vehicle and inflict injury or death to occupants is weighted at 10. A more severe type, a plunging avalanche hitting the highway at high speed or tumbling vehicles off the highway with even greater damage potential, is weighted at 12.

Where a long record of avalanche occurrence exists, for instance with paths intersecting a long-established highway, the occurrence frequency (or its inverse, the return period) for different avalanche sizes is readily established. For the Lynn Canal routes, limited occurrence data are available from six years of observations, which have been weighted to be consistent with long-term climate trends.

Interpretation of avalanche path characteristics such as degree and extent of vegetation damage also plays a role. In northern Southeast Alaska, for example, the limit of the last 30-year avalanche cycle is clearly visible as a line delineating trees of different ages.

These extrapolations are incorporated in the AHI calculations. They also come into play for calculating typical volumes of snow deposited on the proposed highway and consequent volumes of avalanche debris that must be removed in order to re-open the highway.

In the avalanche atlas section of this report some paths list an AHI of zero or near-zero. Any paths that might possibly affect an alignment were included in the identification, mapping, and numbering. Paths avoided by the current proposed alignments are retained in the mapping and numbering system as reminders of their presence during the design phase of the project.

Several methods for factoring in such additional socioeconomic factors as the shape, size, and value of vehicles and their contents have been developed. These additions can be useful in assigning resources within an operational program; but this study is using the AHI calculation for comparison with other highways, but it has only been used for a few transportation corridors. The basic AHI calculation method has the most highways available for comparison, and the operational records of existing highways in the same AHI range provide the easiest and most accurate basis for estimation of likely risks and societal costs.

There is not an accepted method for calculating absolute risk of avalanche deaths on transportation corridors. The encounter probability term as used for the AHI is an oversimplified calculation that yields results inconsistent with experience when it is used to try to calculate likely death rates. An international committee working on the problem has yet to agree on a suitable calculation method, and the established standard for evaluating risk is still comparison of the risk management records of highways with similar AHI numbers.

4.3. *AHI Changes from Earlier Avalanche Studies*

The AHI values for the East Lynn Canal route differ from those in the 1995 study of the route (Glude and Mears, Snow Avalanche Technical Report, Environmental Impact Statement Considerations, Juneau Access route EIS, 1995) and from the 2004 and 2005 studies (Glude and Mears, Appendix J Snow Avalanche Report, Juneau Access Improvements Supplemental Draft Environmental Impact Statement) due to several changes:

a. Geotechnical and environmental studies resulted in the 2013 alignment on the East Lynn Canal route. Geotechnical studies since the 2004 and 2005 avalanche reports recommended moving the alignment upslope in some paths to reach suitable ground conditions. Since avalanche frequency increases markedly with elevation, these alignment changes require use of snowsheds on three paths to reach acceptable AHI levels.

b. The Winter Average Daily Traffic (WADT) forecasts for both routes have been updated to 495 for the East Lynn Canal route and 405 for the West Lynn Canal route, as compared with 700 and 500 on the 2004 and 2005 studies.

c. New structural and operational mitigation options, including snowsheds, elevated fills, bridges, and advanced explosive delivery methods, have been developed to bring the new AHI values to acceptable levels.

d. The acceptable AHI level has evolved from the earlier North American target AHI of 30 or less to 30 to 40 or less because studies for the suburban, very high-traffic Utah State Highway 205 (Little Cottonwood Canyon SR-210 Transportation Study) considered an AHI of 40 as adequate.

As mentioned in the summary at the beginning of this report, the unmitigated AHIs for both the East and West Lynn Canal alternatives (288 and 101, respectively) are in the “very high hazard” or “high hazard” category. According to Schaerer (1989), Mears (1993), and UDOT (2006), a highway with an AHI over 40 should have a full program of mitigation through hazard reduction and risk management, as discussed in the mitigation section of this report, to reach the target residual AHI of 30 to 40 or less.

4.4. *Avalanche Debris Deposited on the Highway*

Avalanche debris must be cleared from a highway before reopening. Debris may consist of clean snow but often also contains entrained vegetation, rocks, and soil. Avalanche debris is compressed to a density that is typically two to three times the snow density in the upper portions of the avalanche path. Transportation departments are usually able to calculate a per-unit cost estimate for snow removal; avalanche debris removal, because it is deeper, stronger, and denser, is an additional cost. The budget calculations in this report use avalanche debris removal costs based on DOT&PF records.

An average annual volume of avalanche debris deposited on the proposed highway alignment was estimated from the AHI calculations using the following procedure:

1. The annual frequency and width (length on highway) of light, deep, and plunging avalanches were calculated.

2. An average highway width of 45 feet (13.7m) was assumed for two driving lanes and shoulders that would need to be cleared of debris. Average highway width was multiplied by avalanche width to determine the highway area covered.

3. An average debris depth of four feet (1.2m) was assumed based on author Arthur I Mears' experience, understanding that the depth will usually be greater on the side of the highway closest to the avalanche and less on the downhill side; the four foot (1.2m) depth is an average of the more frequent light-snow avalanches (in the one to four foot (0.3 to 1.2m) depth range), and the less frequent deep snow avalanches.

Mitigation measures may cause debris volumes listed below in Table 3 to depart from this estimate. The volumes listed are spreadsheet output and are not rounded. Their level of precision is to the nearest thousand. Preferred East and West Lynn options are in bold.

Alignment Alternative	Average Annual Debris yd^3	Average Annual Debris m^3
East Lynn no Snowsheds	62957	48134
East Lynn with Snowsheds	**39905**	**30510**
West Lynn	**34142**	**26103**

5. Regional Snowfall

Snowfall is not calculated into avalanche hazard evaluation or used to develop mitigation options. Avalanche studies are based on hard data from actual avalanche occurrences, rather than indirect calculation from snowfall figures.

Snowfall for Alaska projects must always be estimated from the records that are available in the region. These observations are usually incomplete, and taken over a relatively short period of record, so snowfall figures are rough estimates only.

Following are average seasonal snowfall figures from the climate database at the Juneau National Weather Service Forecast Office, rounded to the nearest inch. All stations except Pleasant Camp are at sea level. These figures are for the snow season period of October 1 - April 30. The period of record varies from location to location, and includes both El Niño (a cyclical warming of sea temperature) and La Niña (a cooling sea temperature cycle) conditions. In the 2014 Draft SEIS, the weather figures were not updated from the original 2005 studies. These figures are updated in the Final SEIS with what is currently available online and from the Juneau office of the National Weather Service, including their periods of record,

Juneau Airport (1981 to 2010)	87" (2.2 m)
Lena Point (1983 to 2015)	80" (2.0 m)
Tee-Harbor area (station no longer exists)	145" (3.7 m)
Haines downtown (2000-2015)	165" (4.2 m)
Haines Airport (1972-2013; no longer records snowfall)	133" (3.4 m)
Haines Highway, Pleasant Camp (2001-2015)	236" (6.0 m)
Skagway Airport (1965 to 2010; no longer records snowfall)	49" (1.2 m)
Skagway (harbor; no longer records snowfall)	37" (0.9 m)
Skagway Power (downtown; 2001-2015)	52” (1.3 m)

Retired National Weather Service meteorologist Robert Kanan’s best estimate of Lynn Canal average seasonal snowfall at sea level, away from the base of the mountains, is about 140" (3.6m) in the area from just north of Lena Point north to a line approximately from the Endicott River to Berners Bay. He estimates snowfall north of the Endicott River to Berners Bay line to Haines at about 100" (2.5 m). This distribution is mostly due to longer duration snowfall along, and within a few miles north of, the cold air mass of the Arctic front when it becomes stationary across Lynn Canal.

There is a roughly 3x magnitude increase with elevation in the summer precipitation from downtown Juneau to the backside of Mount Juneau at about 2500-2800 feet (760-855 m), according to mid-1960s Bureau of Land Management data studied by Robert Kanan. Thane Road avalanche studies done for DOT&PF by Fesler, Mears, and Fredston in 1990 support the 3x sea level versus mountain precipitation estimation multiplier. They found that snow depths recorded by the Soil Conservation Service at 1650’ (500m) elevation at Cropley Lake near Eaglecrest ski area were between 2.5 and 3.4 times those at 500’ (150m) elevation in the same Fish Creek drainage on Douglas Island. Precipitation reported in circa-1917 Gastineau Mining Co. records for Sheep Creek, on the Juneau-area mainland at 690 feet (210m), and at Perseverance Mine, at

1180 feet (360m) in the Gold Creek valley behind downtown Juneau were roughly 2.5 times greater than those recorded in Juneau for the same period.

This precipitation difference between sea level and higher elevation of about 300 percent, especially with steep terrain, is thought by Kanan to hold consistent in similar circumstances. If two locations are reasonably near each other, and exposed to similar wind flow, the primary cause of differences in precipitation with respect to elevation is orographic lifting, which causes increased precipitation as moist air rises and cools when it moves over the mountains.

Snowfall estimates along Lynn Canal are based on sparse data. The snow gradient is probably greater across Lynn Canal from west to east over a distance of about ten miles (16.1km) than the snow gradient along the 60 miles (96.6km) of Lynn Canal from south to north. This is because of the orographic lifting effects of the steeper terrain, especially on the east side.

The Taiya Inlet area is often under the influence of strong downslope conditions that reduce precipitation in snow events, resulting in much less snow near sea level. For example, Skagway had 455 consecutive days with no measurable snowfall from November 29, 1937 to December 29, 1938.

The Haines area snowfall gradient increases up the Chilkat River because it also becomes closer to steep terrain. Haines can get very large snowfalls; for example, on February 1, 1991 Haines received 38" (0.97m) in one day.

Proximity to steep terrain may be the most important factor for snowfall near sea level. The Annex Creek Power Plant on Taku Inlet is a good example, with an average of 244" (6.2m) of low-elevation snow per year.

The contrast between Lena Point and Tee Harbor is probably the result of southerly low-level flow being diverted around Auke Mountain to create an area of low-level convergence, which increases precipitation as airmasses meet in the vicinity of Tee Harbor. A similar low-level convergence area extending farther north probably occurs due to the funneling effect of the Montana Creek to Windfall Lake corridor.

These factors suggest that the snowfall along the base of the mountains on the east side is higher than over Lynn Canal, probably not by the full 300 percent it would be at altitude, but very likely 150 percent of the amount farther away from the mountains.

In the course of the aerial avalanche observations, three distinct snowfall zones were noted on the east side: a zone where snowfall was heavy enough to obscure terrain features, from Berners Bay to Yeldagalga Creek; a zone where terrain features were visible through thinner snowcover, from Yeldagalga Creek to the Katzehin River; and a zone where thin snow cover on easily-visible terrain features, from the Katzehin River north up Taiya Inlet.

The estimates presented in the original 2005 study are unchanged by the new data, and the estimated average snowfall at starting zone elevations along the East Lynn Canal route from Berners Bay to the Katzehin River can be best described as ranging from about 150” (3.8 m) toward the north to 210” (5.3 m) toward the south, in keeping with the snowfall zones described above. The east side average would thus be an estimated 179” (4.6m). The figure for all of Lynn Canal, from Berners Bay to Skagway, is useful as regional climate information along the entire route, including those portions served by ferries.

The West Lynn side is somewhat drier due to the downslope flow component there, but the close proximity of high mountains to the alignment balances that effect. Snowfall at starting zone elevations is comparable to that on the east side, but sea-level snowfall is more comparable to that over the water. That suggests an estimated snowfall of 140 inches (3.6 m) from William Henry Bay to the Endicott River area, and 100 inches (2.5 m) from there to Haines. The average for the West side is thus estimated at 120 inches (3.0 m).

Snowfall Map

6. Avalanche Mitigation

Avalanche mitigation is the use of hazard reduction and risk management to reduce the avalanche risk on a given highway. Figure 4A shows risk-reduction figures. These are generally expressed as a proportion of the unmitigated AHI, which strictly speaking is not a measure of risk, but which serves well as a relative measure, for the few highways in Switzerland (CH), British Columbia (BC) and Colorado (CO) which have documentation of the effectiveness of their avalanche programs. The range of residual AHI cited in the studies for each highway is listed, as well as its average, and the average for all the highways studied.

Figure 4A: Highway Residual Avalanche Hazard Comparison

Highway	Residual Risk Factor Range	Average Residual Risk Factor	Daily Observa-tions & Forecasts	Forecasting, Closure, & Explosives	Structural Mitigation; Special Explosives Methods
Coquihalla Hwy, BC+	0.18 - 0.40	0.38	minimal	minimal	full
Icefields Parkway, BC*	0.26	0.26	intermittent	intermittent	none
Fluela Pass, CH+	0.23 - 0.29	0.26	normal	normal	explosives
Fluela Pass, CH+	0 - 0.40	0.20	normal	closures only	none
Red Mtn/Molas, CO*	0.19 - 0.24	0.22	normal	normal	1 shed
Lukmanier Pass, CH+	0.09 - 0.14	0.12	normal	prolonged	explosives
Gothard Pass, CH+	0.02 - 0.15	0.18	normal	prolonged	none
Rogers Pass, BC*	0.04	0.04	extensive	extensive	extensive
Average		0.21			

* Based on actual avalanche occurrence records.
+ Calculated, based on estimated risk reduction.

6.1. *Mitigated AHI Target Value*

Like most avalanche standards, acceptable mitigated AHI values are not absolutes, but are established as a standard of care defined by current industry practice. The target residual AHI of 30 to 40 or less was chosen because it is accepted as an adequate level of mitigation for similar highways in North America.

Figures 4B and 4C below detail the level of avalanche mitigation on the North American highways for which figures are available.

For most highways in the tables, unmitigated AHI multiplied by 0.21 is used to calculate Residual AHI, using the average residual risk as calculated in Figure 4a.

A Residual AHI factor of 0.04 is used for Rogers Pass based on the reduction calculated for its intensive mitigation program in the Five Mountain Parks Highway Avalanche Study.

The Lynn Canal routes listed here have a Residual AHI factor of 0.3 multiplied by the structurally mitigated AHI value.

Figure 4B: Residual Avalanche Hazard Index (AHI) Comparison

AHI Category	Highway	Unmitigated AHI	Residual AHI
Very High AHI highways	Rogers Pass, BC	1004	40
	Red Mtn. Pass, CO	335	70
	* Seward Highway, AK (Anchorage-Seward, old alignment)	331	70
	* Seward Highway, AK (Anchorage-Girdwood, old alignment)	188	39
	Coal Bank/Molas, CO	108	23
	Average, Very High AHI highways	**393**	**48**
High AHI highways	Berthoud Pass, CO	93	20
	Coquihalla, BC	90	19
	Loveland Pass, CO	80	17
	Wolf Creek Pass, CO	54	11
	Silverton-Gladstone, CO	49	10
	Teton Pass, WY	47	10
	Average, High & Very High AHI highways	**216**	**30**
Moderate AHI highways	Lizard Head Pass, CO	39	8
	I-70 Tunnel Approaches, CO	27	6
	Thane Road, AK	21	4
	Average, all listed highways	**176**	**25**
Lynn Canal	**East Lynn Alt 2B, AK (very high)**	**291**	**28**
	West Lynn, AK (high)	**102**	**18**

* Historical data for AHI calculation is only available for the pre – 1998 Seward Highway alignment.

Figure 4B compares the unmitigated and the mitigated, or residual, AHI levels for highways grouped by AHI range.

The average residual AHI for Very High unmitigated AHI category highways is 48, though the most-exposed portion of the Seward Highway has now been realigned to reduce its avalanche exposure below that listed here. The unmitigated AHI values for the East Lynn Canal routes are in the Very High category. The chosen target residual AHI of 30 to 40 or lower is in the average range for the highways in the next lower AHI category, High and Very High, giving a safety margin of one full step on the AHI scale.

The other highways in the figure are considered to have adequate operational safety margins. An AHI figure of AHI 30 would allow an additional margin of 38 percent.

The unmitigated AHI for the West Lynn Canal route is at the very top of its High category, bordering on Very High. The target AHI 30 to 40 or lower meets the average residual AHI standard for highways in both the High and Very High categories, yielding a similar margin to that for the East Lynn Canal routes.

Figure 4C: AHI Per Unit Distance Comparison

AHI Category	Highway	Unmitigated AHI	Avalanche Zone, Miles	Residual AHI/ Mile	Avalanche Zone, Km	Residual AHI/ Km
Very High AHI highways	Rogers Pass, BC	1004	24.8	1.6	40.0	1.0
	Red Mtn. Pass, CO	335	17.4	4.1	28.0	2.5
	* Seward Highway, AK (Anchorage-Seward, old alignment)	331	88.9	0.8	143.1	0.5
	* Seward Highway, AK (Anchorage-Girdwood, old alignment)	188	16.5	2.4	26.6	1.5
	Coal Bank/Molas, CO	108	34.0	0.7	54.7	0.4
	Average, Very High AHI highways	**393**	**36.3**	**1.9**	**58.5**	**1.2**
High AHI highways	Berthoud Pass, CO	93	16.0	1.2	25.7	0.8
	Coquihalla, BC	90	12.4	1.5	20.0	0.9
	Loveland Pass, CO	80	8.0	2.1	12.9	1.3
	Wolf Creek Pass, CO	54	18.4	0.6	29.6	0.4
	Silverton-Gladstone, CO	49	6.5	1.6	10.5	1.0
	Teton Pass, WY	47	13.8	0.7	22.2	0.4
	Average, High & Very High AHI highways	**216**	**23.3**	**1.6**	**37.6**	**1.0**
Moderate AHI highways	Lizard Head Pass, CO	39	21.0	0.4	33.8	0.2
	I-70 Tunnel Approaches, CO	27	15.0	0.4	24.1	0.2
	Thane Road, AK	21	2.9	1.5	4.6	1.0
	Average, all highways	**176**	**21.1**	**1.4**	**34.0**	**0.9**
Lynn Canal	**East Lynn, AK (very high)**	**291**	**50.5**	**0.6**	**81.3**	**0.3**
	West Lynn, AK (high)	**102**	**33.3**	**0.5**	**53.7**	**0.3**

* Historical data for AHI calculation is only available for the pre – 1998 Seward Highway alignment.

Another way to compare residual AHI is to look at AHI per unit distance as shown in Figure 4C. This method factors in the length of the route, allowing fairer comparison between long and short routes.

The East Lynn Canal routes and the West Lynn Canal route again have mitigated values below the average for the highways in the next lower AHI category, High and Very High, giving a safety margin of one full step on the AHI scale.

6.2. *AHI Values and Risk to Travelers and Workers*

The AHI numbers commonly used in avalanche hazard evaluation do not express the probability of death, damage, or injury per unit time or per thousand travelers, as do studies in some other fields like medicine.

The AHI is used for comparing the hazard rather than quantifying the level of risk. It is a relative index, as noted in Avalanche Hazard Index (AHI) Overview in the **Avalanche Hazard Section**, and in the detailed discussion in the **Technical Appendices** at the back of this report.

Many avalanche-exposed highways have not had their AHI values determined because it is an involved, time-consuming calculation, but the AHI has been calculated for enough avalanche-exposed highways in North America to make it the most useful available method for avalanche hazard comparison.

The AHI numbers cannot be translated directly into probability of adverse encounters and there is no compilation of figures nor accepted methodology available from which to determine absolute probabilities; but the AHI is the established standard for comparison of avalanche risk on transportation corridors, and it allows for easy comparison of the records of corridors with similar AHIs.

6.2.1. Risk Management Analysis of Three Very High AHI Highways

The following discussion and analysis is unchanged from the 2004 and 2005 reports, and is still valid.

The four highways with the highest AHI values listed in this report are Little Cottonwood Canyon at 1045 (target mitigation of 40), Rogers Pass at 1004 (mitigated to 40), Red Mountain Pass at 335 (mitigated to 70), and the old alignment of the Seward Highway from Anchorage to Seward at 331 (mitigated to 70). The best historical records available are for the last three of these.

The Trans-Canada Highway over Rogers Pass in British Columbia has operated for the 42 years since 1962 with a state-of-the-art avalanche program.

There have been no deaths to the traveling public on the Rogers Pass highway, but there have been two highway worker deaths. The same secondary avalanche killed both workers in 1966 while they were clearing debris from an earlier slide. The highway was closed to the public at the time.

There have been 33 avalanche involvements, eight of which resulted in vehicle or building damage and three in injury or death.

Red Mountain Pass in Colorado has had a full avalanche program for the 11 years since the winter of 1992-93.

During that time, there have been no deaths, damaged vehicles, or injuries. There was one involvement. A Colorado DOT truck was hit by an intentionally triggered slide but was undamaged.

Figures for the Seward Highway are available for the 23 years from 1981 through 2004, during which there has been a full avalanche program. There were no deaths to the traveling public. There was one highway worker killed by a secondary avalanche in 2000 while clearing debris from an earlier slide. The highway was closed to the public at the time.

There were 12 avalanche involvements, spanning a range from dust clouds causing loss of control to avalanches striking vehicles, but a breakdown of the involvements was not available in the records. One of the 12 incidents was the 2000 fatality.

Figure 5: Avalanche Risk Summary, Three Very High AHI Highways

Category	Events Per Year
All Avalanche Involvements	0.61
Avalanche Involvements, Damage to Vehicles or Buildings	0.15
Avalanche Involvements, Injuries or Deaths	0.04
Avalanche Deaths, Highway Workers	0.04
Avalanche Deaths, Traveling Public	<0.01

The history of the three Very High AHI highways totals 76 years of combined operational records, summarized in Table 4C.

There have been no deaths to the traveling public, or less than 0.01 deaths per operational year. There have been three deaths to highway workers, or 0.04 per operational year.

The higher risk to highway workers underscores the need for strict adherence to the avalanche program and risk management protocols presented in this study, particularly when reopening the highway after avalanches have occurred. Workers are at risk both during the construction and operations of all highways through avalanche terrain, and such work must be conducted only under the provisions of an operational safety plan and with an active avalanche forecasting, training, and mitigation program.

There have been 46 avalanche involvements, or 0.61 per operational year. A complete breakdown is only available for 53 of those operational years, but those records show 0.15 incidents with vehicle or building damage per operational year and 0.04 with injuries or deaths per operational year.

Figure 6: Effectiveness of Avalanche Programs on Two Very High-AHI Transportation Corridors

Death Rate Without Avalanche Programs	**1.55**
Death Rate With Avalanche Programs	**0.04**
Improvement Factor	**39.24**

Effectiveness of avalanche programs on Very High-AHI highways is best evaluated where death rates per year can be compared for periods with and without avalanche programs.

Before the Trans-Canada Highway was opened over Rogers Pass, the Canadian Pacific Railroad operated for the 76 years from 1885 to 1962 with only flimsy wooden snowsheds for avalanche defense. Records for these early years are incomplete, but the best available references state that “more than 200 people died in avalanches” there.

Red Mountain Pass has been plowed all winter since 1935. In the 57 years of operation until the modern avalanche program began in 1992-93, six people were killed.

The history of these two routes totals 133 years of combined operational records before modern avalanche programs. At least 206 people died, or greater than 1.55 deaths per operational year.

The death rate without modern avalanche programs is almost 39 times the death rate of 0.04 per year for high AHI highways with them. This large difference suggests that avalanche programs are an effective and necessary means of reducing risk to travelers and highway workers.

Figure 7: Comparison of Risks to Alaskans with Highway Avalanche Risk

Cause of Death	Deaths per Year
Alaska, Poisoning	114.80
Alaska, Motor Vehicle Accidents	97.20
Alaska, Other Accidental Death	48.20
Alaska, Drowning and Submersion	27.30
Alaska, Falls	25.60
Alaska, Suffocation/Choking	17.30
Alaska, Air Transport Accidents	14.80
Alaska, Exposure to Smoke, Fire, Flame	12.70
Alaska, Snow Machine Related Accidents	12.40
Alaska, Water Transport Accidents	12.20
Alaska, ATV Related Accidents	8.20
Alaska, Other Transport Accidents	2.80
Alaska, Accidental Discharge of Firearms	2.60
Alaska Highways, Avalanches, Highway Workers	0.06
High AHI Highways, Avalanches, Highway Workers	0.04
Alaska Highways, Avalanches, Traveling Public	<0.03
High AHI Highways, Avalanches, Traveling Public	<0.01

Figure 7 compares a number of risks to Alaskans with highway avalanche risk in terms of deaths per year. Alaska accidental death figures are from State of Alaska Department of Health and Social Services, Division of Public Health, Bureau of Vital Statistics, Unintentional Injury Deaths for Alaska statistics for 2003 - 2013. Alaska and High AHI sources are detailed in Appendix 15 References, under Residual Risk.

Among Alaska highways, only the Seward and the Richardson Highways have full modern avalanche programs. There are limited programs on the Dalton Highway, the Copper River Highway, the Klondike Highway, and Thane Road. The Haines Highway and several other less-traveled roads in Alaska have avalanche issues but no avalanche programs.

Alaska has had no highway avalanche deaths to the traveling public in the 35 years since 1969, and two highway worker avalanche deaths. Both were clearing debris from previous avalanches while the highway was closed to the public. One death was in Southeast Alaska, on Thane Road in 1974.

During the period since 1969, there have been less than 0.03 deaths per year, and there have been 0.06 deaths per year to highway workers. In contrast, the total motor vehicle death rate for Alaska in the 2003 - 2013 ten-year period is 97 deaths per year, over 3000 times the avalanche death rate. One of the highway deaths in this period was from avalanche, one tenth of a percent of the total.

For comparison with non-highway risks, the total Alaska motor vehicle accident death rate for the most recent ten-year period for which figures are available, including off-road accidents, is 97 deaths per year. The rate for poisonings is 115 deaths per year, for other transport accidents including air, water, snowmachine, and ATV, it is 50 deaths per year, for drowning and submersion it is 27 per year, for falls it is 26 per year, and for exposure to smoke, fire, and flame it is 13 per year For other accidental deaths, it is 48 deaths per year.

6.3. *Lynn Canal Avalanche Hazard Reduction Methods*

Hazard refers to the physical characteristics of the avalanche exposure. Hazard reduction encompasses any actions that reduce the hazard from avalanches, such as adjusting the highway alignment to avoid avalanche paths, or constructing physical barriers or snowsheds.

Several hazard reduction techniques have been considered for each Lynn Canal highway alternative.

1. Avoidance

The routes have been carefully adjusted to avoid avalanche paths wherever possible, which is the most effective mitigation measure.

2. Lowest-hazard Locations

Where possible, the alignments have also been adjusted to cross the unavoidable paths at the lowest-hazard locations. This adjustment is the second most-effective mitigation measure. The “unmitigated” AHI calculation for the East and West Lynn Canal alternatives is calculated using these adjusted alignments, even though technically the choice of alignment could be considered part of the mitigation.

Geotechnical studies since the 2004 and 2005 avalanche reports have recommended moving the alignment upslope in some paths to reach suitable ground conditions, reducing the mitigation by location, and requiring snowsheds on three paths to reach acceptable AHI levels.

3. Bridges

Bridges reduce the avalanche risk by allowing most avalanche flows to pass beneath them. Powderblast or exceptionally large slides may still impact the roadway, and avalanches may damage the bridges structurally. We used an averaged AHI reduction factor for bridges of 0.2 times the unmitigated AHI.

4. Elevated Fills

Elevated fills raise the highway to provide a catchment basin for debris. They are proposed in all options for West Lynn Canal paths WLC006, WLC009, and WLC010, and for East Lynn

Canal paths ELC002 and ELC014. Available material may allow these fills to be put in at low incremental cost.

This mitigation option is illustrated schematically below. A catchment basin approximately 330 feet (100m) long uphill of each fill section and roughly 33 feet (10m) high on the uphill side is created by the combination of the cut uphill and the elevated fill. This section would catch and stop most avalanches before the highway driving lanes are reached, thereby reducing the hazard from avalanches. The AHI figures for the elevated fills were reduced by an averaged factor of 0.5 times the unmitigated AHI. Large avalanches would impact the uphill face of the fill producing a unit thrust pressure on the uphill face of the fill. This thrust, the estimated reduction in AHI, and the station limits where mitigation fill is used are shown here.

Figure 8: Elevated Fill Section

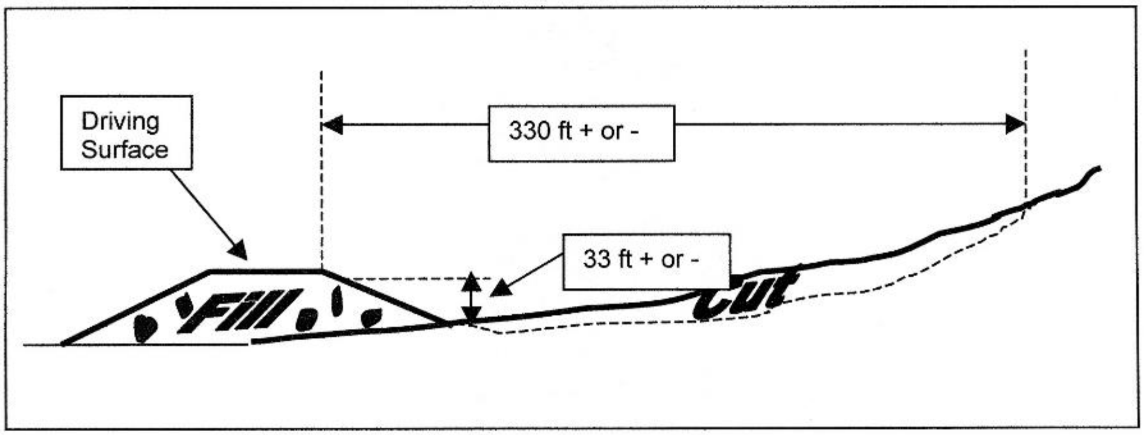


Figure 9: Elevated Fills

Path	Stations	AHI	Mitigated AHI	Thrust
ELC002	1465 through 1486	17.65	8.82	4,200psf (201Kpa)*
ELC014	1688 through 1694	8.8	4.4	6,700psf (321Kpa)*
WLC006A&B	5064 through 5087	35.83	17.91	**
WLC009A&B	5771 through 5795	23.74	11.87	**
WLC010C	5941 through 5947*	1.2	0.6	**

* Location would be field-verified in design phase. Thrust must be converted to normal and shear components when fill shape is known, during the final design process.

** Additional topographic coverage would be needed for calculations in design phase.

5. Snowsheds

Expensive structural hazard reduction techniques such as snowsheds are most cost-effective and efficient if they are targeted at the highest-hazard paths. The avalanche hazard is not uniformly distributed over all the avalanche paths. Some paths are large and frequent; others are small and infrequent. *The majority of the hazard on both alignments is concentrated in a few avalanche paths*. The following figures list the paths by decreasing AHI. The three highest-AHI paths contain over half of the total East Lynn Canal AHI.

The Unmitigated and Mitigated AHI columns take into account structural mitigation reduction factors on a path by path basis. The first tallies at the bottom are for structural mitigation only, without applying the additional blanket reduction factor for avalanche forecasting and use of explosives, including remote exploders. The final figures are for the full avalanche program, including forecasting and the use of exploders and other explosives; as well as structural mitigation.

Maps, photos, and detailed information on each path are in the Avalanche Path Atlas section of this report.

Figure 10: East Lynn Canal Avalanche Paths by AHI

Path #	Path Group	Unmitigated AHI	Structurally Mitigated AHI	Notes
ELC019	S Yeldagalga	58.35	0.00	800'/244m snowshed
ELC021	S Yeldagalga	47.14	0.00	400'/122m snowshed
ELC006	Eldred Rock	42.82	8.56	bridge 0.2x
ELC025	N Yeldagalga	19.23	11.54	bridge 0.2x for half
ELC002	N Kensington	17.70	8.85	33'/10m elevated fill 0.5 x
ELC020	S Yeldagalga	16.25	0.00	300' snowshed
ELC026-1	N Yeldagalga	12.00	12.00	
ELC014	Eldred Rock	8.88	4.44	33'/10m elevated fill 0.5 x
ELC026	N Yeldagalga	8.77	1.75	bridge 0.2x
ELC024	S Yeldagalga	8.50	8.50	
ELC023	S Yeldagalga	4.73	4.73	
ELC009	Eldred Rock	4.55	4.55	
ELC008	Eldred Rock	4.22	0.84	bridge 0.2x
ELC031-1	Wild Bird	3.93	3.93	new path
ELC031-2	Wild Bird	3.93	3.93	new path
ELC018	S Yeldagalga	4.08	4.08	
ELC012	Eldred Rock	3.39	0.68	bridge 0.2x
ELC010	Eldred Rock	3.02	3.02	
ELC029	N Yeldagalga	2.97	0.59	bridge 0.2x
ELC011	Eldred Rock	2.71	2.71	
ELC028	N Yeldagalga	2.24	0.45	bridge 0.2x
ELC005	Eldred Rock	2.19	0.44	bridge 0.2x
ELC027	N Yeldagalga	1.93	1.93	
ELC028-1	N Yeldagalga	1.46	1.46	
ELC013	Eldred Rock	1.35	1.35	
ELC028-2	N Yeldagalga	0.99	0.99	
ELC003	N Kensington	0.74	0.74	
ELC019-1	S Yeldagalga	0.60	0.60	
ELC001	Berners Bay	0.58	0.58	
ELC031	N Yeldagalga	0.42	0.00	tunnels
ELC035	N Katzehin	0.23	0.05	fill 0.2x

Path #	Path Group	Unmitigated AHI	Structurally Mitigated AHI	Notes
ELC017	S Yeldagalga	0.19	0.04	bridge 0.2x
ELC007	Eldred Rock	0.17	0.17	
ELC016	S Yeldagalga	0.15	0.03	bridge 0.2x
ELC022	S Yeldagalga	0.14	0.14	
ELC030	N Yeldagalga	0.12	0.12	
ELC004	N Kensington	0.08	0.08	
ELC015	Eldred Rock	0.05	0.05	
ELC032	S Katzehin	0.03	0.03	
ELC034	S Katzehin	0.03	0.03	
ELC003-1	N Kensington	0.02	0.02	
ELC033	S Katzehin	0.02	0.02	
ELC005-1	Eldred Rock	0.01	0.01	
Total	**Without Exploders**	290.89	94.02	
Total	**With Exploders & Forecasting**	87.27	28.21	

Figure 11: West Lynn Canal Avalanche Paths by AHI

Path #	Path Group	Unmitigated AHI	Structurally Mitigated AHI	Notes
WLC006A	Sullivan	17.96	8.98	elevated fill 0.5x
WLC006B	Sullivan	17.96	8.98	elevated fill 0.5x
WLC006C	Sullivan	17.96	17.96	
WLC009A	Rainbow	11.92	5.96	elevated fill 0.5x
WLC009B	Rainbow	11.92	5.96	elevated fill 0.5x
WLC009C	Rainbow	11.92	5.96	elevated fill 0.5x
WLC007	Sullivan	2.54	0.51	bridge 0.2x
WLC008	Rainbow	2.11	0.42	bridge 0.2x
WLC010A	Pyramid	1.21	0.61	elevated fill 0.5x
WLC010B	Pyramid	1.21	0.61	elevated fill 0.5x
WLC010C	Pyramid	1.21	0.61	elevated fill 0.5x
WLC010D	Pyramid	1.21	0.61	elevated fill 0.5x
WLC005	Sullivan	0.89	0.89	
WLC 001A	S Endicott	0.54	0.54	
WLC 001B	S Endicott	0.54	0.54	
WLC002A	S Endicott	0.51	0.51	
WLC002B	S Endicott	0.26	0.26	
WLC003	N Endicott	0.00	0.00	
WLC004	N Endicott	0.00	0.00	
Total	**Without Exploders**	101.89	59.91	
Total	**With Exploders & Forecasting**	30.57	17.97	

The listings in Figures 10 and 11 above include unmitigated AHI and reductions for structural mitigation and for a program of forecasting and exploders or explosives.

Snowsheds are used on Paths LC019, and LC020 and LC021 in all the current East Lynn Canal options. They have the disadvantages of high capital cost, light/shadow vision problems, ice formation, requiring maintenance, and being something for cars to run into; but well-designed sheds virtually eliminate exposure to avalanches, and they are widely and successfully used in Europe and Japan.

Most snowsheds are reinforced concrete shed-roofed galleries poured in place, as illustrated below in Figure 15. An alternative design concept that was considered in the 2004 and 2005 Juneau Access studies is a metal multiplate arch “half culvert”. Subsequent experience with similar designs in Scandinavia has shown that they are unable to resist deformation due to the differential backfill load on a slope, even when backfilled on both sides. The arch shape works well, but requires reinforced concrete of sufficient thickness to resist distortion from differential loading, as illustrated below in Figure 14. Openings for lighting and ventilation are not shown, but should be included in snowshed design.

Colorado avalanche and natural hazards consulting engineers Mears and Wilbur developed preliminary estimated 2013 costs for the three snowsheds on the East Lynn Canal alignment, based on comparison with other snowsheds in North America. Their figures assume a design with two lanes with no lighting, mechanical ventilation or real-time traffic monitoring.

The initial basis for cost comparison is the cost per unit length and lanes, which corresponds approximately to shed roof area. The costs in Figure 12 include original costs and inflation adjustments based on the ENR (Engineering News Record) Construction Cost Index.

Figure 12: Snowshed Cost Comparison, Mears and Wilbur

Highway	Location	Length (ft)	Lanes	Year	Original Cost	Original Cost/lane /ft.	Inflation Factor*	inflation Adjusted Cost/lane/ ft.	Comments
I-90	**Snoqualmie Pass, WA**	1200	6	2010	$14.0m	$1,946	1.06	$2,068	Bid, but not built; Replaced with bridge.
US 189	**Provo Canyon, UT**	130	4	2003	$1.6m	$3,077	1.42	$4,374	Designed, not bid or built; insufficient funds.
BC 5	**Coquihalla, Canada**	935	6	1987	$17.1m	$3,049	2.16	$6,585	Large guiding walls, heated pavement.
US 550	**East Riverside, CO**	180	2	1986	$1.6m	$4,450	2.22	$9,859	Designed for impact from both sides of canyon.

Highway	Location	Length (ft)	Lanes	Year	Original Cost	Original Cost/lane /ft.	Inflation Factor*	inflation Adjusted Cost/lane/ ft.	Comments
Juneau Access - ELC	**ELC Culvert Shed Est.**	1500	2	2006	$10.5m	$3,500	1.21	$4,223	Estimate from 2006 EIS Appendix J.
Juneau Access- ELC	**ELC Concrete Shed Est.**	1500	2	2006	$19.7m	$6,568	1.21	$7,923	Estimate from 2006 EIS Appendix J.

Mears and Wilbur estimated static snow loads for the snowsheds, based on the avalanche-debris depth calculated and an assumed deposit density of 31 pcf (500 kg/m3). These numbers are based on measurements of avalanche deposit density, evaluation of the terrain in the runout zone, the tendency for lateral spreading, and observations of avalanches in recent years in this area.

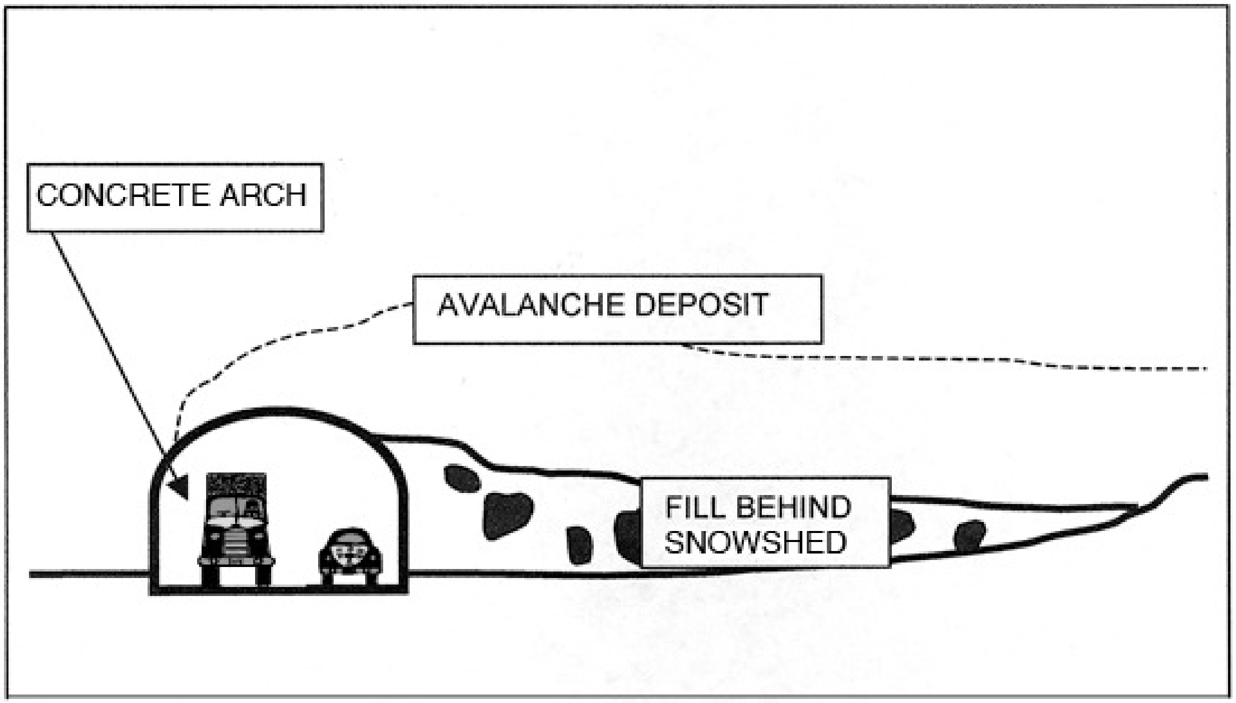
Based on the data and adjustments for inflation, design factors and location, and designing for the 50 to 100 year return period design-magnitude avalanche, they estimated total loads and preliminary costs as shown in Figure 13.

These preliminary figures are the only snowshed cost estimates presented in this study. More detailed cost estimates for the snowsheds and ferry terminal protective berm, based Alaskan on construction experience, were developed by DOT&PF as part of the highway construction budgets that are presented in the Technical Alignment Report. Please note that the avalanche program budgets in this study do not include the construction cost of the berms, snowsheds, or elevated fills that are budgeted separately as part of the highway construction.

Figure 13: East Lynn Canal Snowshed Loading and Cost Estimates, Mears and Wilbur

Path	Length (ft)	Length (m)	Approx. Static Loads (psf)	Estimated Cost Range
ELC019	800	243.8	1250 psf	$11.2 to $16.0 million
ELC020	300	91.4	1750 psf	$4.2 to $6.0 million
ELC021	400	121.9	1750 psf	$5.6 to $8.0 million

Figure 14: Concrete Arch Snowshed



Above, a conceptual sketch of concrete arch snowshed design with backfilled ramp to reduce impact pressure on the uphill side. Depending on site configuration, backfill can also be used on the downhill side, but most snowshed designs omit the fill on that side in favor of openings or reinforced windows that provide lighting and ventilation.

Below, a typical shed-roof gallery concrete snowshed in Davos, Switzerland. This snowshed has been cut into the runout zone of the avalanche path and backfilled so avalanches flow smoothly over it. Mesh-filled windows on the downhill side allow for lighting and ventilation while limiting the amount of snow that can enter.

Figure 15: Shed-roof Gallery Snowshed, Davos, Switzerland

6.4. *Operational Avalanche Risk Management Program*

Risk refers to the consequences of exposure to avalanches. Risk management practices reduce the avalanche risk to travelers through operational methods such as avalanche forecasting, warnings, highway closures, and explosives work to release unstable snow when the highway is closed. *Residual risk* is the risk that remains after mitigation through both hazard reduction and risk management.

The key elements of an avalanche risk management program are avalanche forecasting, highway closure, and explosive delivery to clear unstable snow masses during closure periods.

The available highway risk reduction figures listed in Figure 4 suggest that the AHI can be lowered to roughly 0.2 times the unmitigated level, but a more conservative residual AHI of 0.3 has been used here.

6.4.1. Goals

The goal of the Lynn Canal program outlined here is to operate the highways within acceptable limits of risk to both travelers and workers, not simply to keep the highway open. A clear understanding of that goal is crucial to the success of the risk management program. There are no written U.S. standards for highway avalanche programs, but the proposed program would meet the established standard of care as defined by common professional practices.

6.4.2. Staffing

Under both the East Lynn and West Lynn Canal alternatives, two full-time and one seasonal avalanche specialists are the core staff of the avalanche program. This staffing level ensures that at least two specialists are on duty every day during the avalanche season.

Highway maintenance crews would assist the avalanche crew with explosive delivery work, as well as with debris removal and other avalanche-related maintenance functions.

This staffing level would allow the two full-time forecasters to alternate working as the forecaster in charge for three days weekly, with the seasonal forecaster covering the seventh day of the workweek. The entire crew would be on duty around the clock when slides are running, as is standard with avalanche operations.

6.4.3. Staff Qualifications

Lead avalanche specialists should have minimum qualifications of ten winters working fulltime as an avalanche specialist, at least four years of professional-level avalanche forecasting experience in a lead position, U.S. Level I and II avalanche training, U.S. or Canadian professional-level avalanche operations training, or equivalent training and experience, and familiarity with local weather patterns and snow conditions. The senior lead avalanche specialist should also have avalanche explosives experience and experience in developing and operating a major transportation corridor avalanche program or comparable industrial program, demonstrate a commitment to continuing education, and maintain membership in relevant professional associations.

The second avalanche specialist should have at least four years of professional-level avalanche forecasting experience, U.S. or Canadian professional-level avalanche operations training, or equivalent training and experience, demonstrate a commitment to continuing education, and maintain membership in relevant professional associations.

Seasonal forecasters should have at least two years of professional-level avalanche forecasting experience, have U.S. Level I and II avalanche training, Canadian Level I training, or equivalent or higher training or experience, demonstrate a commitment to continuing education, and maintain membership in relevant professional associations.

All avalanche workers would receive additional training in explosives handling and the particular delivery methods to be used. Blaster's training, gunner school, Daisy Bell training, and manufacturer's blaster box or other remote exploder training, as needed for the explosive delivery methods in use, should be required before operations begin.

If the program will use artillery, the crew must all have gunners' school training that qualifies them to form a three-person team of Gunner, Loader, and Assistant Gunner. The Gunner position requires three years' experience and two sessions of gunners' school.

All avalanche workers should have emergency medical training to a minimum level of Emergency Trauma Technician (ETT), Wilderness First Responder (WFR), or Outdoor Emergency Care (OEC).

All avalanche workers should be advanced skiers, snowshoe- snowboarders or splitboarders, with the skill and fitness necessary to climb to starting zone elevations, perform field tests in adverse weather conditions, and descend safely and rapidly within a winter workday.

6.4.4. Avalanche Forecasting Program

The forecasting program would use direct field observations of snowpack conditions in combination with weather data and forecasts to continuously monitor the avalanche danger to travelers and highway workers, and to determine the best timing for use of explosives and highway closure.

Observations
During avalanche season, regular field observations, weather logs, and records of avalanche activity would be kept, and a daily avalanche forecast issued each morning for DOT&PF crews, with updates as conditions change. Field operations, observations, and data recording should follow American Avalanche Association guidelines.

The forecasting program should include regular starting-zone-elevation field snow testing and observation to determine the presence of weak layers and the relationship between snowpack stress, strength, energy balance, and structure.

Weather Monitoring and Data Management
Two ridge-level weather stations and one mid-elevation station should be used under the East Lynn and West Lynn alternatives. The purpose of the mid-elevation station is to assist in monitoring thaw and rain-on-snow events, to serve as the backup wind sensor, and to provide snow height and precipitation data at an elevation where wind drifting is not a major factor.

The East Lynn Canal ridgetop weather stations should be near the Eldred Rock and South Yeldagalga, paths. The mid-level station should be near the South Yeldagalga paths.

The West Lynn Canal ridgetop weather stations should be near the South Endicott, or Sullivan and Rainbow paths. The mid-level station should be near the Rainbow paths. Telemetry would relay weather data for upload to a server and website with archiving and graphing capability to deliver yearly, monthly, weekly, and daily views.

An avalanche program requires a data management and technical support system. Good data management yields the most accurate forecasts and can incorporate such useful improvements as GIS-based nearest-neighbor data sorting.

The weather stations would use propane generators, thermoelectric generators, or other best-available technology for de-icing, in order to work without AC line power on ridgetop locations in the coastal Alaskan climate. These installations would be costly, but ordinary weather stations are not adequate for the heavy rime icing conditions that are the norm in these mountains.

Remote weather stations in coastal Alaska require frequent maintenance and de-riming. Helicopter and staff time has been allocated for this purpose, and the program is designed to operate, as do all avalanche programs in coastal Alaska, with interruptions in weather data.

Explosives Program
Explosives are used in combination with temporary highway closures to release unstable snow so highways can be reopened once debris is cleared. Explosives handling, delivery, and security practices must follow American Avalanche Association and avalanche industry professional guidelines and applicable laws.

Details of the explosive program will depend on the explosive delivery option chosen. All avalanche workers should have specific training in the explosives handling and delivery methods to be used before operations begin.

Safety should be allowed to take precedence over efficiency in the first few years, as blasting procedures are refined and practiced. Speed, safety, and efficiency will develop from thorough training and drilling.

Avalanche explosives historically have dud (unexploded charge) rates of less than one percent. Double capping and fusing further reduces the dud rate. Dud locations must be noted and duds destroyed at the end of the season. A small chip that reflects a signal from a searching unit, known as a RECCO tag, can be attached to each charge delivered by helicopter or blaster box to help locate duds, which could otherwise be difficult to find in the thick brush of the avalanche paths. Unexploded howitzer rounds are best located with a metal detector or magnetometer.

The Daisy Bell and fixed gas exploders have no potential for producing duds.

6.4.5. Highway Closure Program

Conservative highway closure criteria, minimal closure time, and maximum avalanche risk reduction options have been chosen. The goal of the combined hazard reduction and risk management program is to have a residual AHI at or below the target of 30 to 40. Good risk management for the traveling public is achieved by assuring a smooth flow of traffic through avalanche zones when the highway is open, and identifying refuge points with plowed turnouts outside the avalanche zones where travelers can wait when highways are blocked by slides or for explosive work.

If explosive work must be delayed, or if instability is developing too rapidly for explosive work to keep pace, longer highway closures would be used. For prolonged closures, both the East Lynn and West Lynn Canal routes would have shuttle ferries available to provide transportation across the closed section.

People who are stopped at the Katzehin terminal due to road closures will have the option of returning to Haines/Skagway on the Alaska Class Ferry to await the road re-opening or stay at the Katezhin terminal for the road re-opening. Careful monitoring of avalanche conditions and preventive closures of the highway should keep people from being stopped at the Katzehin Terminal or being trapped between slides. In the unlikely event that people are trapped between slides, and depending on the situation and length of closure, emergency services from Juneau would be deployed. Traveling on any Alaskan road in the winter, travelers should be prepared for unexpected stops and delays.

The Juneau Access plan provides for alternative ferry transportation between Haines, Skagway, and Juneau in the event of a road closure of more than one day. The maximum anticipated duration of any avalanche related road closure is two days. The Alaska Class Ferries would be used and have a capacity of 53 vehicles, which through modeling shows to have enough capacity for the route. If during these closures, more vehicles need to be transported, then additional sailings would be made.

Signage
Prominent highway signs at each end of the highway should inform travelers that they are entering a route with potential avalanche hazard, advise them not to stop or stand in avalanche zones during avalanche season, and provide a key to color-coded signs along the highway. Color-coded signs with maintenance location reference, path number, path name, and a warning against stopping or standing from November 1 through May 1 should mark the edges of each

avalanche zone. Suggested color-coding is yellow for entering a zone and green when leaving a zone.

Signs should be posted in winter at all turnouts, trailheads, and backcountry access areas warning of explosive work and remote exploders, highway closures, avalanche areas, and the potential presence of duds. Special signage should be used to warn backcountry travelers to stay clear of any areas with blaster boxes or other fixed explosive delivery installations.

Sweep
DOT&PF maintenance workers should sweep the highway to clear any travelers before closure, moving from the center out to get the DOT&PF crew out of the corridor at the same time as the traveling public. Extra time should be budgeted to deal with such typical complications as stuck or slow vehicles. Sweep crews should have two workers per vehicle whenever possible.

Steel gates at both ends of each highway section subject to avalanche risk should be used to ensure that no vehicles enter the closed area. Notice should be given to the public through the news media and to aviators through the FAA before explosive work is initiated.

Strandings
The Katzehin Ferry Terminal would be available for use, should travelers be stranded and decide not to return to Haines or Skagway on a ferry. The Katzehin Ferry Terminal is heated and has restrooms. Katzehin Ferry Terminal will be available as temporary 24 hour emergency refuge.

According to GCI cellular phone coverage maps online in 2016 at http://gci.cellmaps.com/#, there is CDMA coverage along most of both the East and West Lynn Canal routes, though it has a few gaps and weak spots. GSM cellular phone coverage is limited to southern Lynn Canal near Juneau, and near Haines and Skagway. Expansion of cellular phone coverage should be encouraged to facilitate emergency communications.

6.4.6. Highway Operations Procedures

Avalanche season highway operations should be conducted following a project-specific, fully detailed avalanche risk management plan, as required under Alaska case law on worker safety. Crews should be trained in avalanche procedures and equipped with avalanche emergency kits. The discussion here is a sample overview of the common provisions of avalanche plans, and is not intended as a substitute for a detailed plan.

The avalanche program must begin with the construction phase of the project, including early installation and testing of fixed exploders and other mitigation measures, with ample time allowed to ensure that they are operating reliably before crews are depending on them.

The plan will then be updated as the program shifts to operation of a road open to the traveling public, a very different situation. Avalanche plans require at least annual review and revision.

No avalanche debris should be cleared without approval from the on-duty avalanche specialist. The specialist should consider visibility, presence of residual snow in avalanche starting zones, terrain hazards, availability of spotters and equipment and other risk factors. No avalanche debris should be cleared when visibility is poor due to darkness or conditions such as fog.

All cuts in avalanche debris should be daylighted, opening the downslope side of the cut as the cut is made. Cuts with vertical walls on both sides are traps for operators in the event of a secondary slide.

All heavy equipment should have enclosed cabs and should be equipped with avalanche self-rescue gear and operators should be trained in avalanche safety and rescue procedures. Operators working in avalanche zones during avalanche season should wear beacons and should remain in radio communication with a dispatcher.

Radios should have frequencies for communication with law enforcement and aircraft used in the program, as well as for DOT&PF maintenance, base, and avalanche forecasting staff. Repeaters should be installed to provide uninterrupted radio communication throughout the alignment.

DOT&PF vehicles should carry small emergency caches and weatherproofed copies of avalanche maps for the route, referenced to maintenance location markers, with avalanche refuge areas, rescue caches, and shelters marked.

Highway Avalanche Danger Descriptors can be found in Technical Appendix 5, and samples of the kind of highway operations and closure guidelines for specific avalanche danger levels that should be a part of the avalanche operations plan are in the Technical Appendices at the end of this report.

7. Avalanche Path Atlas - Overview

This section has location maps for all the East and West Lynn Canal avalanche paths, followed by paired pages of photos and key information for each path.

The "ELC" or "LC" East Lynn Canal path numbers are unchanged from the original 1995 study (Mears and Glude, Snow Avalanche Technical Report, Environmental Impact Statement Considerations, Juneau Access route EIS, 1995). Paths that have been added since 1995 have a dash and sequential number following the next lower path number. The "WLC" numbers designate the mapped West Lynn Canal paths.

Any paths that might possibly affect an alignment are included in the atlas. Paths avoided by the current alignments have an AHI of zero, but are retained in the mapping and numbering system.

The path group provides a general location relative to the few named places along Lynn Canal.

Latitude and longitude coordinates for the centerline of the path on the alignment are provided as an approximate geographic locator. The coordinates were taken from DOT&PF's master design program, but they have changed slightly as the alignment has been refined.

Path widths are scaled from detailed DOT&PF maps. Maximum width is defined as the widest evident slide, a large but infrequent event. Typical width is the width of most of the slides that reach the bottom of the path.

Starting elevation is the highest point in the avalanche starting zone, taken from USGS topographic maps.

The width and elevation numbers are taken from maps created in U.S. units (i.e., feet) and converted to metric units (meters). The conversions are not accurate to the meter, but are left unrounded here to avoid biasing further calculations.

Elevation class is used to group avalanches with similar starting zone elevations for quick reference. The same convention is followed in the 1995 report. Low-elevation paths start below 1200' (370m), medium-low-elevation paths start between 1200' and 2000' (370m-610m), medium-high-elevation paths start between 2000' and 3000' (610m-910m), and high-elevation paths start above 3000' (910m).

Path size follows the classification system used in the 1995 report:

a. *Small paths* are typically gullies, rock slabs, landslides, and talus slopes at low to middle elevations (under 1,200 feet or 370m); many are in steep, cliffy areas. Snow avalanches are not the primary mass-wasting process in most of them, but they are nonetheless capable of producing avalanches when conditions are suitable. The more active small paths may produce numerous light and even deep avalanches affecting the alignment with serious consequences due to steep terrain.

b. *Medium-sized paths* are typically gullies or narrow paths at middle to high elevation (1,200-3,000 feet, or 370-910m). In these paths, the starting zones are small or the paths have other factors that limit the avalanche size and frequency.

c. *Large path*s have classic, high-elevation (3,000 feet, or 910m, and higher) starting zones, and track and runout characteristics that promote frequent and large avalanches.

d. *Very large paths* are larger than any paths on the existing Southeast Alaska highway system; that is, they have higher and wider starting zones. They produce larger and more frequent avalanches.

Path type and runout angle qualitatively describe the starting zone, track, and the transition to the runout zone. Detailed measurements have not been taken at this stage of study.

8. Atlas - East Lynn Canal Maps

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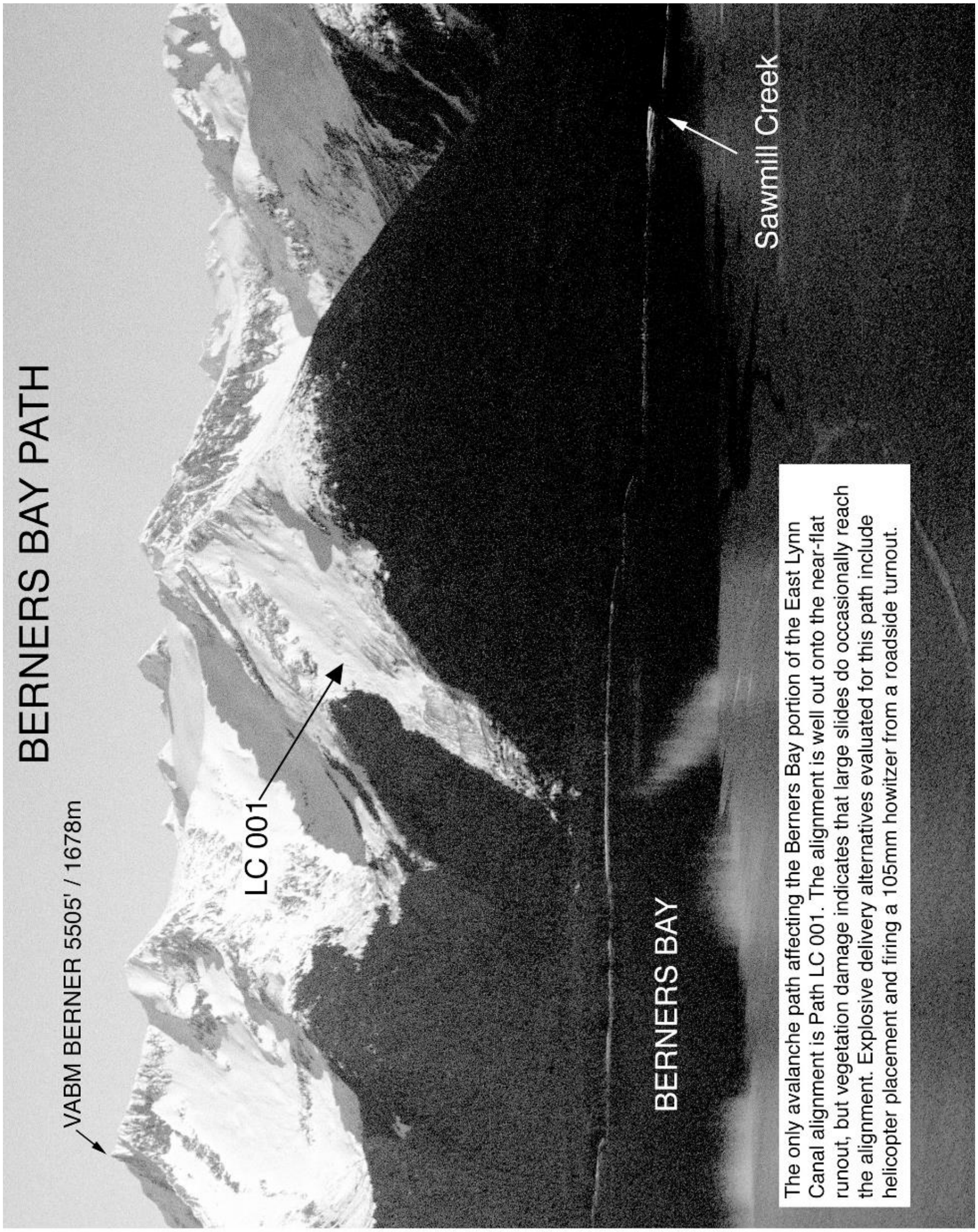
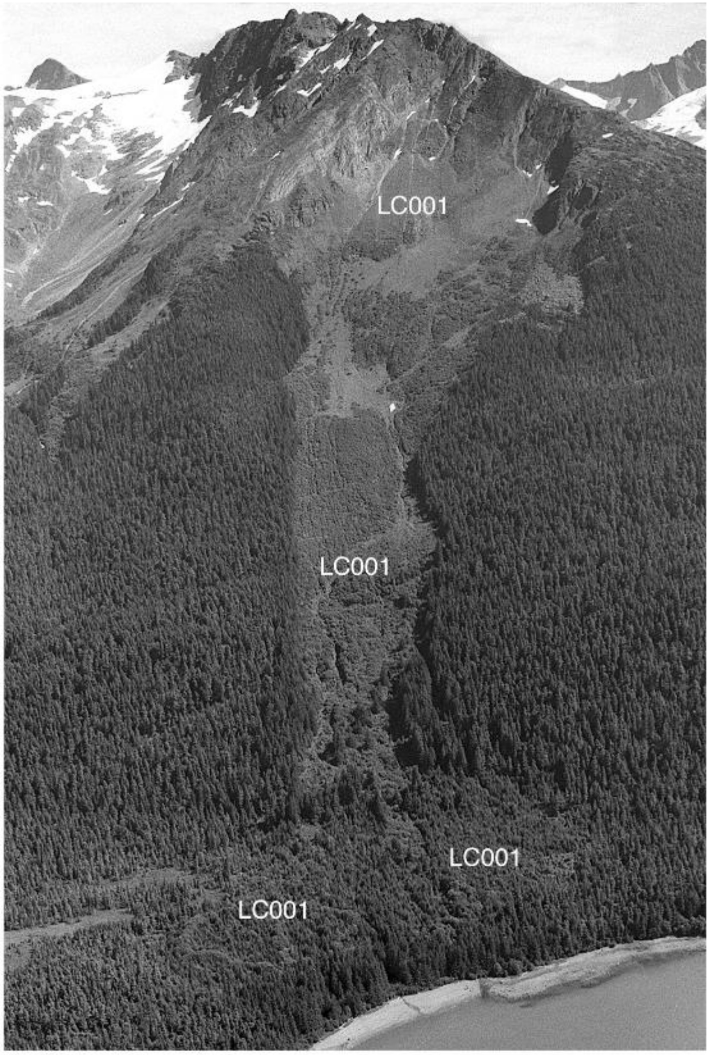
9.Atlas - East Lynn Canal Avalanche Paths




LC001
LC001
LC001
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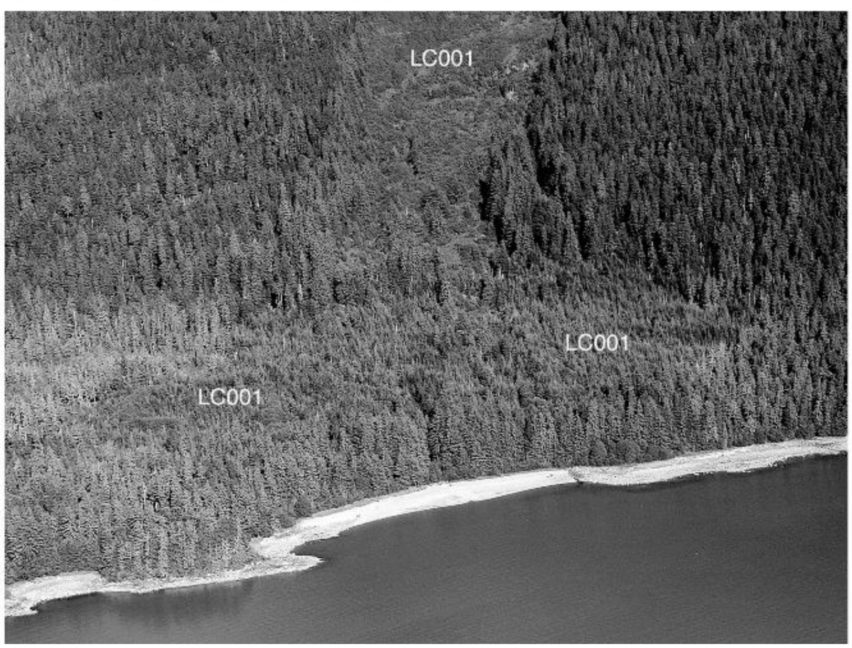
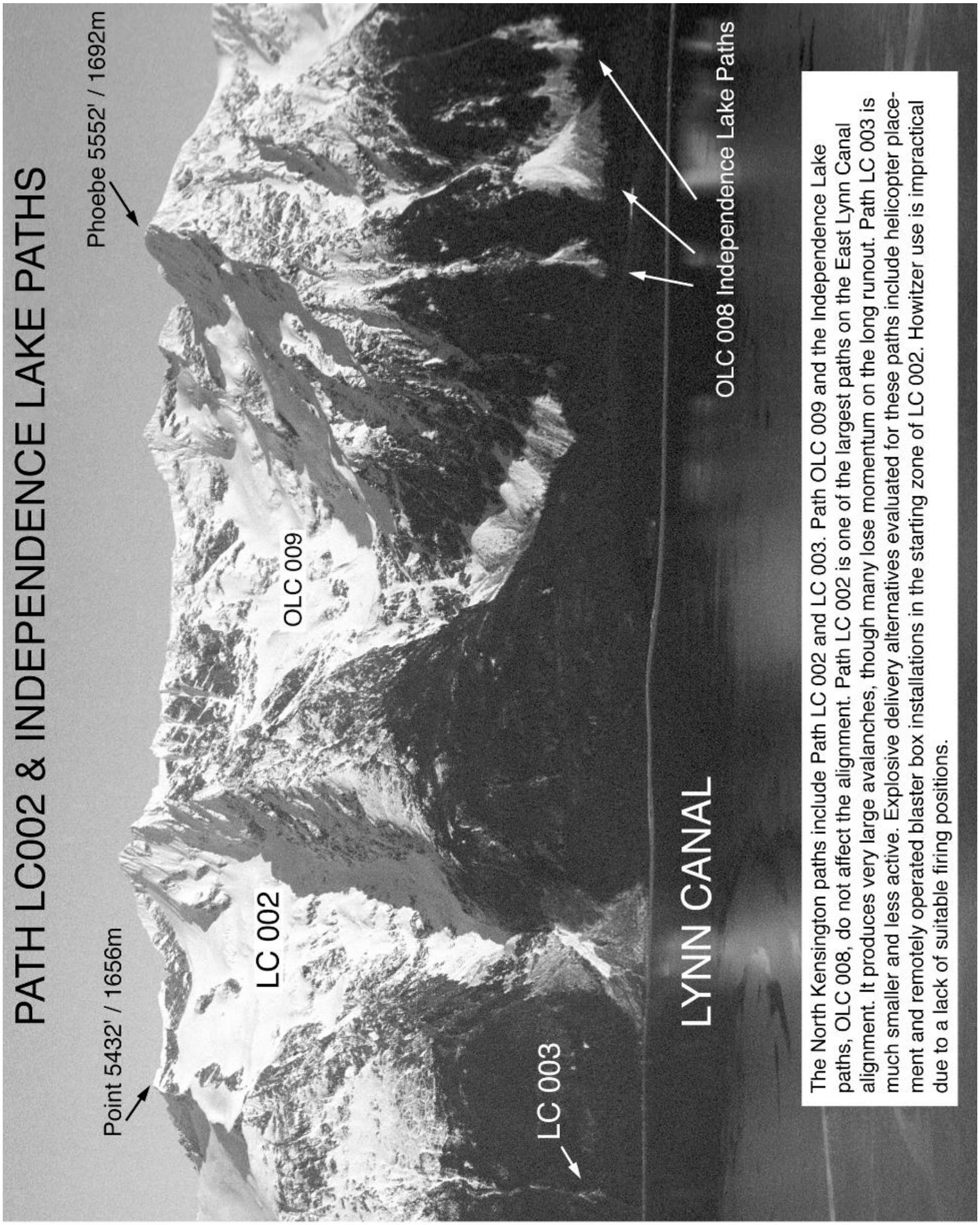
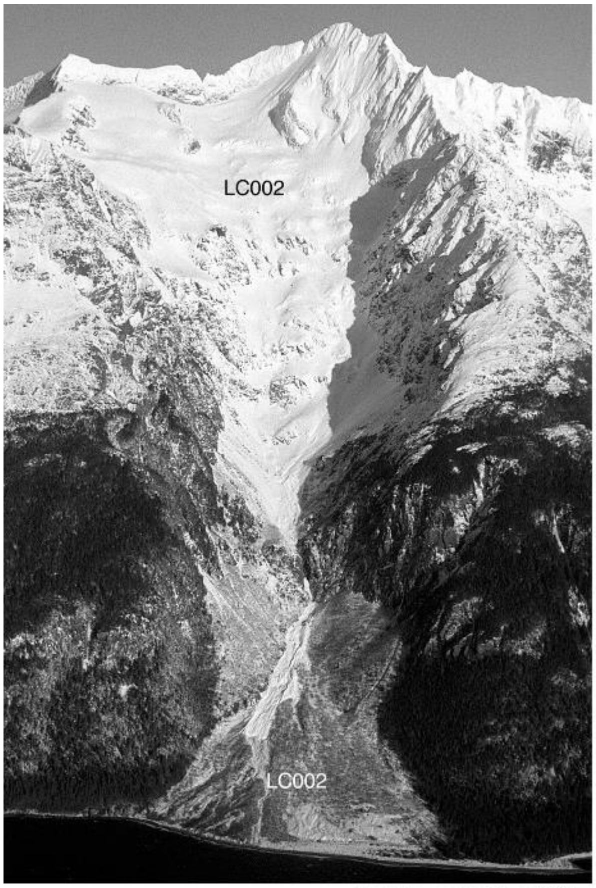
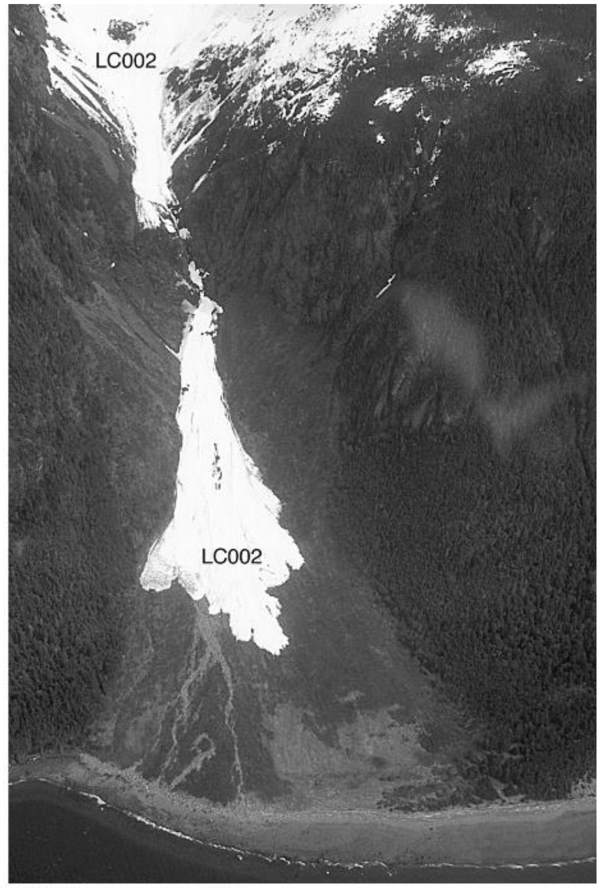

LC001
LC001
LC001

Path: LC001

Path Group:	Berners Bay
Latitude-Longitude:	58.441688-134.553822
Max Width:	1900 feet / 579 meters
Typical Width:	1000 feet / 305 meters
Starting Elevation:	4900 feet / 1493 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	W
Path Type:	classic confined; wide track
Runout Angle:	decreases abruptly
Unmitigated Avalanche Hazard Index (AHI):	0.58
Structural Mitigation:	None
Structurally Mitigated AHI:	0.58
AHI with Forecasting and Exploders:	0.17


PATH LC002 & INDEPENDENCE LAKE PATHS
Point 5432' / 1656m
Phoebe 5552' / 1692m
LC 002
OLC 009
LC 003
LYNN CANAL
OLC 008 Independence Lake Paths
The North Kensington paths include Path LC 002 and LC 003. Path OLC 009 and the Independence Lake paths, OLC 008, do not affect the alignment. Path LC 002 is one of the largest paths on the East Lynn Canal alignment. It produces very large avalanches, though many lose momentum on the long runout. Path LC 003 is much smaller and less active. Explosive delivery alternatives evaluated for these paths include helicopter placement and remotely operated blaster box installations in the starting zone of LC 002. Howitzer use is impractical due to a lack of suitable firing positions.


LC002
LC002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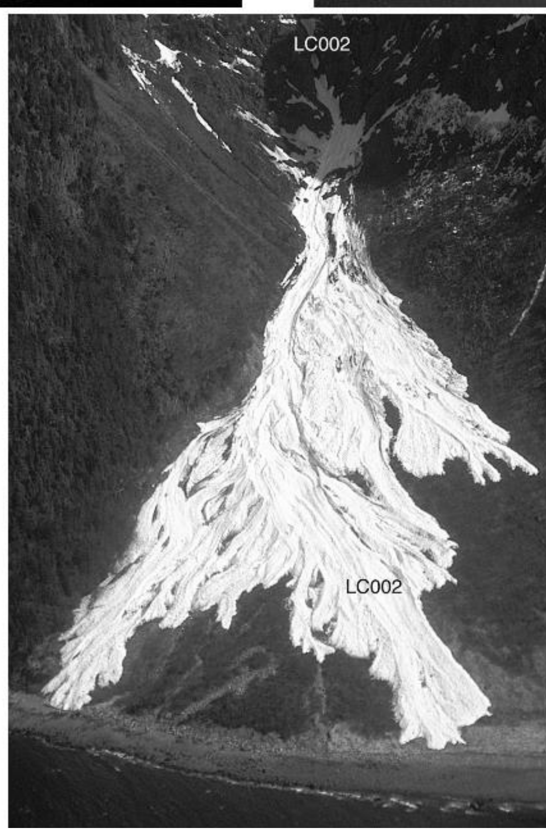
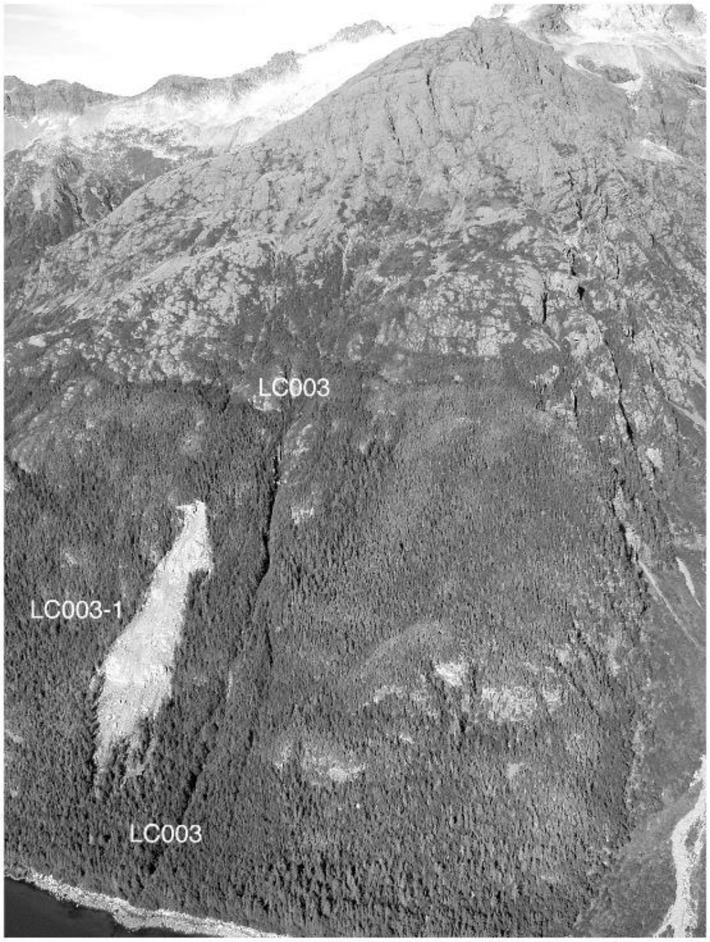
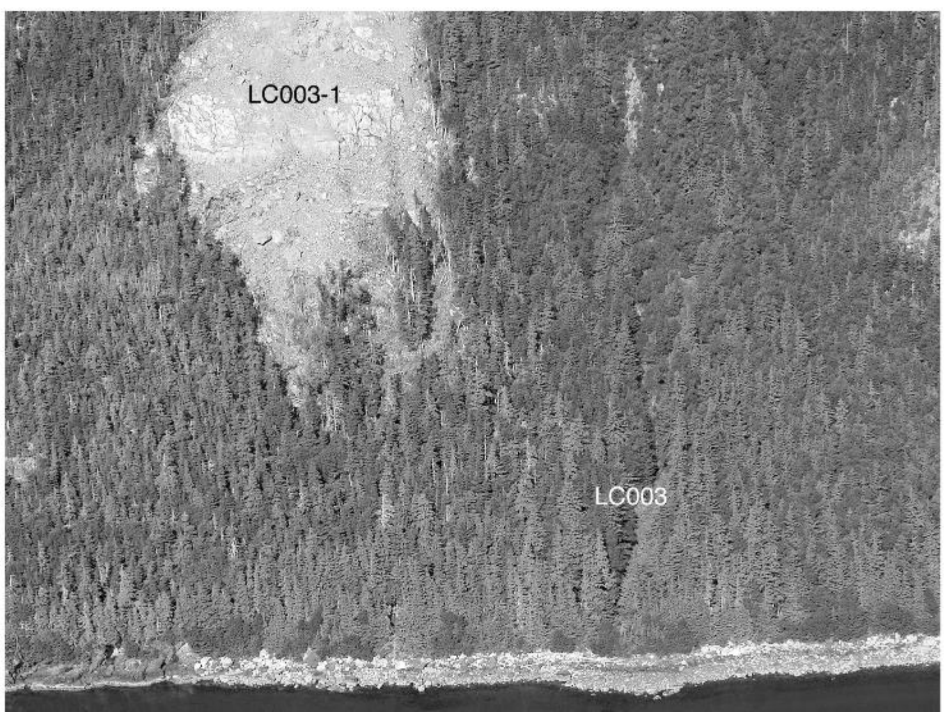

LC002
LC002

Path: LC002

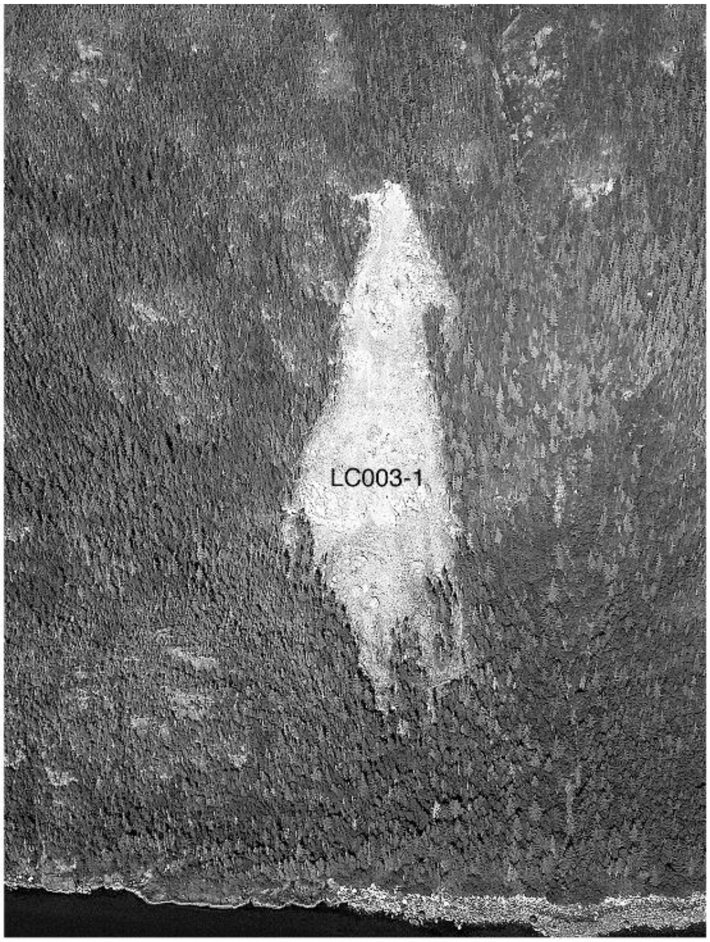
Path Group:	North Kensington
Latitude-Longitude:	58.542239 -135.091832
Max Width:	2115 feet / 645 meters
Typical Width:	500 feet / 152 meters
Starting Elevation:	5900 feet / 1798 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	WSW
Path Type:	classic confined; very wide track
Runout Angle:	decreases gradually
Unmitigated avalanche hazard index (AHI):	17.65
Structural Mitigation:	33 foot / 10meter elevated fill, 0.5x
Structurally Mitigated AHI:	8.82
AHI with Forecasting and Exploders:	2.65

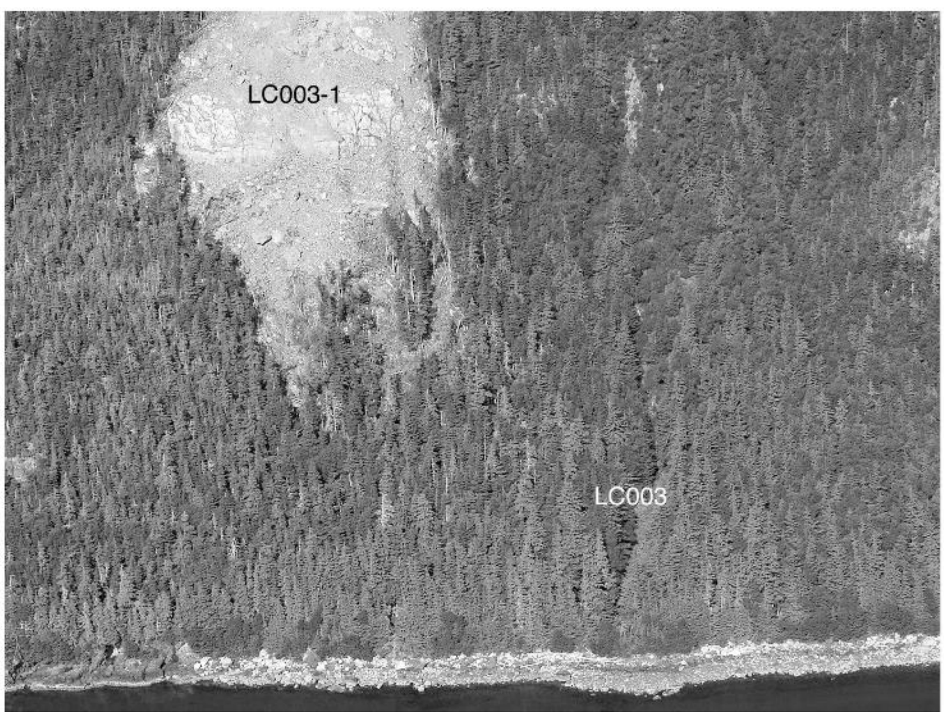

LC003
LC003-1
LC003


LC003-1
LC003

Path: LC003

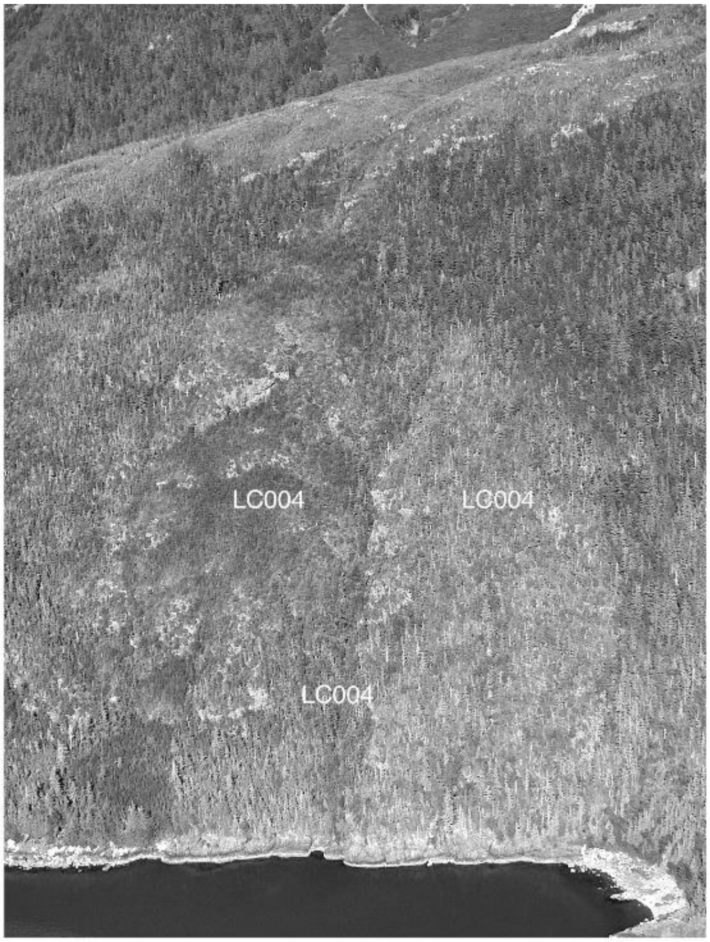
Path Group:	North Kensington
Latitude-Longitude:	58.54455 -135.09301
Max Width:	130 feet / 40 meters
Typical Width:	130 feet / 40 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	broad face
Start Aspect:	WSW
Path Type:	narrow gully
Runout Angle:	steep
Unmitigated avalanche hazard index (AHI):	0.74
Structural Mitigation:	None
Structurally Mitigated AHI:	0.74
AHI with Forecasting and Exploders:	0.22

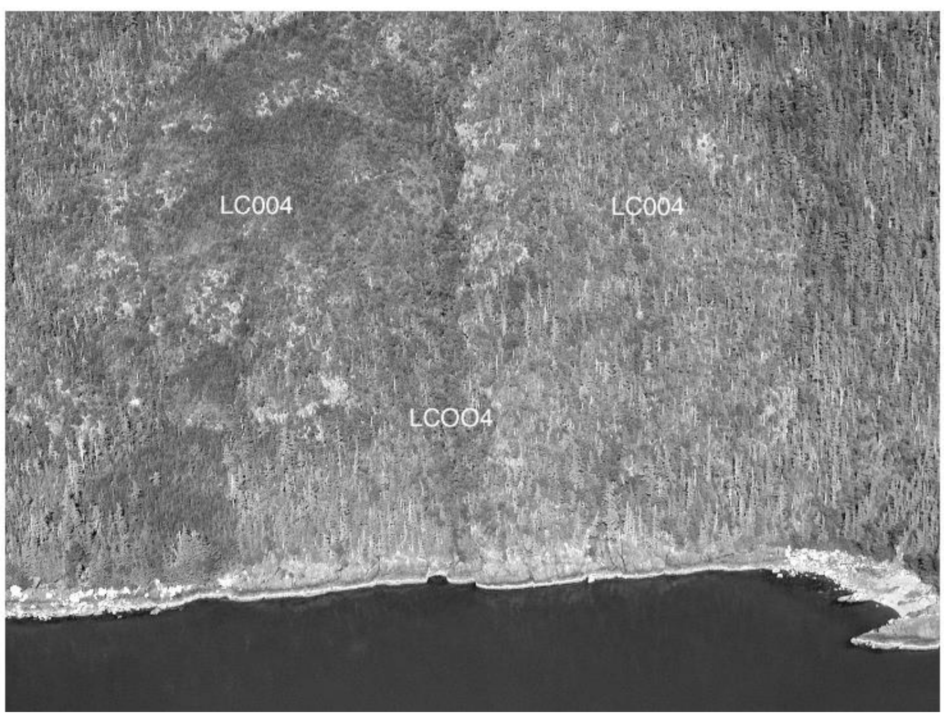

LC003-1


LC003-1
LC003

Path: LC003-1

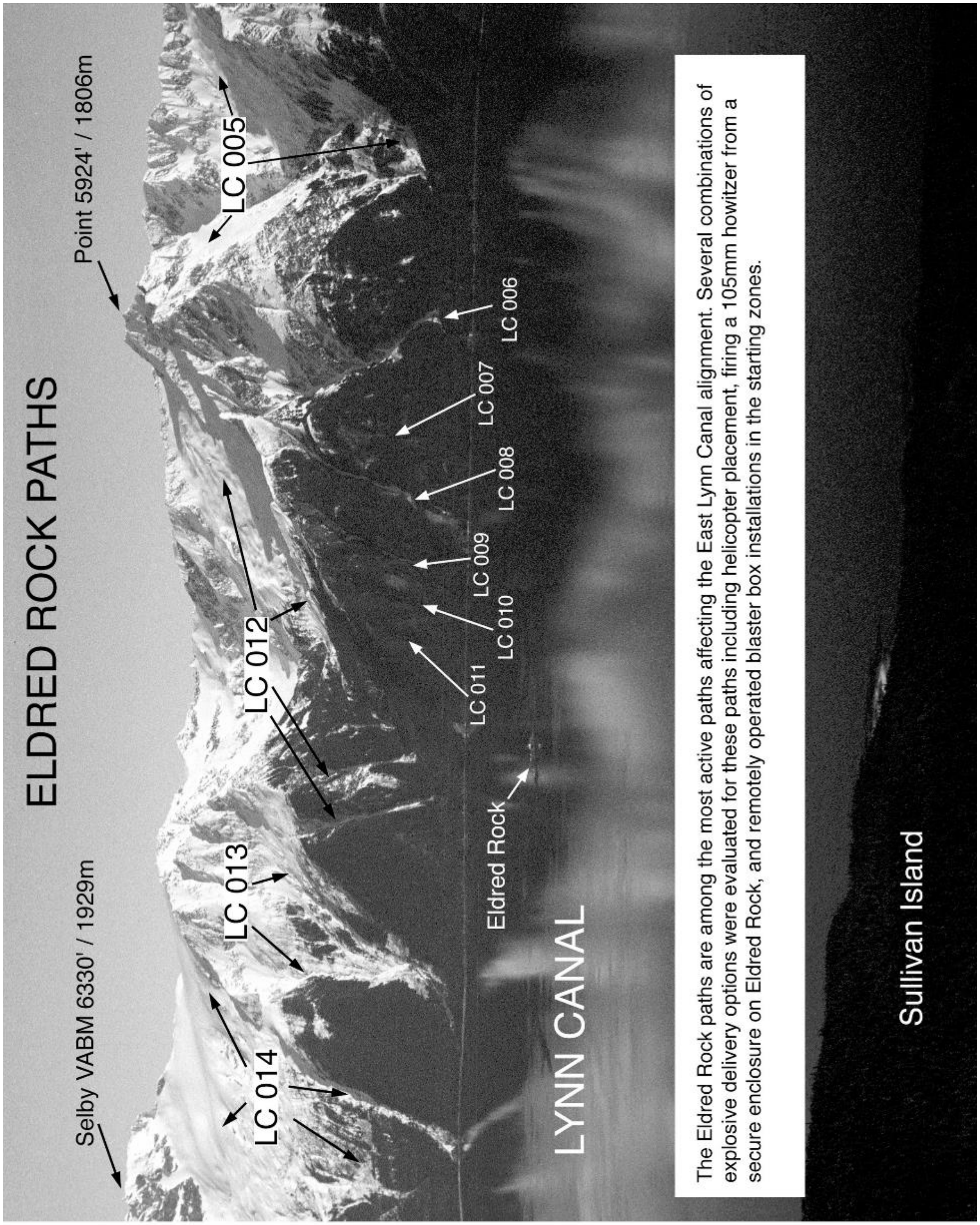
Path Group:	North Kensington
Latitude-Longitude:	58.544894 -135.093227
Max Width:	380 feet / 116 meters
Typical Width:	0 feet / meters (usually stops above alignment)
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	landslide scar
Start Aspect:	WSW
Path Type:	2001 landslide scar
Runout Angle:	decreases moderately
Unmitigated avalanche hazard index (AHI):	0.02
Structural Mitigation:	None
Structurally Mitigated AHI:	0.02
AHI with Forecasting and Exploders:	0.01


LC004
LC004
LC004

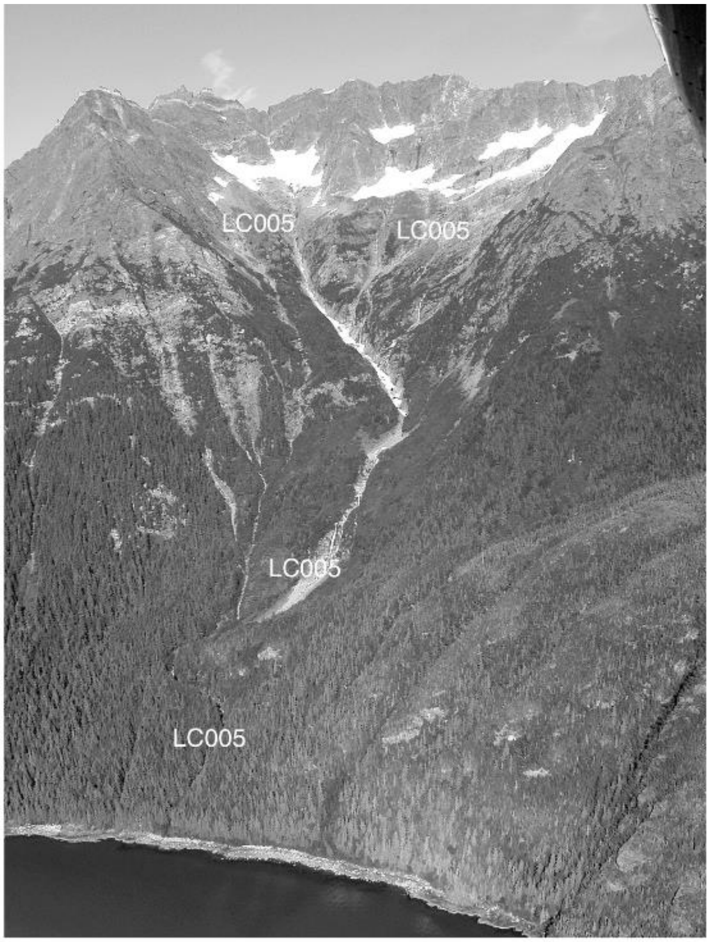

LC004
LC004
LCOO4

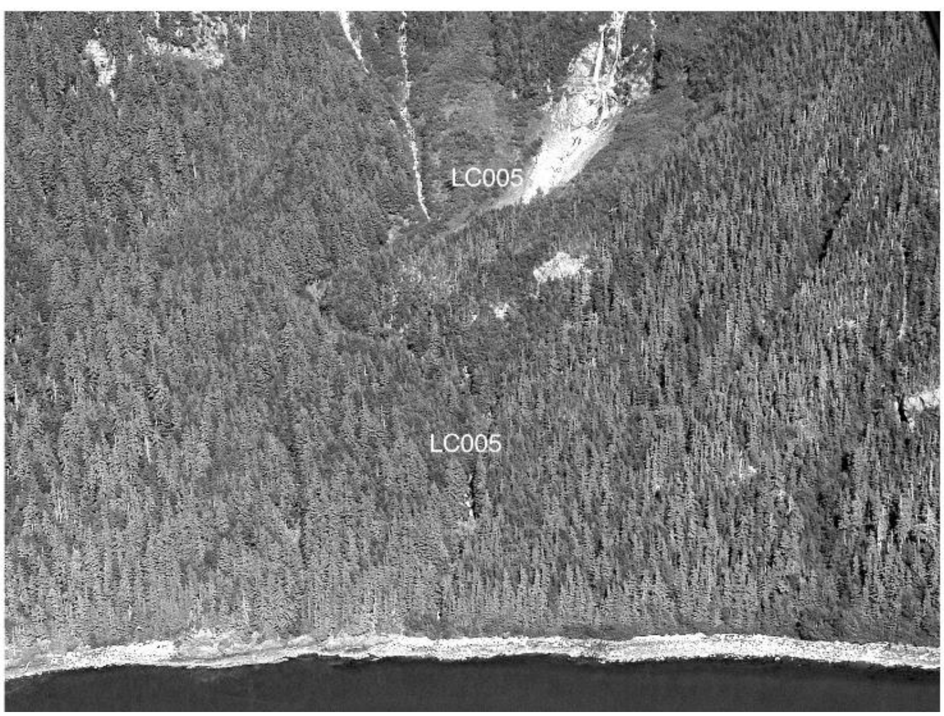
Path: LC004

Path Group:	North Kensington
Latitude-Longitude:	58.563007 -135.102606
Max Width:	1330 feet / 405 meters
Typical Width:	140 feet / 43 meters
Starting Elevation:	1000 feet / 305 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	open scrub forest
Start Aspect:	WSW
Path Type:	open scrub forest and small gully
Runout Angle:	steep
Unmitigated avalanche hazard index (AHI):	0.08
Structural Mitigation:	None
Structurally Mitigated AHI:	0.08
AHI with Forecasting and Exploders:	0.02



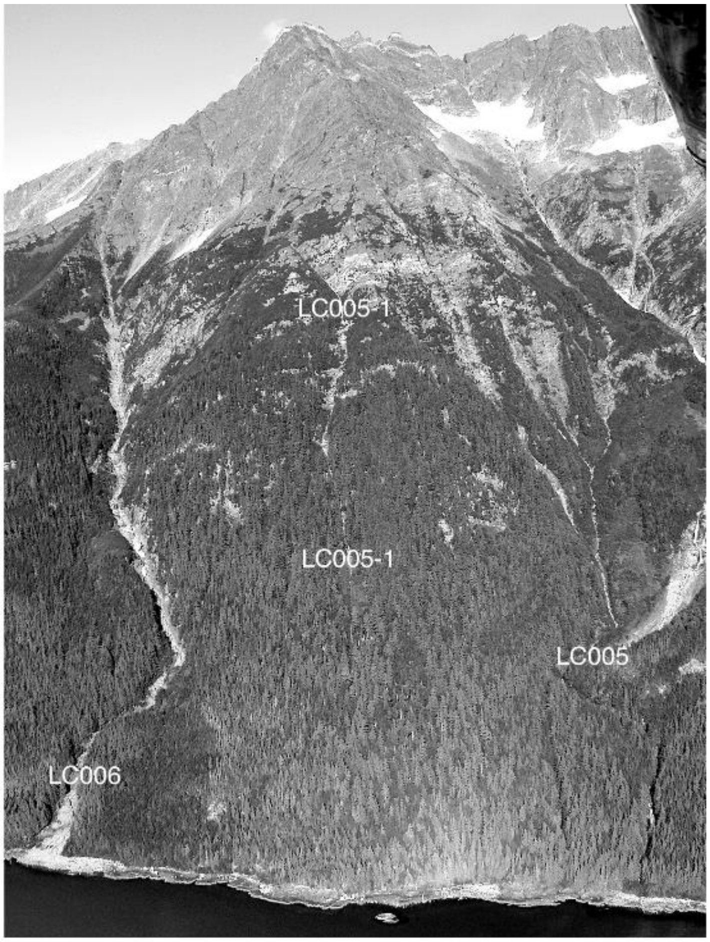
The Eldred Rock paths are among the most active paths affecting the East Lynn Canal alignment. Several combinations of explosive delivery options were evaluated for these paths including helicopter placement, firing a 105mm howitzer from a secure enclosure on Eldred Rock, and remotely operated blaster box installations in the starting zones.

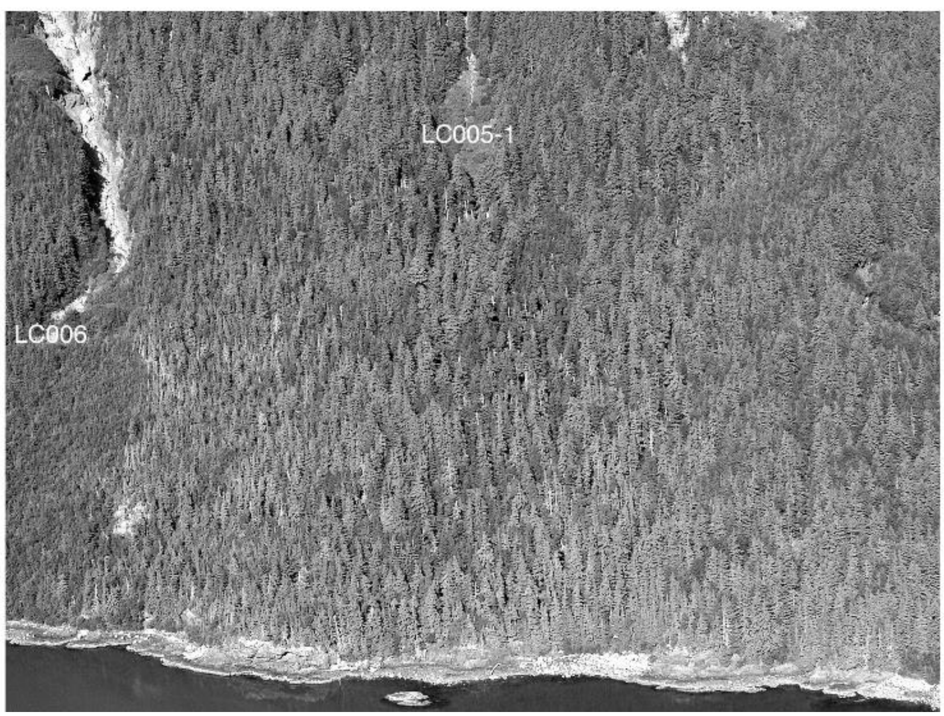

LC005
LC005
LC005
LC005


LC005
LC005

Path: LC005

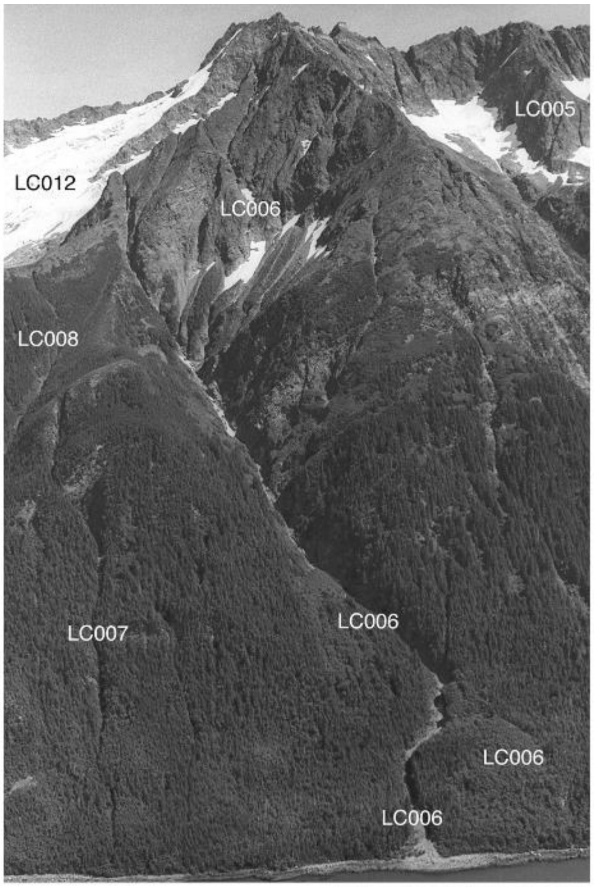
Path Group:	Eldred Rock
Latitude-Longitude:	58.571584 -135.101956
Max Width:	1150 feet / 351 meters
Typical Width:	150 feet / 46 meters
Starting Elevation:	5500 feet / 1676 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl
Start Aspect:	W
Path Type:	confined to 600’ (183 m); steep gully below
Runout Angle:	usually stops on bench; steep again below
Unmitigated avalanche hazard index (AHI):	2.19
Structural Mitigation:	Bridge 0.2 x
Structurally Mitigated AHI:	0.44
AHI with Forecasting and Exploders:	0.13

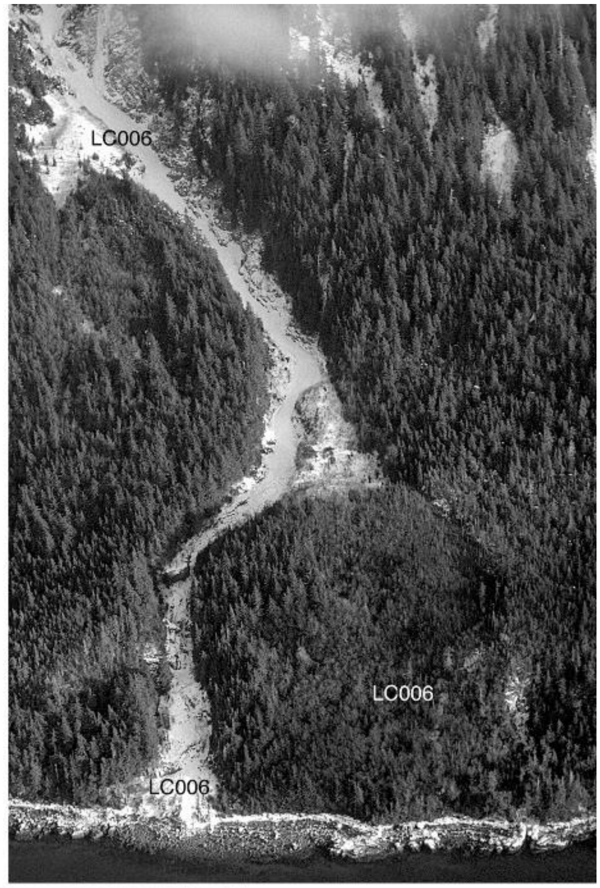

LC005-1
LC005-1
LC005
LC006


LC005-1
LC006

Path: LC005-1

Path Group:	Eldred Rock
Latitude-Longitude:	58.572924 -135.102566
Max Width:	100 feet / 30 meters
Typical Width:	0 feet / meters (usually stops above alignment)
Starting Elevation:	3100 feet / 945 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	slight gully
Start Aspect:	WSW
Path Type:	shallow gully
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.01
Structural Mitigation:	None
Structurally Mitigated AHI:	0.01
AHI with Forecasting and Exploders:	0.00


LC005
LC012
LC006
LC008
LC007
LC006
LC006
LC006


LC006
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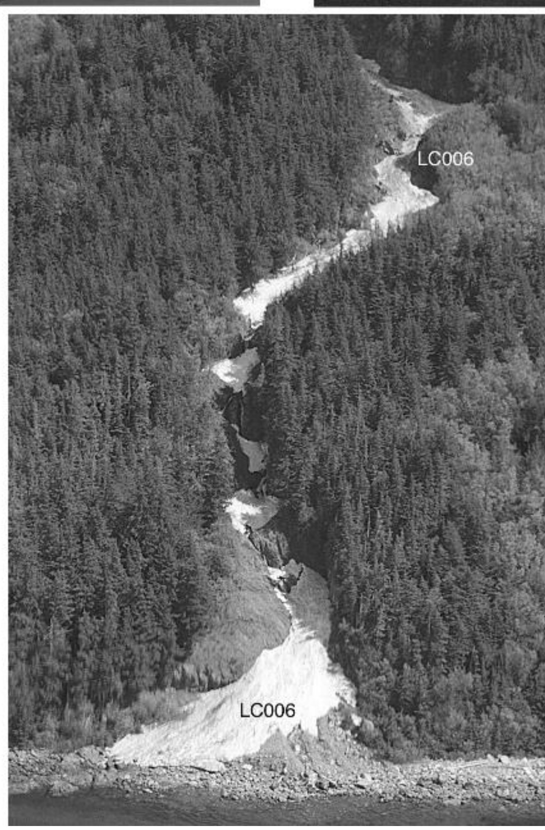
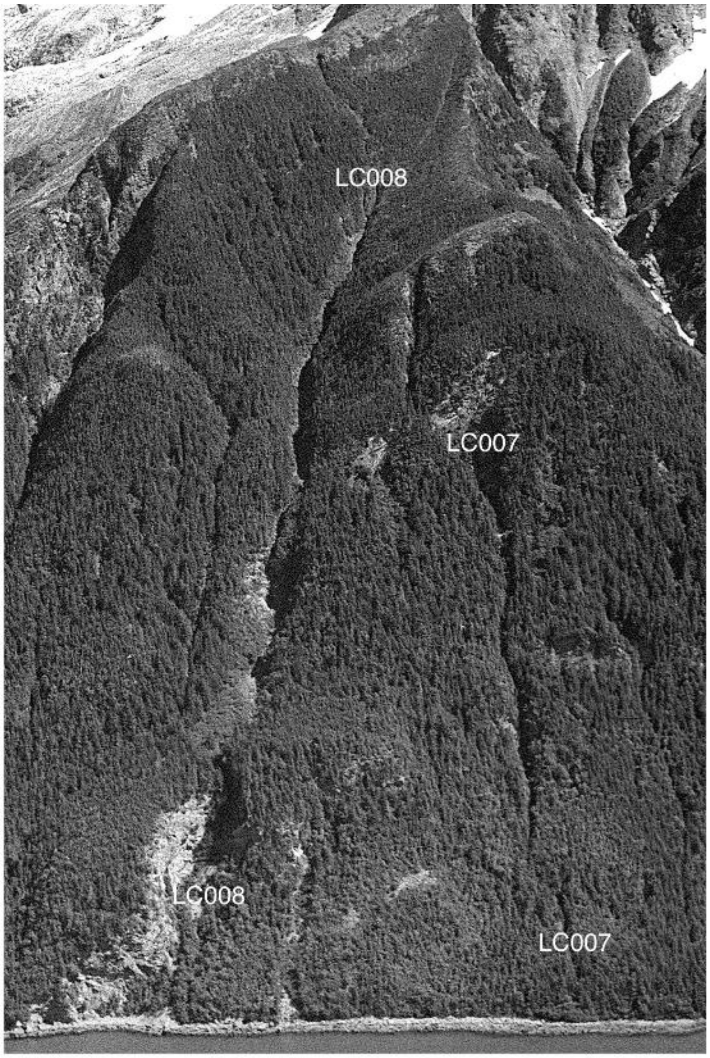
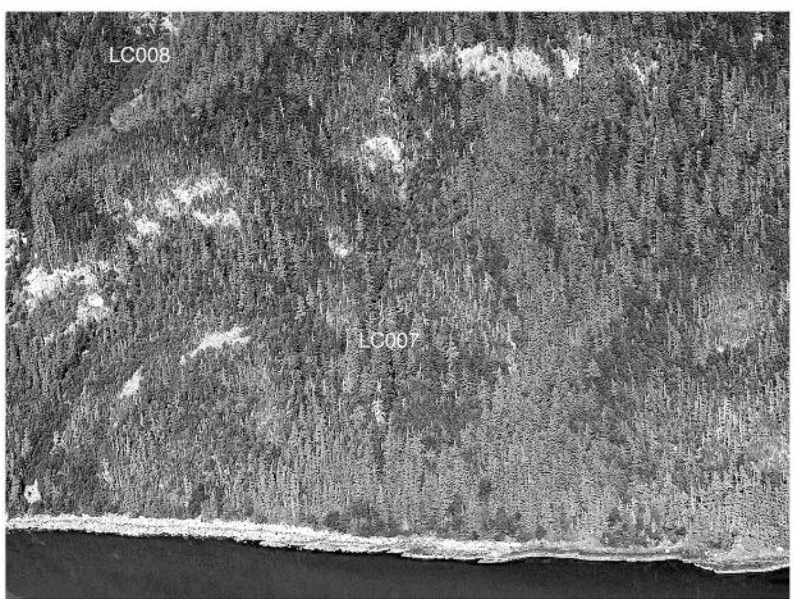

LC006
LC006

Path: LC006

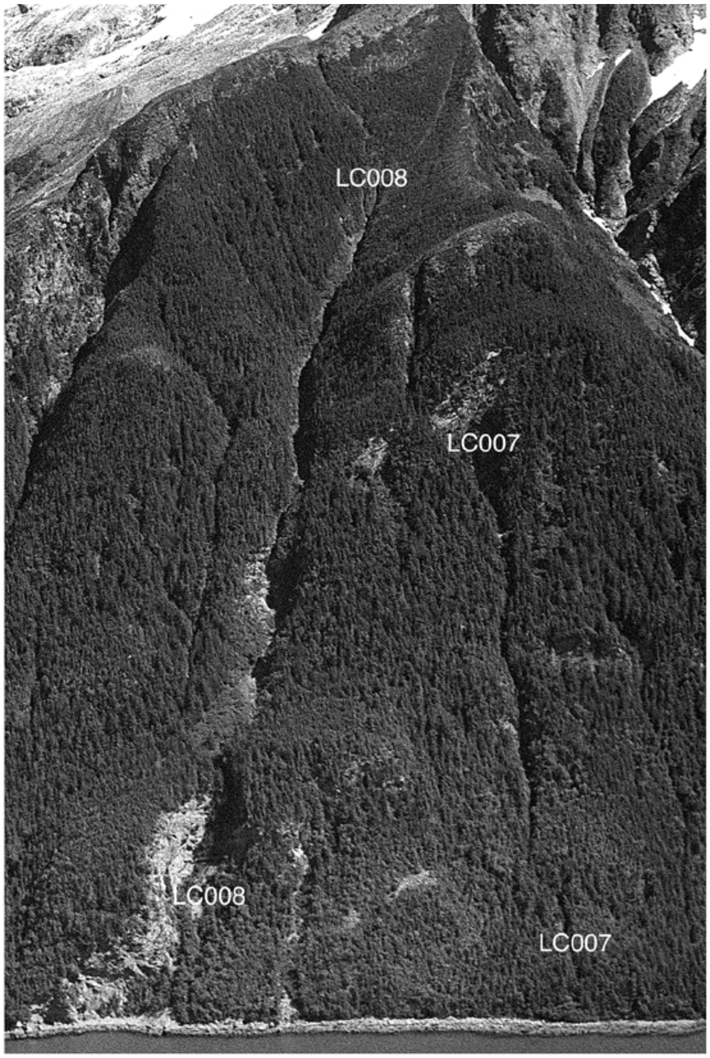
Path Group:	Eldred Rock
Latitude-Longitude:	58.574197 -135.102504
Max Width:	1200 feet / 366 meters
Typical Width:	270 feet / 82 meters
Starting Elevation:	5100 feet / 1554 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big gullied bowl
Start Aspect:	W
Path Type:	classic confined, angled track
Runout Angle:	decreases moderately
Unmitigated avalanche hazard index (AHI):	42.82
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	8.56
AHI with Forecasting and Exploders:	2.57

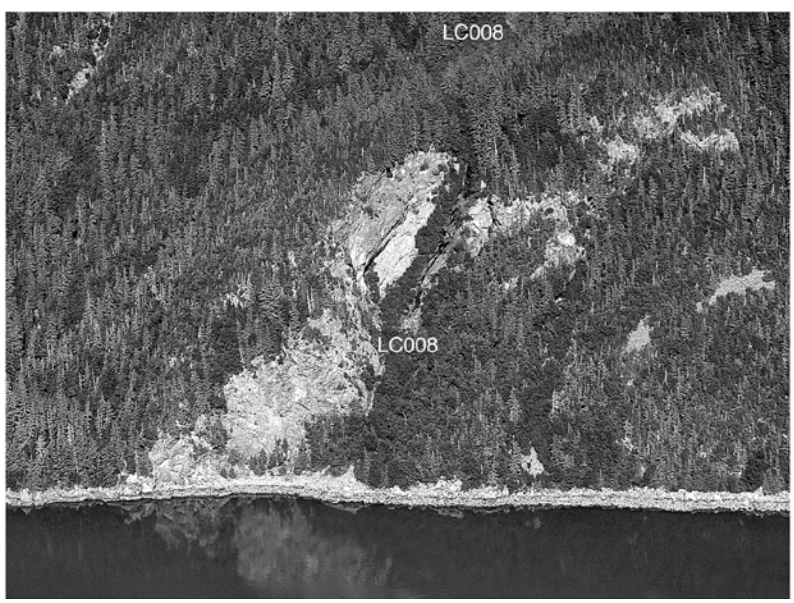

LC008
LC007
LC008
LC007


LC008
LC007

Path: LC007

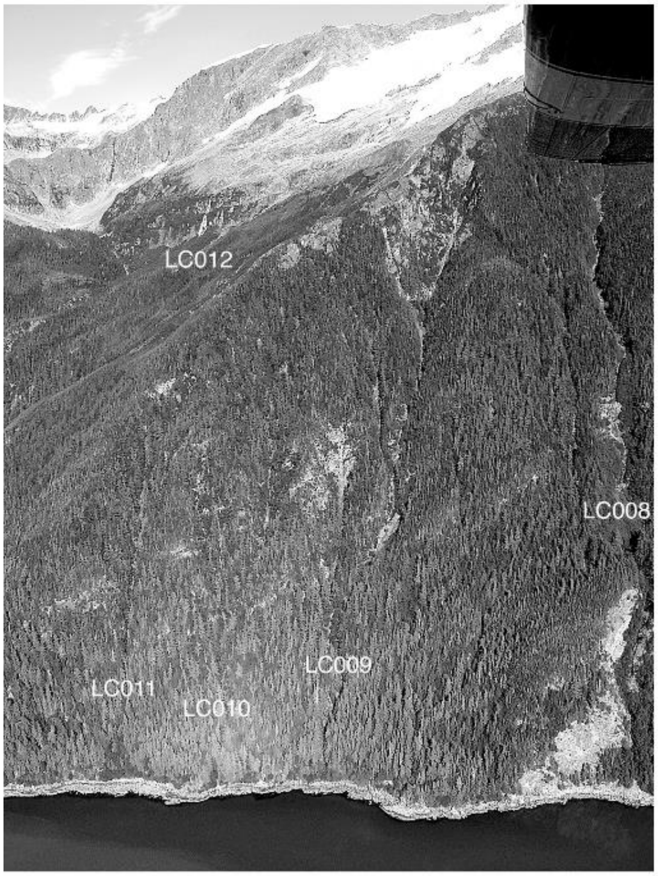
Path Group:	Eldred Rock
Latitude-Longitude:	58.575893 -135.102543
Max Width:	380 feet / 116 meters
Typical Width:	75 feet / 23 meters
Starting Elevation:	2100 feet / 640 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	small bowl/gully
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.17
Structural Mitigation:	None
Structurally Mitigated AHI:	0.17
AHI with Forecasting and Exploders:	0.05

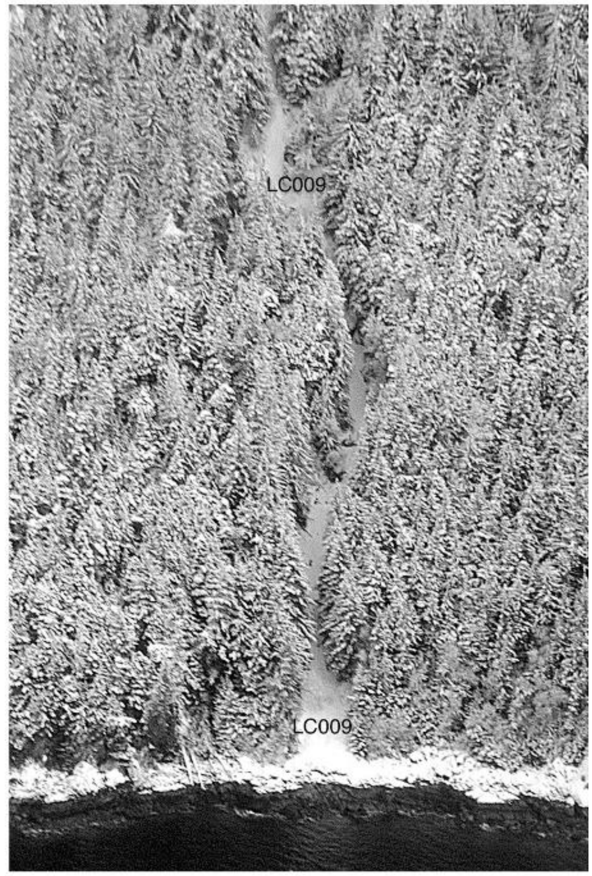

LC008
LC007
LC008
LC007

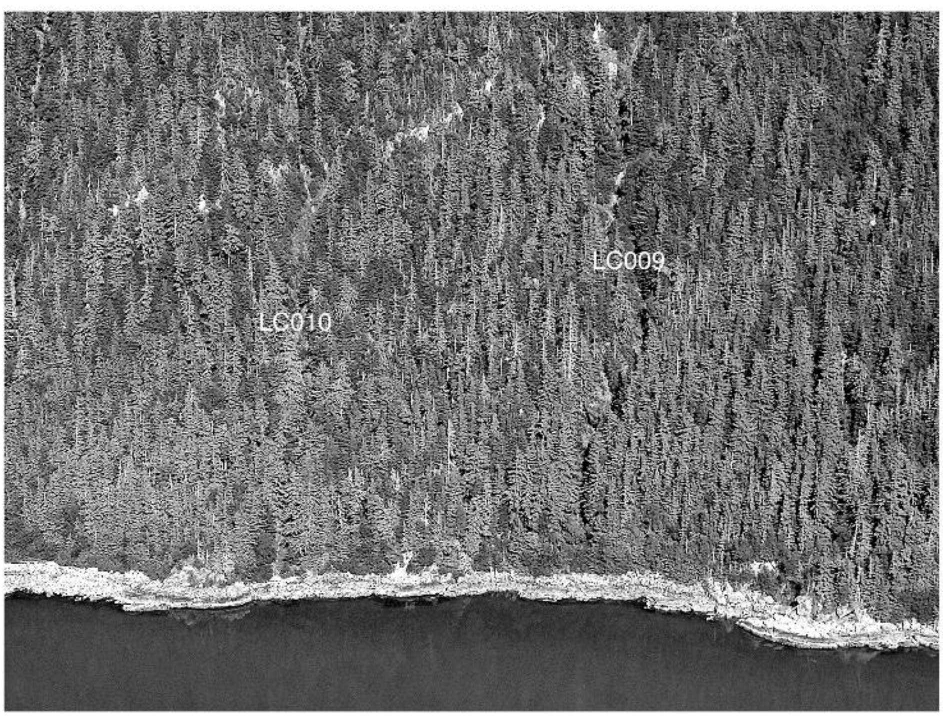

LC008
LC008

Path: LC008

Path Group:	Eldred Rock
Latitude-Longitude:	58.580951 -135.102467
Max Width:	1040 feet / 317 meters
Typical Width:	170 feet / 52 meters
Starting Elevation:	3400 feet / 1036 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	medium bowl
Start Aspect:	W
Path Type:	classic confined
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	4.22
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.84
AHI with Forecasting and Exploders:	0.25

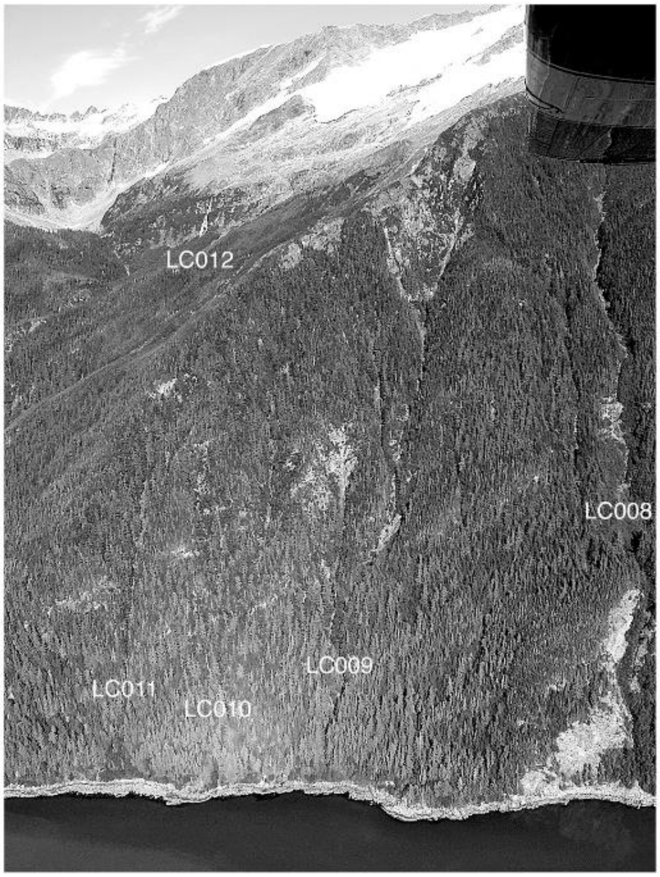

LC012
LC008
LC011
LC010
LC009


LC009
LC009


LC009
LC010

Path: LC009

Path Group:	Eldred Rock
Latitude-Longitude:	58.582368 -135.102472
Max Width:	110 feet / 34 meters
Typical Width:	90 feet / 27 meters
Starting Elevation:	2700 feet / 823 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	small bowl and gullies
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	slight decrease
Unmitigated avalanche hazard index (AHI):	4.55
Structural Mitigation:	None
Structurally Mitigated AHI:	4.55
AHI with Forecasting and Exploders:	1.36


LC012
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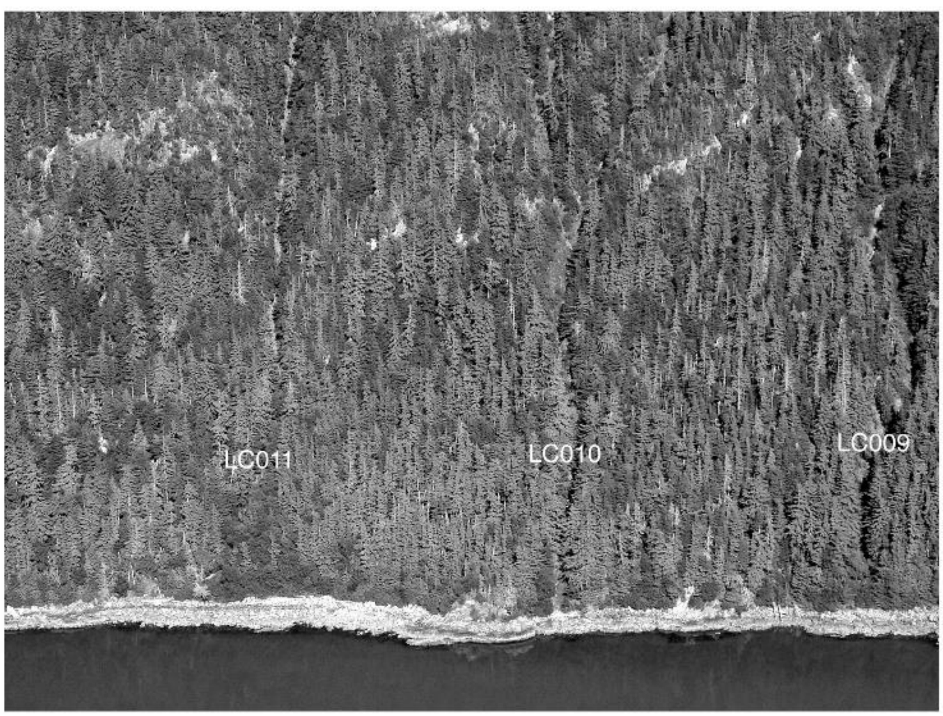
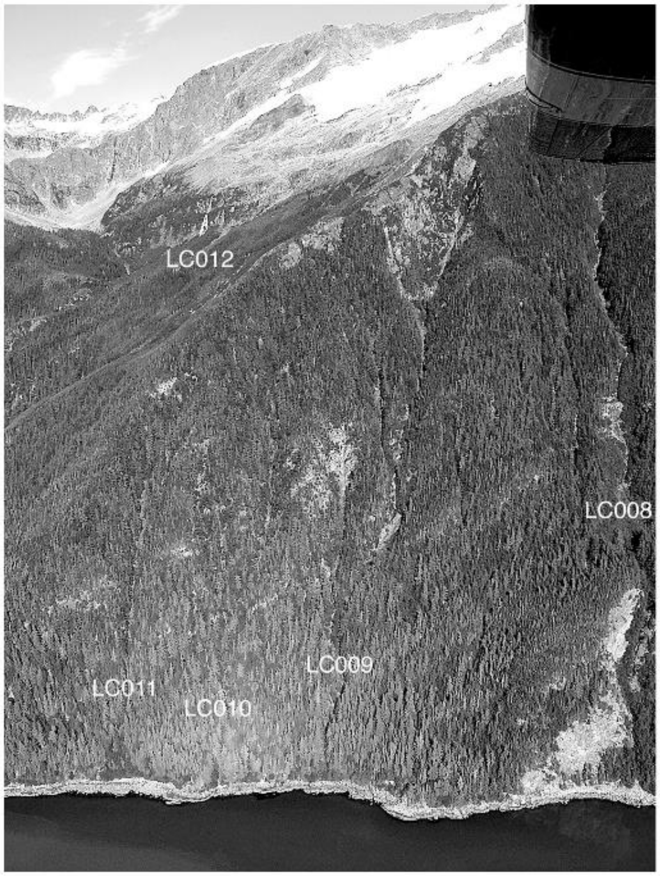
LC011
LC010


LC011
LC010
LC009

Path: LC010

Path Group:	Eldred Rock
Latitude-Longitude:	58.58277 -135.102473
Max Width:	100 feet / 30 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	narrow gully
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	slight decrease
Unmitigated avalanche hazard index (AHI):	3.02
Structural Mitigation:	None
Structurally Mitigated AHI:	3.02
AHI with Forecasting and Exploders:	0.91


LC012
LC008
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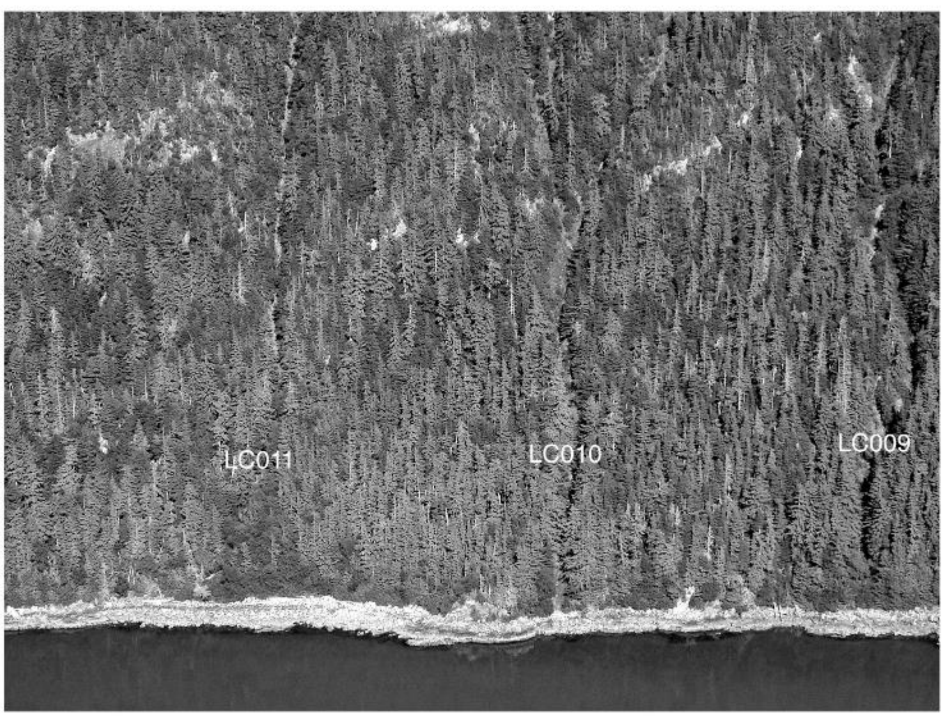
LC010


LC011
LC010
LC009

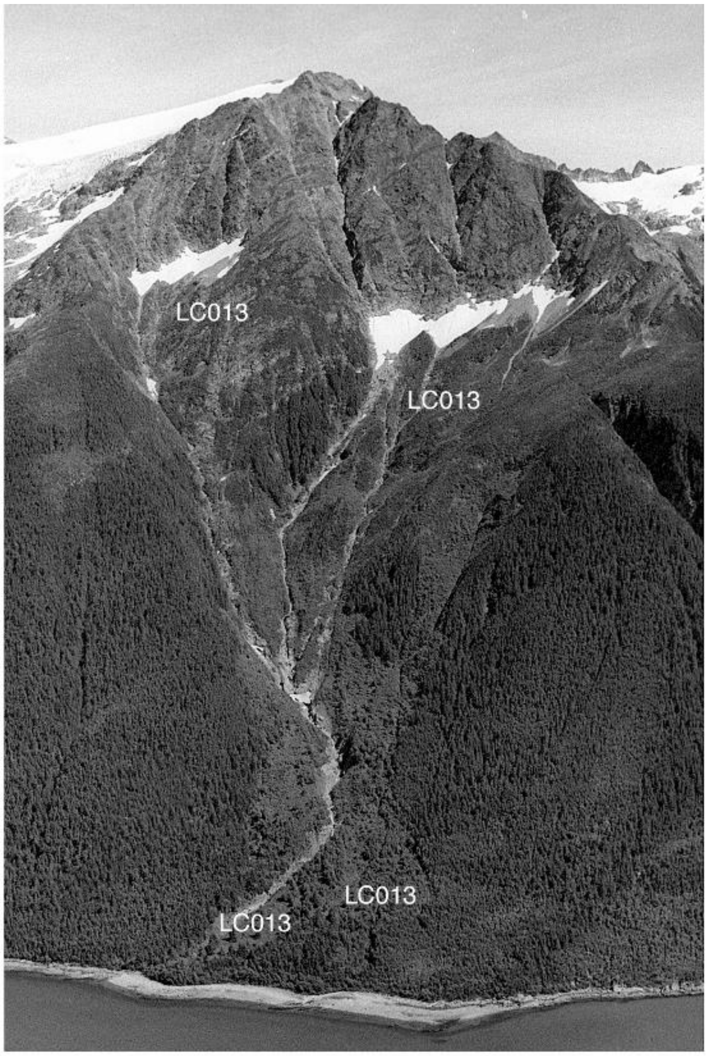
Path: LC011

Path Group:	Eldred Rock
Latitude-Longitude:	58.583286 -135.102475
Max Width:	110 feet / 34 meters
Typical Width:	90 feet / 27 meters
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	narrow gully
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	slight decrease
Unmitigated avalanche hazard index (AHI):	2.71
Structural Mitigation:	None
Structurally Mitigated AHI:	2.71
AHI with Forecasting and Exploders:	0.81


LC012
LC012
LC012
LC012

Path: LC012

Path Group:	Eldred Rock
Latitude-Longitude:	58.585938 -135.102898
Max Width:	1190 feet / 363 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	5924 feet / 1806 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl and broad gullies
Start Aspect:	W
Path Type:	bowl & gullies to 500’ (153m); narrow gully
Runout Angle:	moderate decrease to usual stop on bench; steep
Unmitigated avalanche hazard index (AHI):	3.39
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.68
AHI with Forecasting and Exploders:	0.20


LC013
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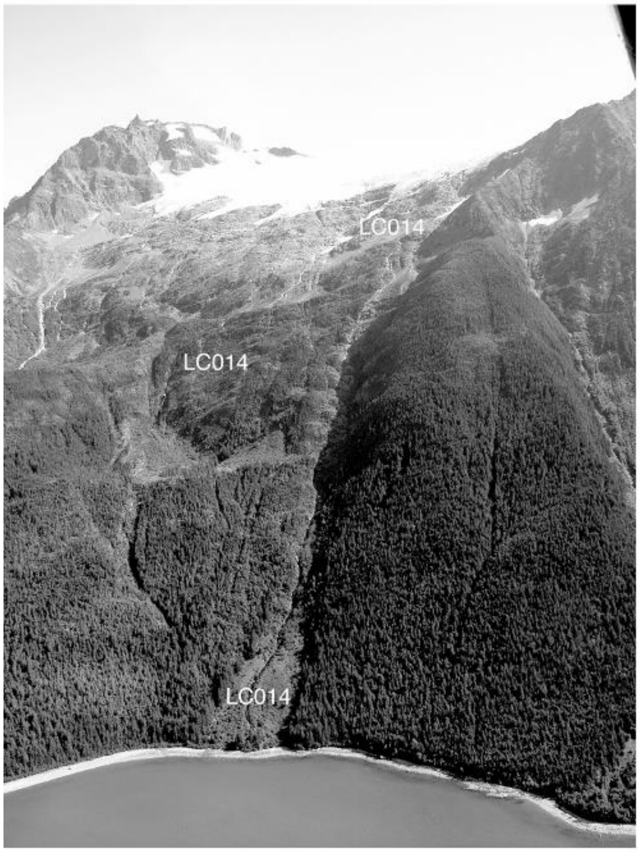
LC013
LC013


LC013
LC013

Path: LC013

Path Group:	Eldred Rock
Latitude-Longitude:	58.593939 -135.103925
Max Width:	2860 feet / 872 meters
Typical Width:	340 feet / 104 meters
Starting Elevation:	5300 feet / 1615 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	two big gullied bowls
Start Aspect:	W
Path Type:	classic confined
Runout Angle:	decreases gradually
Unmitigated avalanche hazard index (AHI):	1.35
Structural Mitigation:	None
Structurally Mitigated AHI:	1.35
AHI with Forecasting and Exploders:	0.40


LC014
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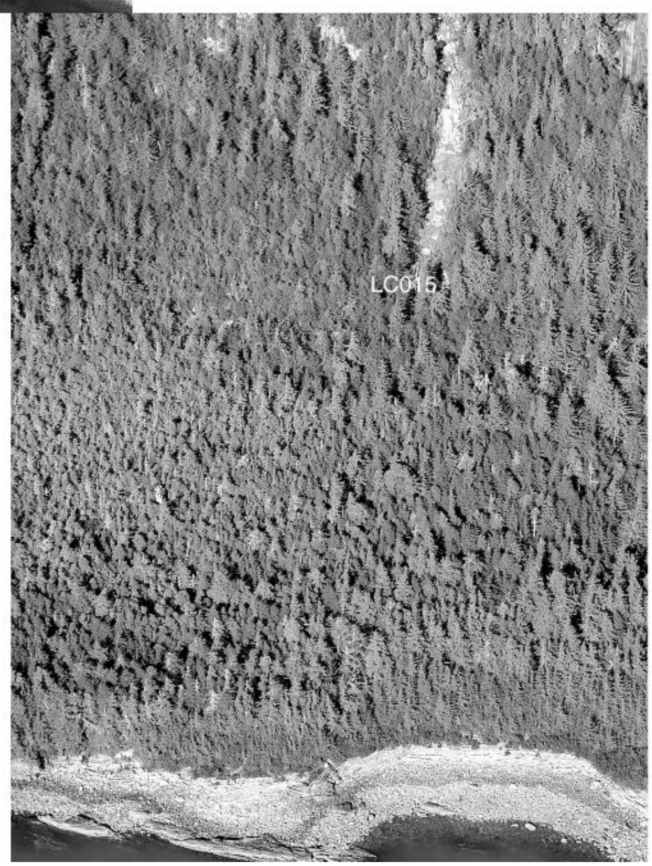
LC014


LC014

Path: LC014

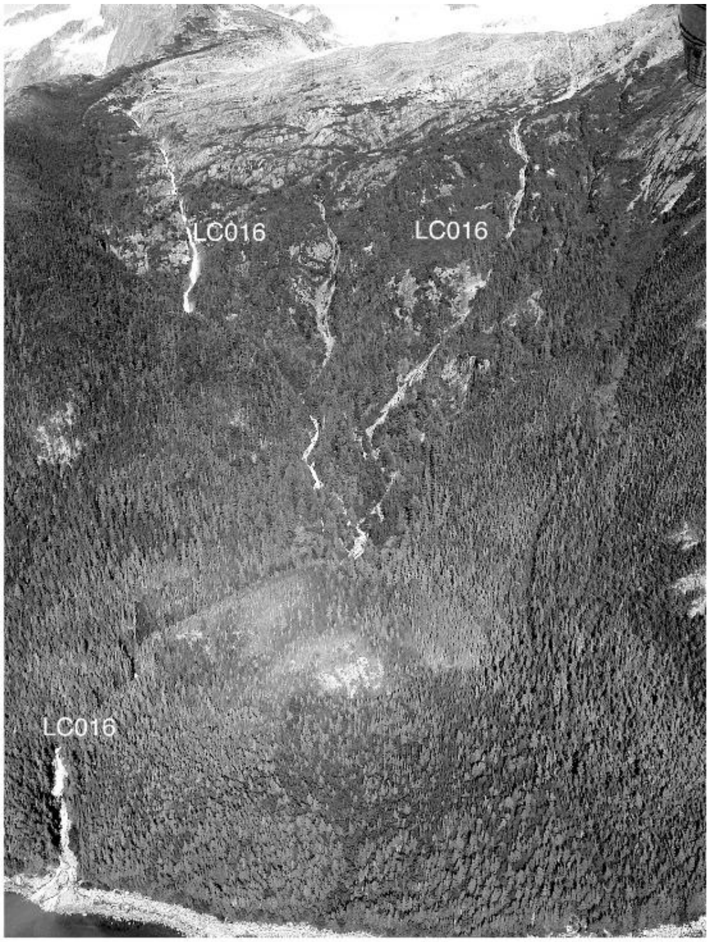
Path Group:	Eldred Rock
Latitude-Longitude:	58.595964 -135.103751
Max Width:	750 feet / 229 meters
Typical Width:	120 feet / 37 meters
Starting Elevation:	4700 feet / 1432 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	rollover, very broad bowl
Start Aspect:	W
Path Type:	broad confined main path; broad track
Runout Angle:	decreases gradually
Unmitigated avalanche hazard index (AHI):	8.88
Structural Mitigation:	33 foot / 10meter elevated fill 0.5x
Structurally Mitigated AHI:	4.44
AHI with Forecasting and Exploders:	1.33


LC015


LC015

Path: LC015

Path Group:	Eldred Rock
Latitude-Longitude:	59.012272 -135.115548
Max Width:	60 feet / 18 meters
Typical Width:	0 feet / 0 meters (usually stops above alignment)
Starting Elevation:	800 feet / 244 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	cliff notch
Start Aspect:	WSW
Path Type:	gully in cliff
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.05
Structural Mitigation:	None
Structurally Mitigated AHI:	0.05
AHI with Forecasting and Exploders:	0.02


LC016
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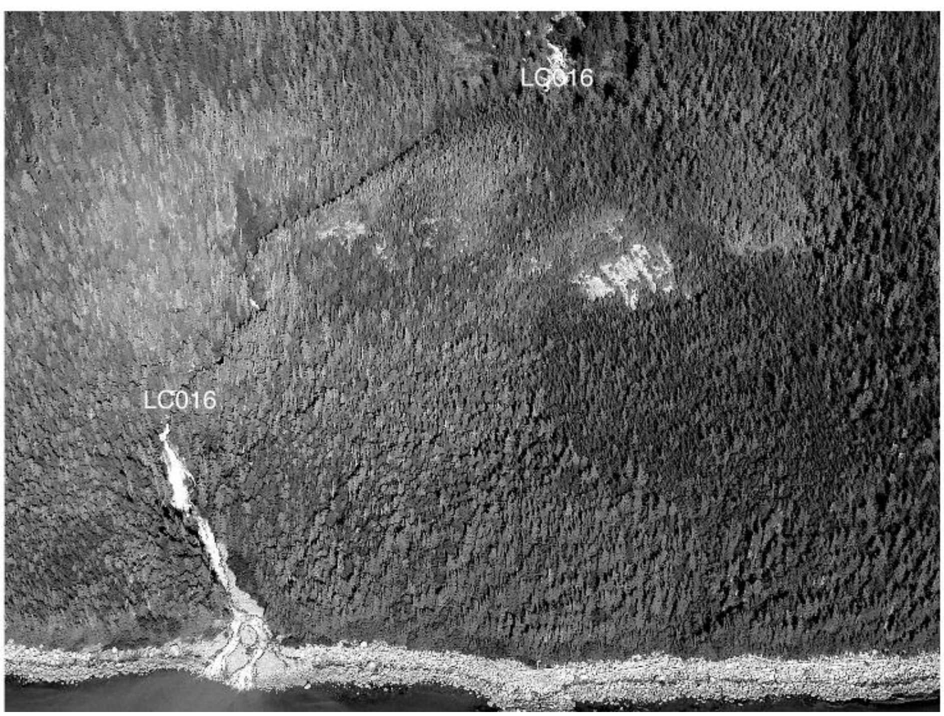
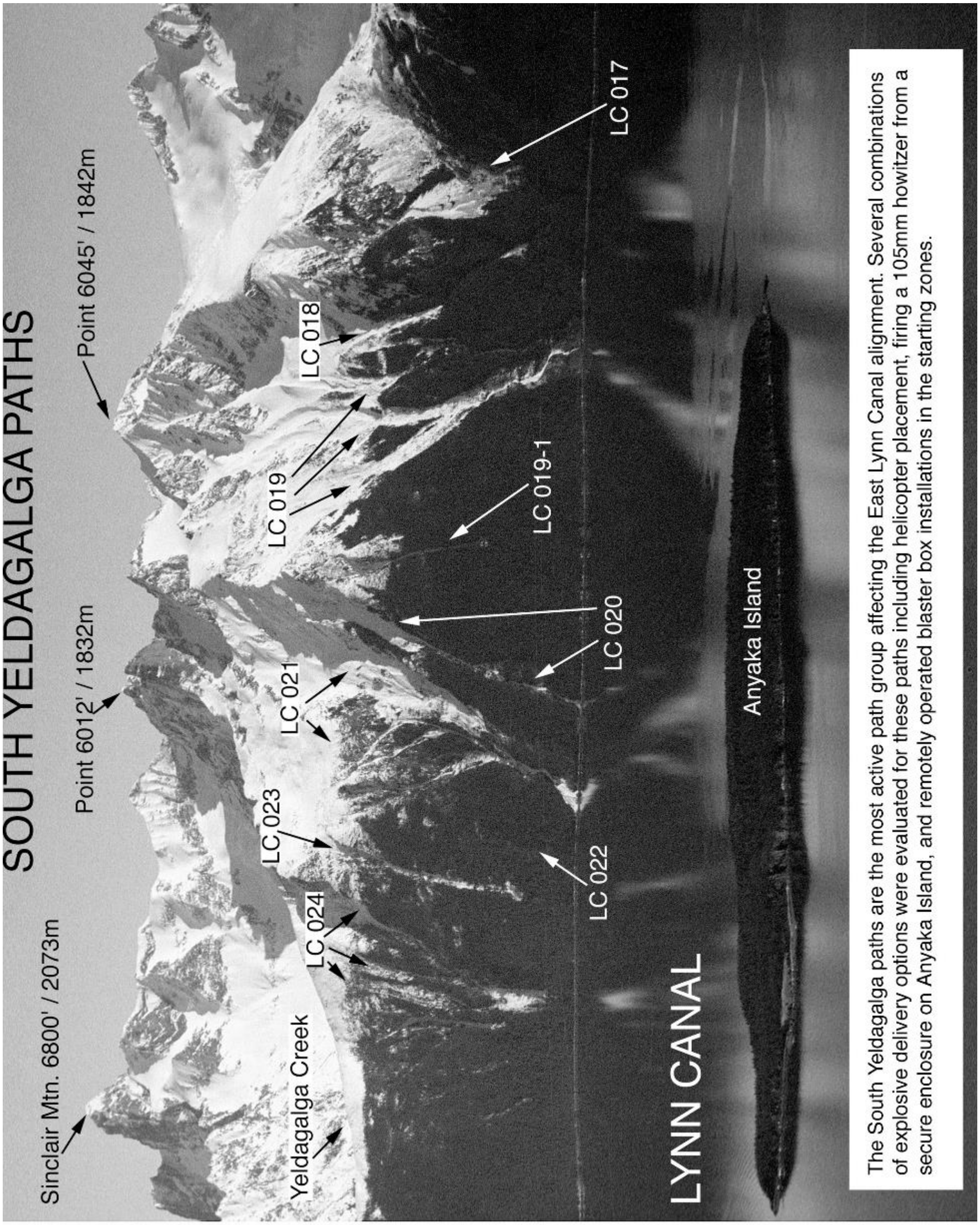
LC016

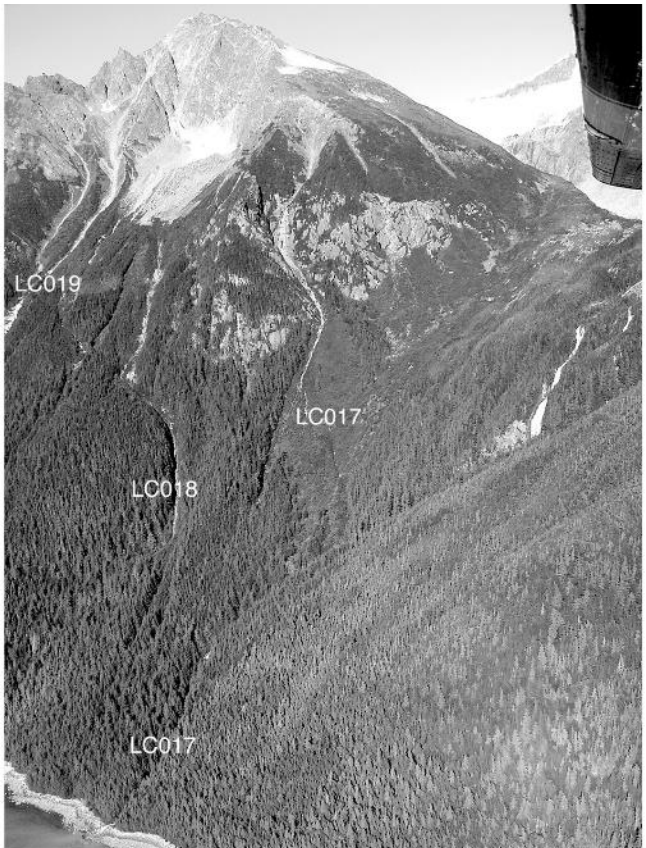

LC016
LC016

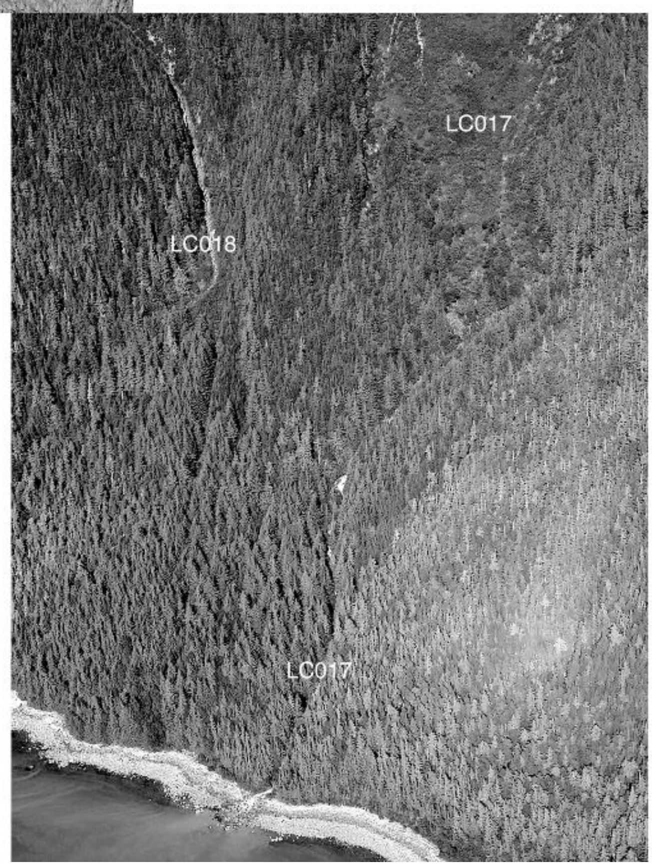
Path: LC016

Path Group:	South Yeldagalga
Latitude-Longitude:	59.015936 -135.120994
Max Width:	2290 feet / 698 meters
Typical Width:	210 feet / 64 meters
Starting Elevation:	3200 feet / 975 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	glacier and rollover; former ice avalanche path
Start Aspect:	W
Path Type:	broad start, track; runout gully; spillover
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.15
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.03
AHI with Forecasting and Exploders:	0.01



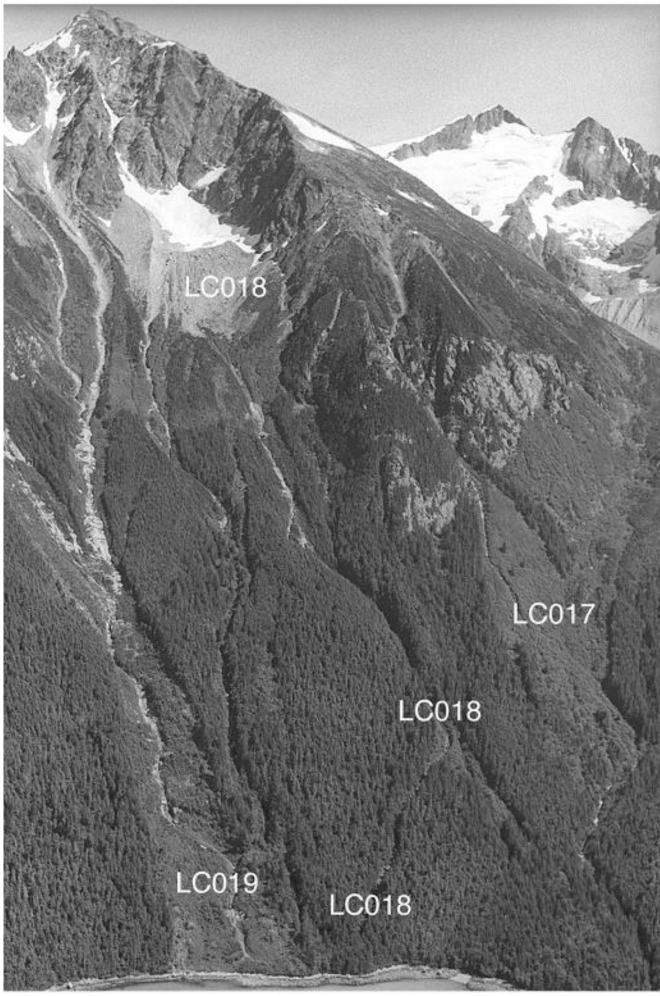
The South Yeldagalga paths are the most active path group affecting the East Lynn Canal alignment. Several combinations of explosive delivery options were evaluated for these paths including helicopter placement, firing a 105mm howitzer from a secure enclosure on Anyaka Island, and remotely operated blaster box installations in the starting zones.

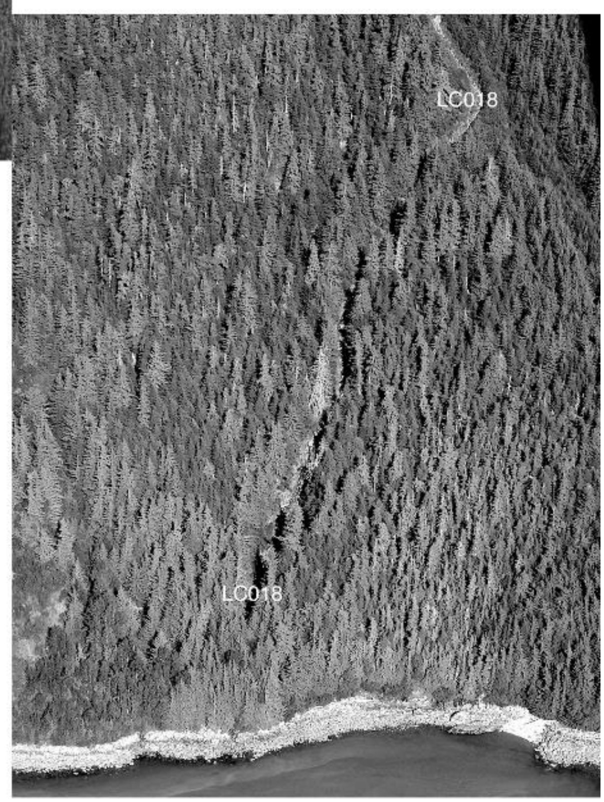

LC019
LC017
LC018
LC017


LC017
LC018
LC017

Path: LC017

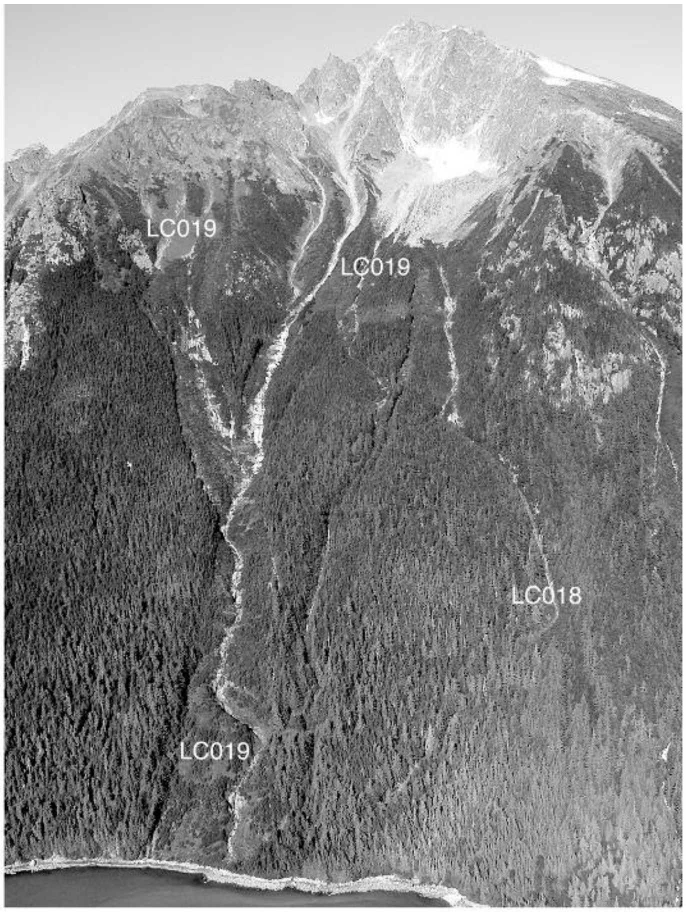
Path Group:	South Yeldagalga
Latitude-Longitude:	59.025529 -135.115683
Max Width:	1420 feet / 433 meters
Typical Width:	170 feet / 52 meters
Starting Elevation:	4800 feet / 1463 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	broad face
Start Aspect:	W
Path Type:	face to bowl and gullies
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.19
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.04
AHI with Forecasting and Exploders:	0.01

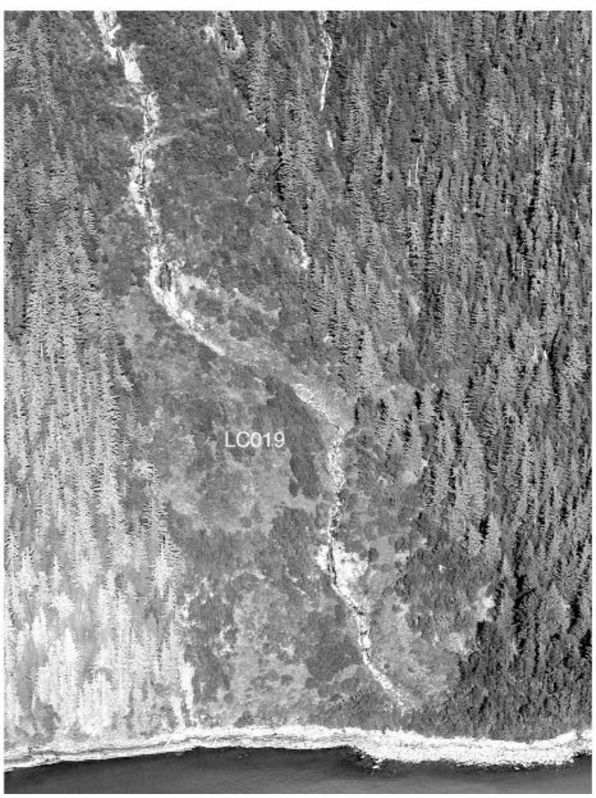

LC018
LC017
LC018
LC019
LC018


LC018
LC018

Path: LC018

Path Group:	South Yeldagalga
Latitude-Longitude:	59.030621 -135.115461
Max Width:	980 feet / 299 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	4700 feet / 1432 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	part of big bowl
Start Aspect:	W
Path Type:	bowl to narrow gully
Runout Angle:	decreases moderately; combines with LC019
Unmitigated avalanche hazard index (AHI):	4.08
Structural Mitigation:	None
Structurally Mitigated AHI:	4.08
AHI with Forecasting and Exploders:	1.22

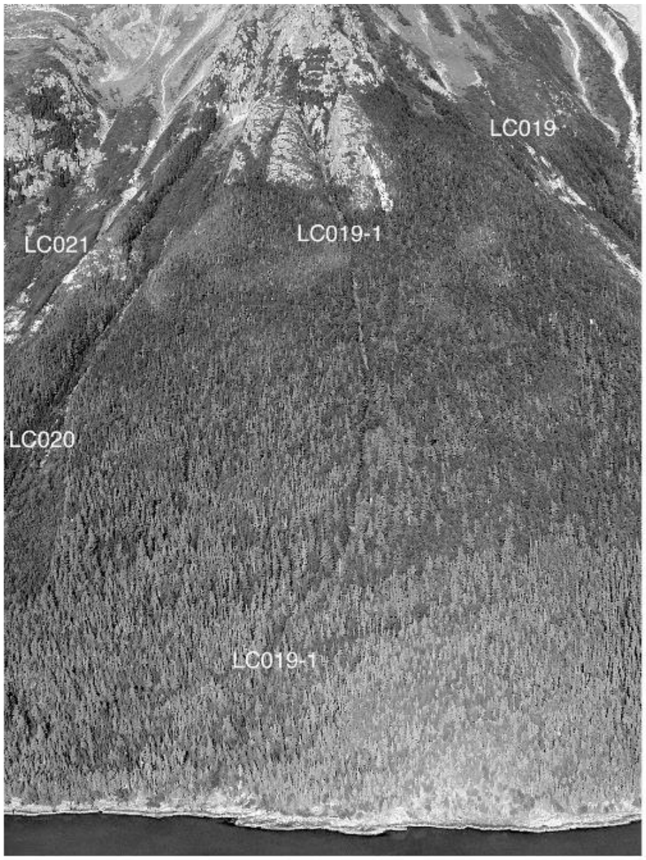

LC019
LC019
LC018
LC019

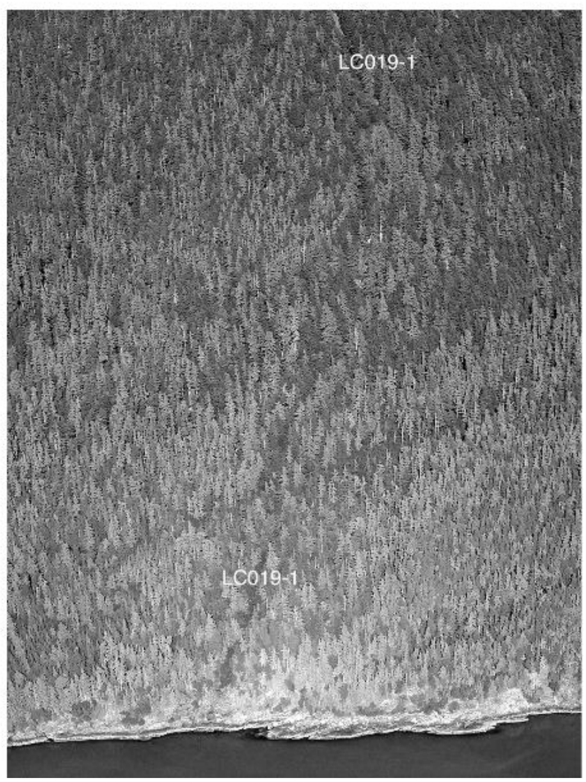

LC019


LC019
LC018
LC019

Path: LC019

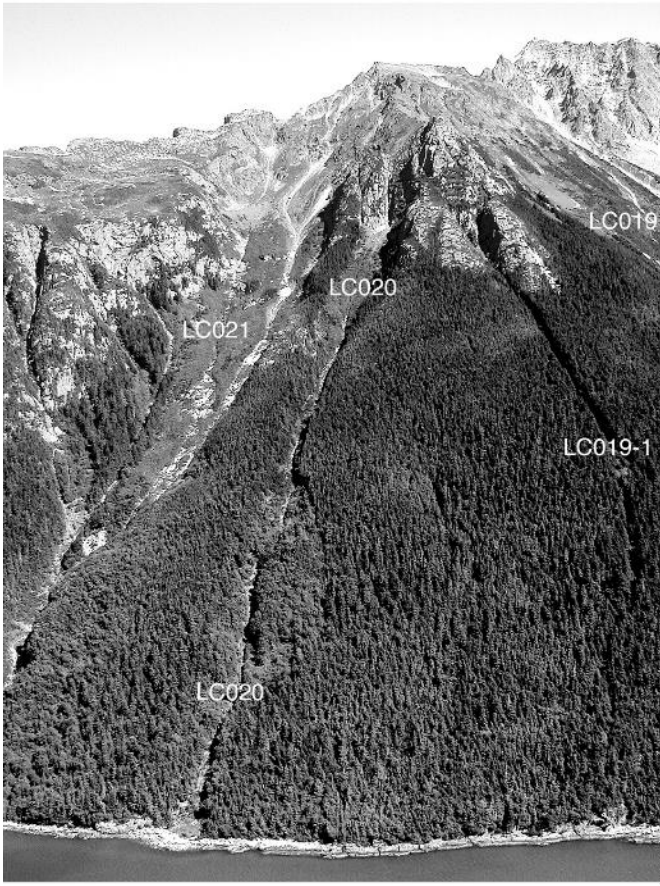
Path Group:	South Yeldagalga
Latitude-Longitude:	59.0311 -135.11558
Max Width:	980 feet / 299 meters
Typical Width:	500 feet / 152 meters
Starting Elevation:	6300 feet / 1920 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	WSW
Path Type:	confined; broad track feeds from several areas
Runout Angle:	slight decrease; combines with LC018
Unmitigated avalanche hazard index (AHI):	58.35
Structural Mitigation:	800 foot / 244 meter snowshed
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00

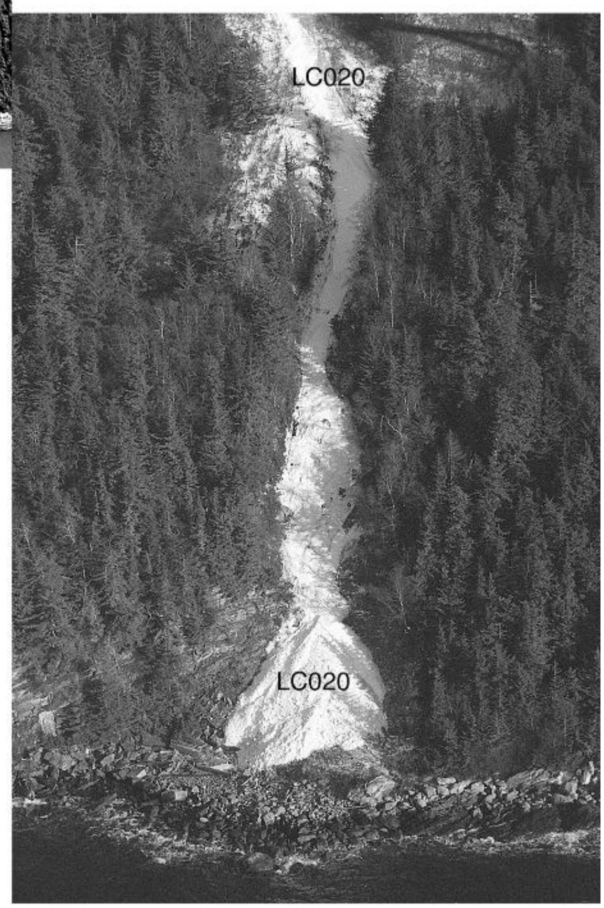

LC019
LC019-1
LC021
LC020
LC019-1


LC019-1
LC019-1

Path: LC019-1

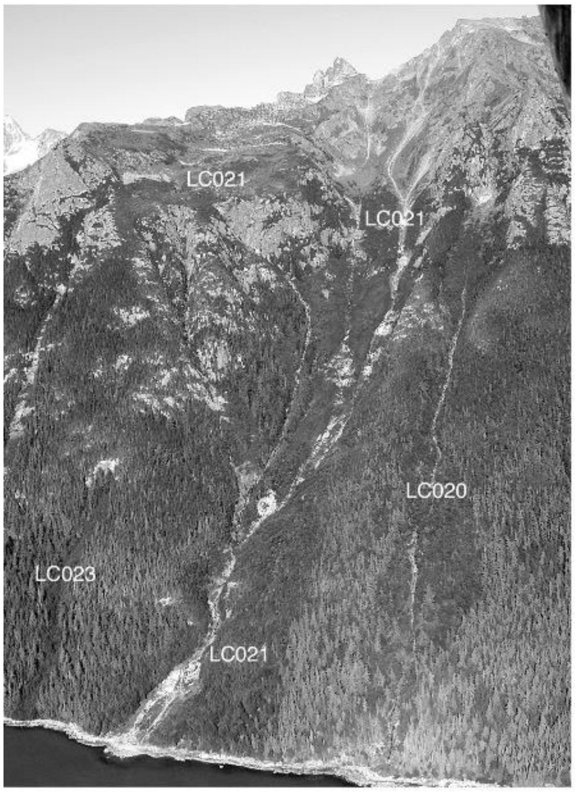
Path Group:	South Yeldagalga
Latitude-Longitude:	59.033816 -135.121281
Max Width:	80 feet / 24 meters
Typical Width:	0 feet / 0 meters (usually stops above alignment)
Starting Elevation:	3200 feet / 975 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	small bowl
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.60
Structural Mitigation:	None
Structurally Mitigated AHI:	0.60
AHI with Forecasting and Exploders:	0.18

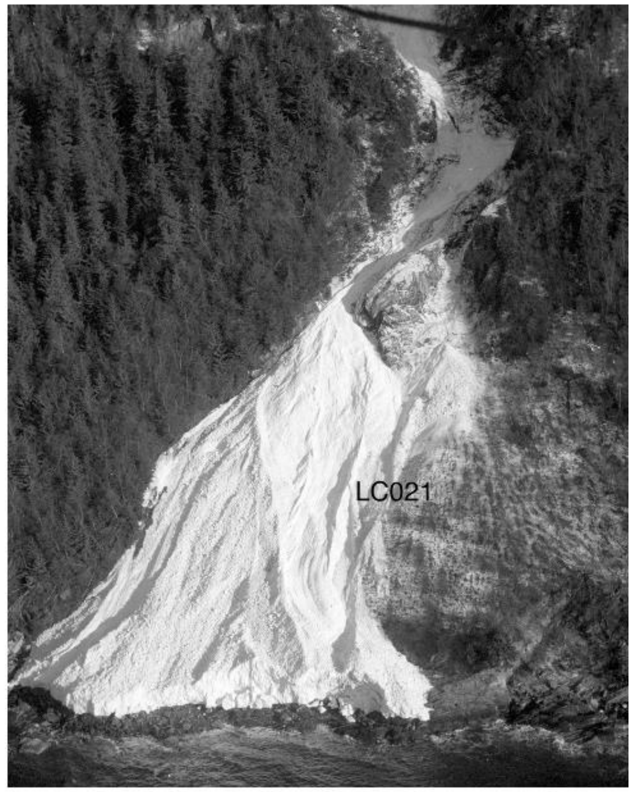

LC019
LC020
LC021
LC019-1
LC020


LC020
LC020

Path: LC020

Path Group:	South Yeldagalga
Latitude-Longitude:	59.03537 -135.121583
Max Width:	400 feet / 122 meters
Typical Width:	160 feet / 49 meters
Starting Elevation:	3700 feet / 1128 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	small bowl
Start Aspect:	WNW
Path Type:	classic confined, broad gully track
Runout Angle:	slight decrease; very active path
Unmitigated avalanche hazard index (AHI):	16.25
Structural Mitigation:	300 foot / 91m snowshed
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00

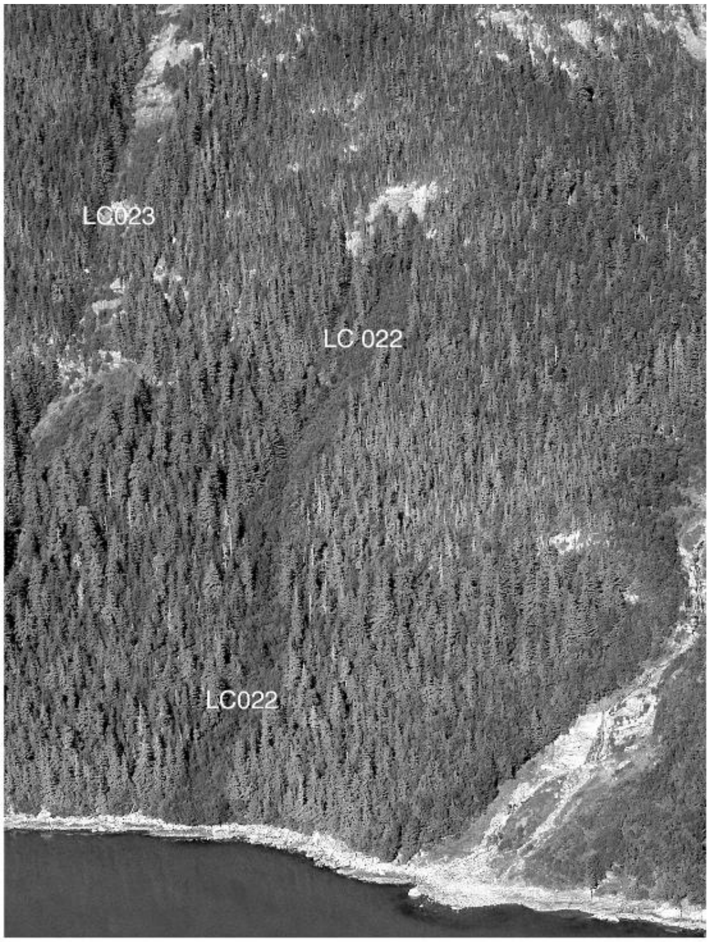

LC021
LC021
LC020
LC023
LC021

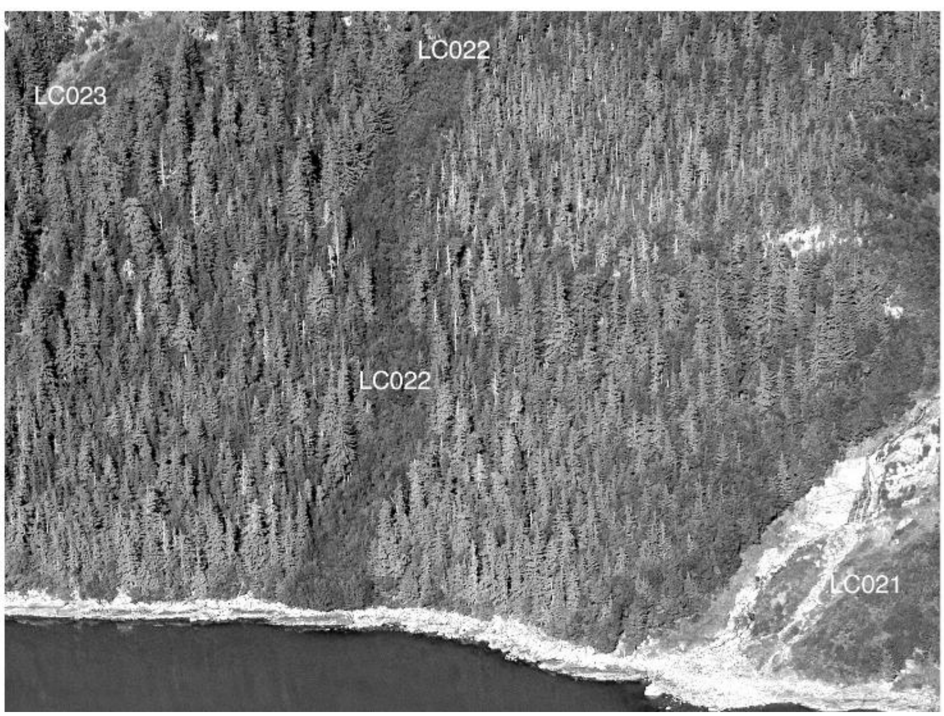

LC021


LC021
LC021

Path: LC021

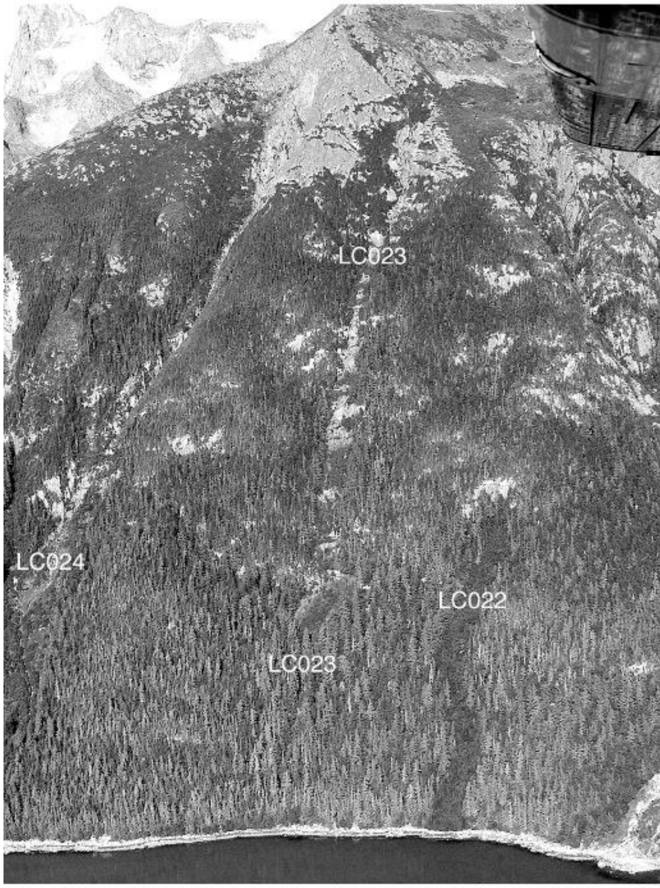
Path Group:	South Yeldagalga
Latitude-Longitude:	59.040632 -135.121461
Max Width:	1240 feet / 378 meters
Typical Width:	600 feet / 183 meters
Starting Elevation:	4800 feet / 1463 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	W
Path Type:	classic confined, very large bowl to broad gully
Runout Angle:	slight decrease; most active path on route
Unmitigated avalanche hazard index (AHI):	47.14
Structural Mitigation:	400 foot / 122 meter snowshed
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00


LC023
LC 022
LC022


LC022
LC023
LC022
LC021

Path: LC022

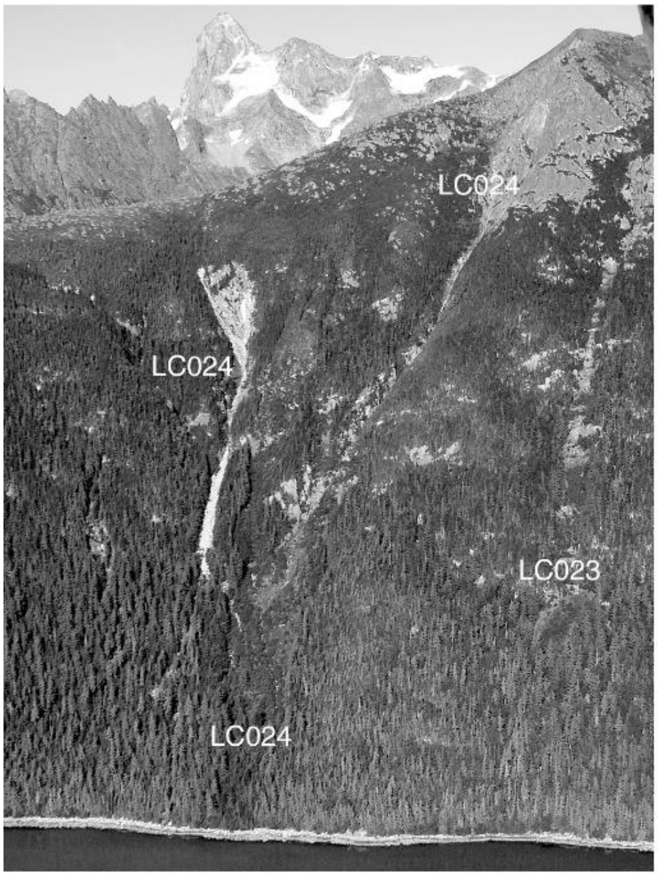
Path Group:	South Yeldagalga
Latitude-Longitude:	59.04131 -135.121194
Max Width:	110 feet / 34 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	small rock slab and talus
Start Aspect:	W
Path Type:	small unconfined track
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	0.14
Structural Mitigation:	None
Structurally Mitigated AHI:	0.14
AHI with Forecasting and Exploders:	0.04

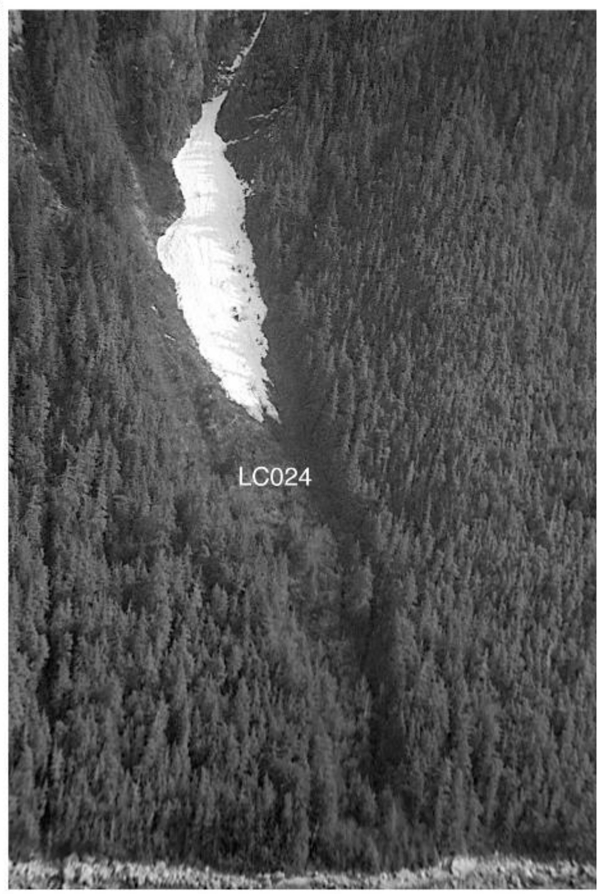

LC023
LC024
LC022
LC023


LC023
LC023

Path: LC023

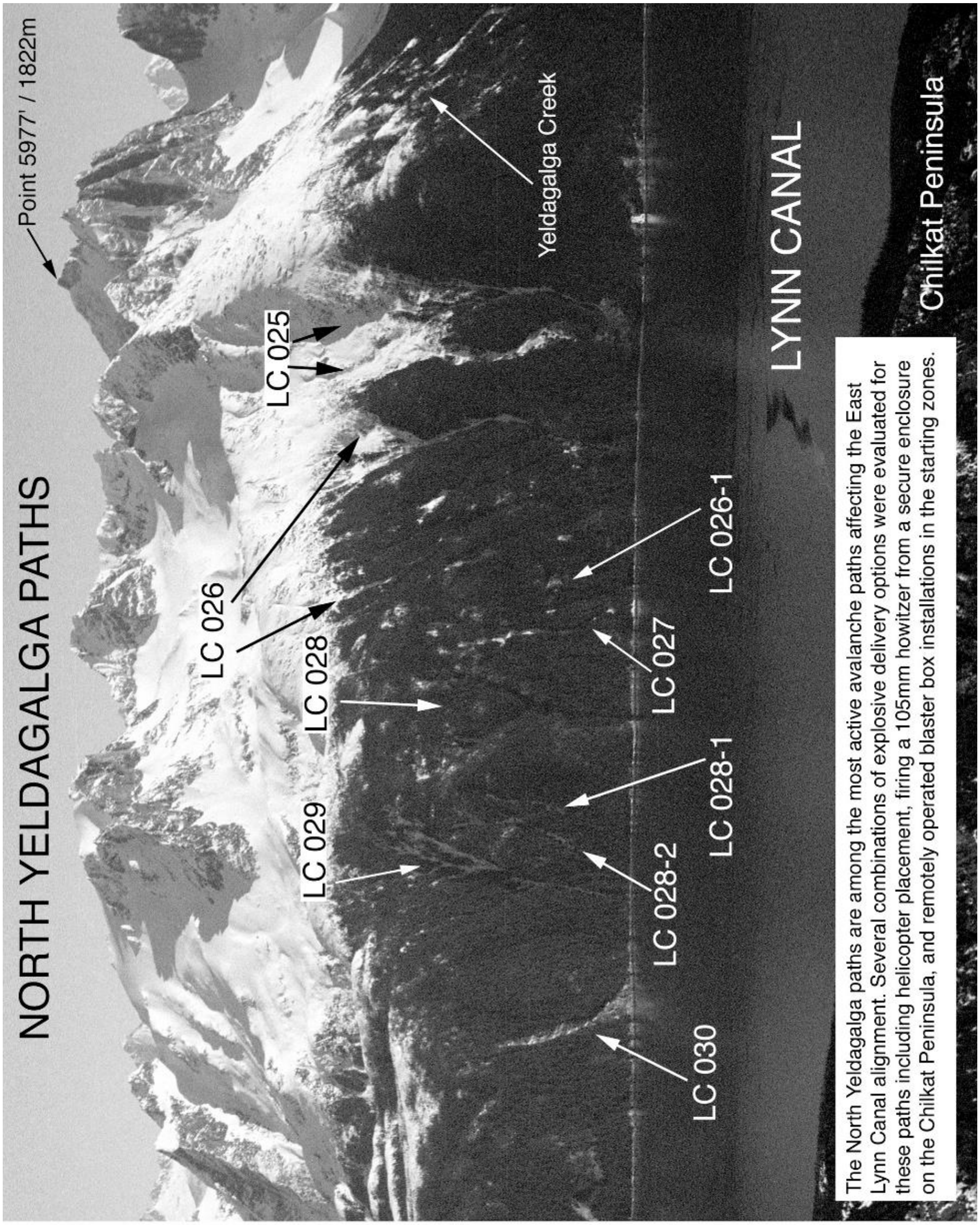
Path Group:	South Yeldagalga
Latitude-Longitude:	59.041891 -135.121213
Max Width:	210 feet / 64 meters
Typical Width:	120 feet / 37 meters
Starting Elevation:	2900 feet / 884 meters
Elevation Class:	medium high
Path Size:	medium
Starting Zone Characteristics:	rock slabs and gully
Start Aspect:	W
Path Type:	narrow gully
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	4.73
Structural Mitigation:	None
Structurally Mitigated AHI:	4.73
AHI with Forecasting and Exploders:	1.42


LC024
LC024
LC023
LC024

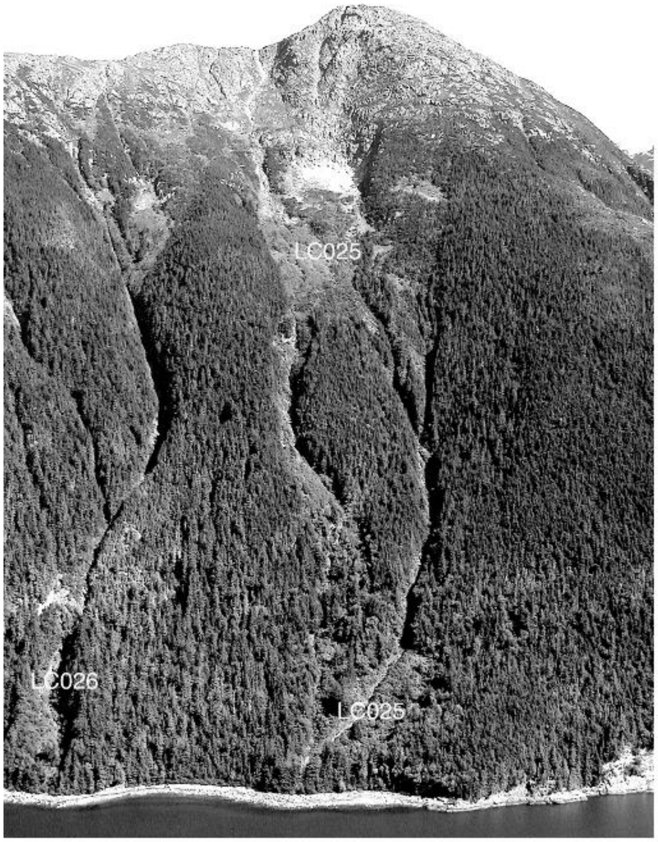

LC024

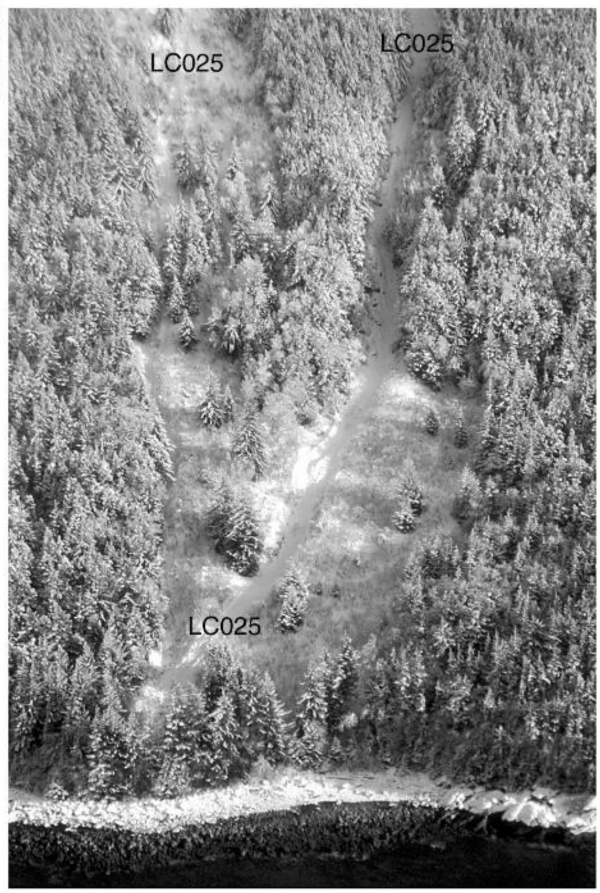
Path: LC024

Path Group:	South Yeldagalga
Latitude-Longitude:	59.043096 -135.121951
Max Width:	270 feet / 82 meters
Typical Width:	190 feet / 58 meters
Starting Elevation:	3700 feet / 1128 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	multiple rock slabs, small bowls and gullies
Start Aspect:	W
Path Type:	wide scrub bowl to short confined track, runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	8.50
Structural Mitigation:	None
Structurally Mitigated AHI:	8.50
AHI with Forecasting and Exploders:	2.55



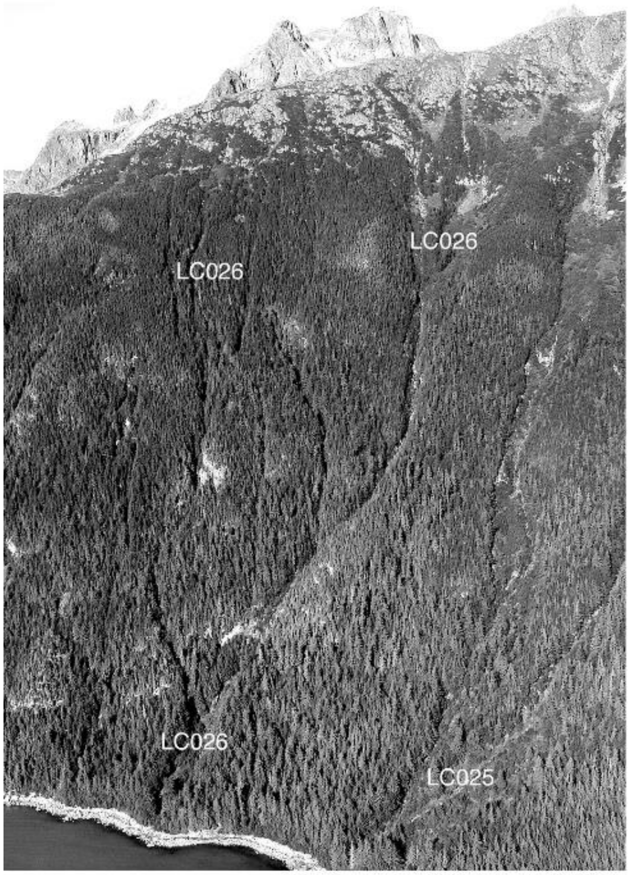
The North Yeldagalga paths are among the most active avalanche paths affecting the East Lynn Canal alignment. Several combinations of explosive delivery options were evaluated for these paths including helicopter placement, firing a 105mm howitzer from a secure enclosure on the Chilkat Peninsula, and remotely operated blaster box installations in the starting zones.

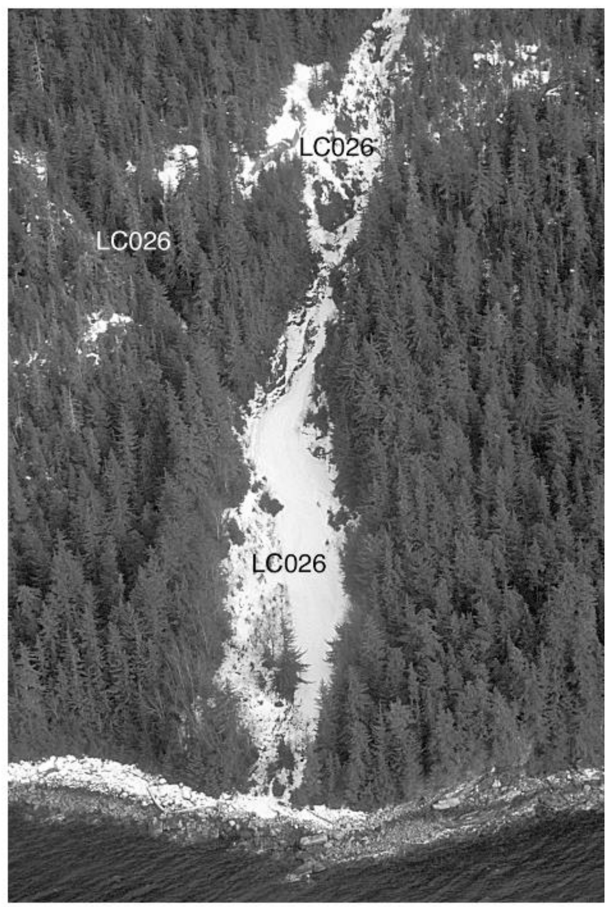

LC025
LC026
LC025


LC025
LC025
LC025

Path: LC025

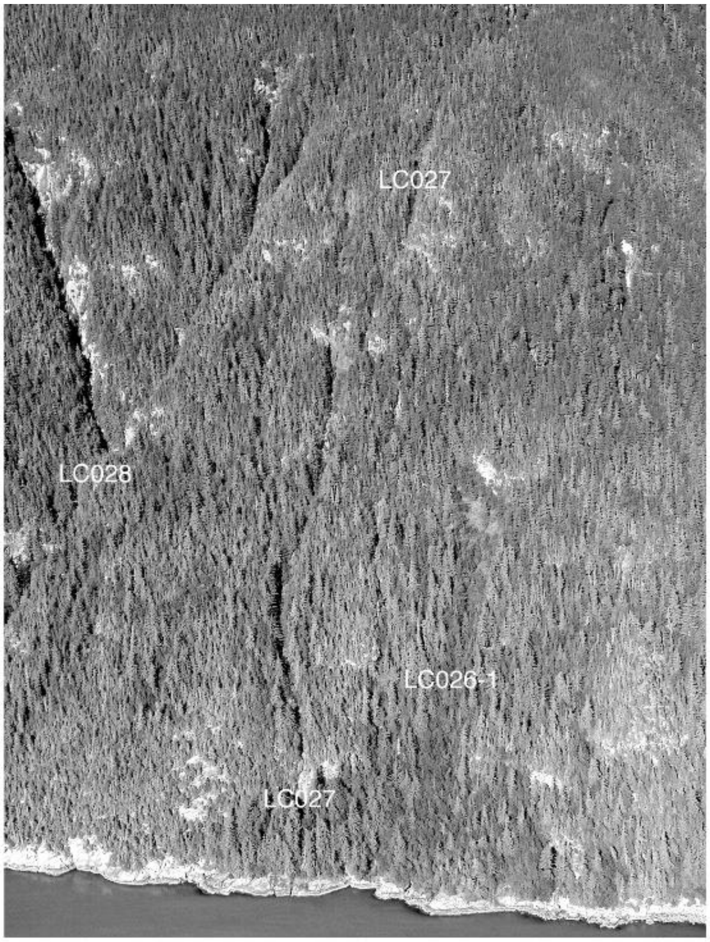
Path Group:	North Yeldagalga
Latitude-Longitude:	59.06421 -135.133654
Max Width:	780 feet / 238 meters
Typical Width:	190 feet / 58 meters
Starting Elevation:	4300 feet / 1311 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	medium gullied bowl
Start Aspect:	W
Path Type:	bowl to twin gullies to single runout
Runout Angle:	decreases markedly
Unmitigated avalanche hazard index (AHI):	19.23
Structural Mitigation:	Bridge 0.2x on one of two gullies
Structurally Mitigated AHI:	11.54
AHI with Forecasting and Exploders:	3.46

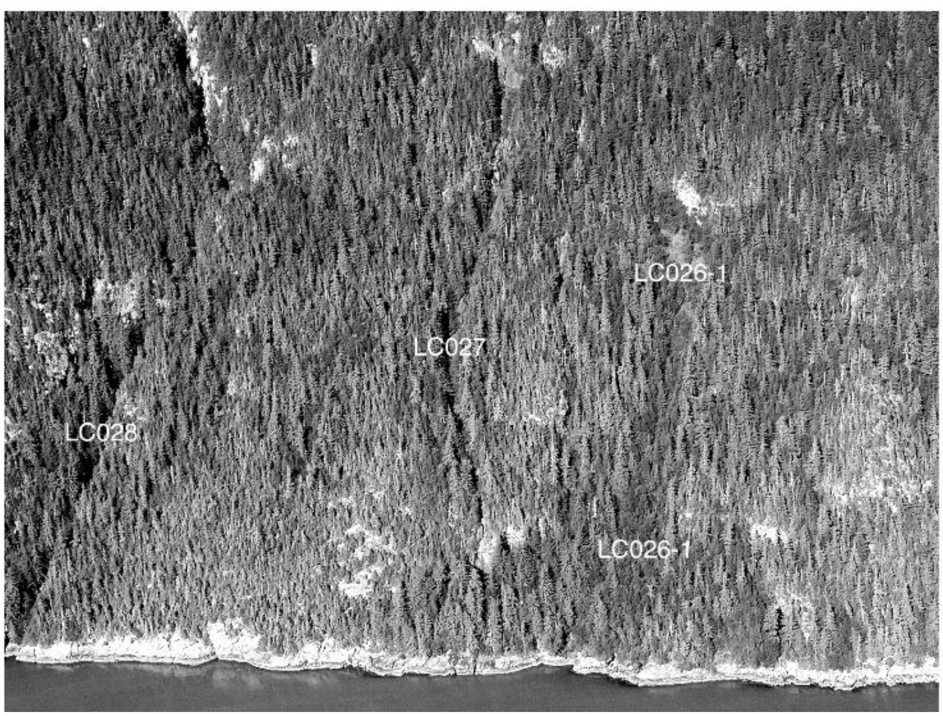

LC026
LC026
LC026
LC025


LC026
LC026
LC026

Path: LC026

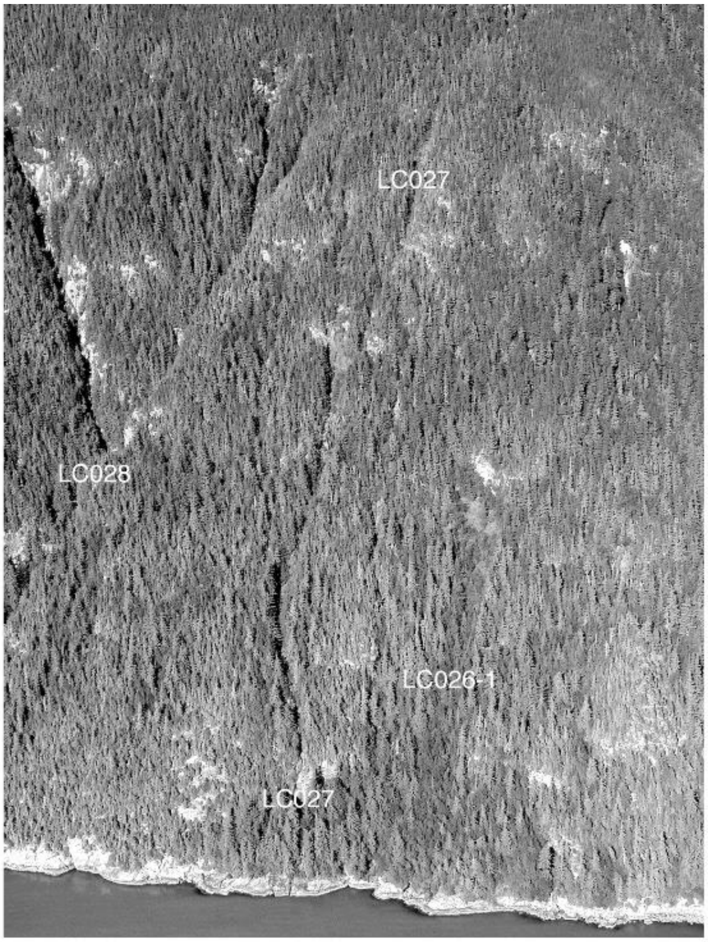
Path Group:	North Yeldagalga
Latitude-Longitude:	59.065077 -135.133771
Max Width:	470 feet / 143 meters
Typical Width:	200 feet / 61 meters
Starting Elevation:	4000 feet / 1219 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	multiple gullies and small bowls
Start Aspect:	WSW
Path Type:	multiple confined gullies to single runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	8.77
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	1.75
AHI with Forecasting and Exploders:	0.53

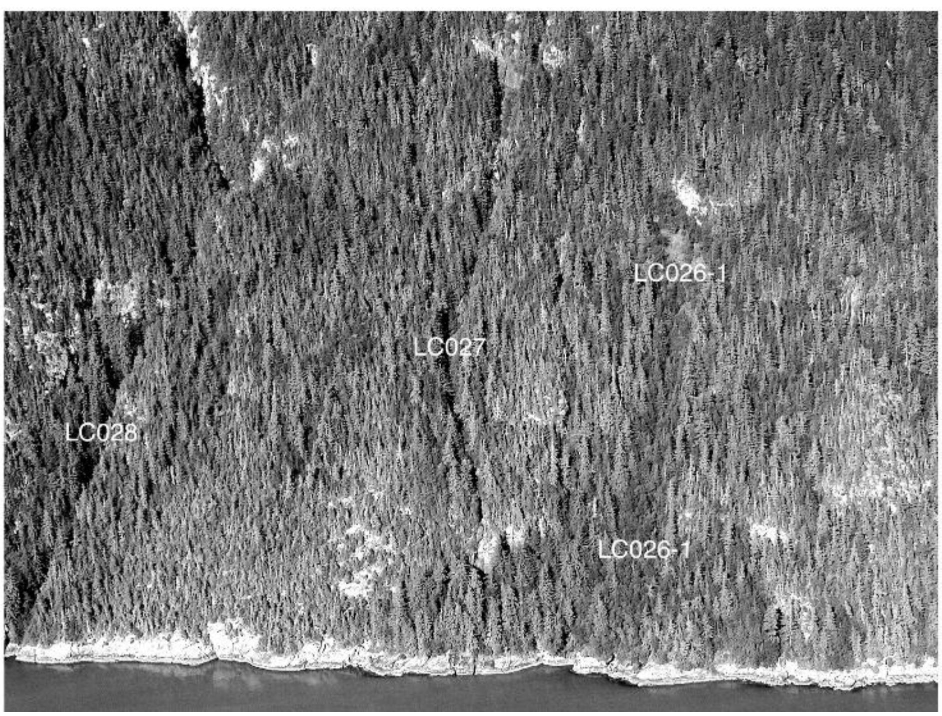

LC027
LC028
LC026-1
LC027


LC026-1
LC027
LC028
LC026-1

Path: LC026-1

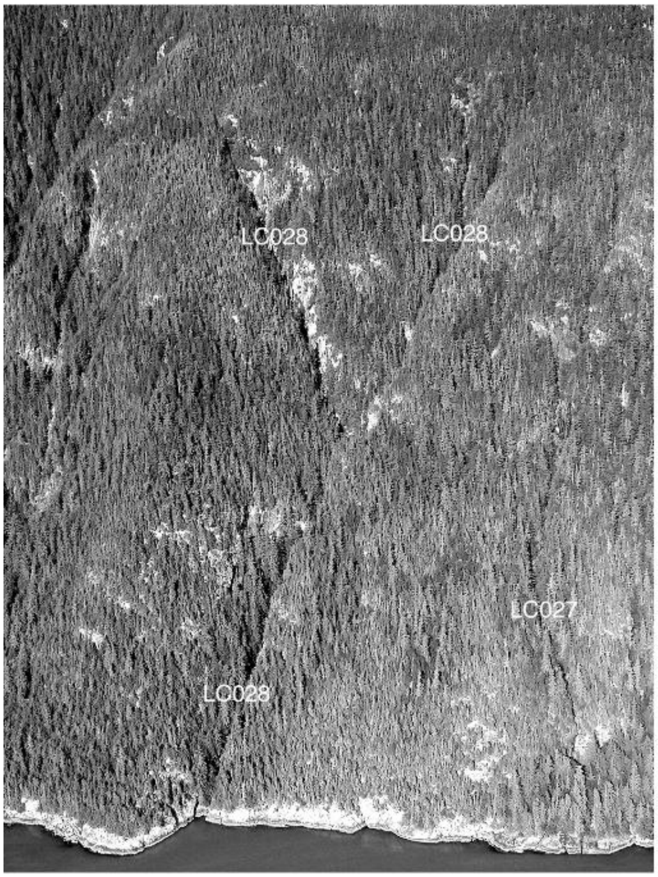
Path Group:	North Yeldagalga
Latitude-Longitude:	59.06565 -135.134064
Max Width:	200 feet / 61 meters
Typical Width:	150 feet / 46 meters
Starting Elevation:	1100 feet / 335 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	small cliff and talus
Start Aspect:	WSW
Path Type:	small unconfined track
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	12.00
Structural Mitigation:	None
Structurally Mitigated AHI:	12.00
AHI with Forecasting and Exploders:	3.60

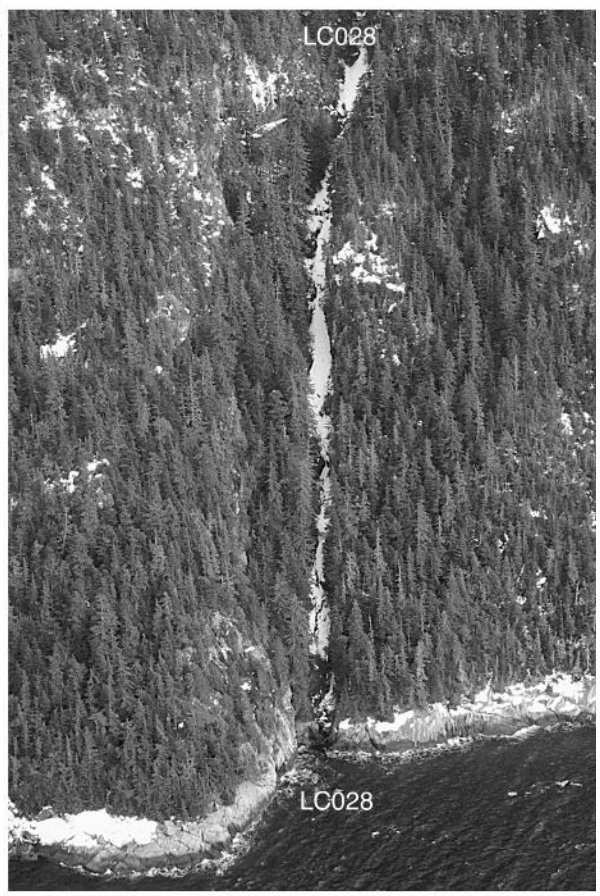

LC027
LC028
LC026-1
LC027


LC026-1
LC027
LC028
LC026-1

Path: LC027

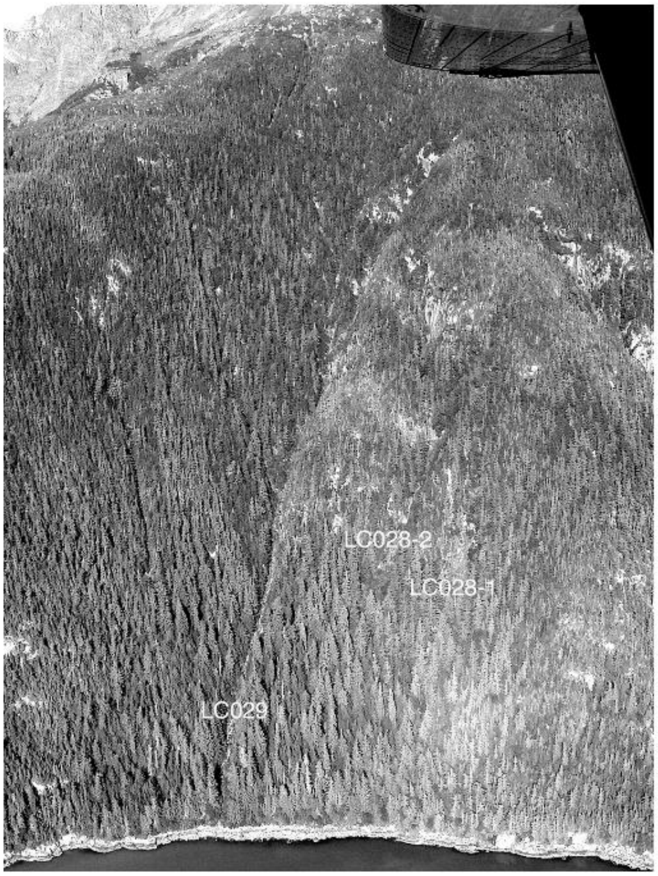
Path Group:	North Yeldagalga
Latitude-Longitude:	59.070492 -135.134359
Max Width:	90 feet / 27 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	2000 feet / 610 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	narrow gully
Start Aspect:	WSW
Path Type:	narrow gully
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	1.93
Structural Mitigation:	None
Structurally Mitigated AHI:	1.93
AHI with Forecasting and Exploders:	0.58

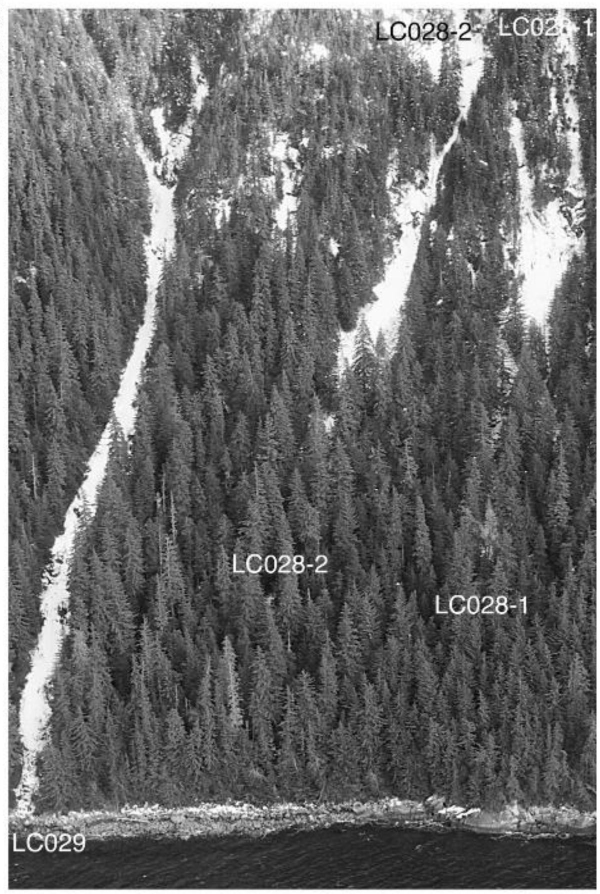

LC028
LC028
LC027
LC028


LC028
LC028

Path: LC028

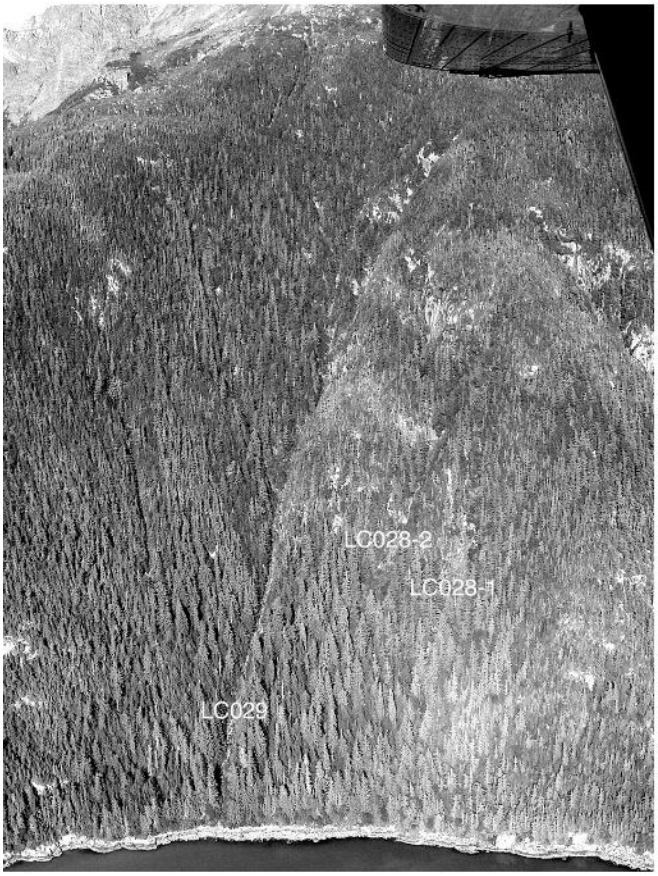
Path Group:	North Yeldagalga
Latitude-Longitude:	59.071671 -135.135194
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	2200 feet / 671 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	two narrow gullies
Start Aspect:	WSW
Path Type:	narrow gully
Runout Angle:	minimal decrease
Unmitigated avalanche hazard index (AHI):	2.24
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.45
AHI with Forecasting and Exploders:	0.13

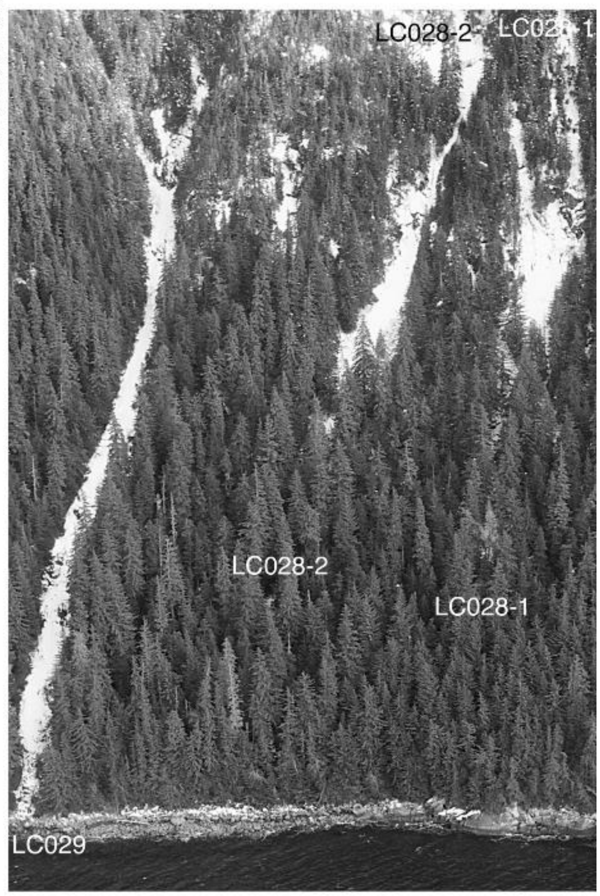

LC028-2
LC028-1
LC029


LC028-2
LC028-2
LC028-1
LC029

Path: LC028-1

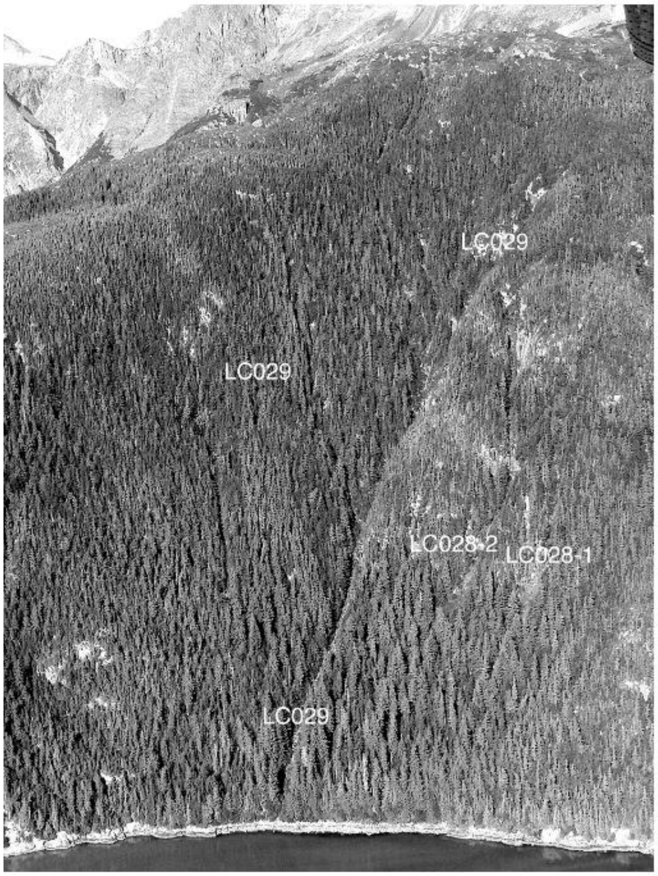
Path Group:	North Yeldagalga
Latitude-Longitude:	59.072328 -135.135484
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	1700 feet / 518 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	scrub forest, gully and cliff
Start Aspect:	WSW
Path Type:	talus and gully in forest
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	1.46
Structural Mitigation:	None
Structurally Mitigated AHI:	1.46
AHI with Forecasting and Exploders:	0.44


LC028-2
LC028-1
LC029


LC028-2
LC028-2
LC028-1
LC029

Path: LC028-2

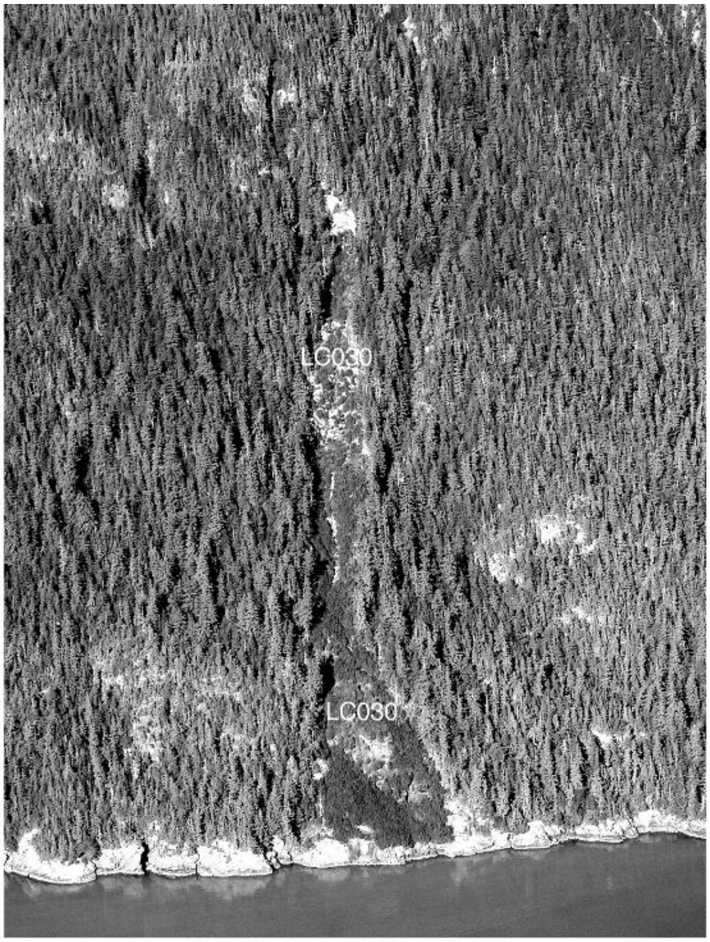
Path Group:	North Yeldagalga
Latitude-Longitude:	59.072747 -135.135494
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	1800 feet / 549 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	scrub forest, gully and cliff
Start Aspect:	WSW
Path Type:	talus and gully in forest
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.99
Structural Mitigation:	None
Structurally Mitigated AHI:	0.99
AHI with Forecasting and Exploders:	0.30

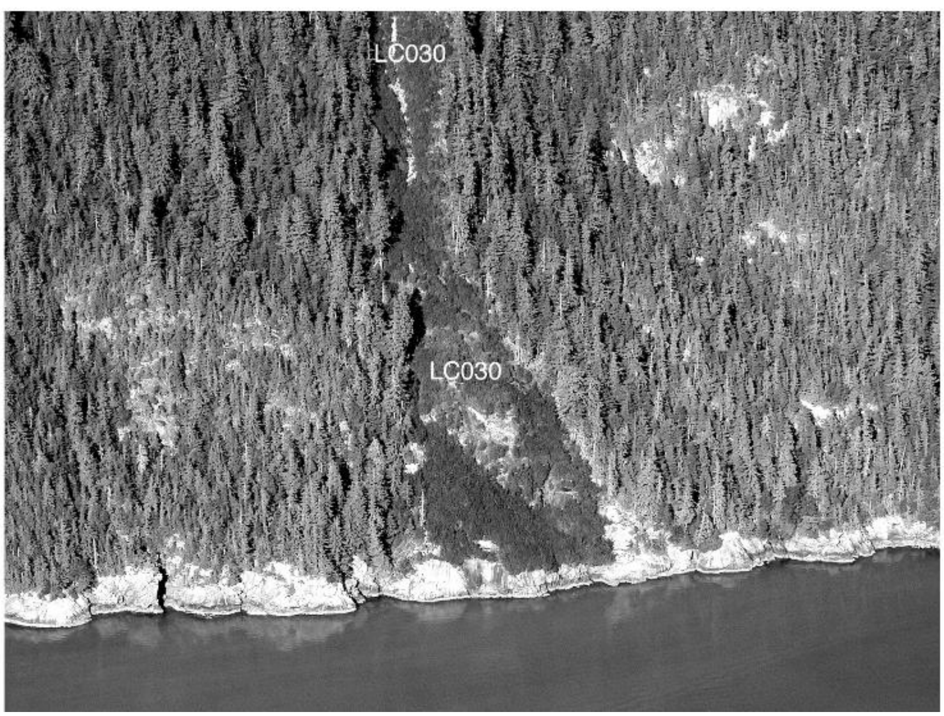

LC029
LC029
LC028-2
LC028-1
LC029


LC028-1
LC029
LC029
LC029

Path: LC029

Path Group:	North Yeldagalga
Latitude-Longitude:	59.073302 -135.135586
Max Width:	150 feet / 46 meters
Typical Width:	100 feet / 30 meters
Starting Elevation:	3000 feet / 914 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	scrub forest bowl and gullies
Start Aspect:	WSW
Path Type:	multiple narrow gullies to single runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	2.99
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.59
AHI with Forecasting and Exploders:	0.18


LC030
LC030


LC030
LC030

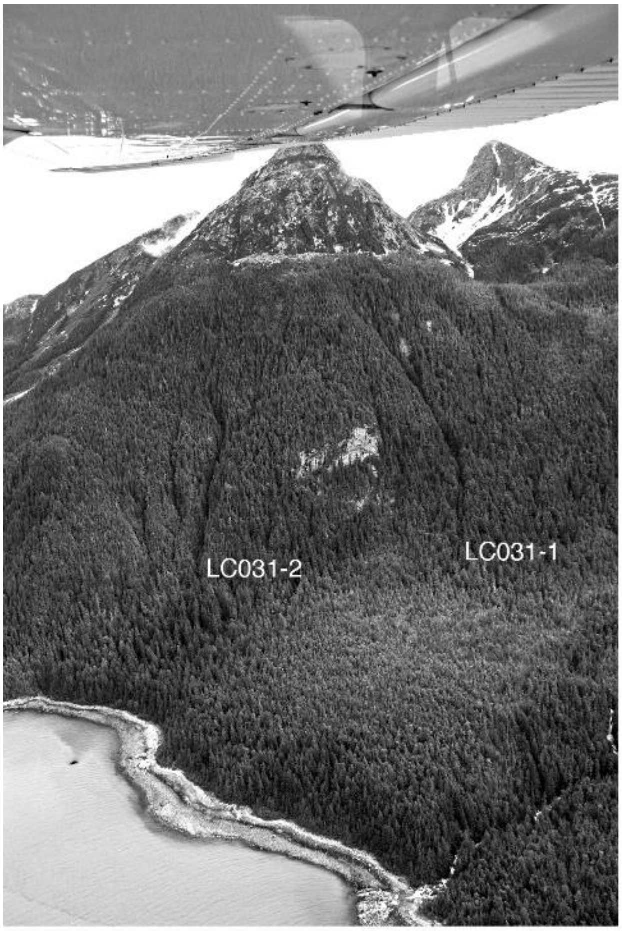
Path: LC030

Path Group:	North Yeldagalga
Latitude-Longitude:	59.074304 -135.140742
Max Width:	460 feet / 140 meters
Typical Width:	250 feet / 76 meters
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	landslide scar
Start Aspect:	WSW
Path Type:	landslide scar
Runout Angle:	minimal decrease
Unmitigated avalanche hazard index (AHI):	0.12
Structural Mitigation:	None
Structurally Mitigated AHI:	0.12
AHI with Forecasting and Exploders:	0.04


LC031

Path: LC031

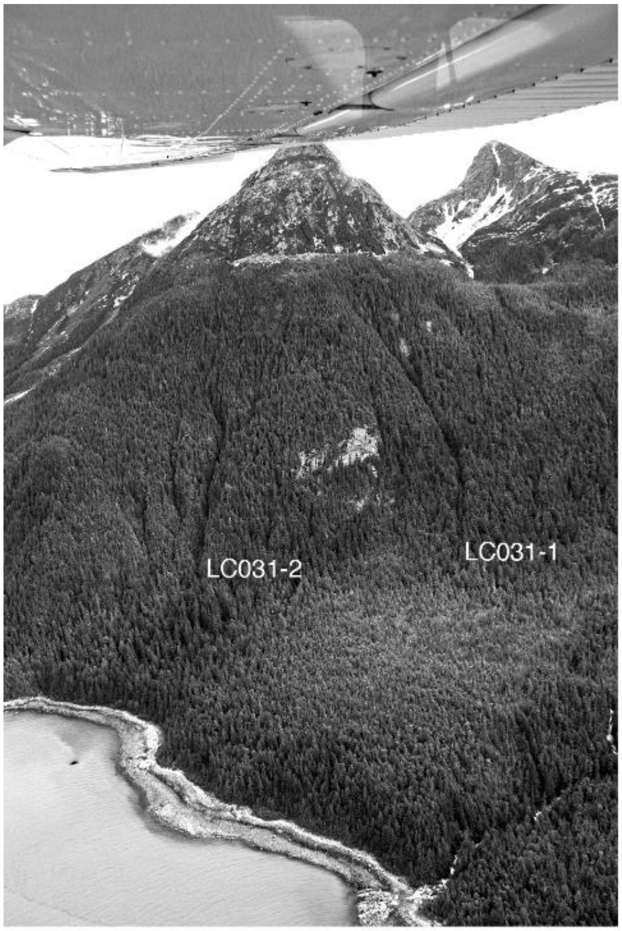
Path Group:	North Yeldagalga
Latitude-Longitude:	59.080947 -135.142847
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	650 feet / 198 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	cliff gully
Start Aspect:	WSW
Path Type:	narrow gully
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	0.42
Structural Mitigation:	Tunnels
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00

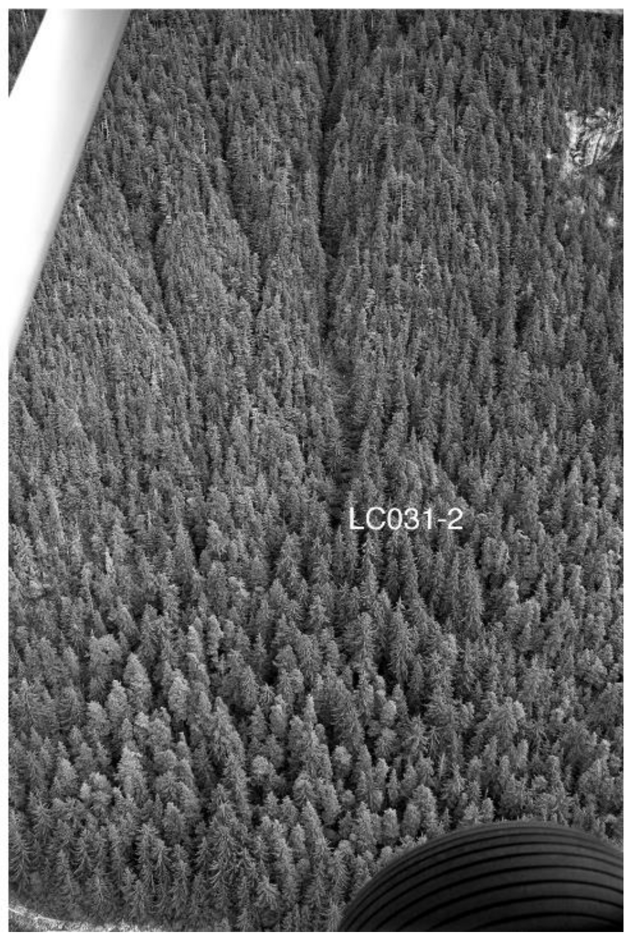

LC031-2
LC031-1


LC031-1

Path: LC031-1

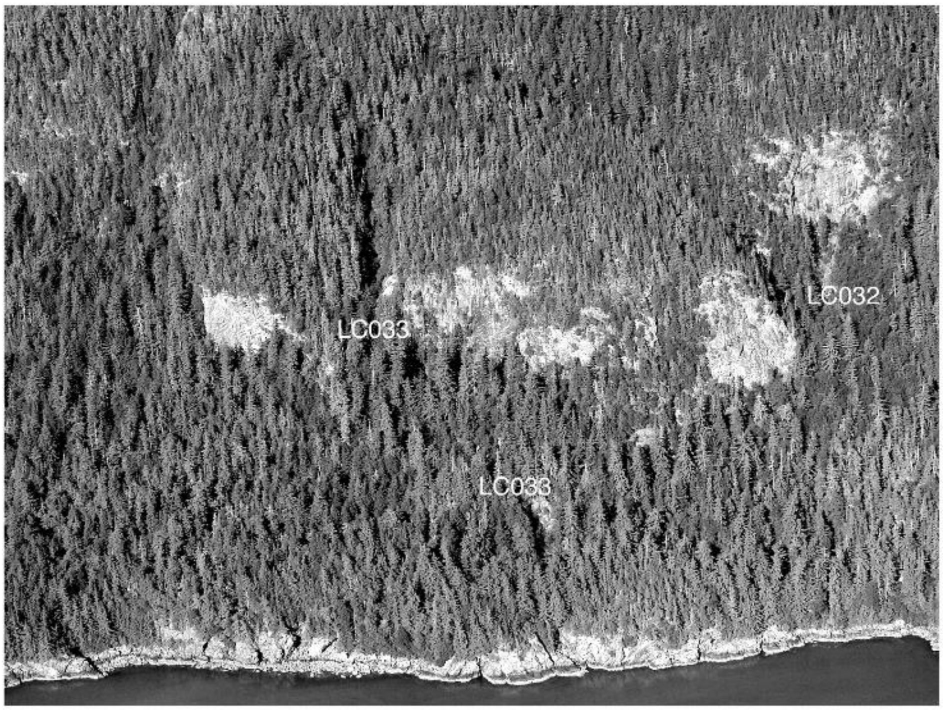
Path Group:	South Katzehin
Latitude-Longitude:	59°09’04.89 -135*14’25.57
Max Width:	80 feet / 25 meters
Typical Width:	66 feet / 20 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	gullied face
Start Aspect:	SW
Path Type:	narrow gully
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	3.93
Structural Mitigation:	None
Structurally Mitigated AHI:	3.93
AHI with Forecasting and Exploders:	1.18


LC031-2
LC031-1


LC031-2

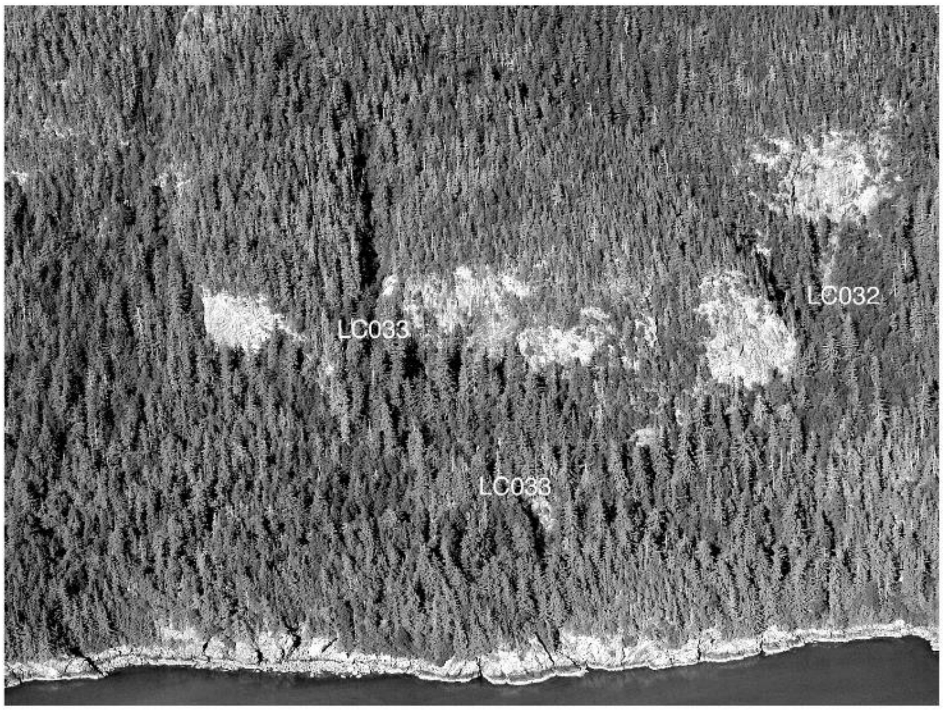
Path: LC031-2

Path Group:	South Katzehin
Latitude-Longitude:	59°09’06.05 -135°14’57.31
Max Width:	66 feet / 20 meters
Typical Width:	49 feet / 15 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	gullied shallow bowl
Start Aspect:	SSW
Path Type:	narrow gully
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	3.93
Structural Mitigation:	None
Structurally Mitigated AHI:	3.93
AHI with Forecasting and Exploders:	1.18


LC033
LC032
LC033

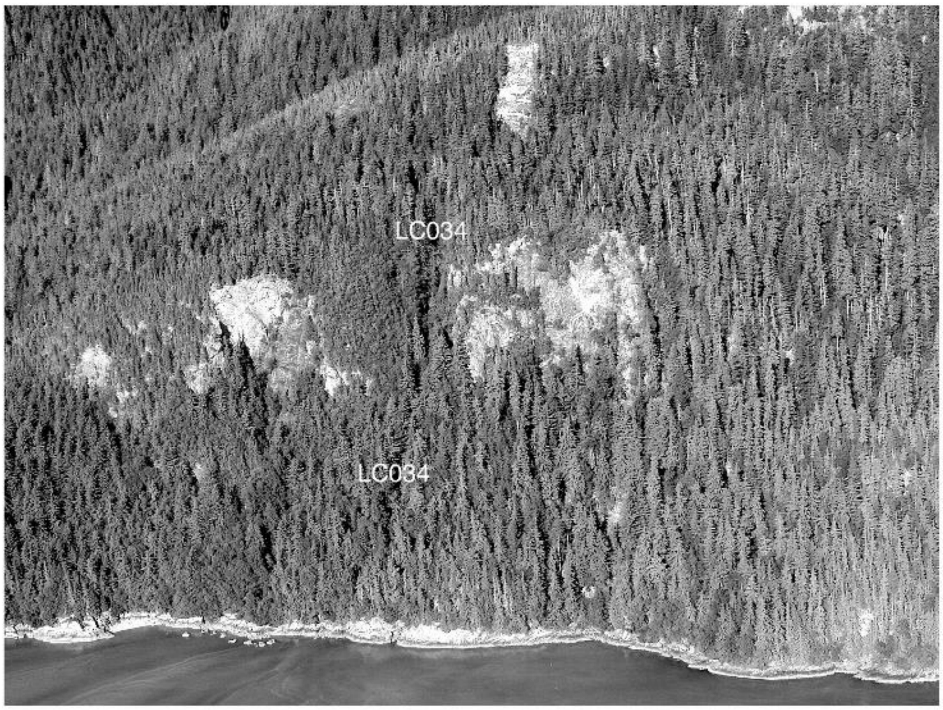
Path: LC032

Path Group:	South Katzehin
Latitude-Longitude:	59.094729 -135.160762
Max Width:	270 feet / 82 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	900 feet / 274 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	gully through cliffs
Start Aspect:	WSW
Path Type:	gully in forest
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	0.03
Structural Mitigation:	None
Structurally Mitigated AHI:	0.03
AHI with Forecasting and Exploders:	0.01


LC033
LC032
LC033

Path: LC033

Path Group:	South Katzehin
Latitude-Longitude:	59.095282 -135.161422
Max Width:	60 feet / 18 meters
Typical Width:	60 feet / 18 meters
Starting Elevation:	900 feet / 274 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	gully through cliffs
Start Aspect:	WSW
Path Type:	gully in forest
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	0.02
Structural Mitigation:	None
Structurally Mitigated AHI:	0.02
AHI with Forecasting and Exploders:	0.001


LC034
LC034

Path: LC034

Path Group:	South Katzehin
Latitude-Longitude:	59.104932 -135.163693
Max Width:	80 feet / 24 meters
Typical Width:	60 feet / 18 meters
Starting Elevation:	700 feet / 213 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	gully through cliffs
Start Aspect:	WSW
Path Type:	gully in forest
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	0.03
Structural Mitigation:	None
Structurally Mitigated AHI:	0.03
AHI with Forecasting and Exploders:	0.01