Juneau Access Improvements Project
Final Supplemental
Environmental Impact Statement

2017 Update to Appendix J
Snow Avalanche Report

Prepared for:

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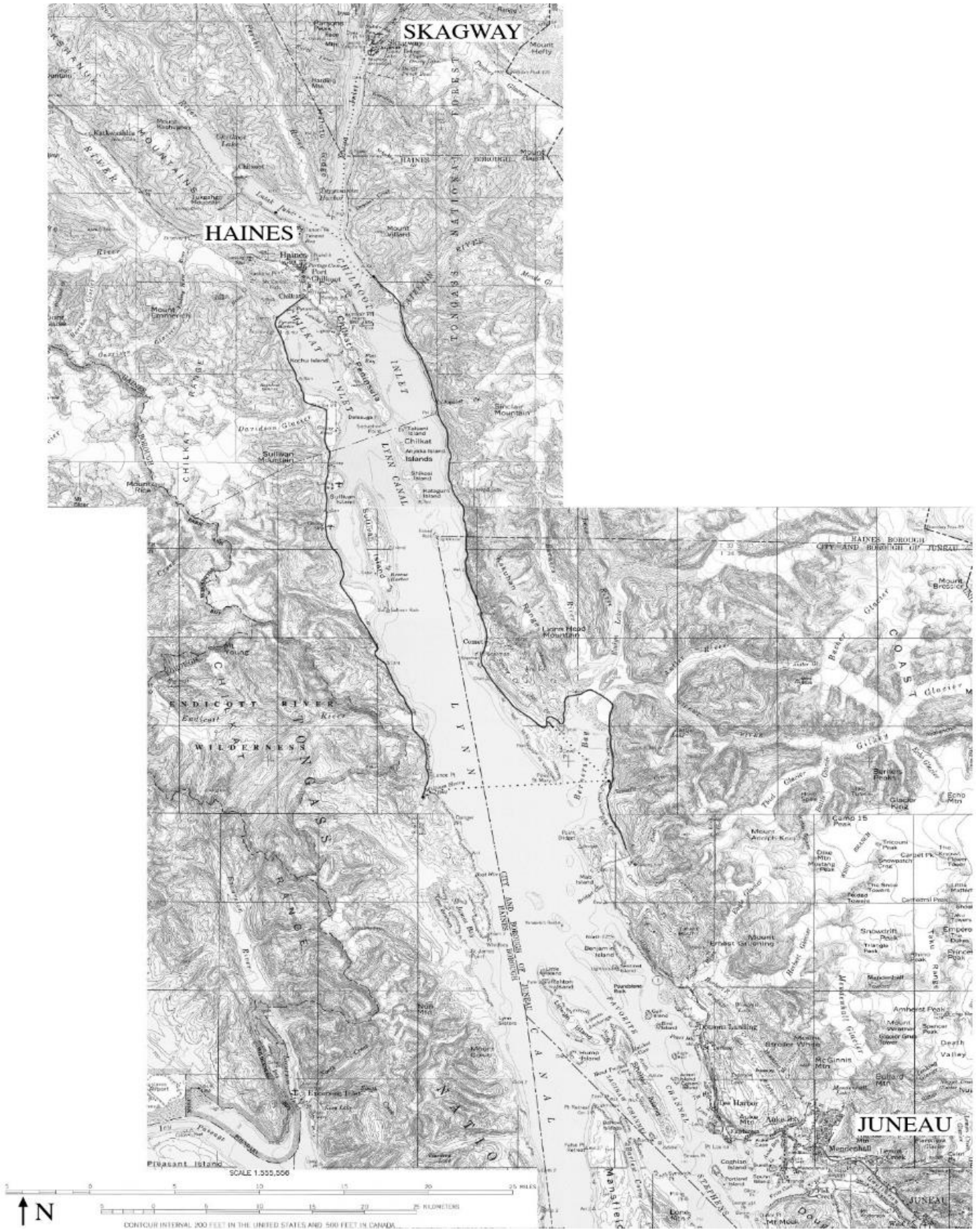


2. Executive Summary

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

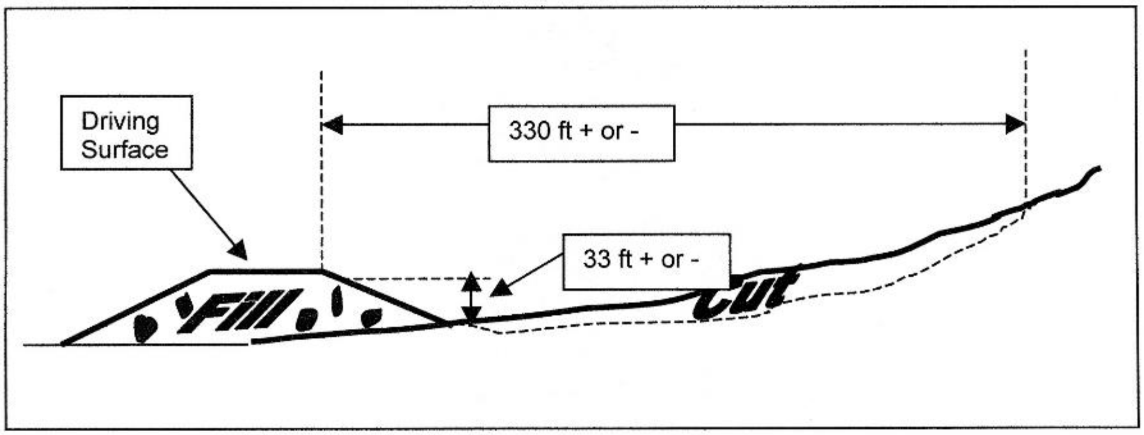


Figure 9: Elevated Fills

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.

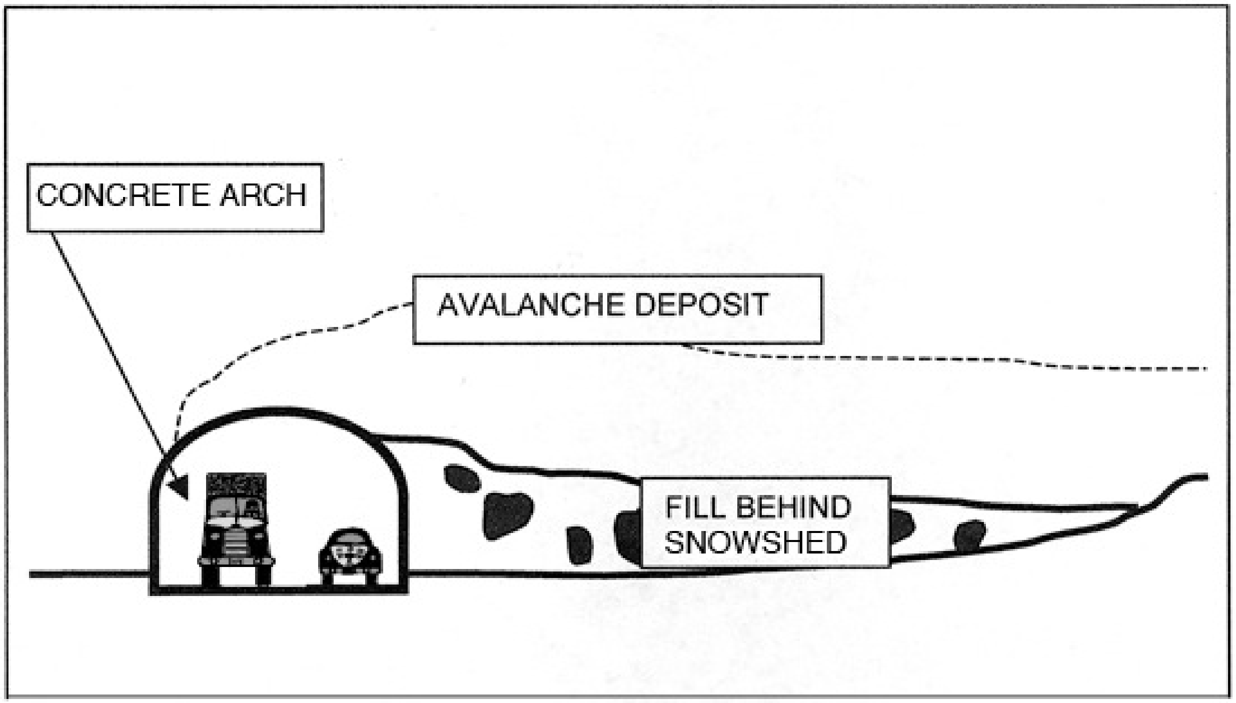
Based on the data and adjustments for inflation, design factors and location, and designing for the 50 to 100 year return period design-magnitude avalanche, they estimated total loads and preliminary costs as shown in Figure 13.

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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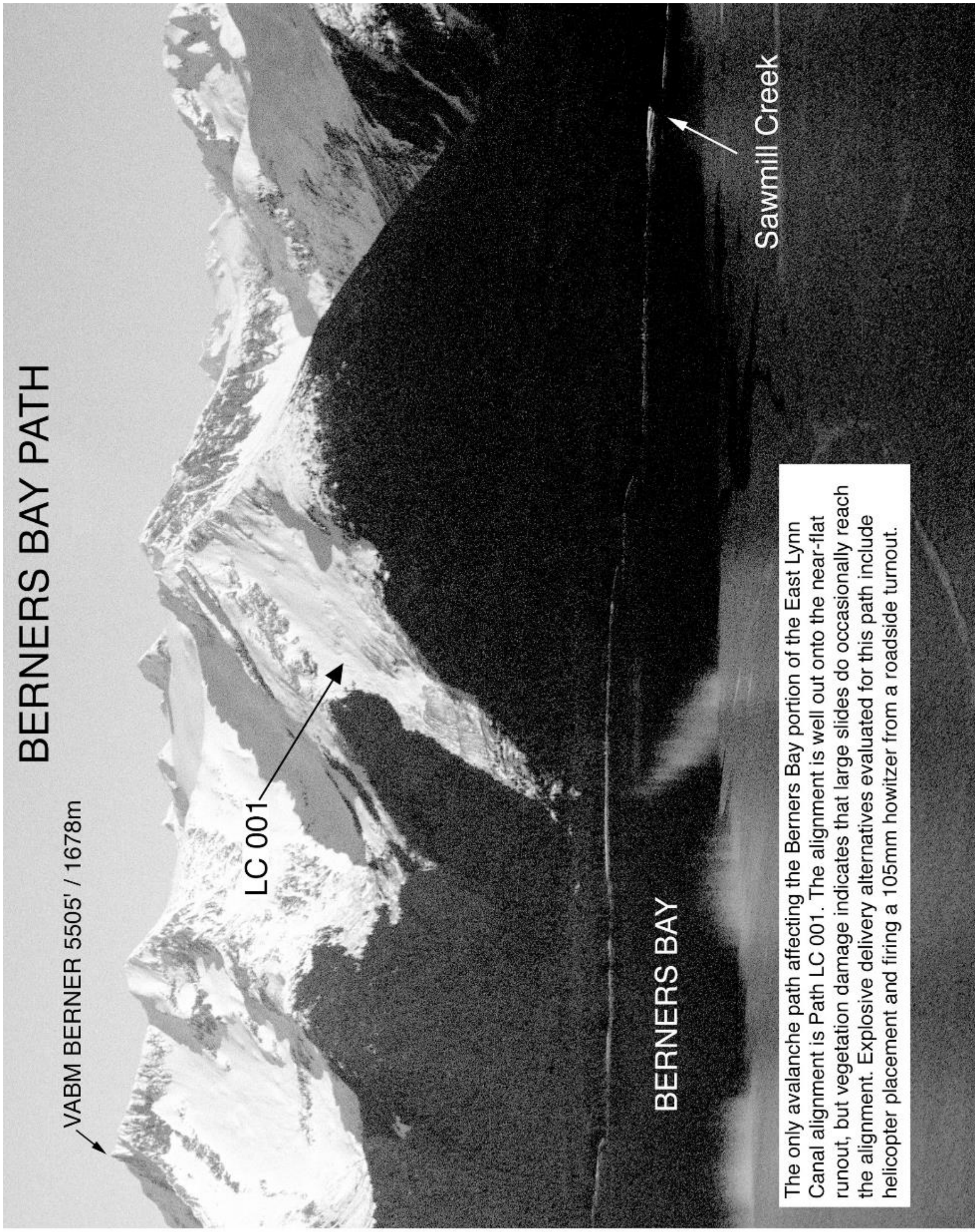
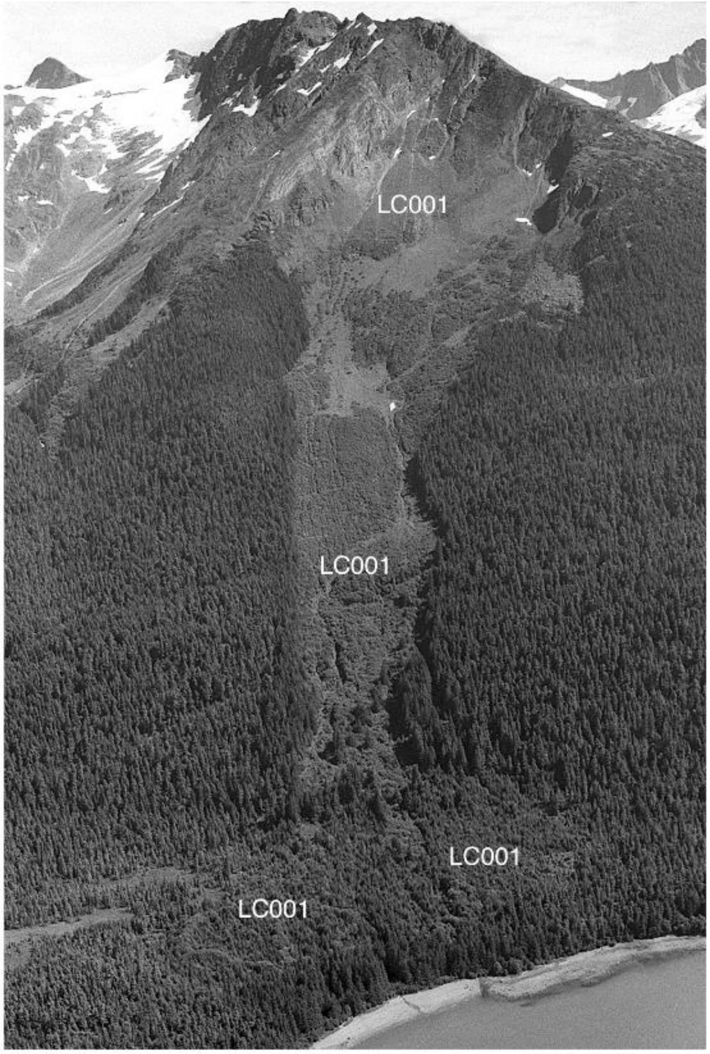
9. Atlas - East Lynn Canal Avalanche Paths

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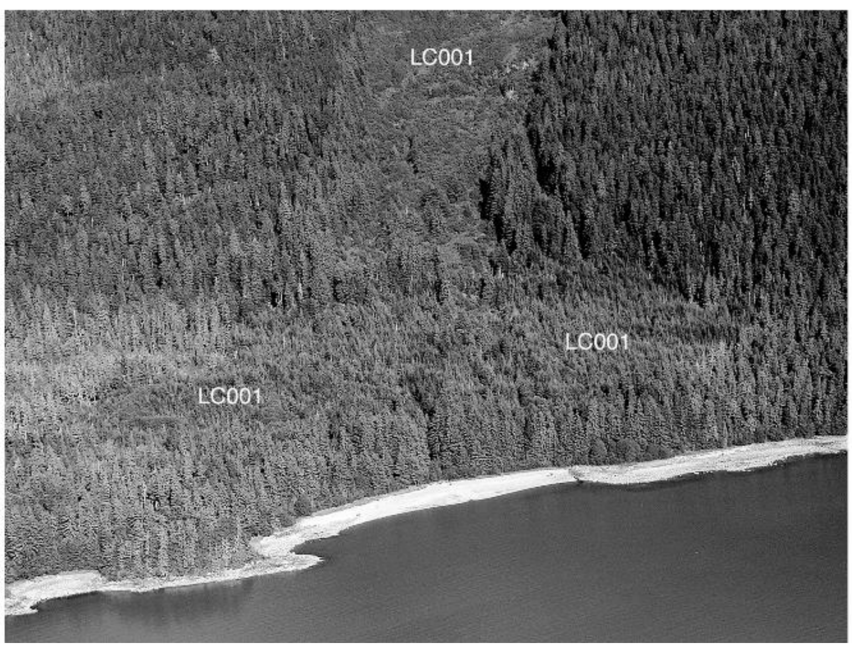
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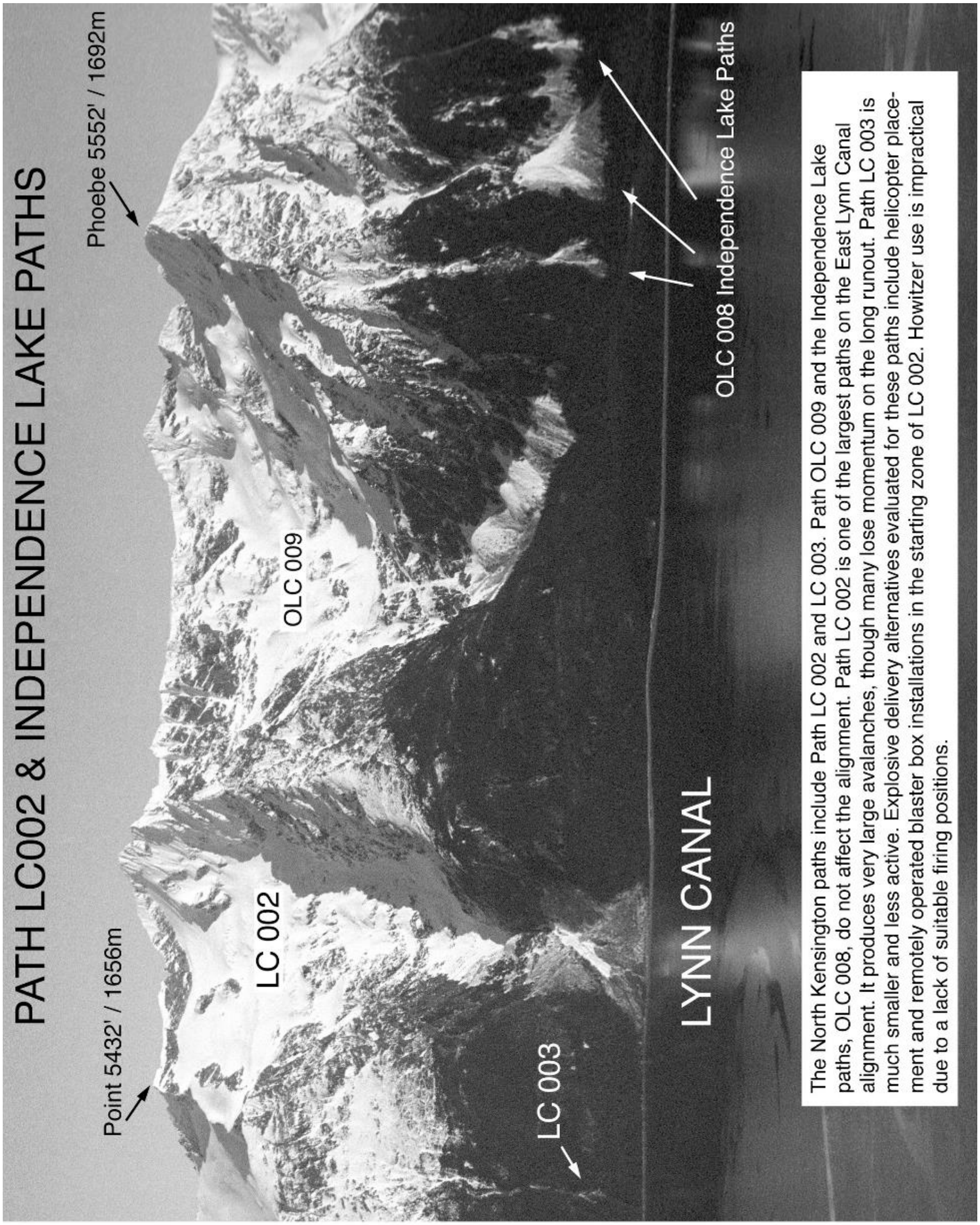
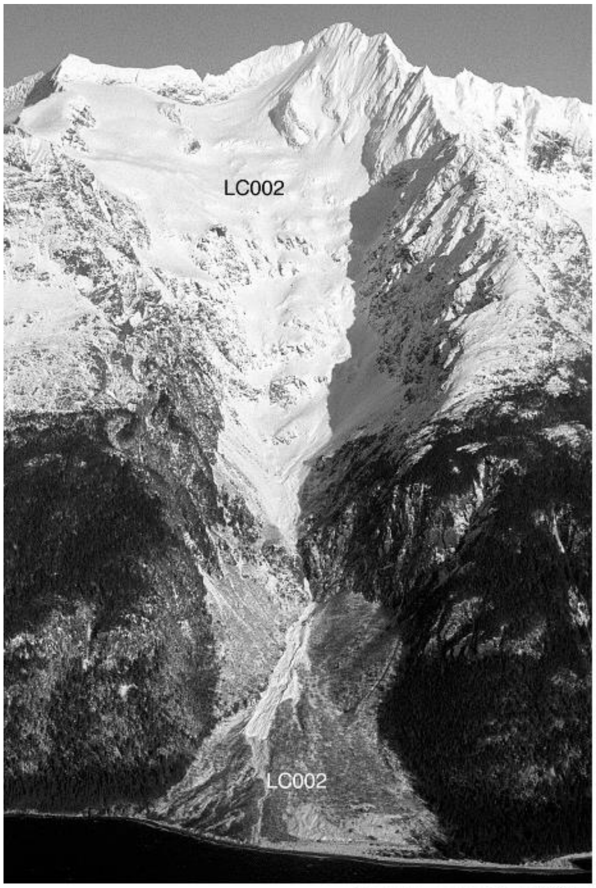
Path: LC001

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

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.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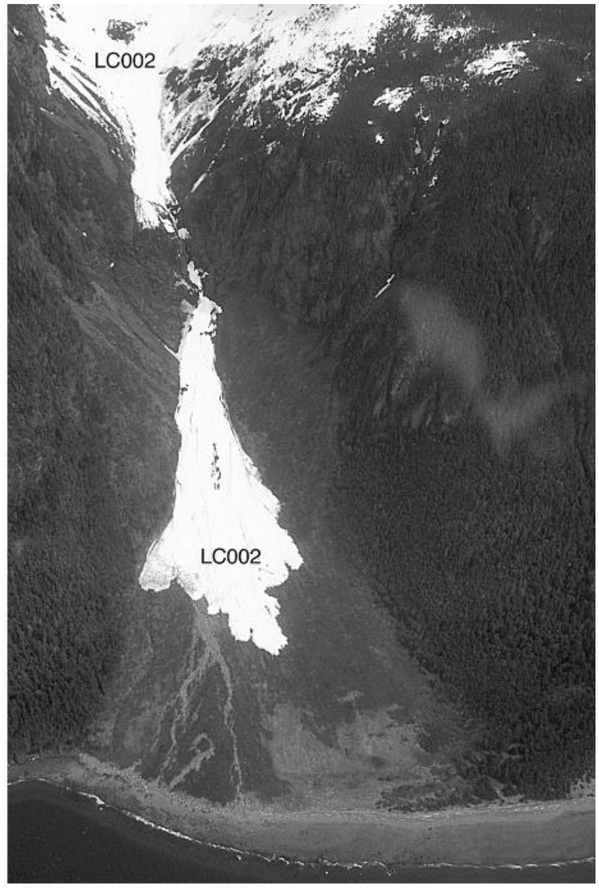
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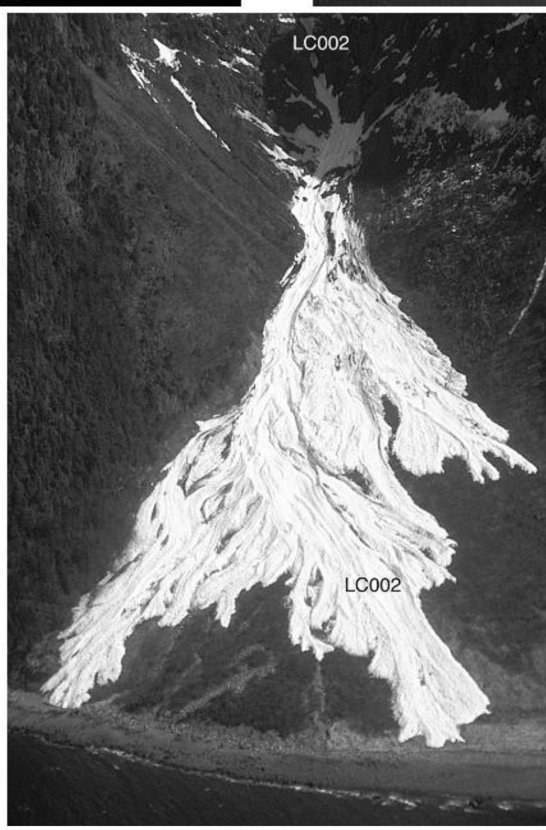
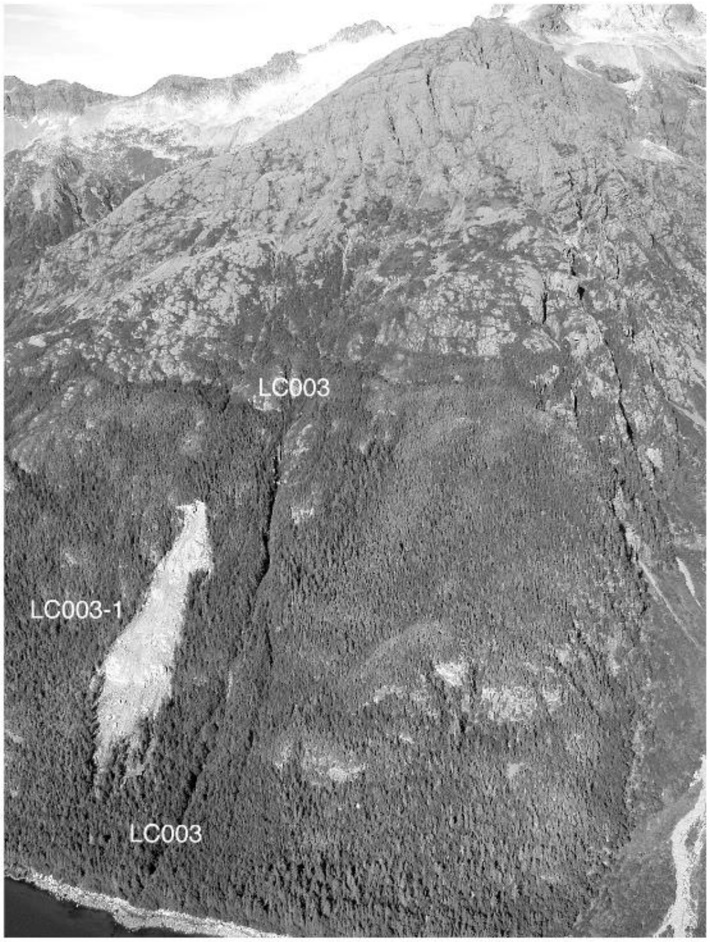
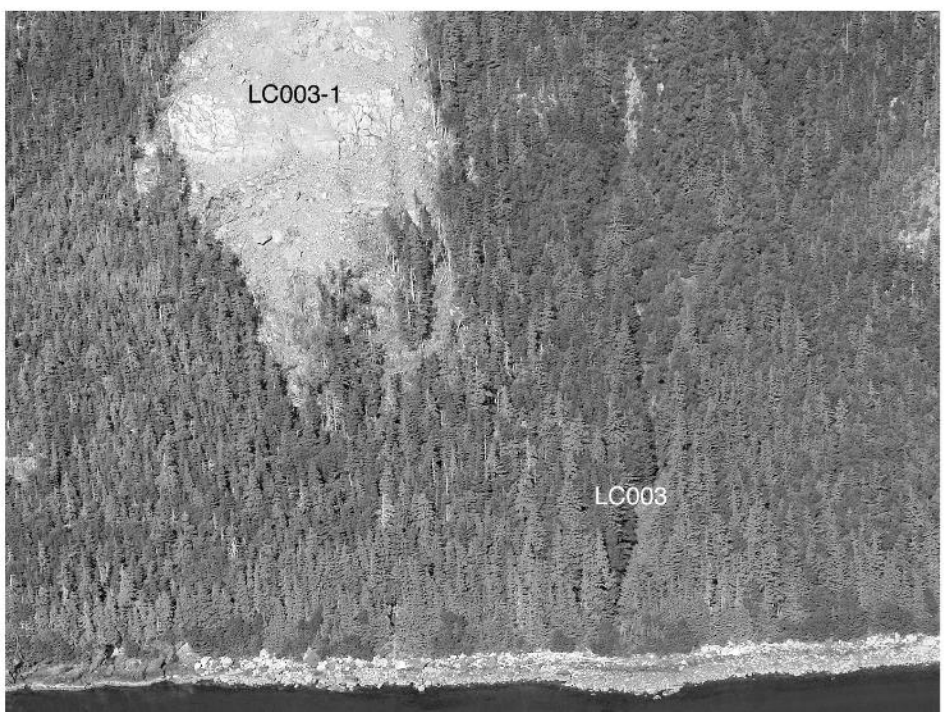

LC002
LC002

Path: LC002

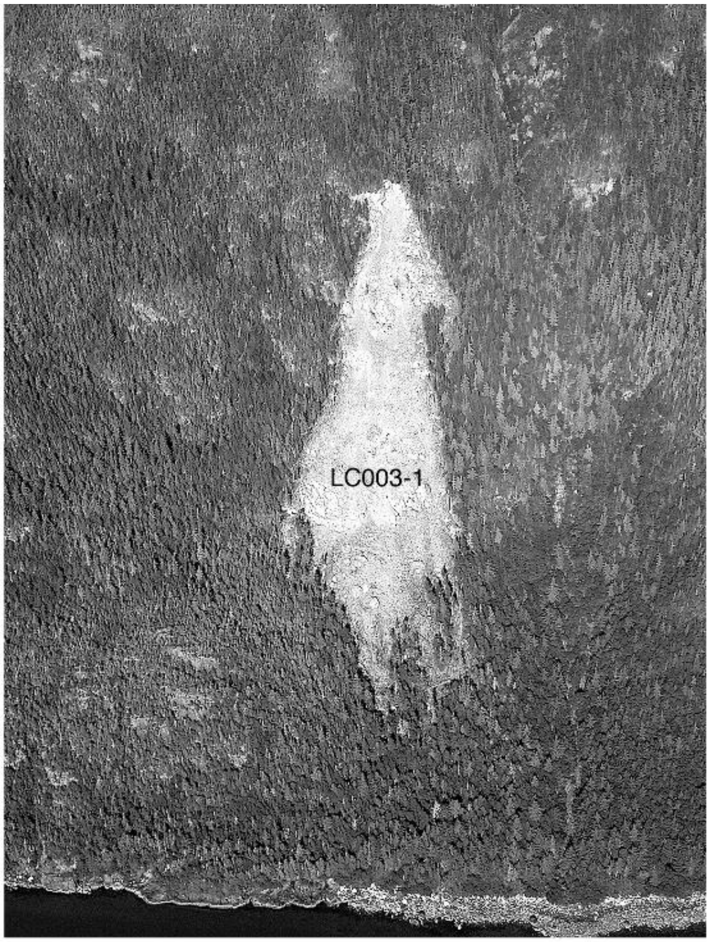
Path Group:	North Kensington
Latitude-Longitude:	58.542239 -135.091832
Max Width:	2115 feet / 645 meters
Typical Width:	500 feet / 152 meters
Starting Elevation:	5900 feet / 1798 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	WSW
Path Type:	classic 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

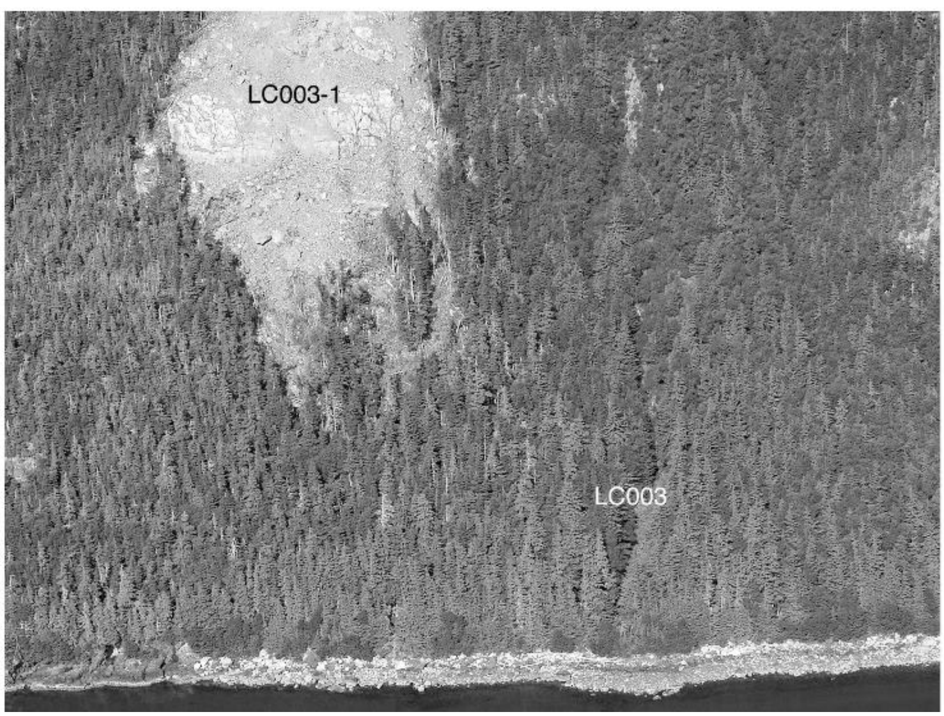

LC003
LC003-1
LC003


LC003-1
LC003

Path: LC003

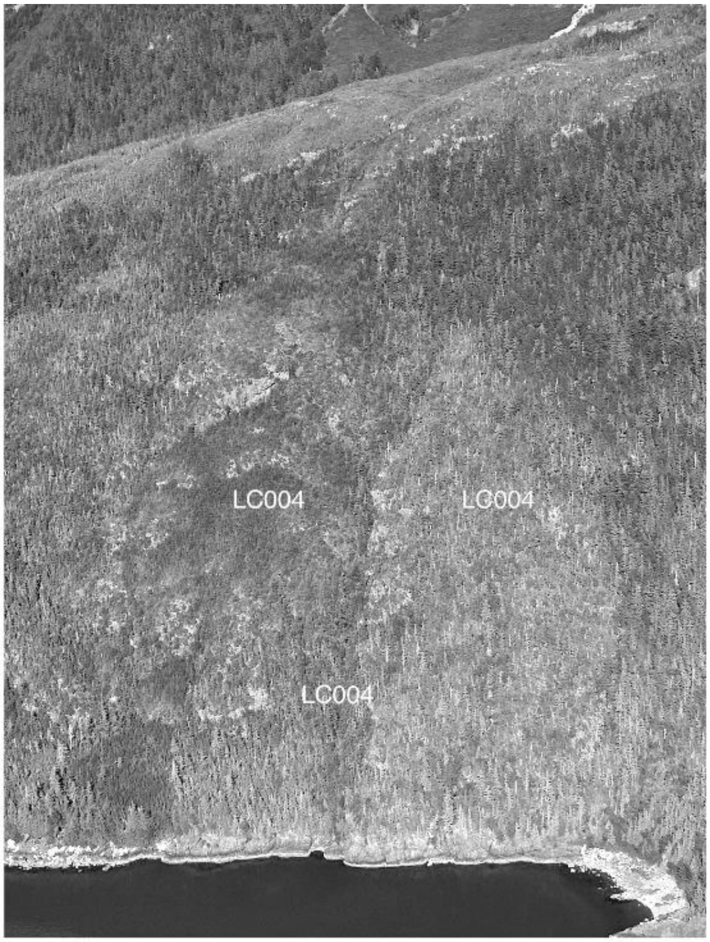
Path Group:	North Kensington
Latitude-Longitude:	58.54455 -135.09301
Max Width:	130 feet / 40 meters
Typical Width:	130 feet / 40 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	broad face
Start Aspect:	WSW
Path Type:	narrow gully
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

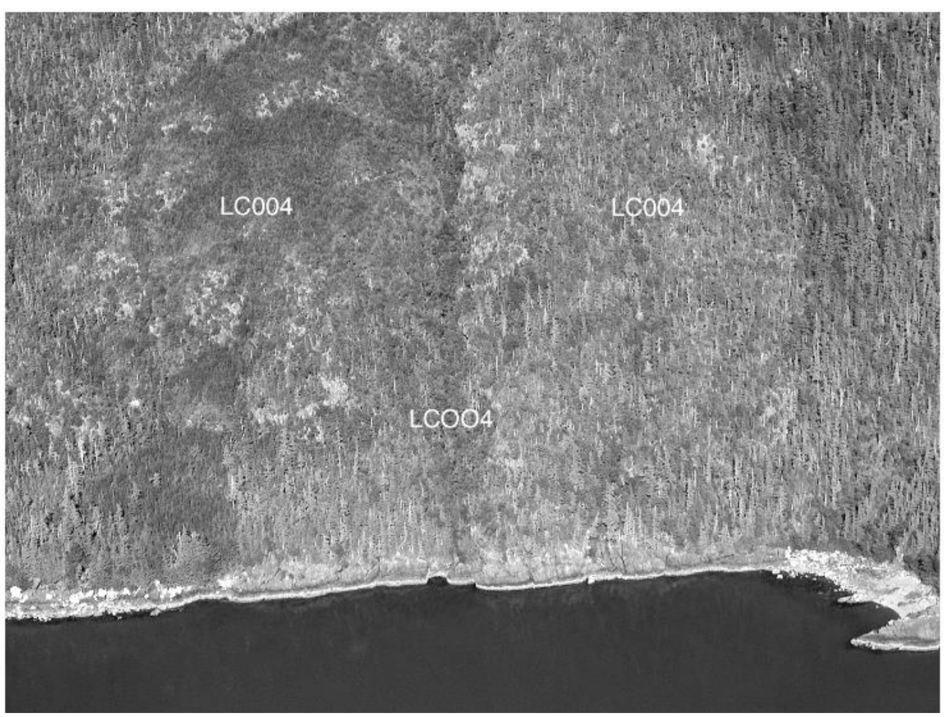

LC003-1


LC003-1
LC003

Path: LC003-1

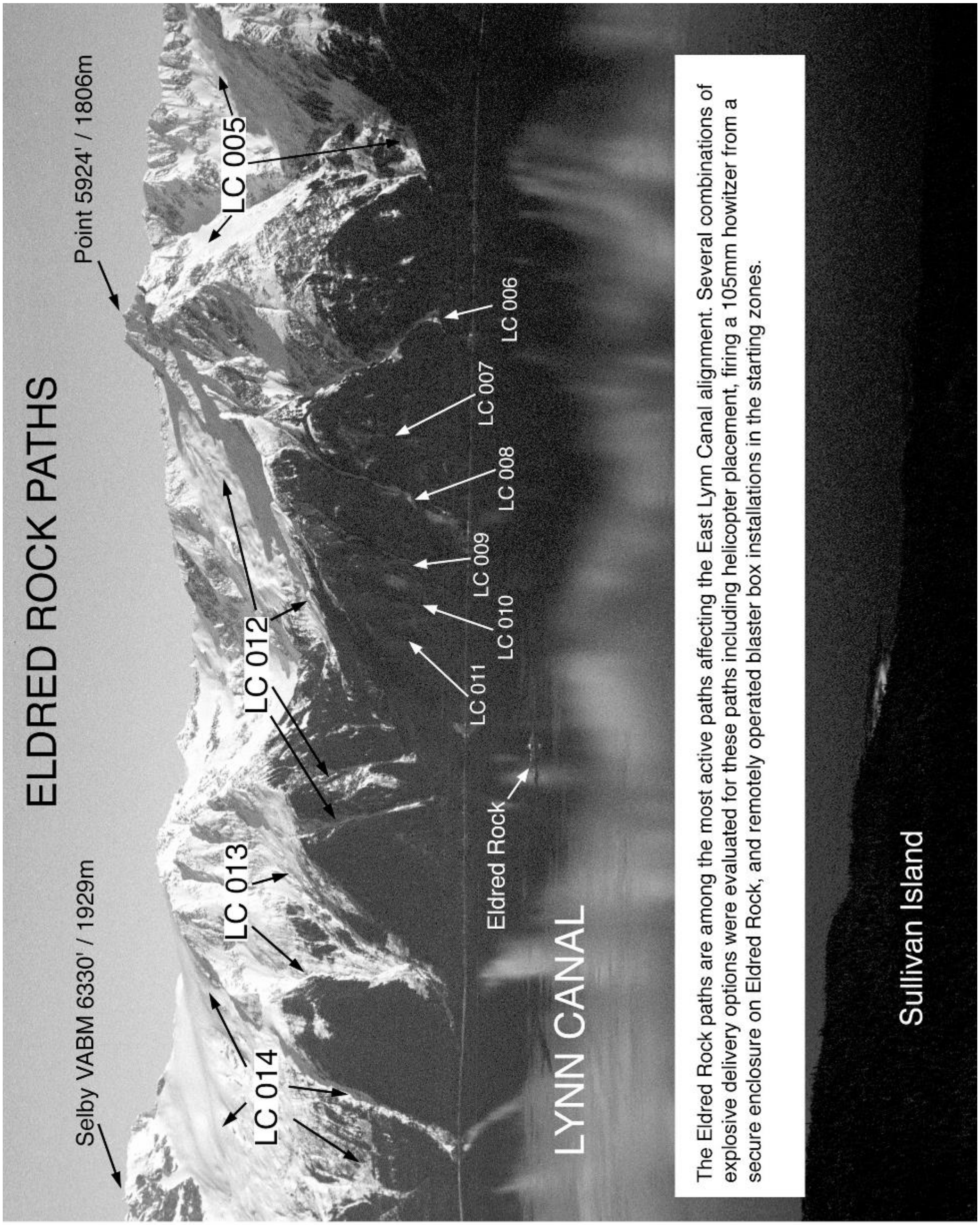
Path Group:	North Kensington
Latitude-Longitude:	58.544894 -135.093227
Max Width:	380 feet / 116 meters
Typical Width:	0 feet / meters (usually stops above alignment)
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	landslide scar
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

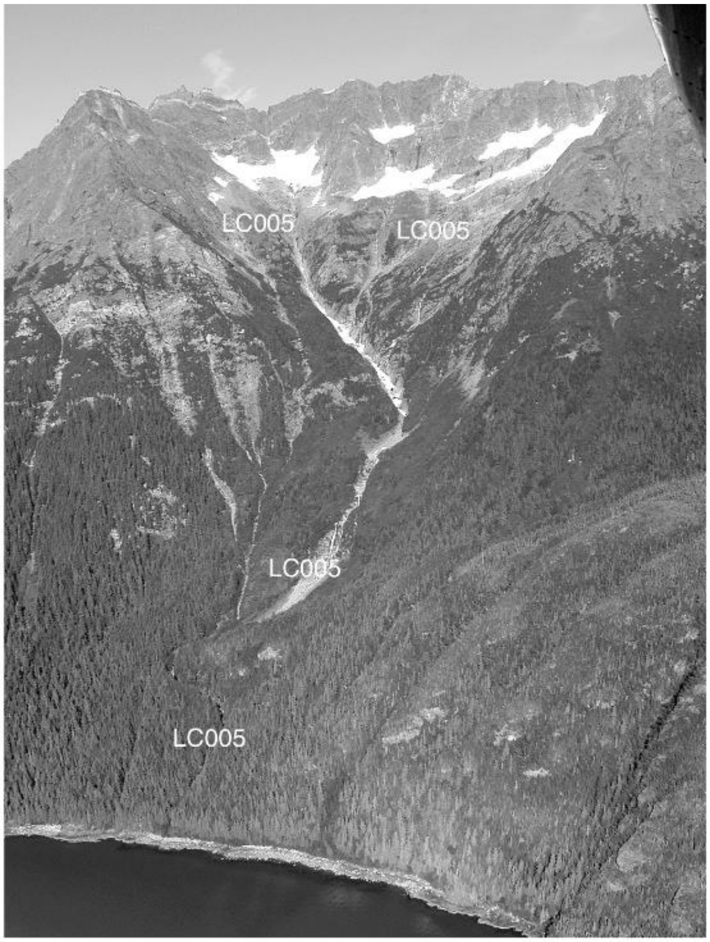

LC004
LC004
LC004

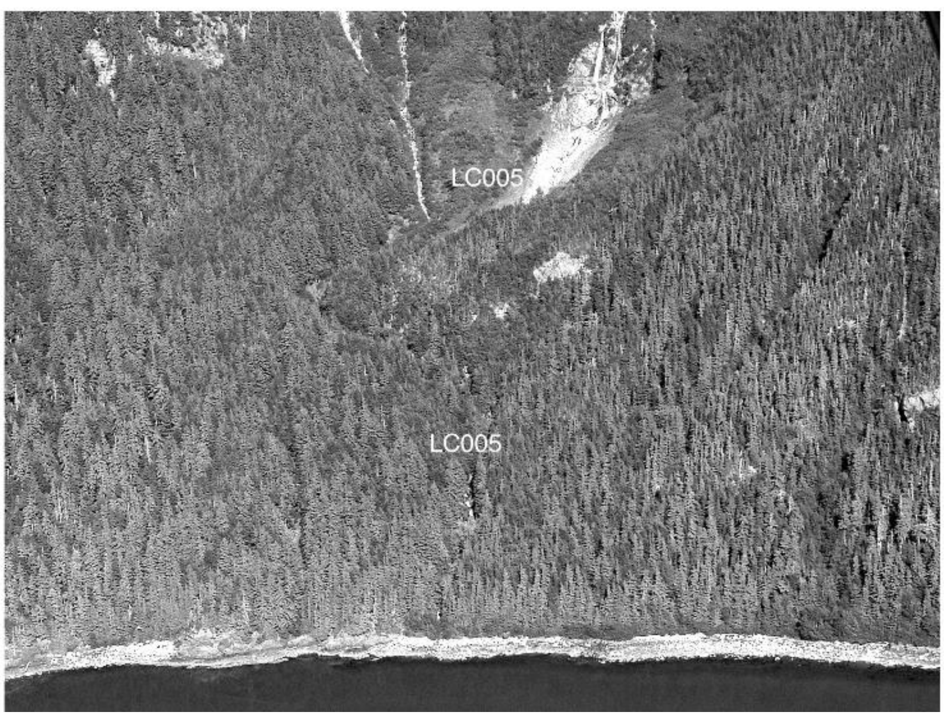

LC004
LC004
LCOO4

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

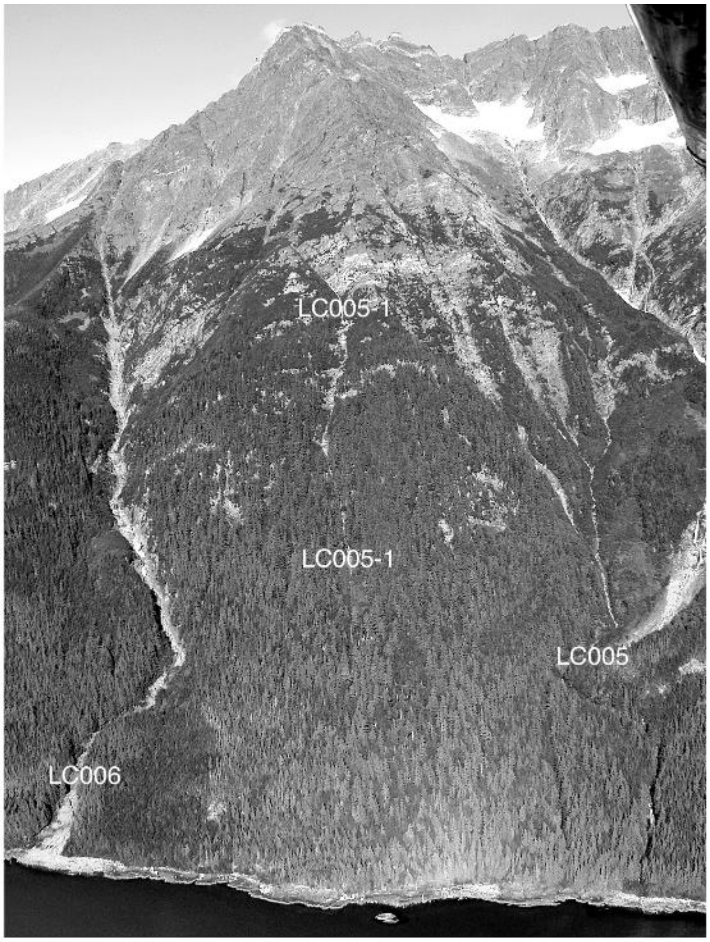

ELDRED ROCK PATHS
Point 5924' / 1806m
Selby VABM 6330' / 1929m
LC 005
LC 006
LC 007
LC 008
LC 009
LC 010
LC 011
LC 012
LC 013
LC 014
Eldred Rock
LYNN CANAL
Sullivan Island
The Eldred Rock paths are among the most active paths affecting the East Lynn Canal alignment. Several combinations of explosive 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.

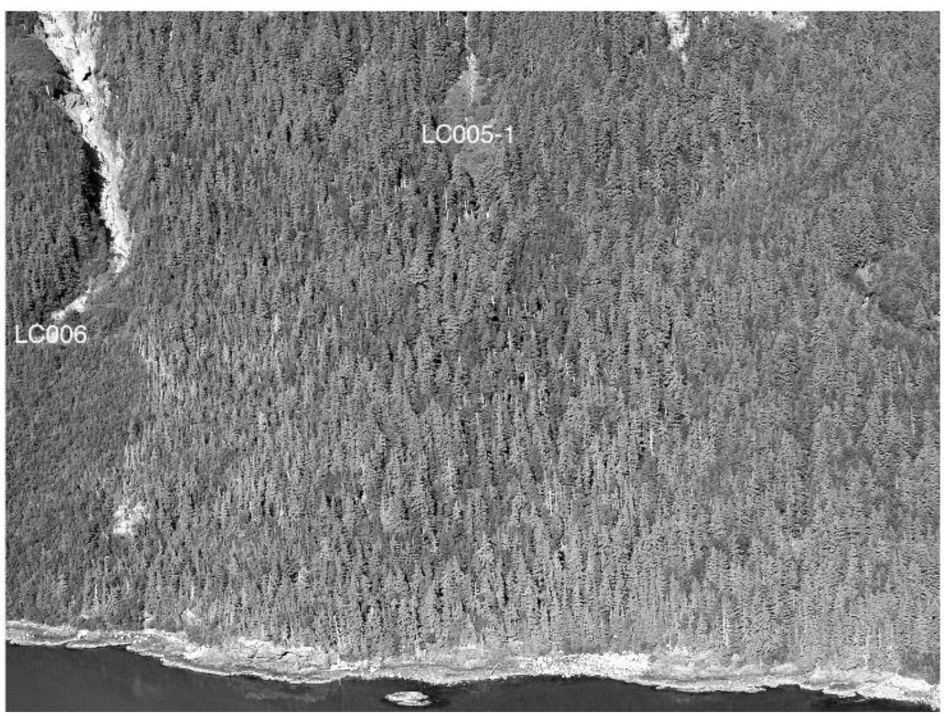

LC005
LC005
LC005
LC005


LC005
LC005

Path: LC005

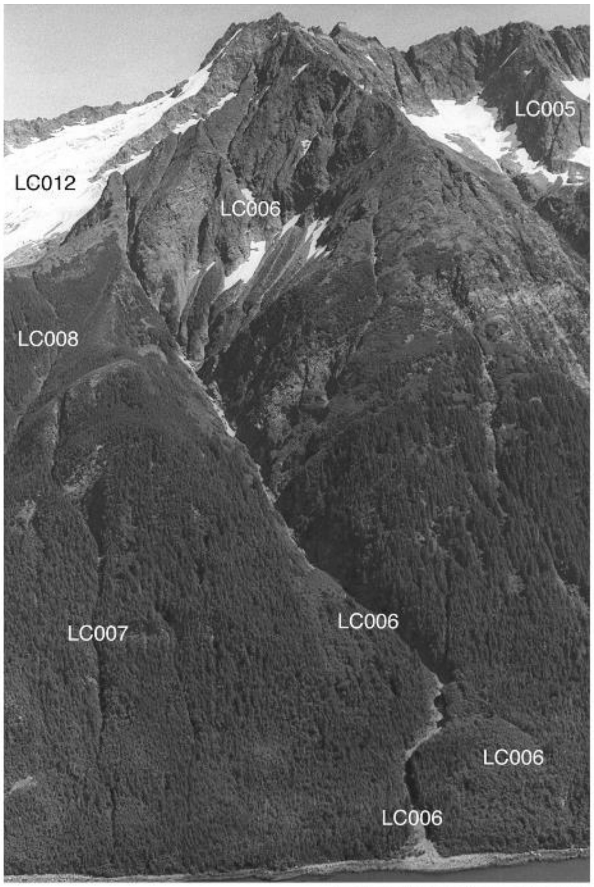
Path Group:	Eldred Rock
Latitude-Longitude:	58.571584 -135.101956
Max Width:	1150 feet / 351 meters
Typical Width:	150 feet / 46 meters
Starting Elevation:	5500 feet / 1676 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl
Start Aspect:	W
Path Type:	confined to 600’ (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

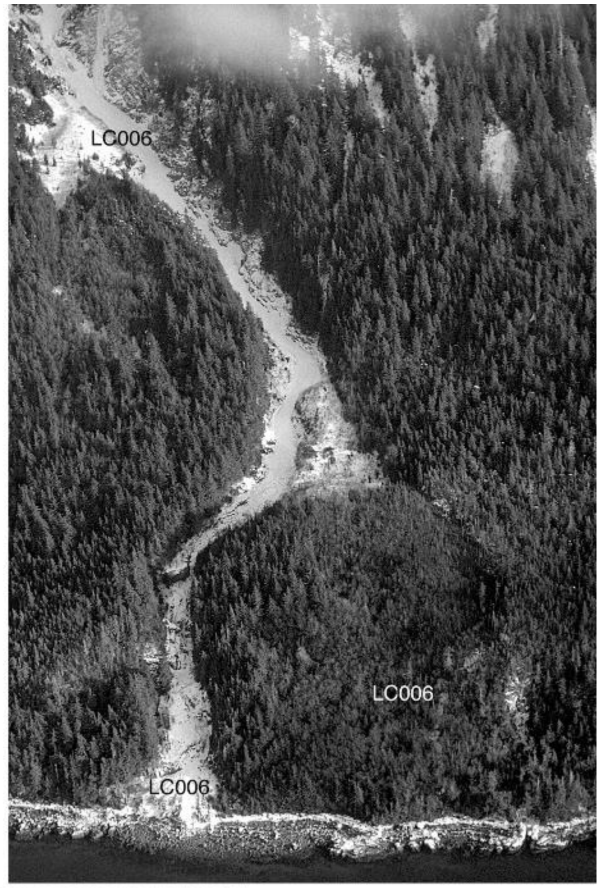

LC005-1
LC005-1
LC005
LC006

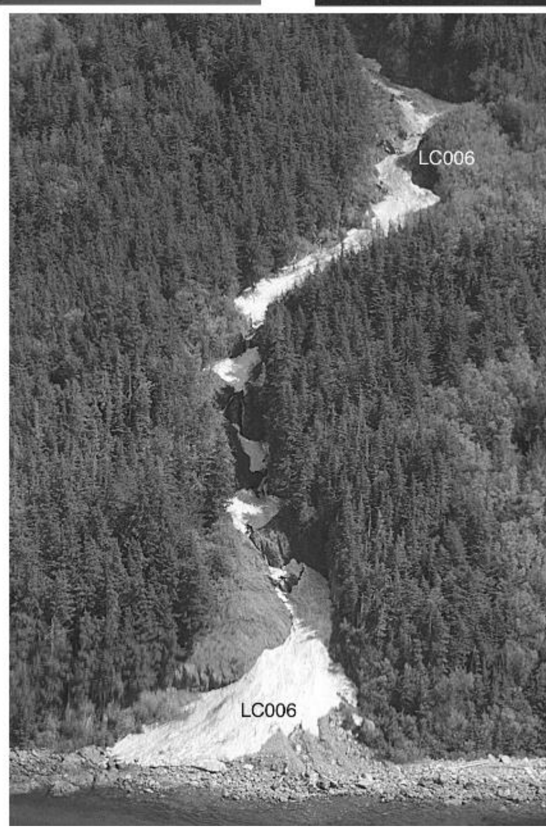

LC005-1
LC006

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

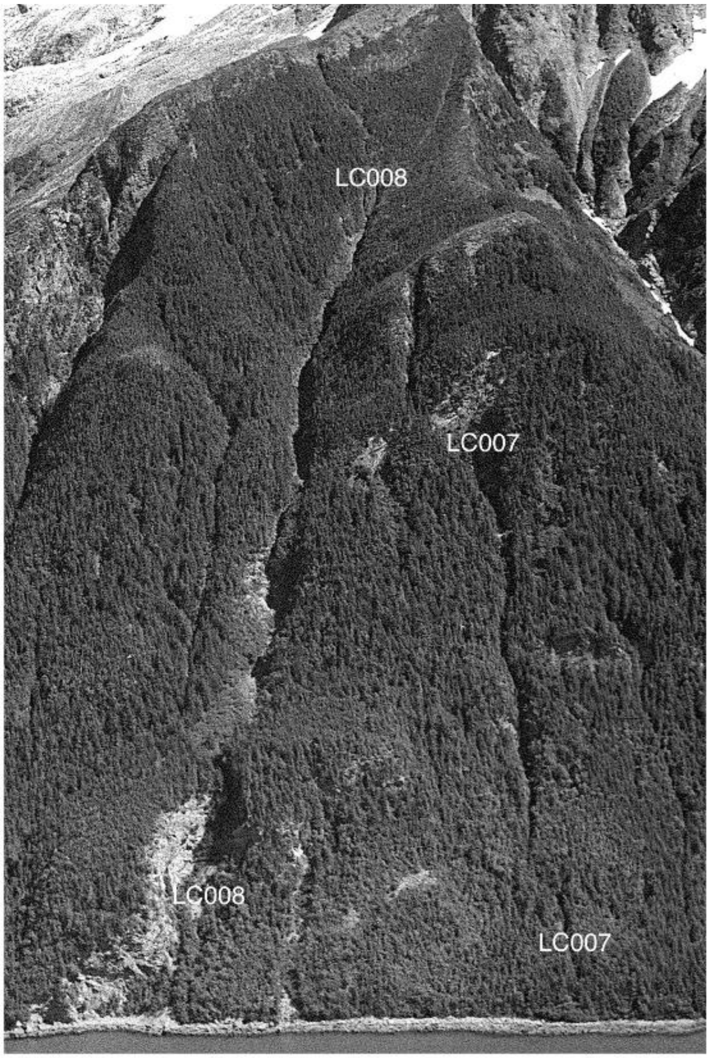

LC005
LC012
LC006
LC008
LC007
LC006
LC006
LC006

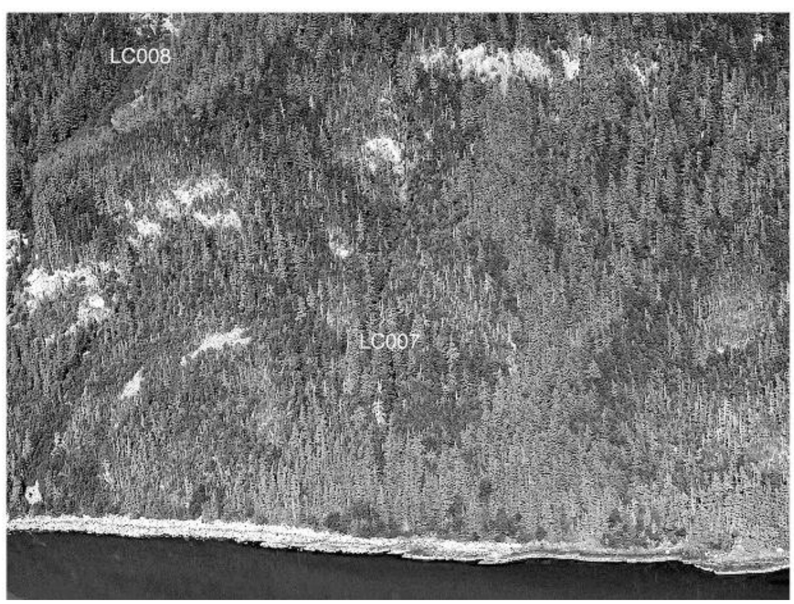

LC006
LC006
LC006


LC006
LC006

Path: LC006

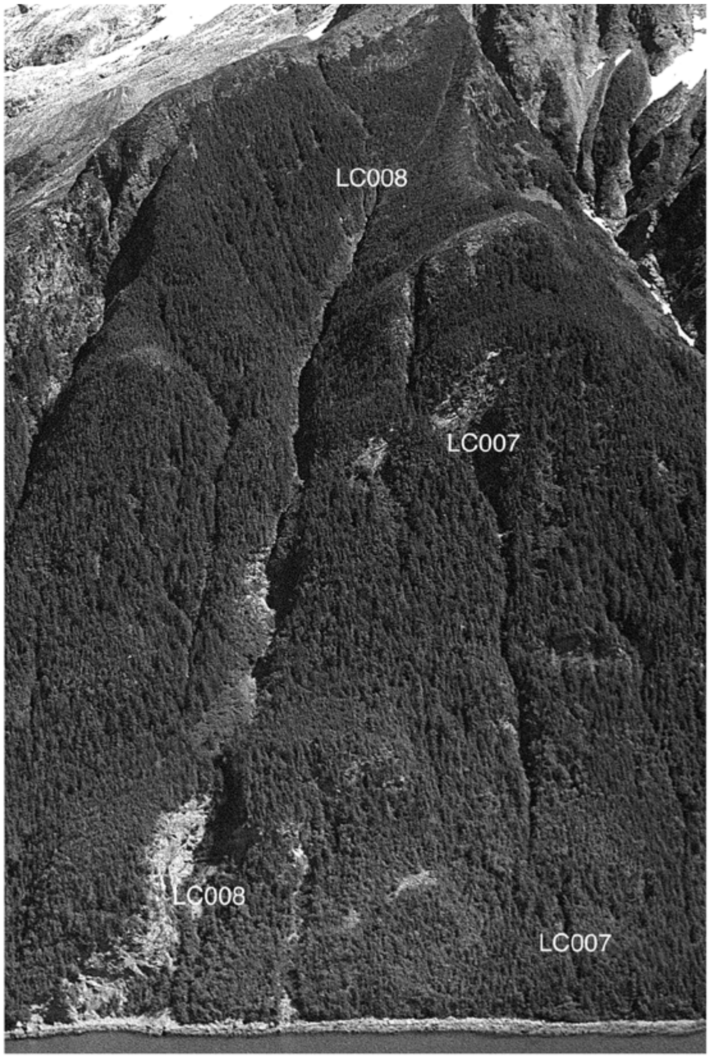
Path Group:	Eldred Rock
Latitude-Longitude:	58.574197 -135.102504
Max Width:	1200 feet / 366 meters
Typical Width:	270 feet / 82 meters
Starting Elevation:	5100 feet / 1554 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big gullied bowl
Start Aspect:	W
Path Type:	classic 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

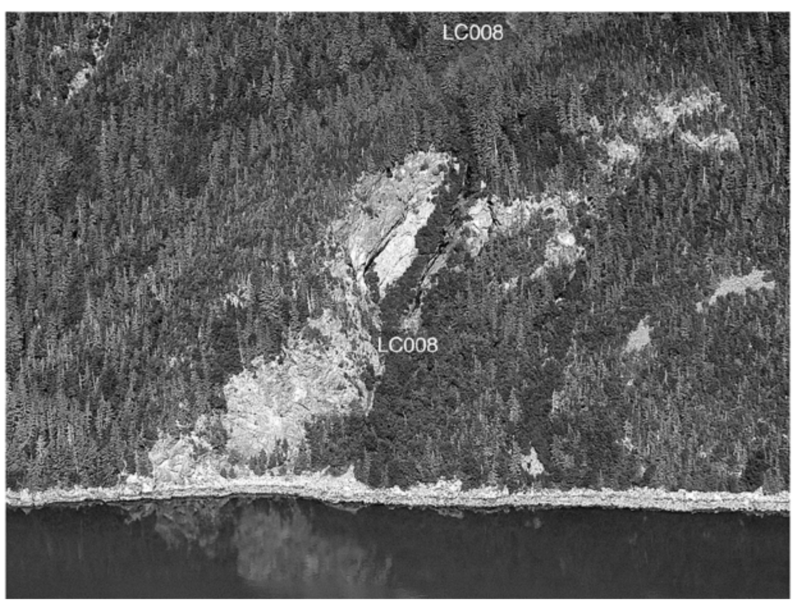

LC008
LC007
LC008
LC007


LC008
LC007

Path: LC007

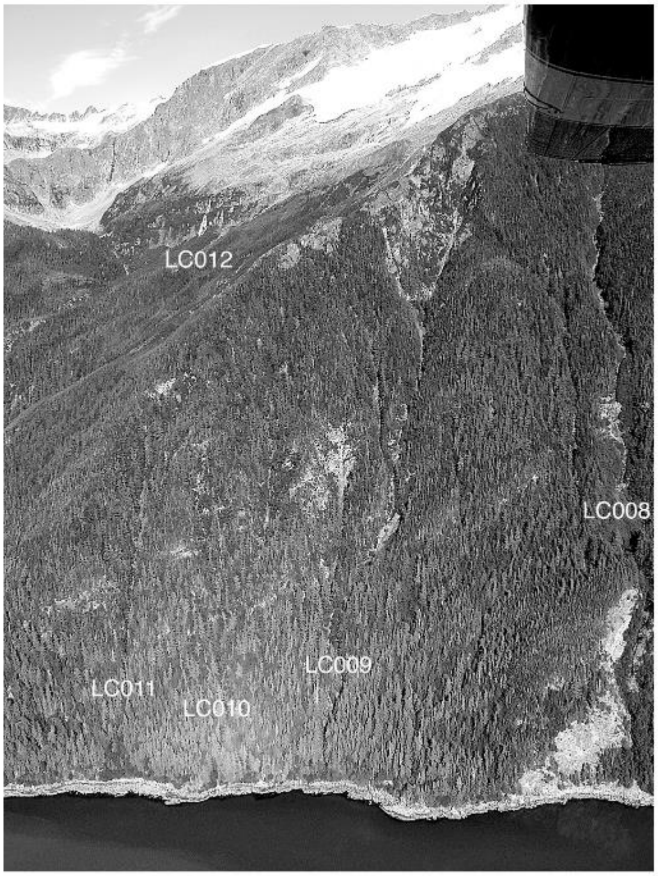
Path Group:	Eldred Rock
Latitude-Longitude:	58.575893 -135.102543
Max Width:	380 feet / 116 meters
Typical Width:	75 feet / 23 meters
Starting Elevation:	2100 feet / 640 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	small bowl/gully
Start Aspect:	W
Path Type:	narrow 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

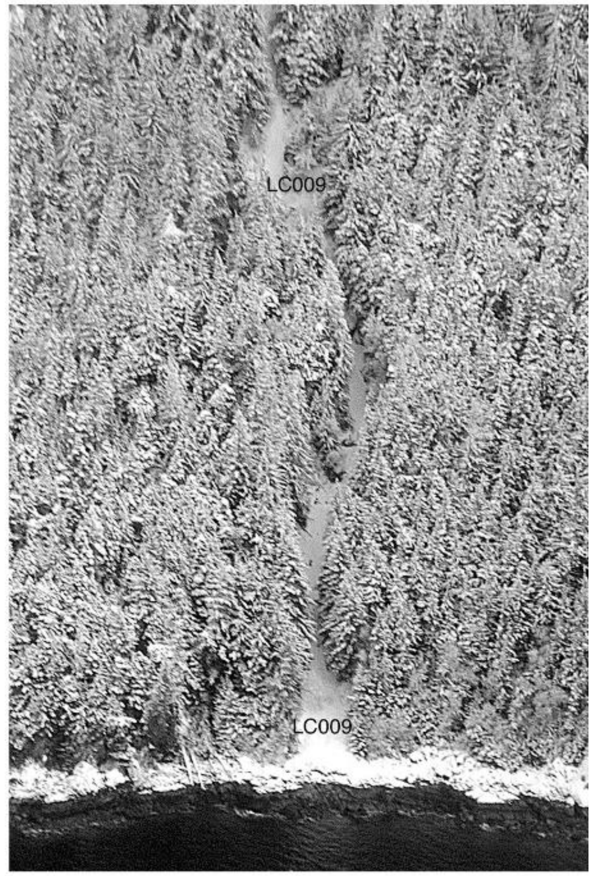

LC008
LC007
LC008
LC007

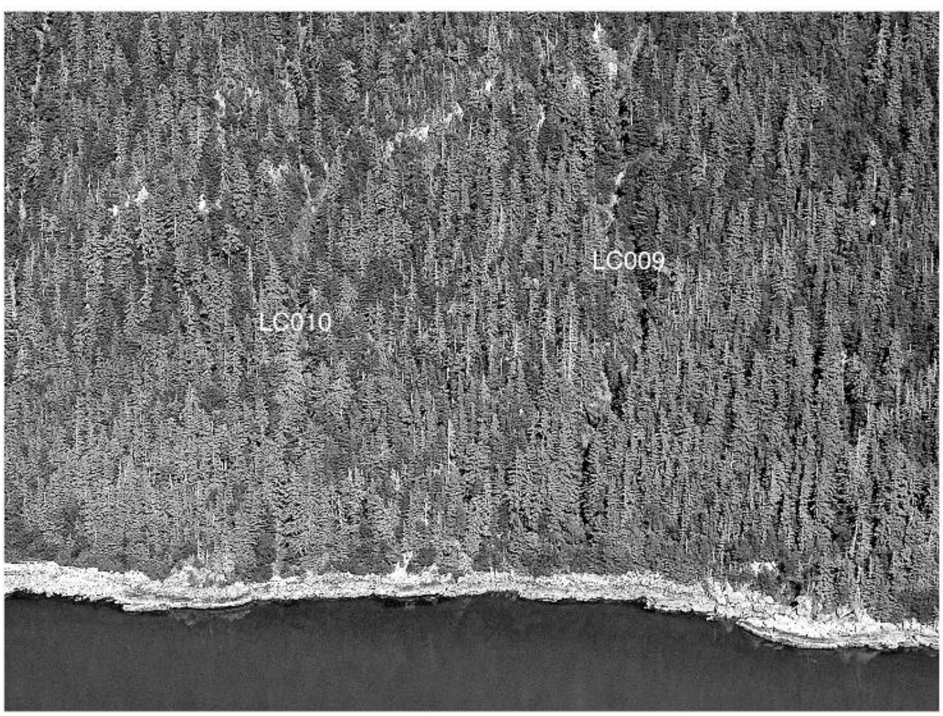

LC008
LC008

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

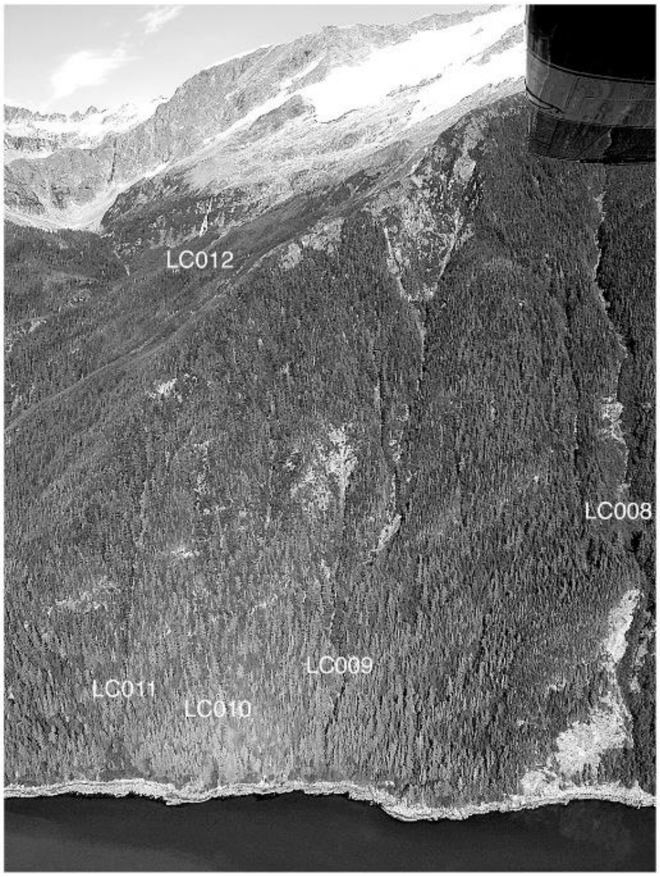

LC012
LC008
LC011
LC010
LC009

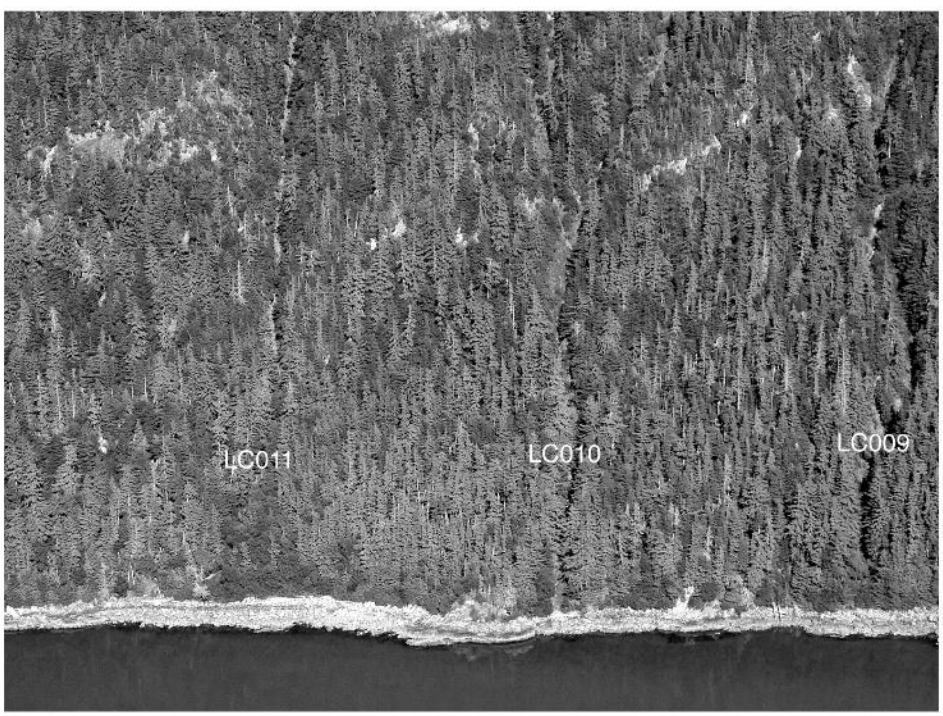

LC009
LC009


LC009
LC010

Path: LC009

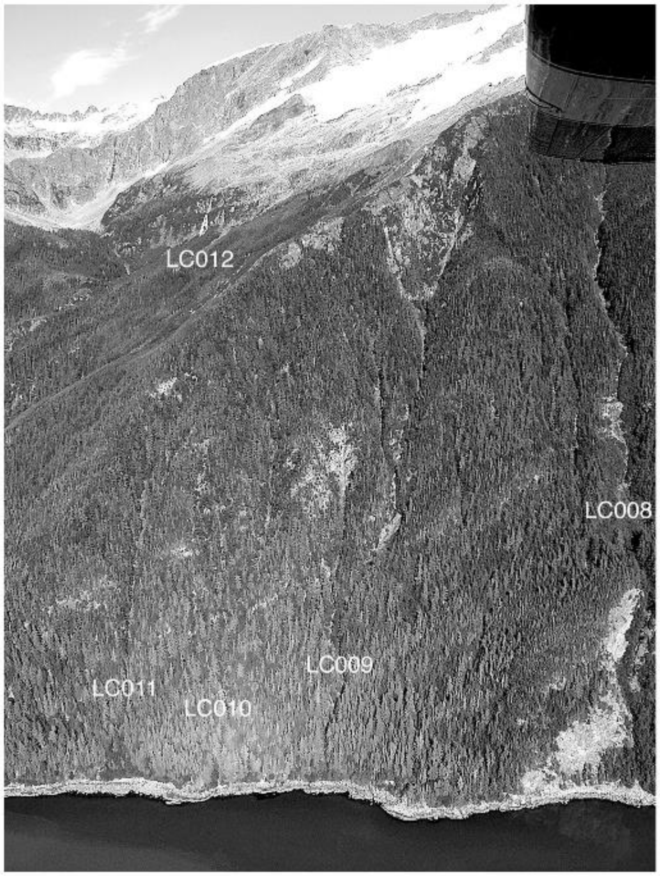
Path Group:	Eldred Rock
Latitude-Longitude:	58.582368 -135.102472
Max Width:	110 feet / 34 meters
Typical Width:	90 feet / 27 meters
Starting Elevation:	2700 feet / 823 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	small bowl and gullies
Start Aspect:	W
Path Type:	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

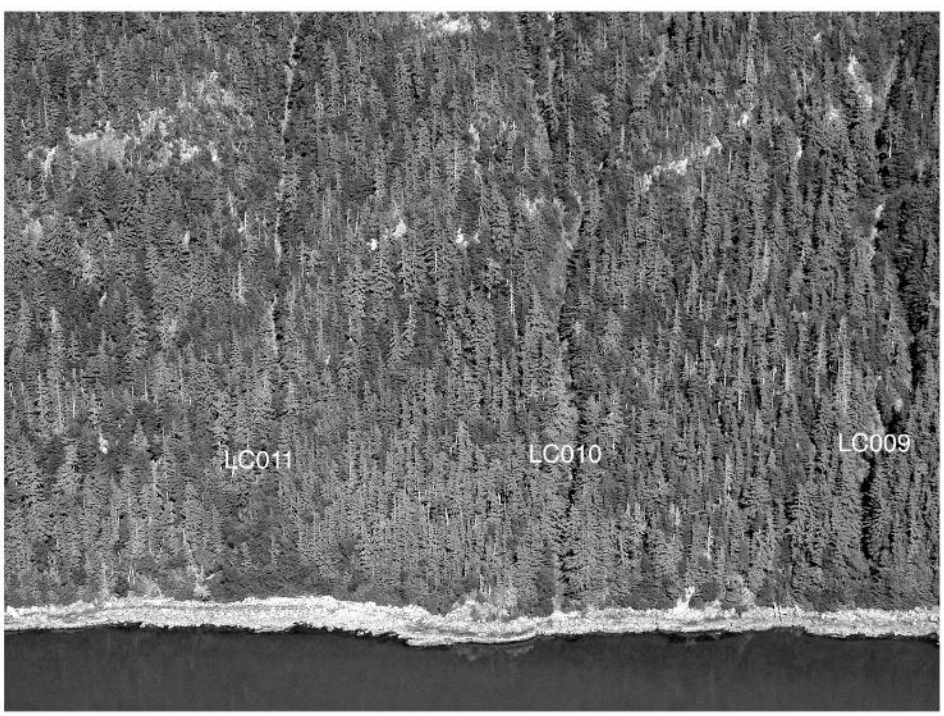

LC012
LC008
LC009
LC011
LC010


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
LC009
LC011
LC010


LC011
LC010
LC009

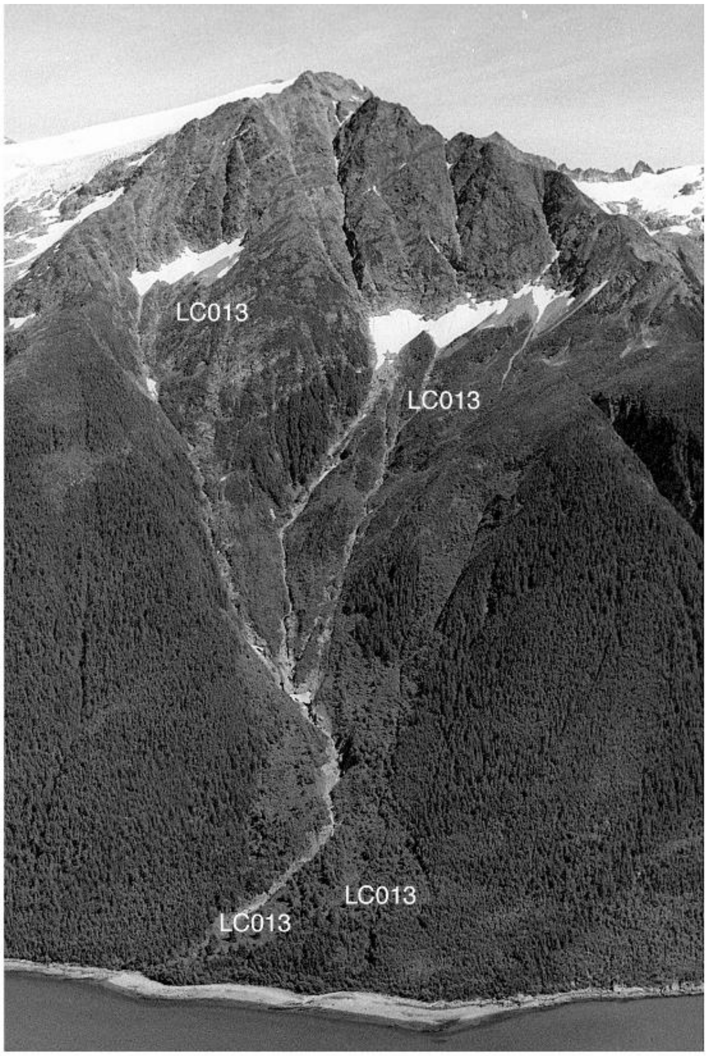
Path: LC011

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

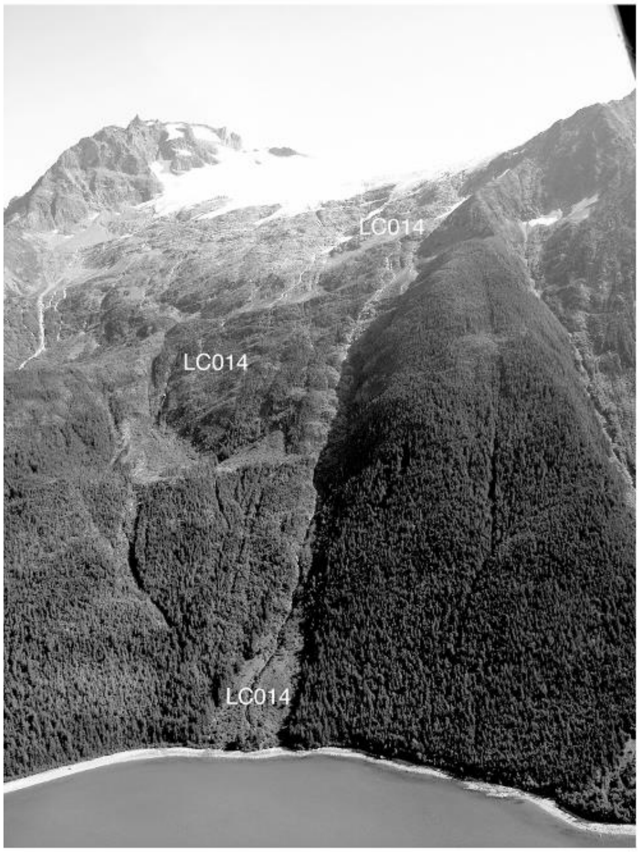
Path Group:	Eldred Rock
Latitude-Longitude:	58.585938 -135.102898
Max Width:	1190 feet / 363 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	5924 feet / 1806 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl and broad gullies
Start Aspect:	W
Path Type:	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

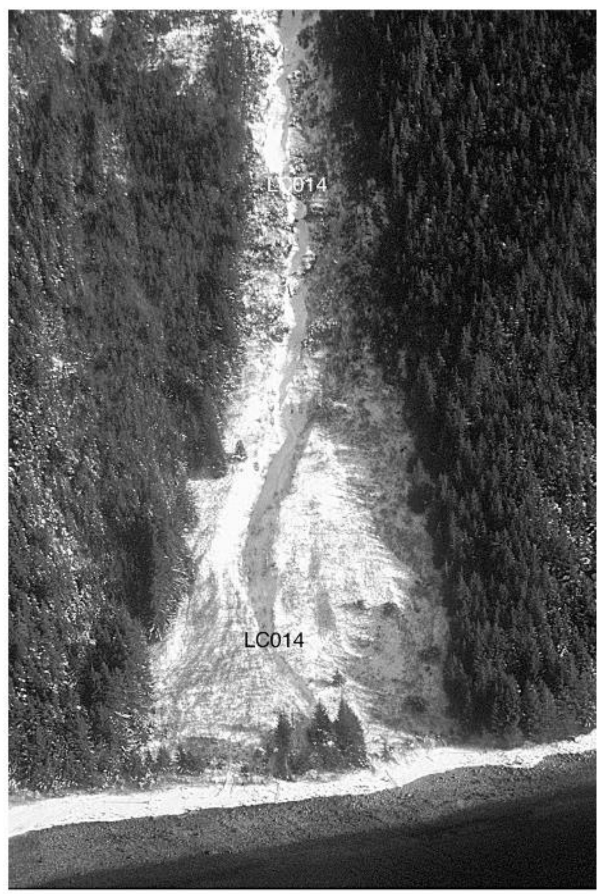

LC013
LC013
LC013
LC013


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

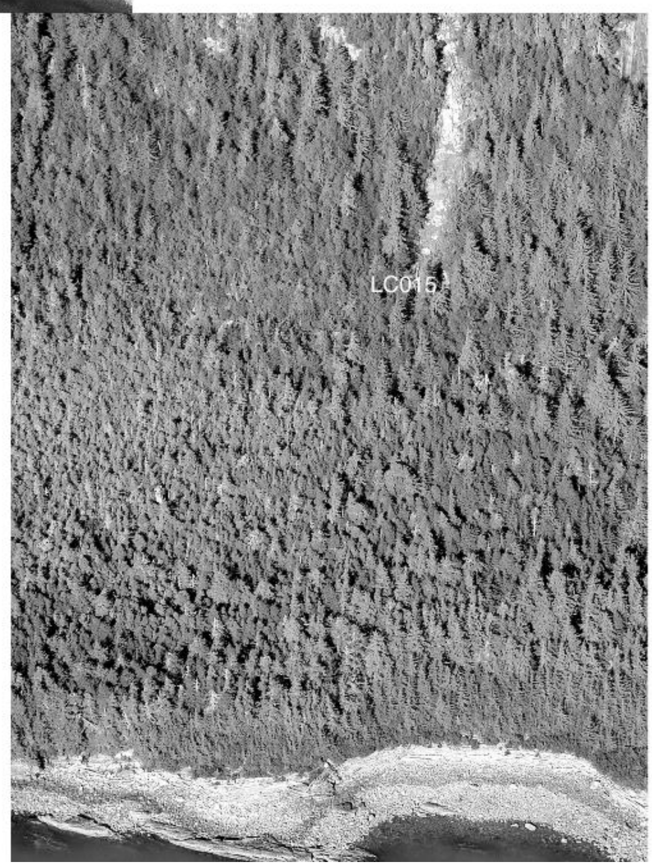

LC014
LC014
LC014


LC014

Path: LC014

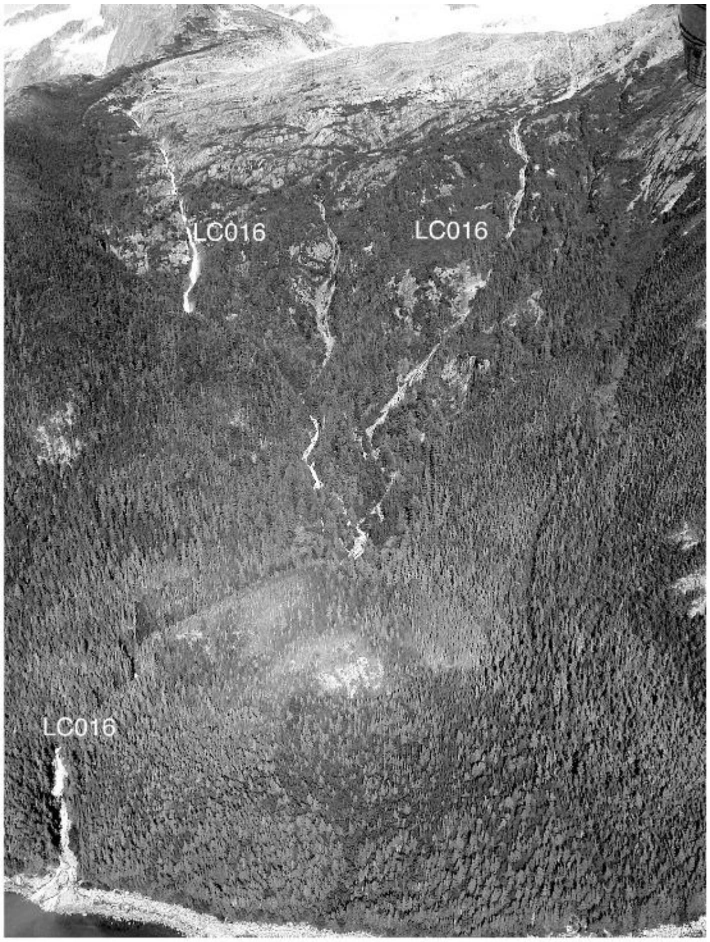
Path Group:	Eldred Rock
Latitude-Longitude:	58.595964 -135.103751
Max Width:	750 feet / 229 meters
Typical Width:	120 feet / 37 meters
Starting Elevation:	4700 feet / 1432 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	rollover, very broad bowl
Start Aspect:	W
Path 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

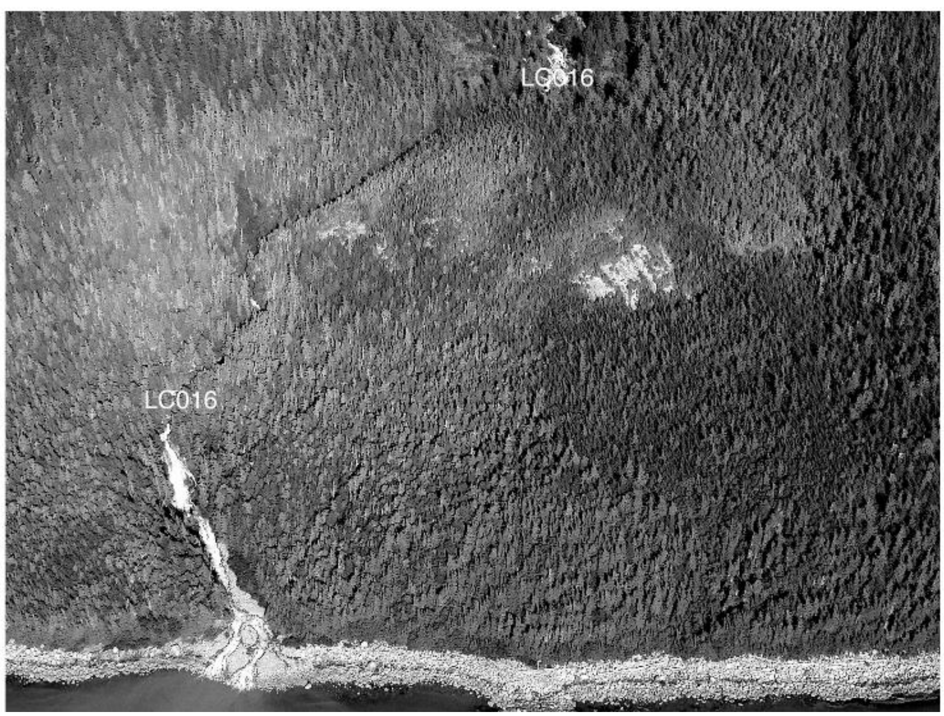

LC015


LC015

Path: LC015

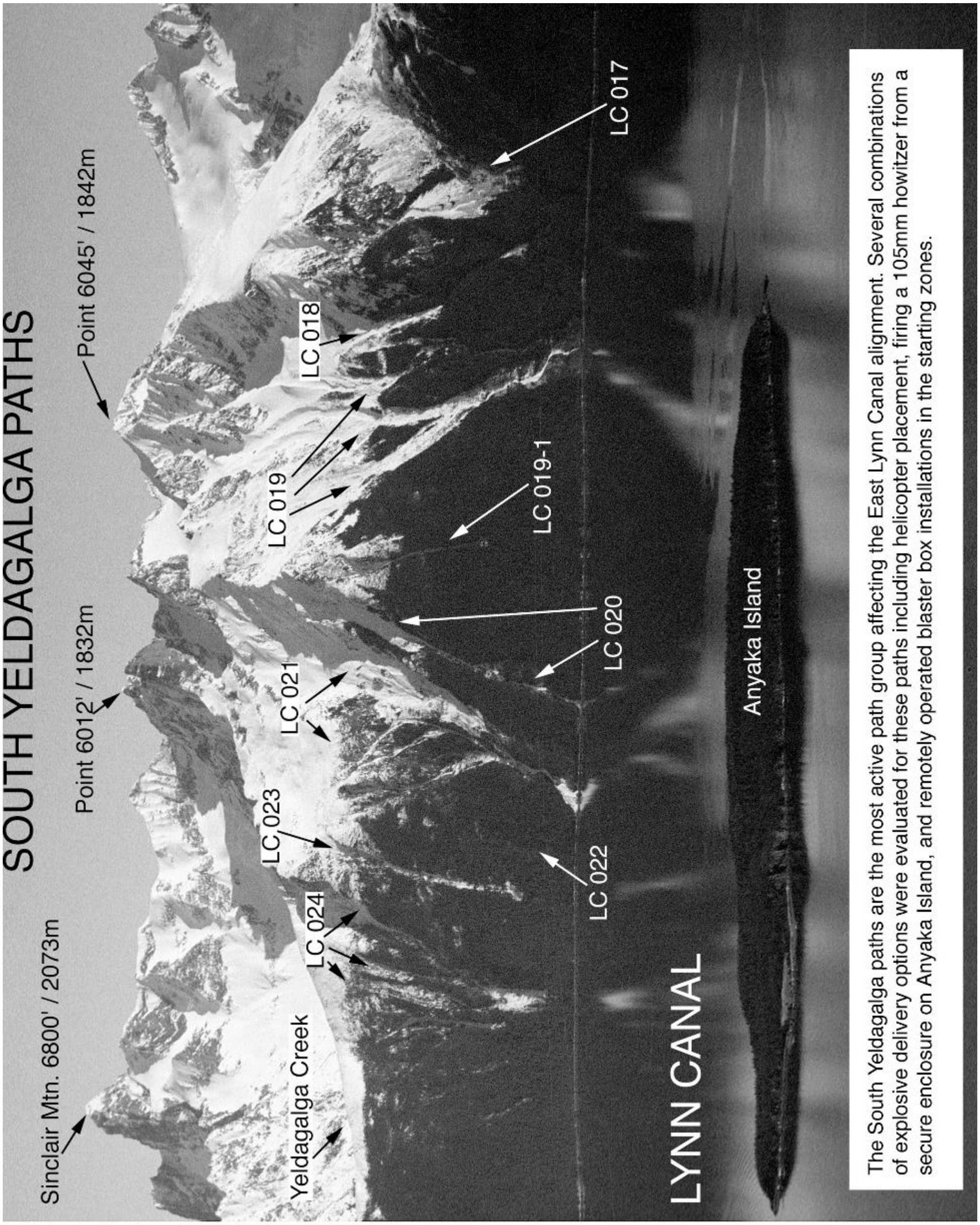
Path Group:	Eldred Rock
Latitude-Longitude:	59.012272 -135.115548
Max Width:	60 feet / 18 meters
Typical Width:	0 feet / 0 meters (usually stops above alignment)
Starting Elevation:	800 feet / 244 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	cliff notch
Start Aspect:	WSW
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
LC016
LC016

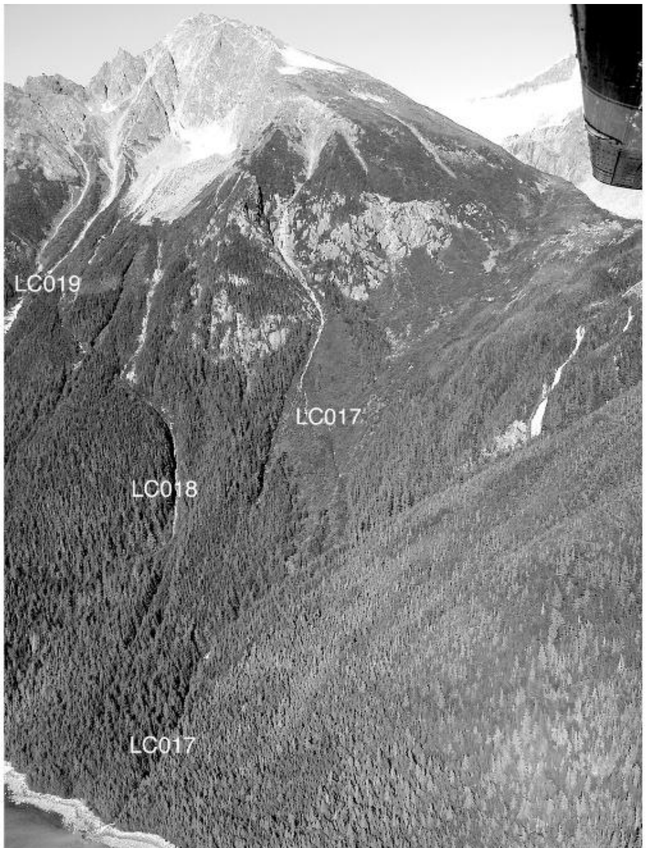

LC016
LC016

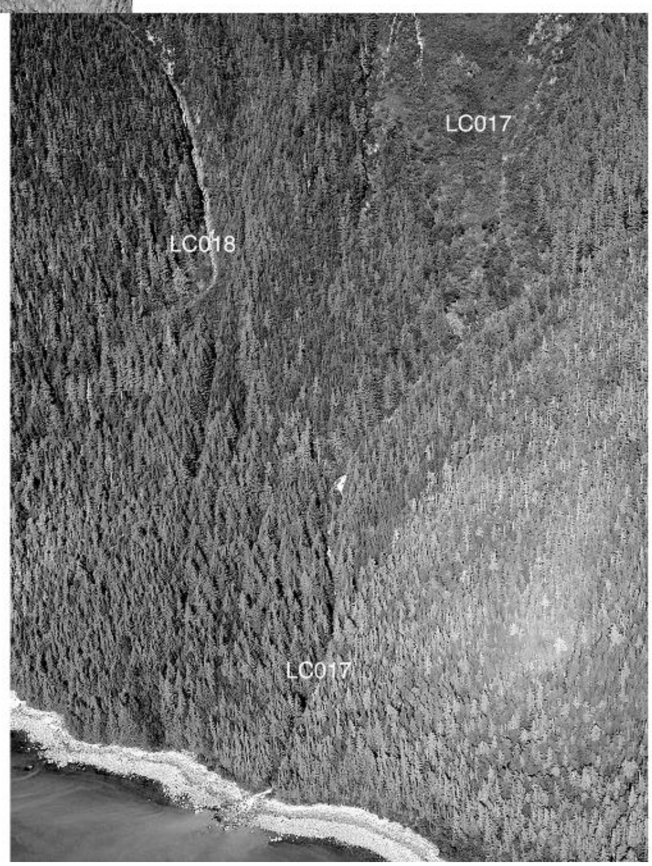
Path: LC016

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



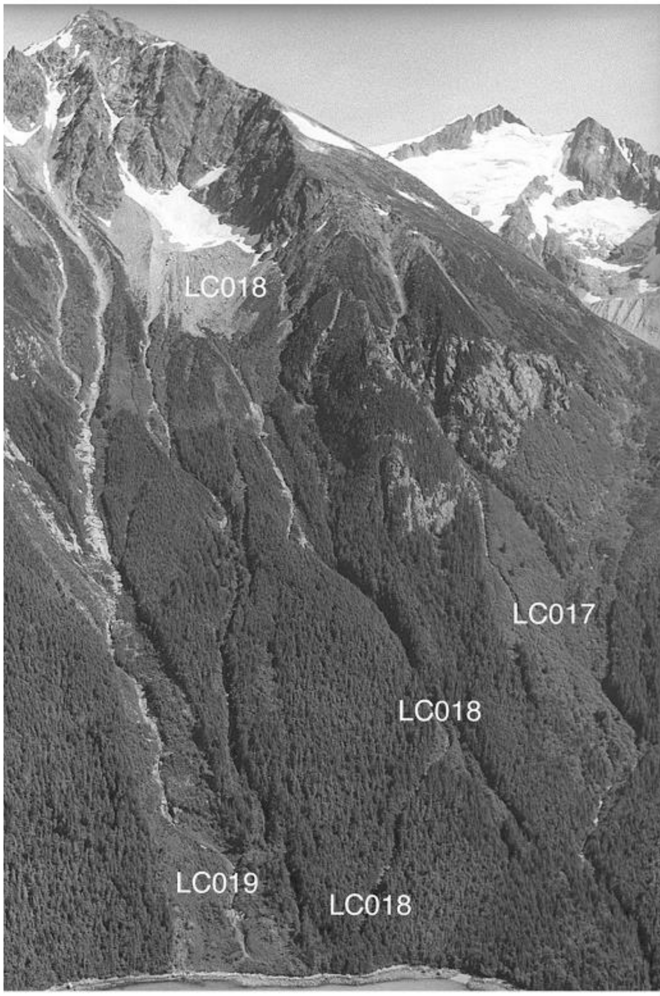
The South Yeldagalga paths are the most active path group affecting the East Lynn Canal alignment. Several combinations of explosive delivery options were evaluated for these paths including helicopter placement, firing a 105mm howitzer from a secure enclosure on Anyaka Island, and remotely operated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

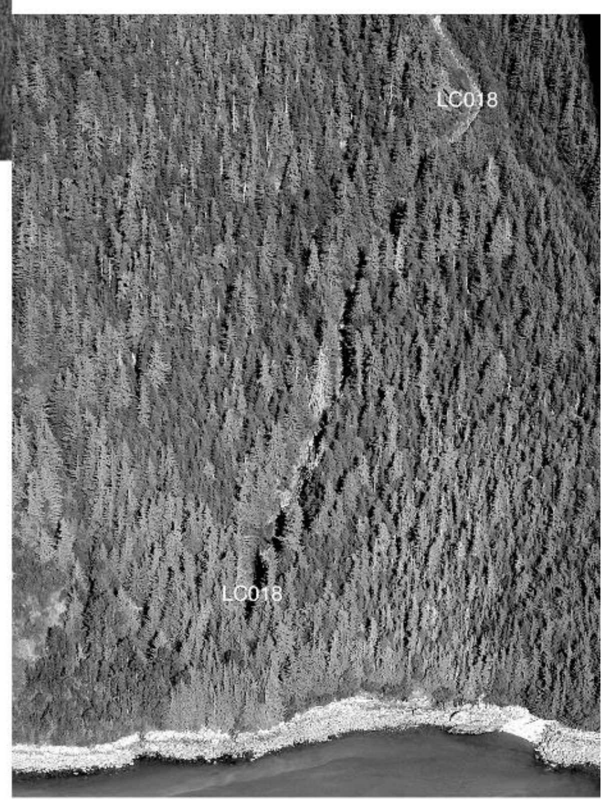

LC019
LC017
LC018
LC017


LC017
LC018
LC017

Path: LC017

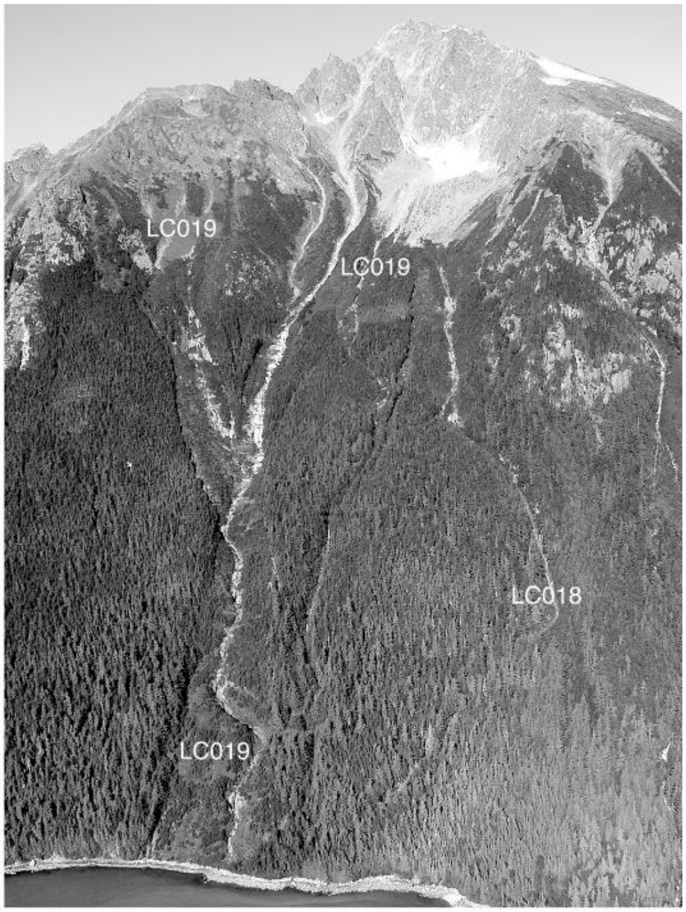
Path Group:	South Yeldagalga
Latitude-Longitude:	59.025529 -135.115683
Max Width:	1420 feet / 433 meters
Typical Width:	170 feet / 52 meters
Starting Elevation:	4800 feet / 1463 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	broad face
Start Aspect:	W
Path Type:	face to 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

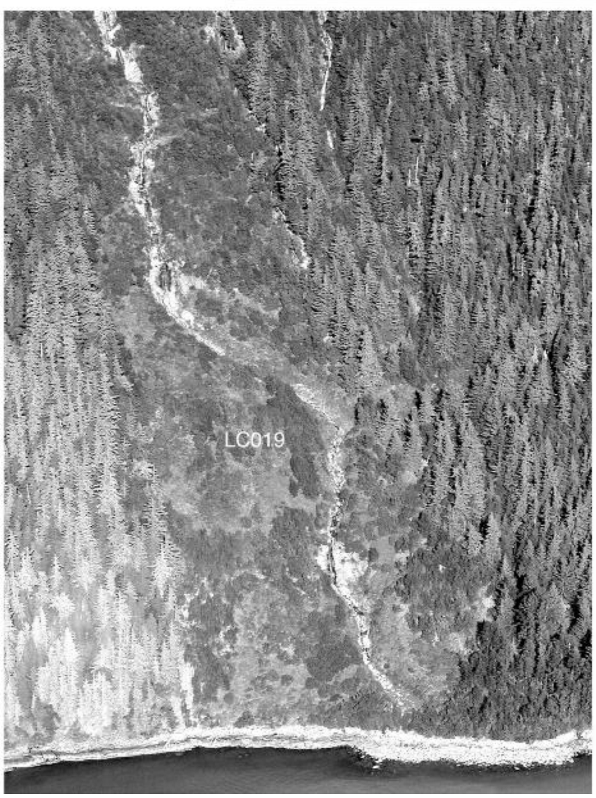

LC018
LC017
LC018
LC019
LC018


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

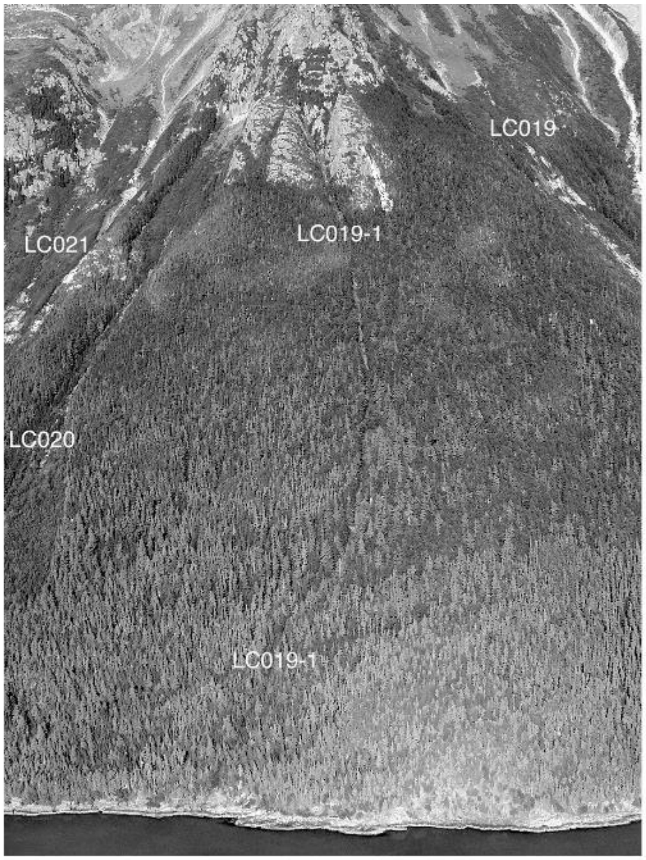

LC019
LC019
LC018
LC019

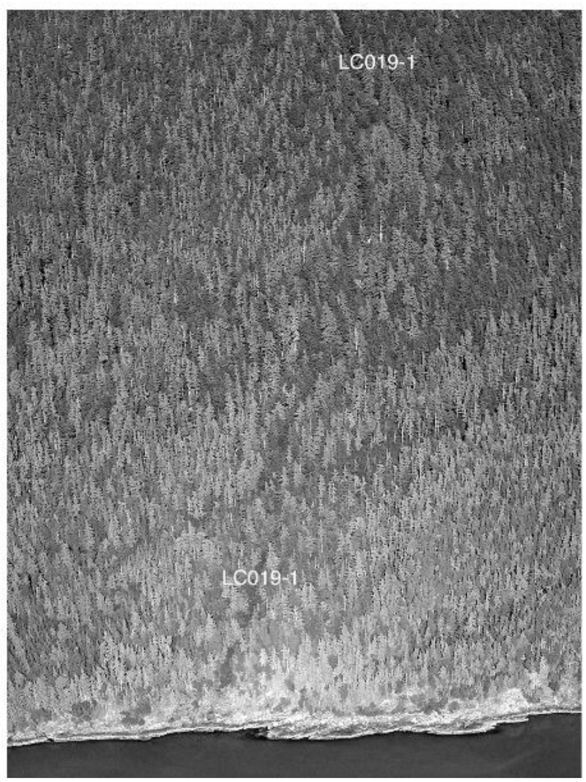

LC019


LC019
LC018
LC019

Path: LC019

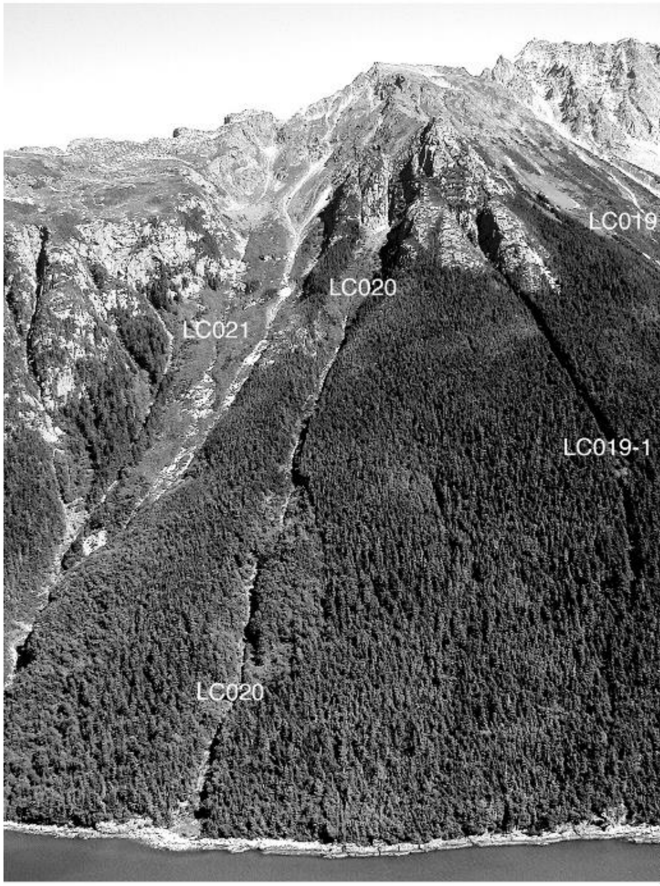
Path Group:	South Yeldagalga
Latitude-Longitude:	59.0311 -135.11558
Max Width:	980 feet / 299 meters
Typical Width:	500 feet / 152 meters
Starting Elevation:	6300 feet / 1920 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	WSW
Path Type:	confined; 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

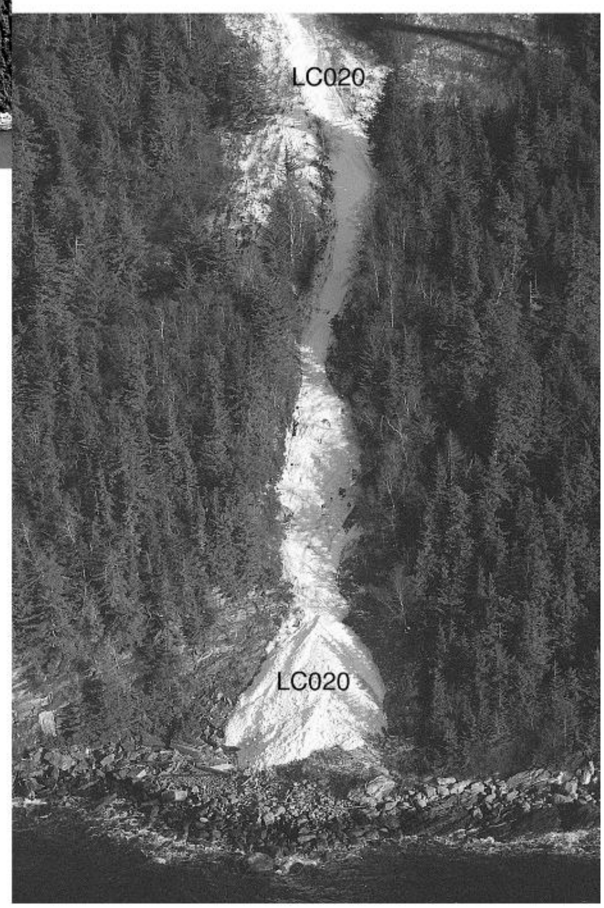

LC019
LC021
LC019-1
LC020
LC019-1


LC019-1
LC019-1

Path: LC019-1

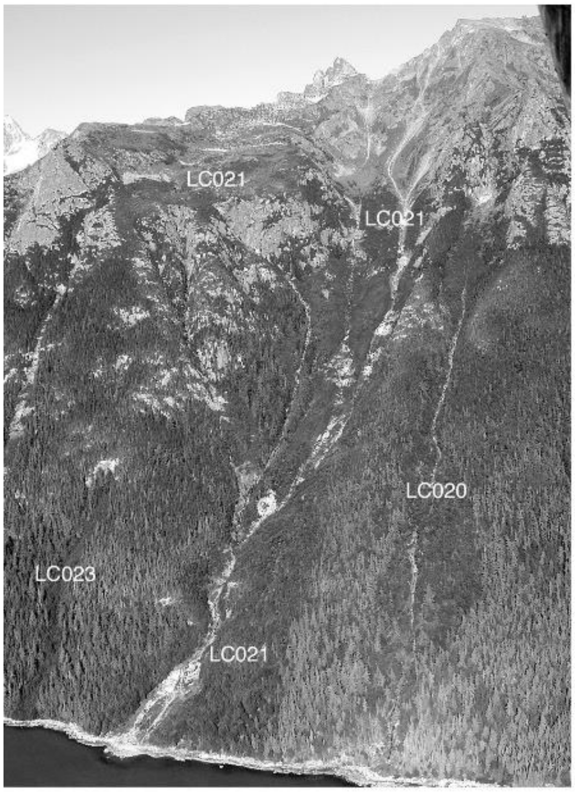
Path Group:	South Yeldagalga
Latitude-Longitude:	59.033816 -135.121281
Max Width:	80 feet / 24 meters
Typical Width:	0 feet / 0 meters (usually stops above alignment)
Starting Elevation:	3200 feet / 975 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	small bowl
Start Aspect:	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

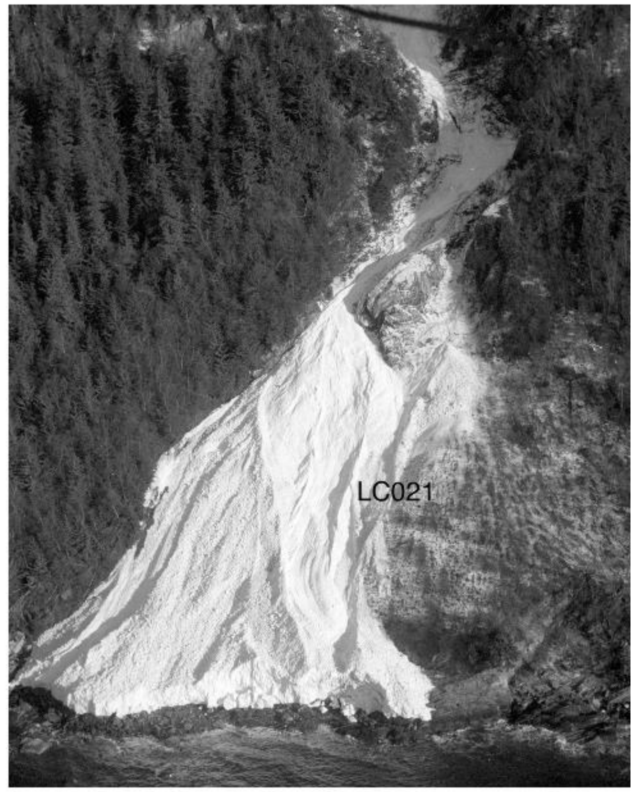

LC019
LC020
LC021
LC019-1
LC020


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

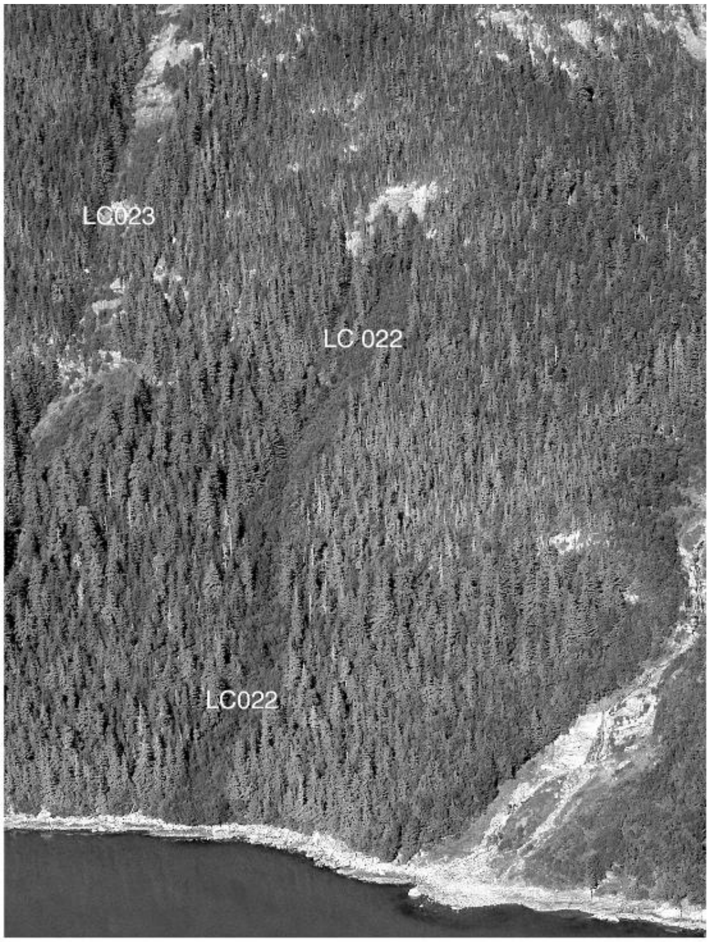

LC021
LC021
LC020
LC023
LC021

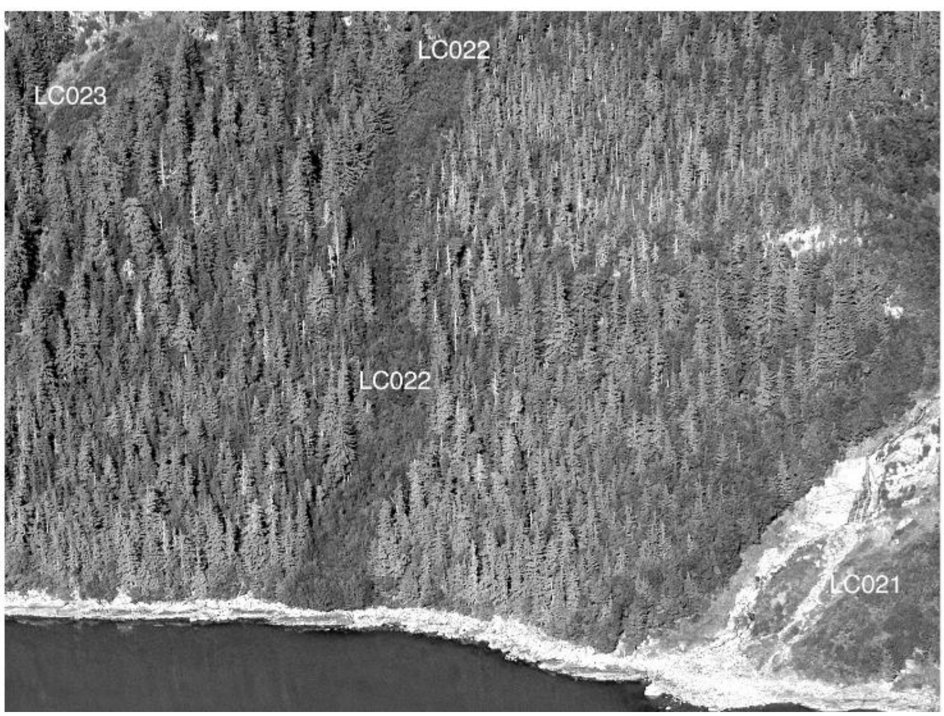

LC021


LC021
LC021

Path: LC021

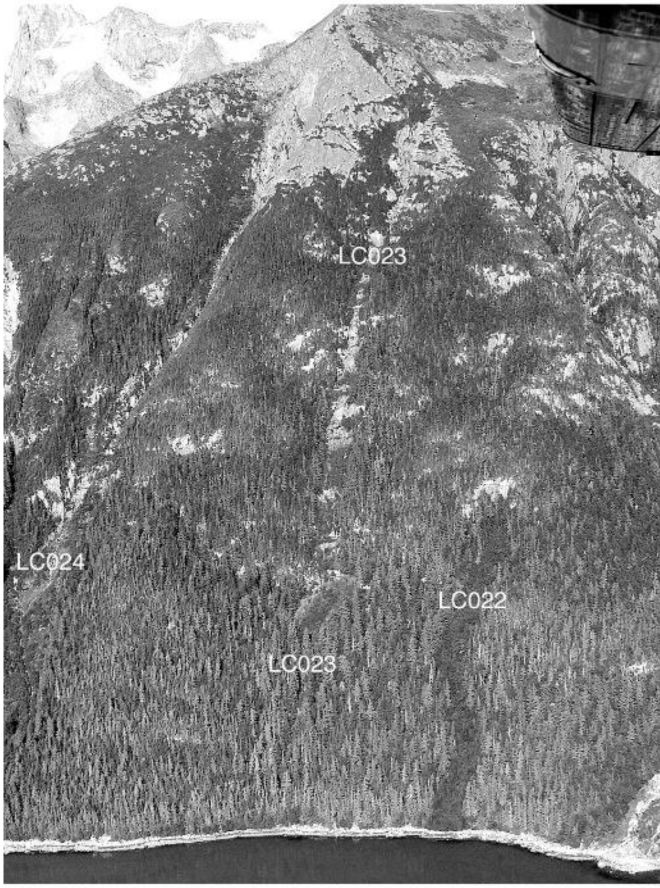
Path Group:	South Yeldagalga
Latitude-Longitude:	59.040632 -135.121461
Max Width:	1240 feet / 378 meters
Typical Width:	600 feet / 183 meters
Starting Elevation:	4800 feet / 1463 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	W
Path Type:	classic 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

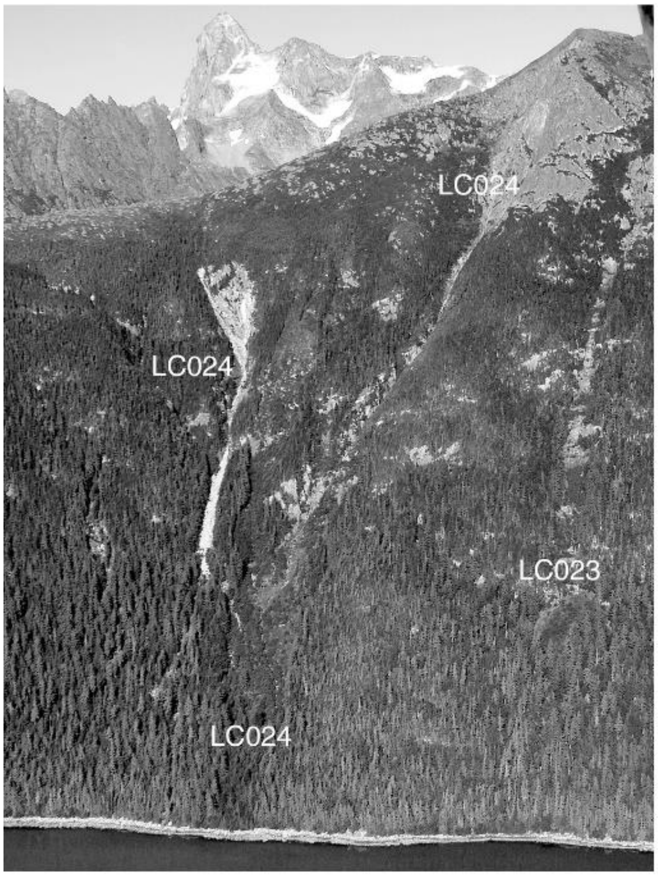
Path Group:	South Yeldagalga
Latitude-Longitude:	59.04131 -135.121194
Max Width:	110 feet / 34 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	1500 feet / 457 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	small rock slab and talus
Start Aspect:	W
Path 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

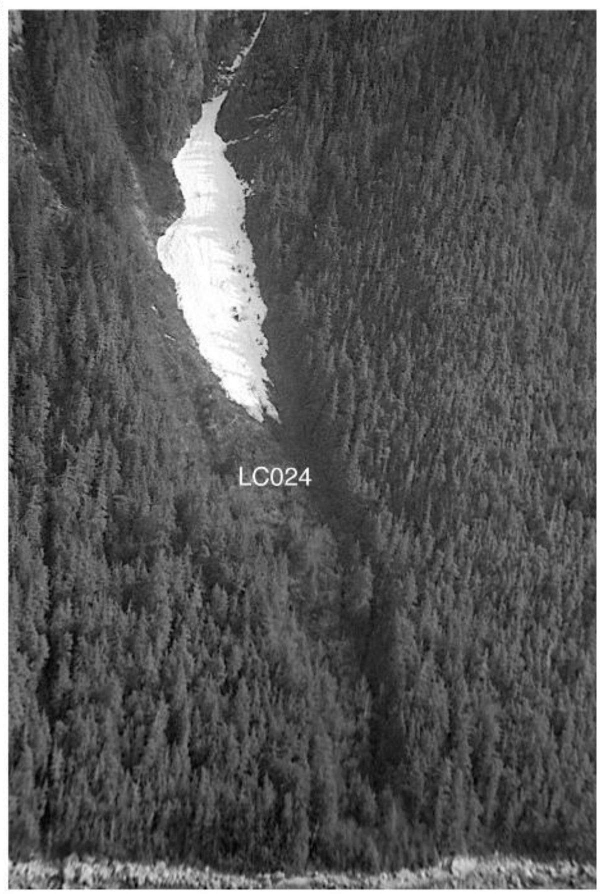

LC023
LC024
LC022
LC023


LC023
LC023

Path: LC023

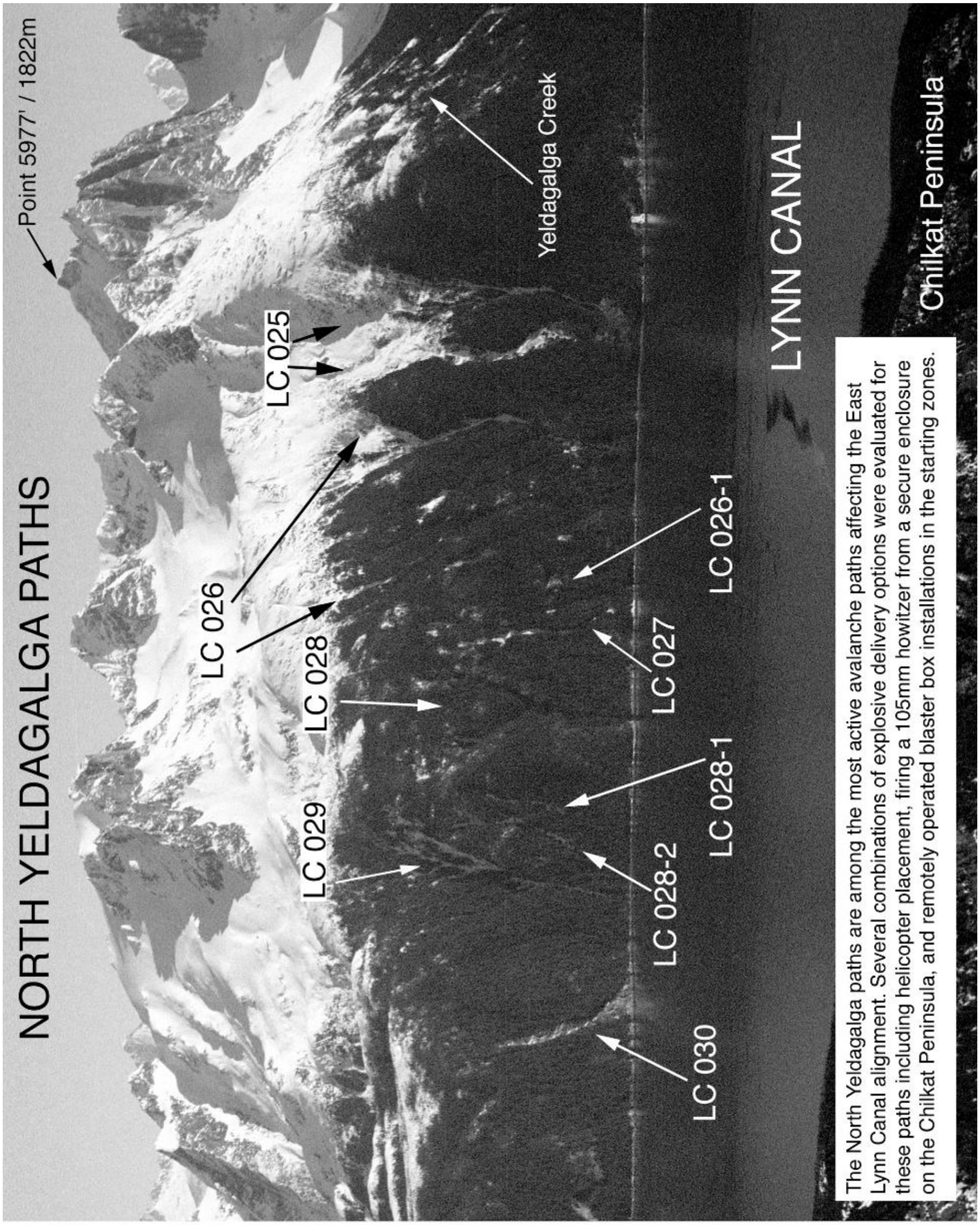
Path Group:	South Yeldagalga
Latitude-Longitude:	59.041891 -135.121213
Max Width:	210 feet / 64 meters
Typical Width:	120 feet / 37 meters
Starting Elevation:	2900 feet / 884 meters
Elevation Class:	medium high
Path Size:	medium
Starting Zone Characteristics:	rock slabs and gully
Start Aspect:	W
Path 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

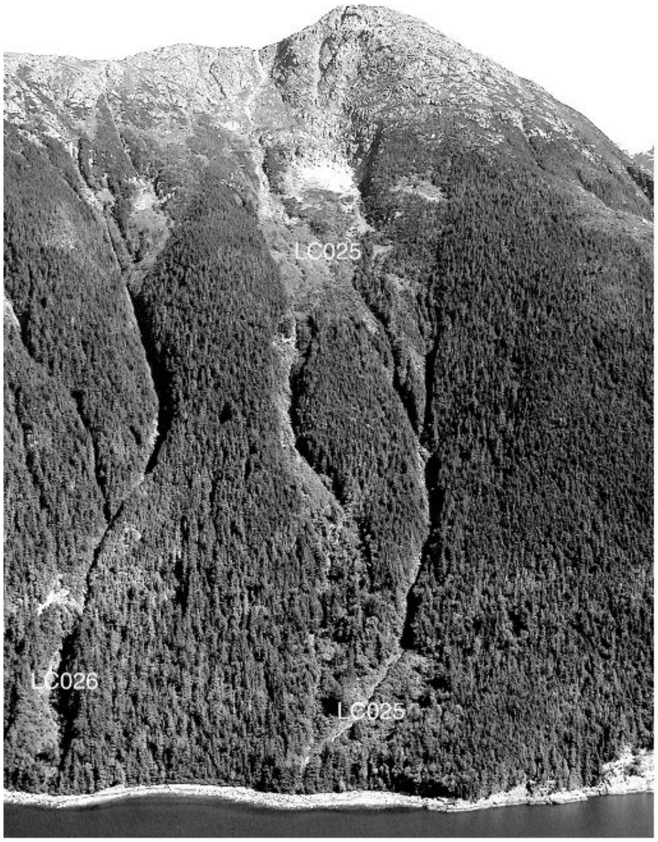

LC024

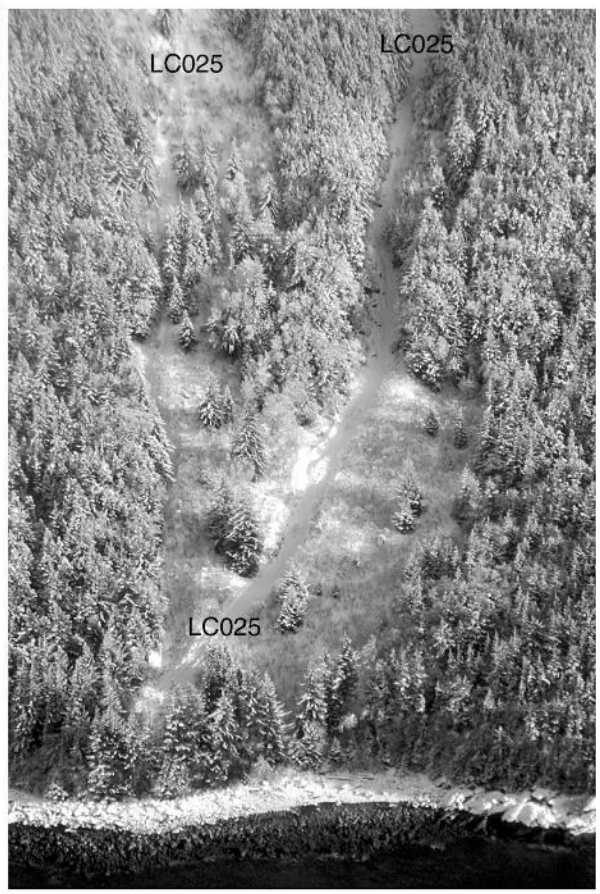
Path: LC024

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



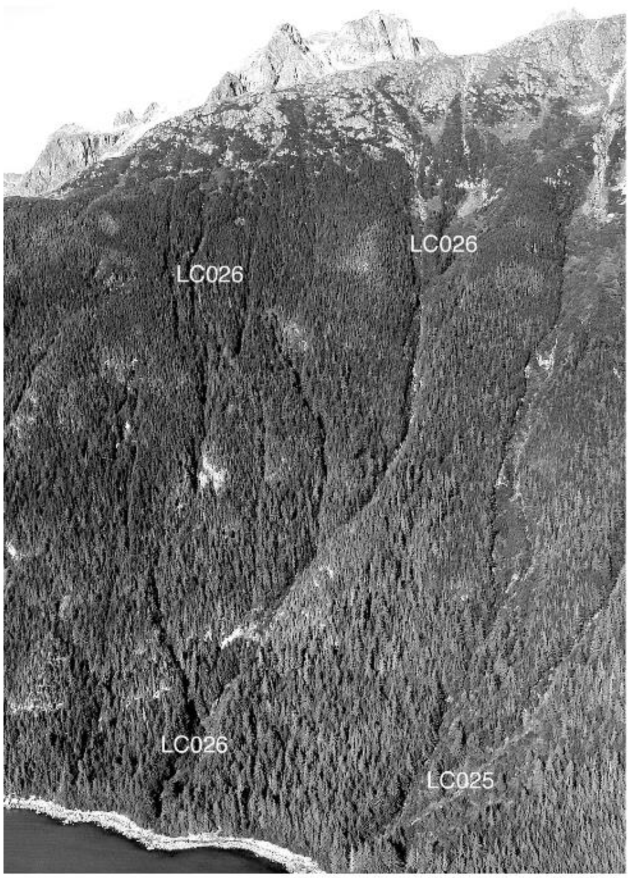
The North Yeldagalga paths are among the most active avalanche paths affecting the East Lynn Canal alignment. Several combinations of explosive delivery options were evaluated for these paths including helicopter placement, firing a 105mm howitzer from a secure enclosure on the Chilkat Peninsula, and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

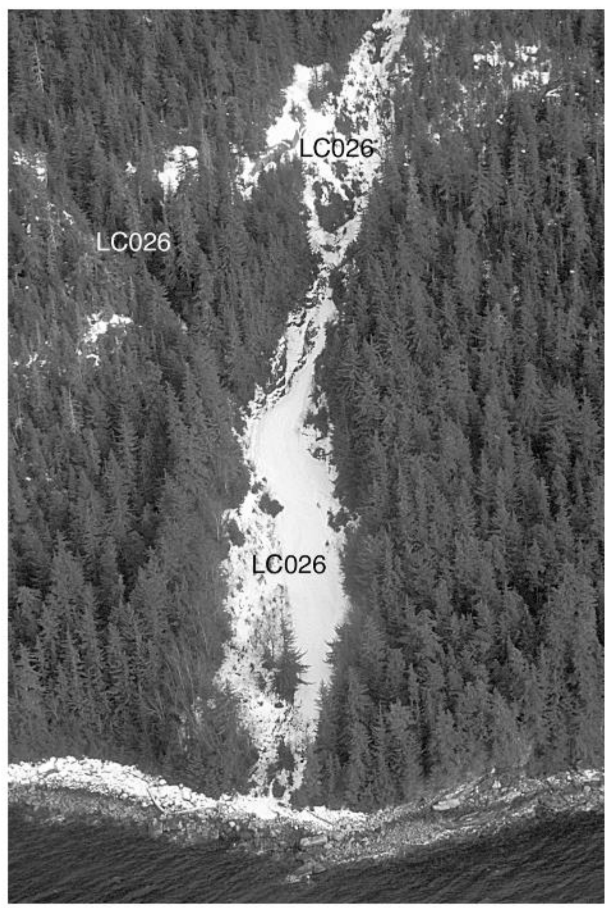

LC025
LC026
LC025


LC025
LC025
LC025

Path: LC025

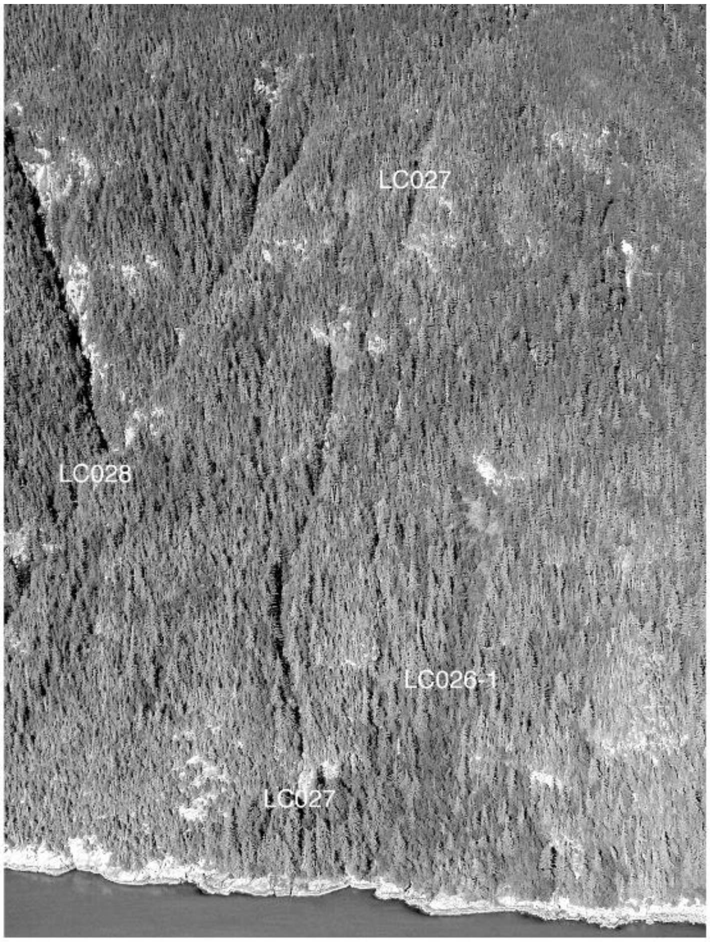
Path Group:	North Yeldagalga
Latitude-Longitude:	59.06421 -135.133654
Max Width:	780 feet / 238 meters
Typical Width:	190 feet / 58 meters
Starting Elevation:	4300 feet / 1311 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	medium gullied bowl
Start Aspect:	W
Path Type:	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

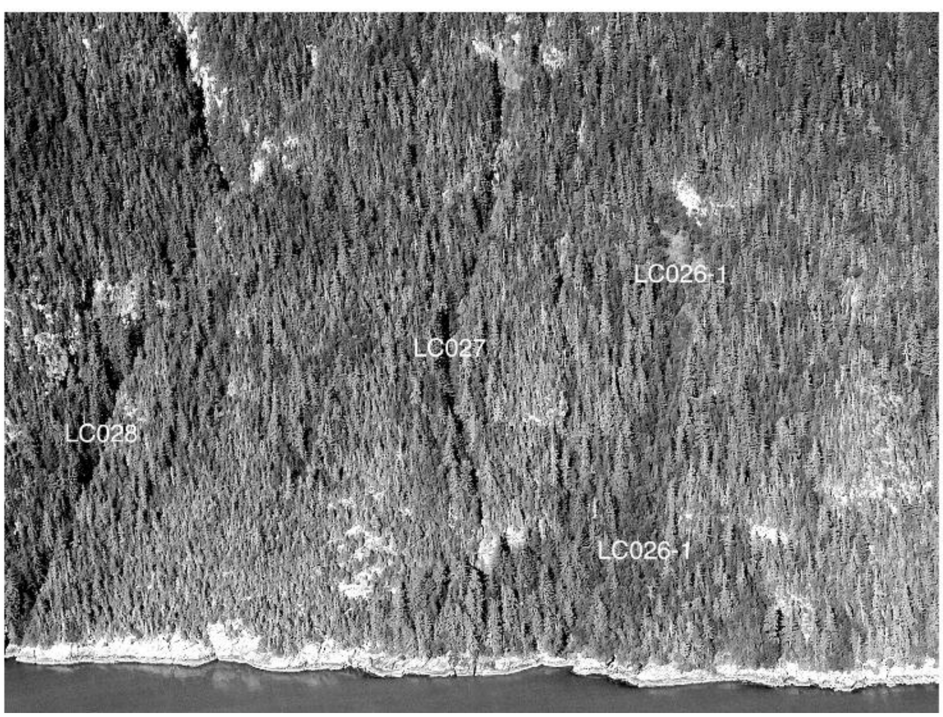

LC026
LC026
LC026
LC025


LC026
LC026
LC026

Path: LC026

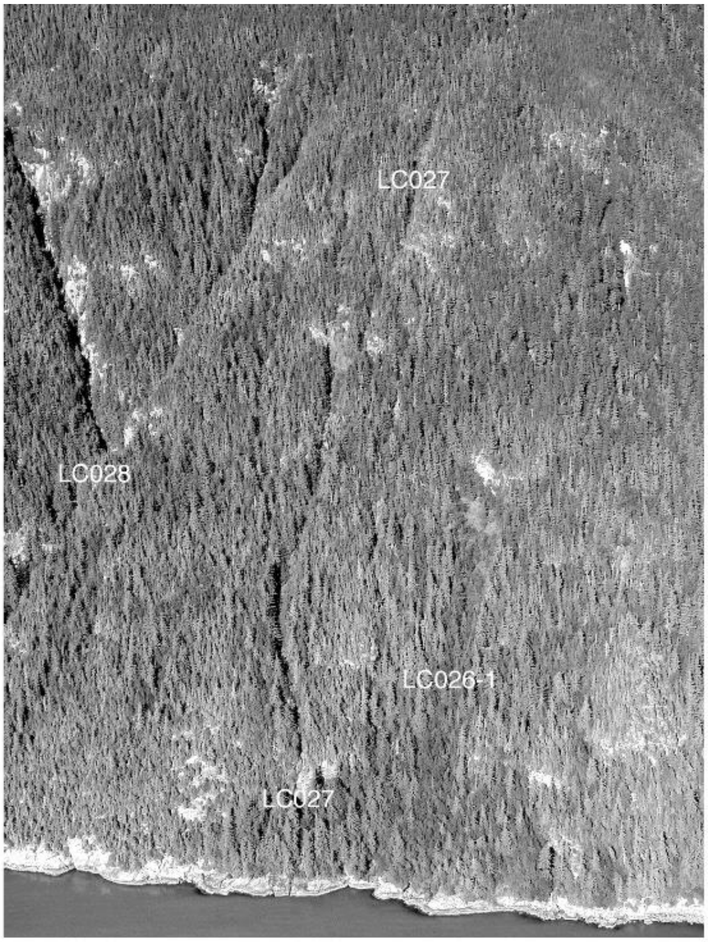
Path Group:	North Yeldagalga
Latitude-Longitude:	59.065077 -135.133771
Max Width:	470 feet / 143 meters
Typical Width:	200 feet / 61 meters
Starting Elevation:	4000 feet / 1219 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	multiple gullies and small bowls
Start Aspect:	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

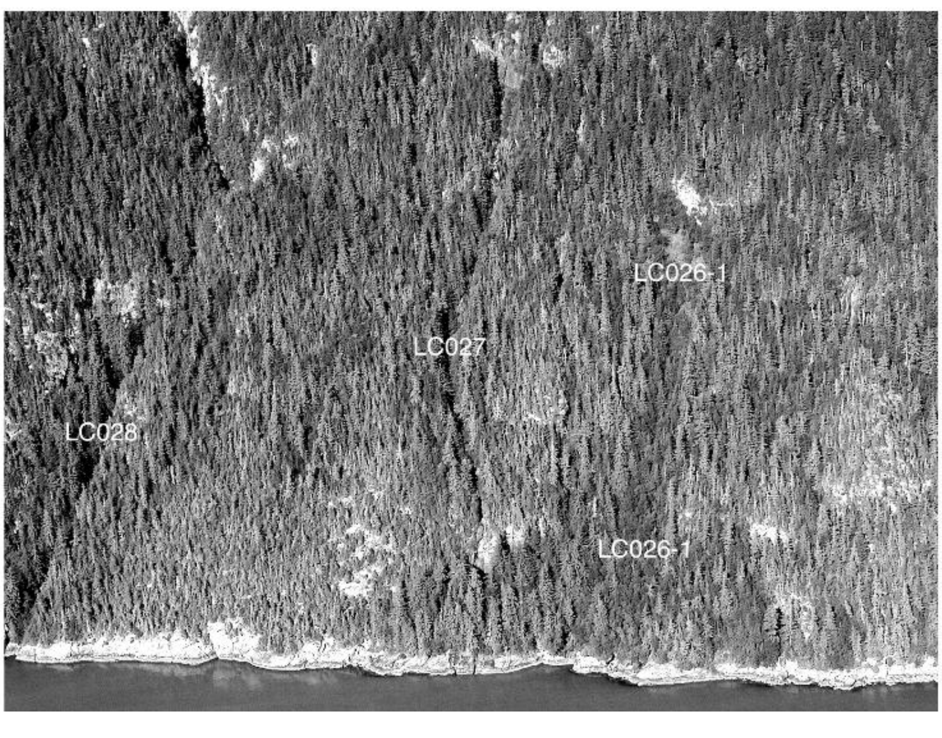

LC027
LC028
LC026-1
LC027


LC026-1
LC027
LC028
LC026-1

Path: LC026-1

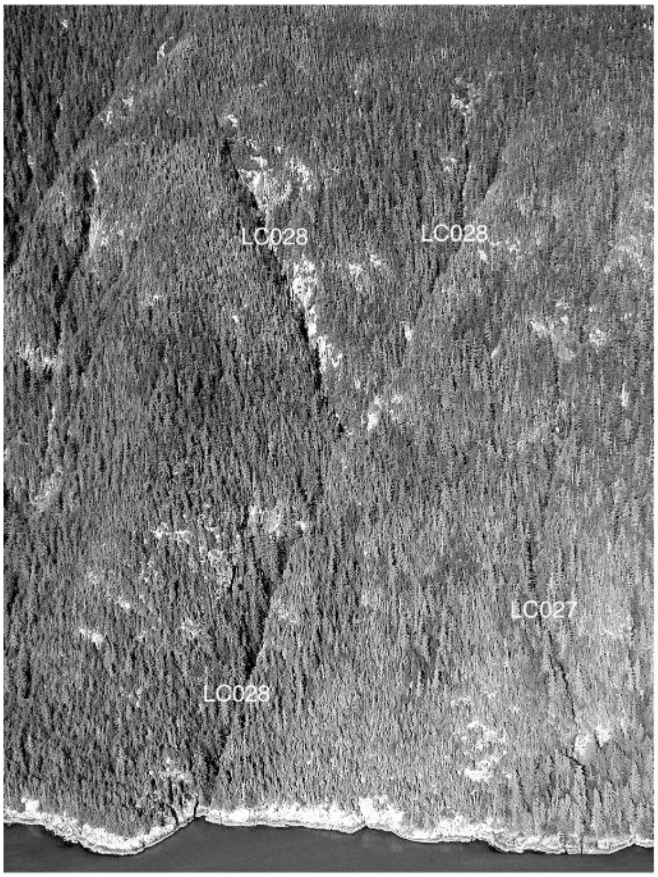
Path Group:	North Yeldagalga
Latitude-Longitude:	59.06565 -135.134064
Max Width:	200 feet / 61 meters
Typical Width:	150 feet / 46 meters
Starting Elevation:	1100 feet / 335 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	small cliff and talus
Start Aspect:	WSW
Path Type:	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

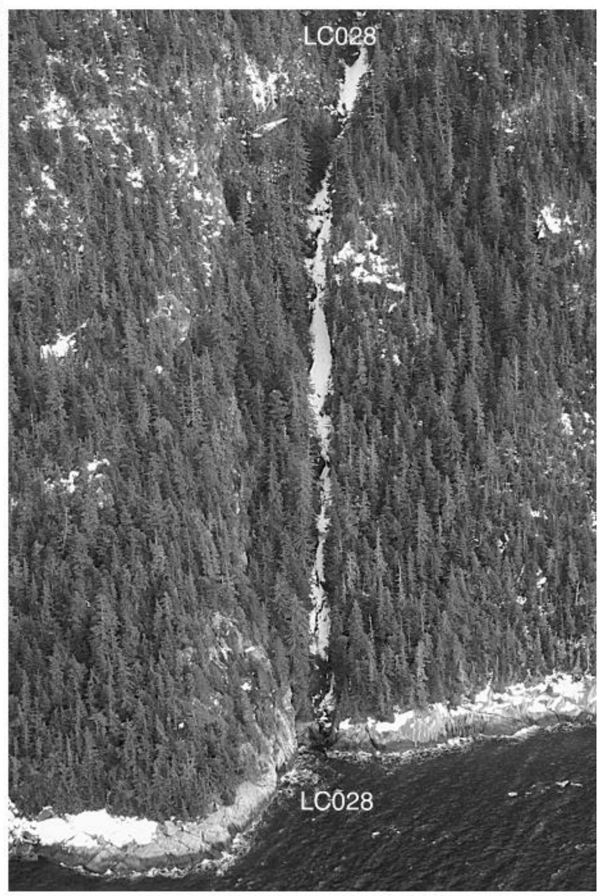

LC027
LC028
LC026-1
LC027


LC026-1
LC027
LC028
LC026-1

Path: LC027

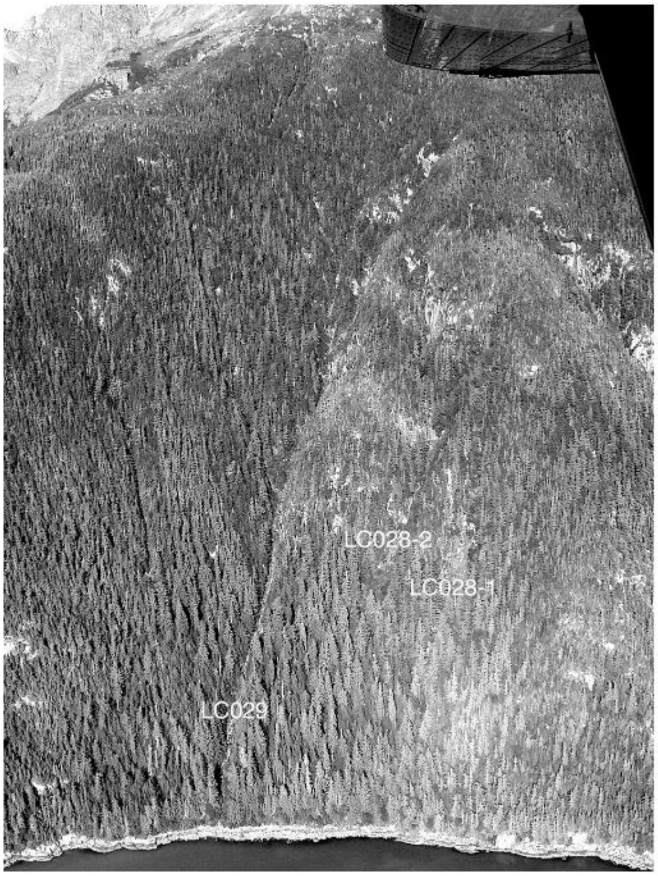
Path Group:	North Yeldagalga
Latitude-Longitude:	59.070492 -135.134359
Max Width:	90 feet / 27 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	2000 feet / 610 meters
Elevation Class:	medium low
Path Size:	small
Starting Zone Characteristics:	narrow gully
Start Aspect:	WSW
Path Type:	narrow 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

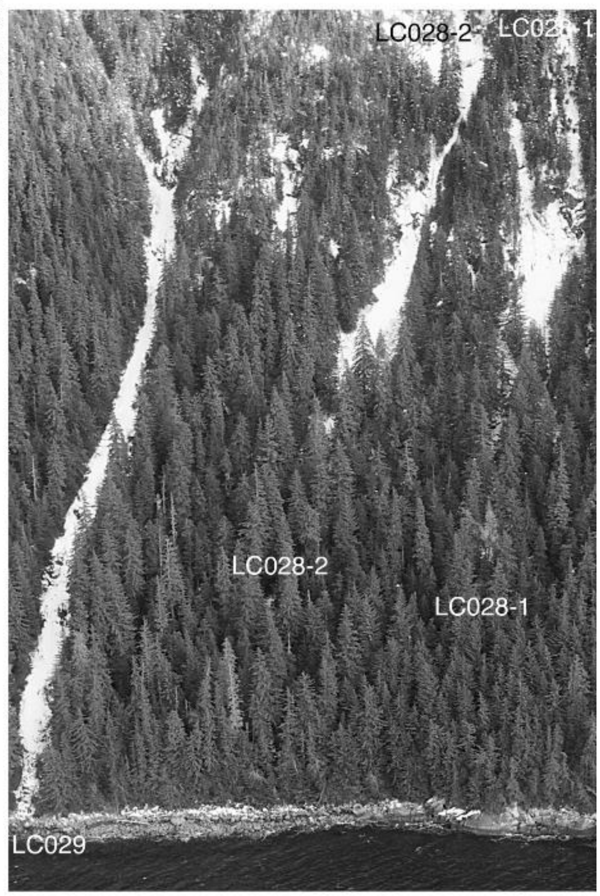

LC028
LC028
LC027
LC028


LC028
LC028

Path: LC028

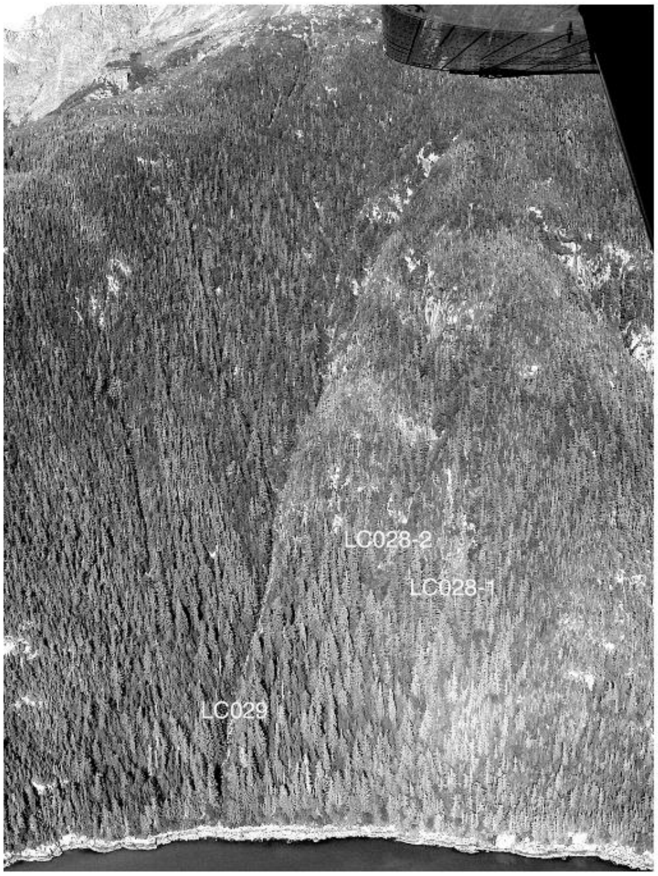
Path Group:	North Yeldagalga
Latitude-Longitude:	59.071671 -135.135194
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	2200 feet / 671 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	two narrow gullies
Start Aspect:	WSW
Path Type:	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

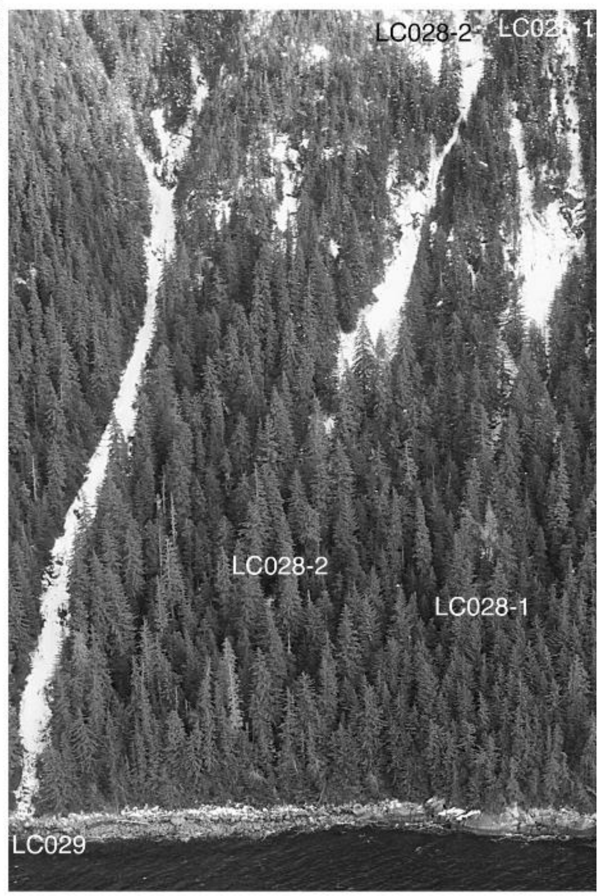

LC028-2
LC028-1
LC029


LC028-2
LC028-2
LC028-1
LC029

Path: LC028-1

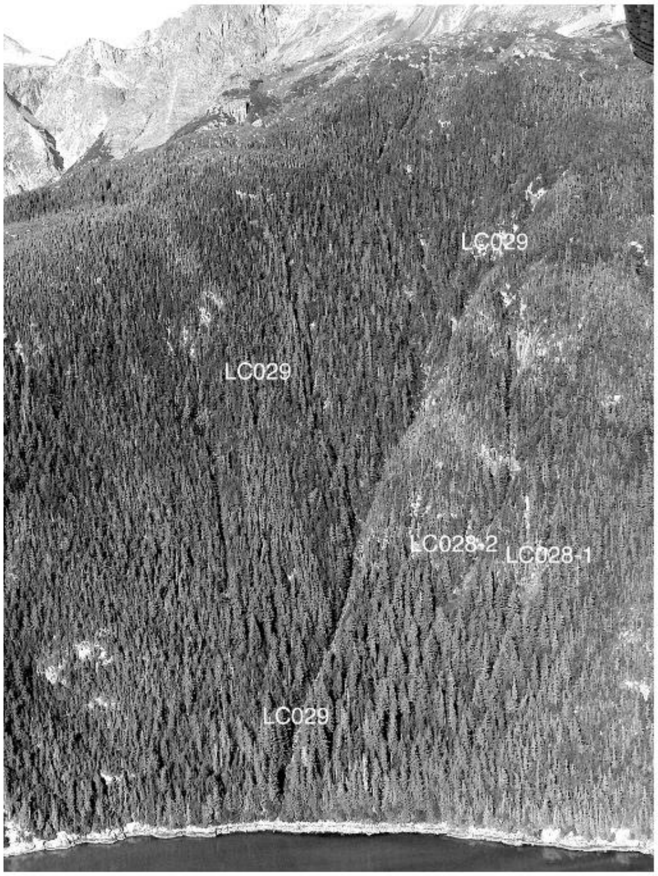
Path Group:	North Yeldagalga
Latitude-Longitude:	59.072328 -135.135484
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	1700 feet / 518 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	scrub forest, gully and cliff
Start Aspect:	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

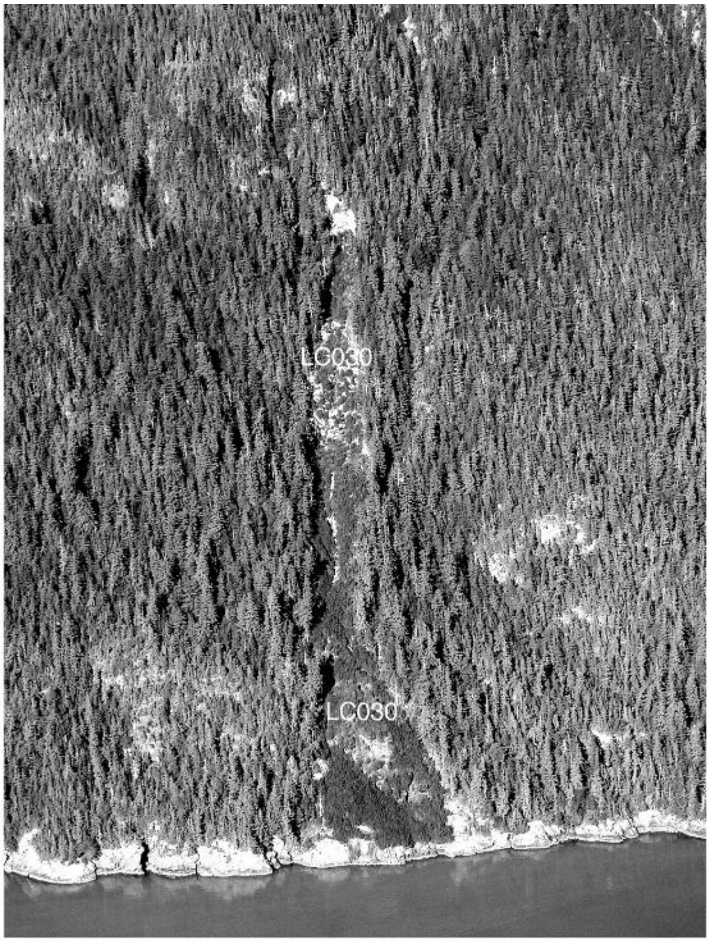
Path Group:	North Yeldagalga
Latitude-Longitude:	59.072747 -135.135494
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	1800 feet / 549 meters
Elevation Class:	medium high
Path Size:	small
Starting Zone Characteristics:	scrub forest, gully and cliff
Start Aspect:	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

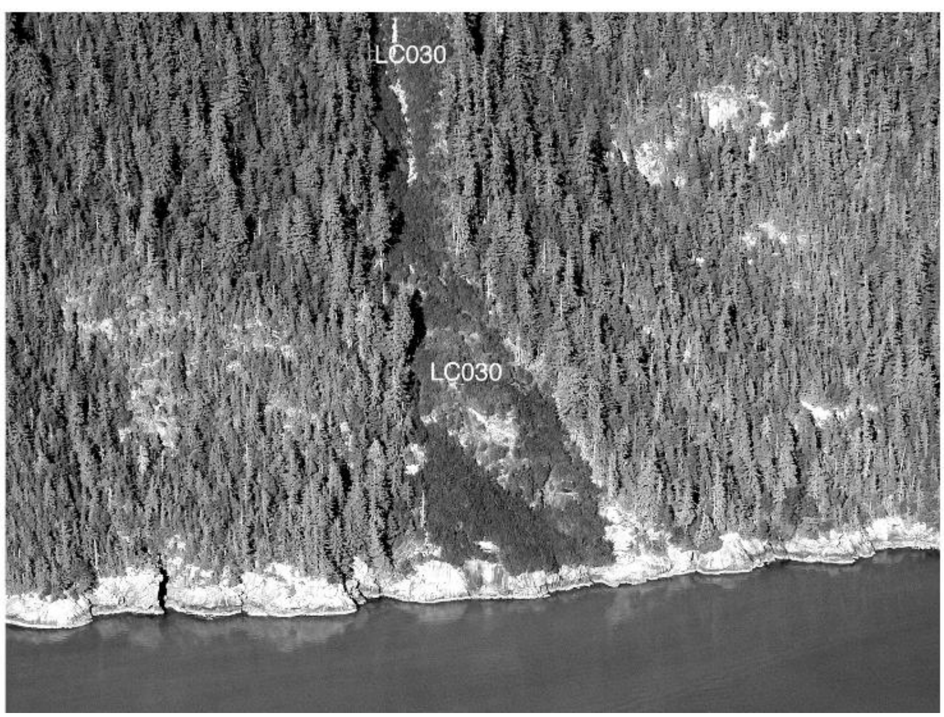

LC029
LC029
LC028-2
LC028-1
LC029


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

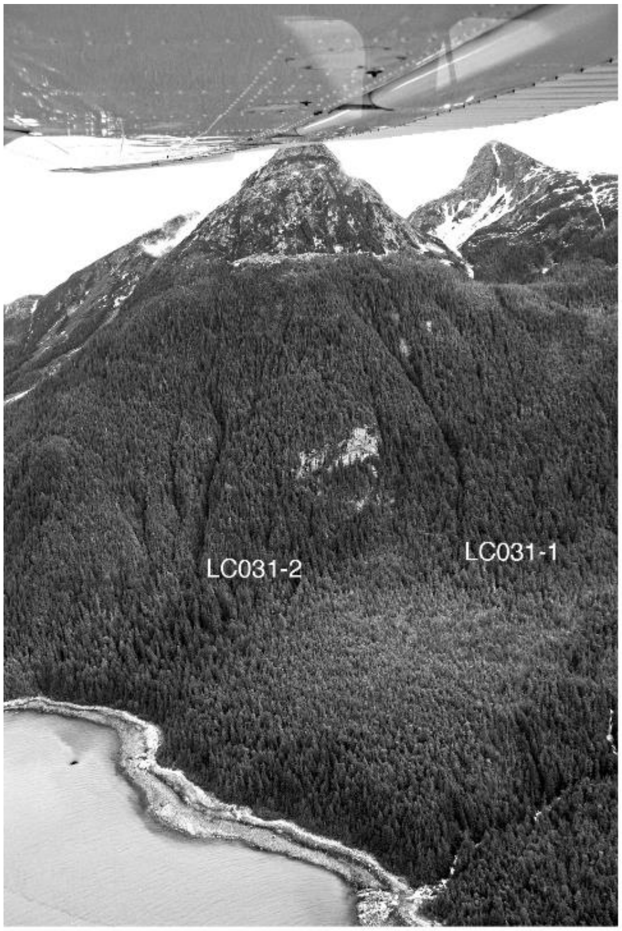
Path: LC030

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

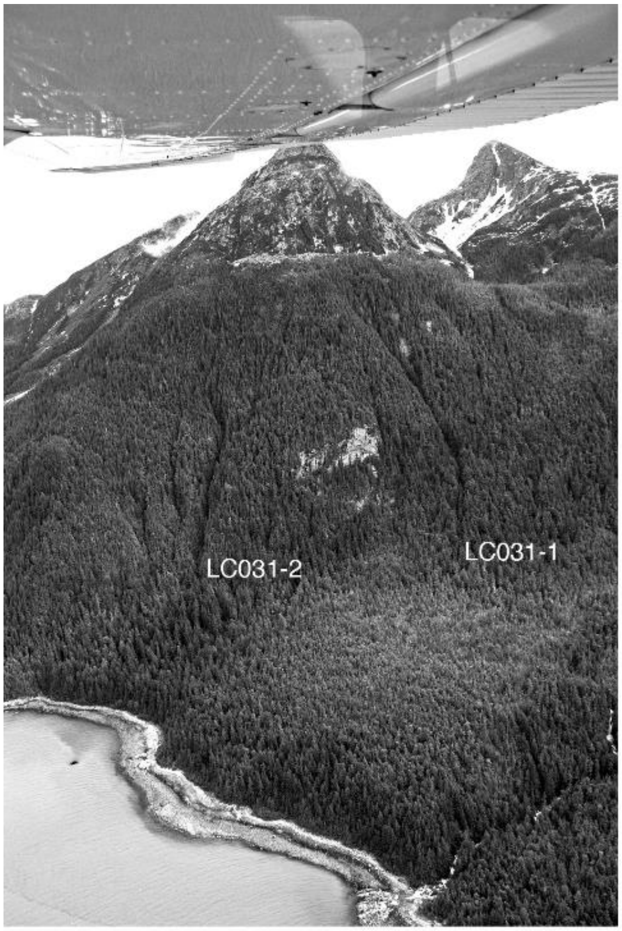
Path Group:	North Yeldagalga
Latitude-Longitude:	59.080947 -135.142847
Max Width:	80 feet / 24 meters
Typical Width:	80 feet / 24 meters
Starting Elevation:	650 feet / 198 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	cliff gully
Start Aspect:	WSW
Path Type:	narrow gully
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

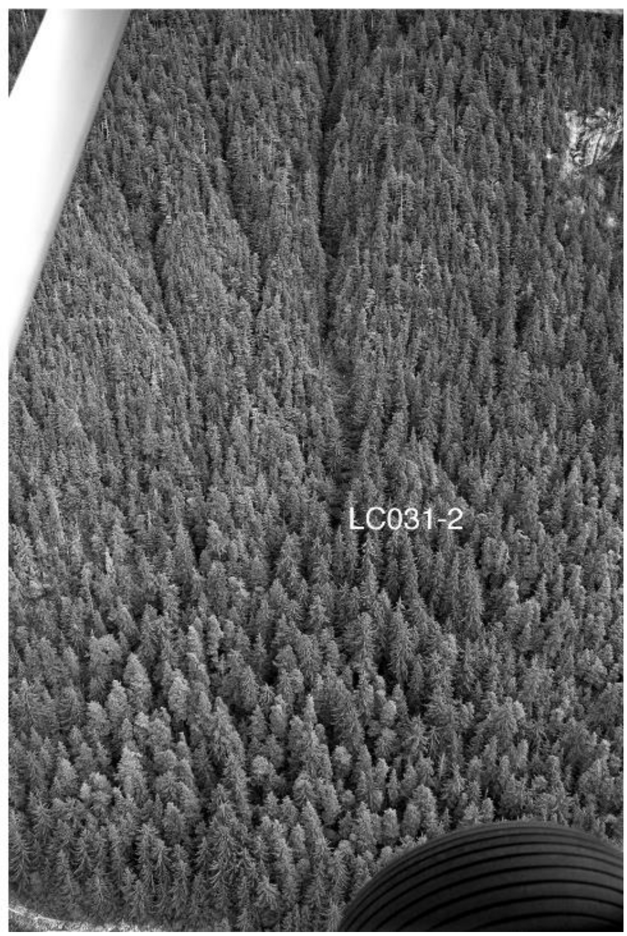

LC031-2
LC031-1


LC031-1

Path: LC031-1

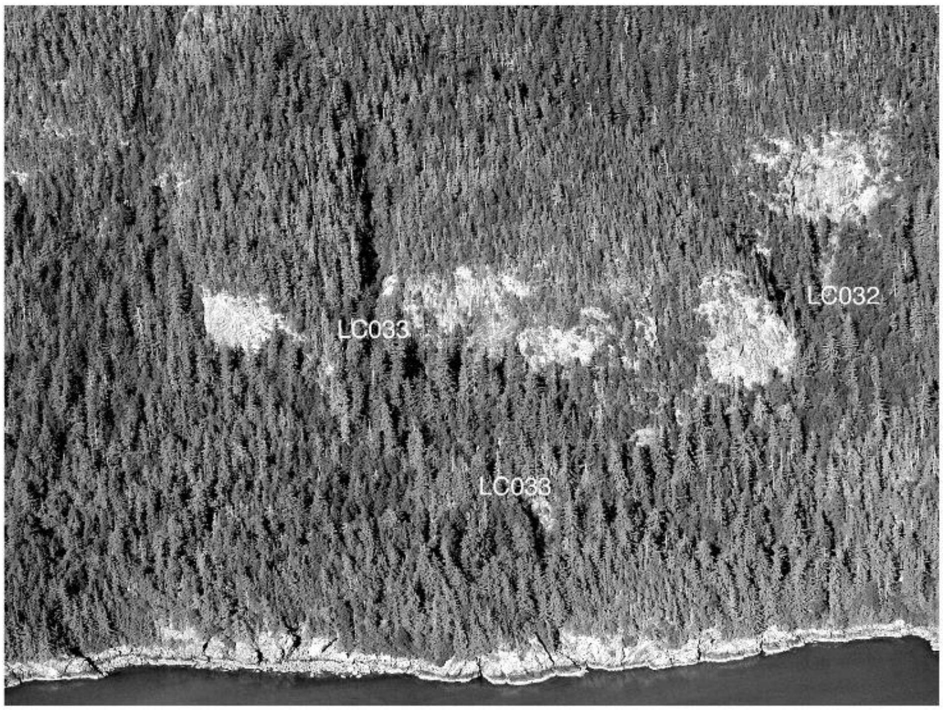
Path Group:	South Katzehin
Latitude-Longitude:	59°09’04.89 -135*14’25.57
Max Width:	80 feet / 25 meters
Typical Width:	66 feet / 20 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	small
Starting Zone Characteristics:	gullied face
Start Aspect:	SW
Path Type:	narrow 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

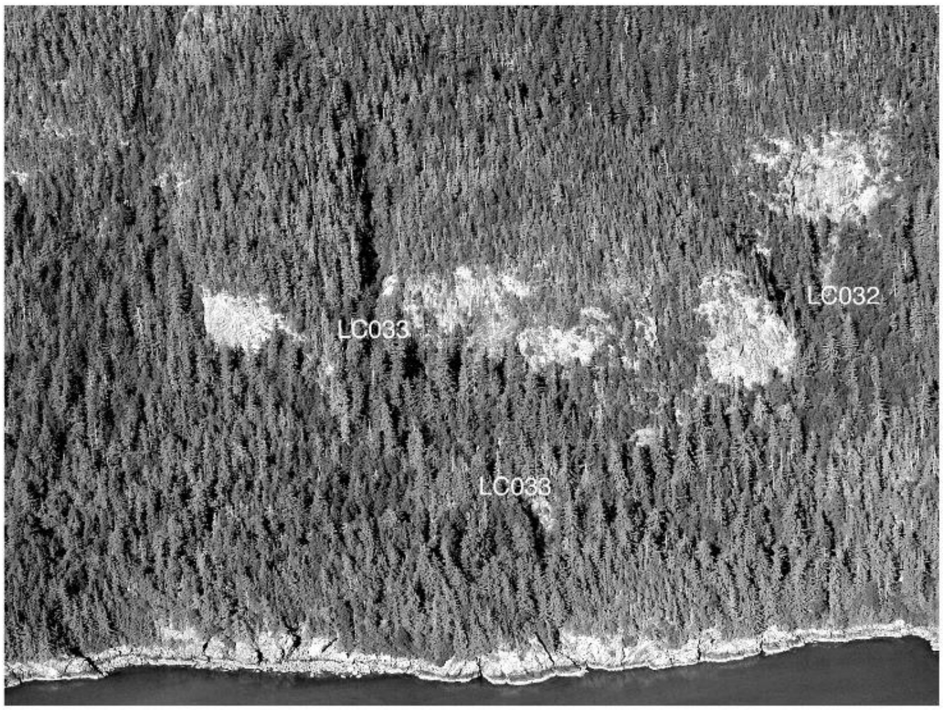
Path: LC031-2

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

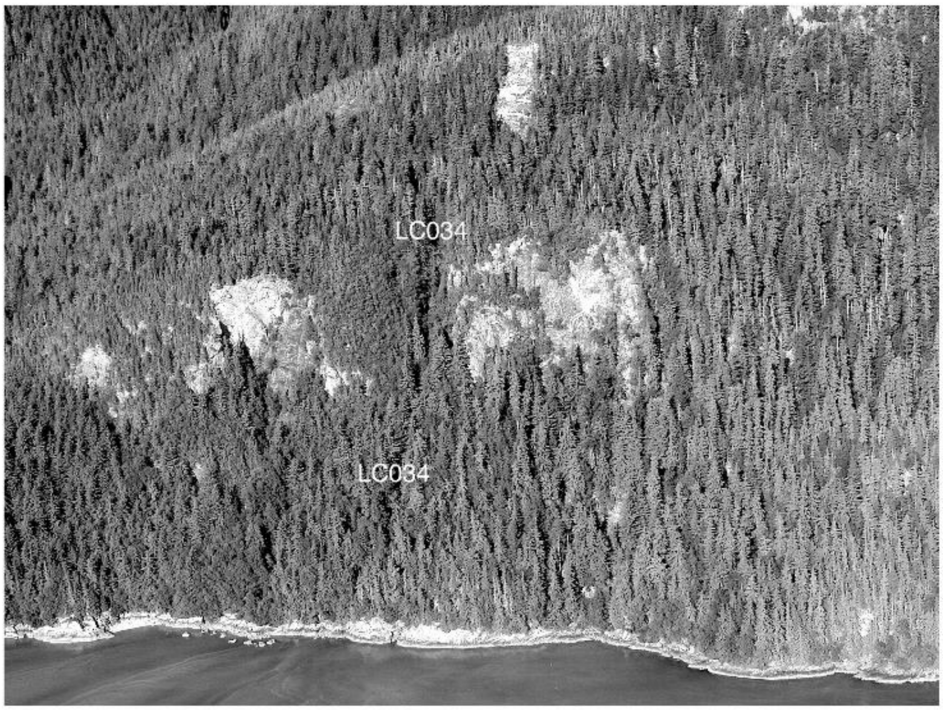
Path: LC032

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

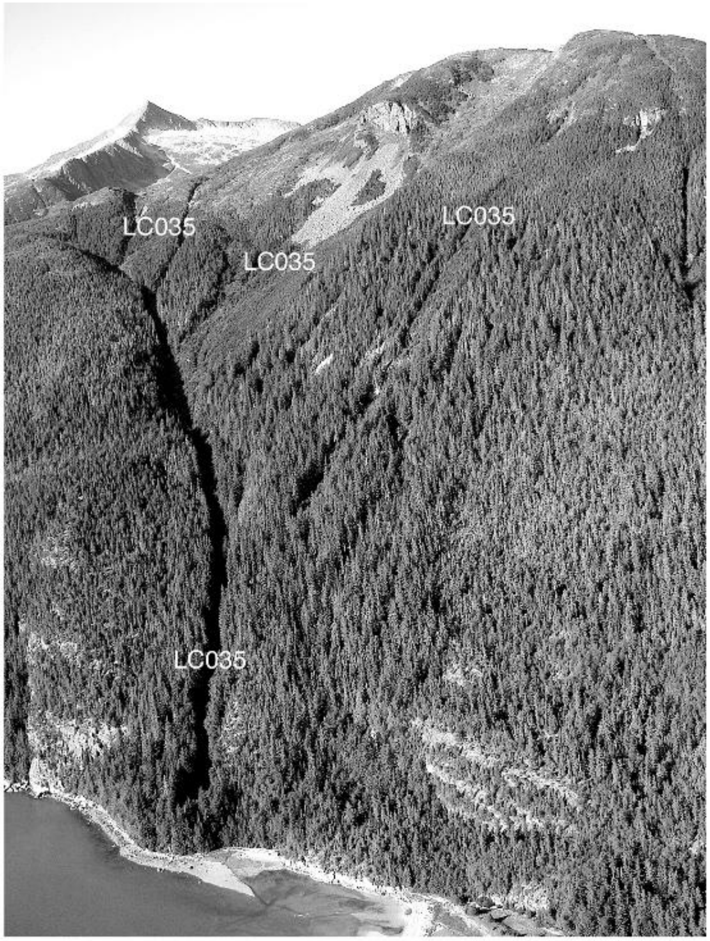
Path: LC033

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

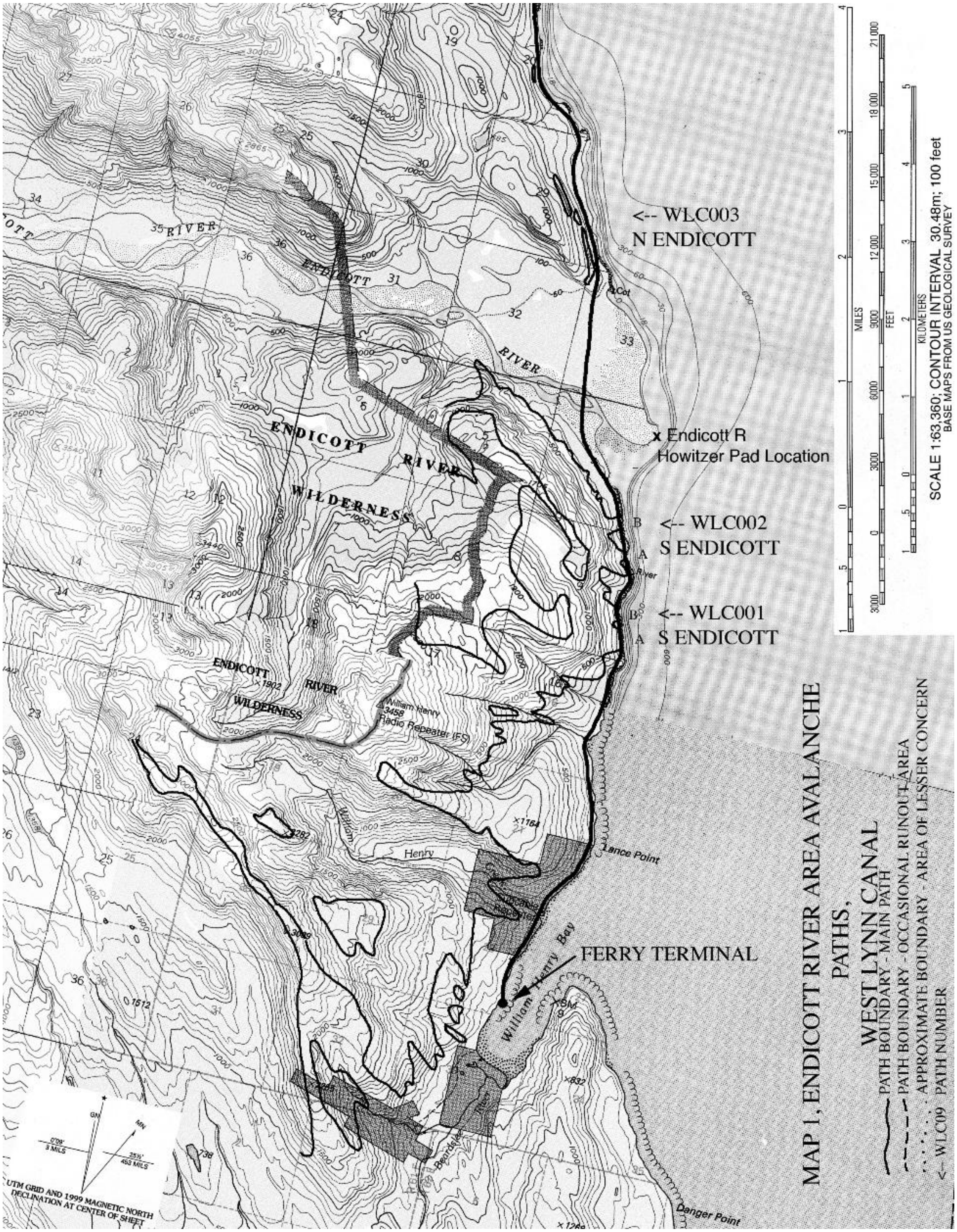

LC035
LC035
LC035
LC035

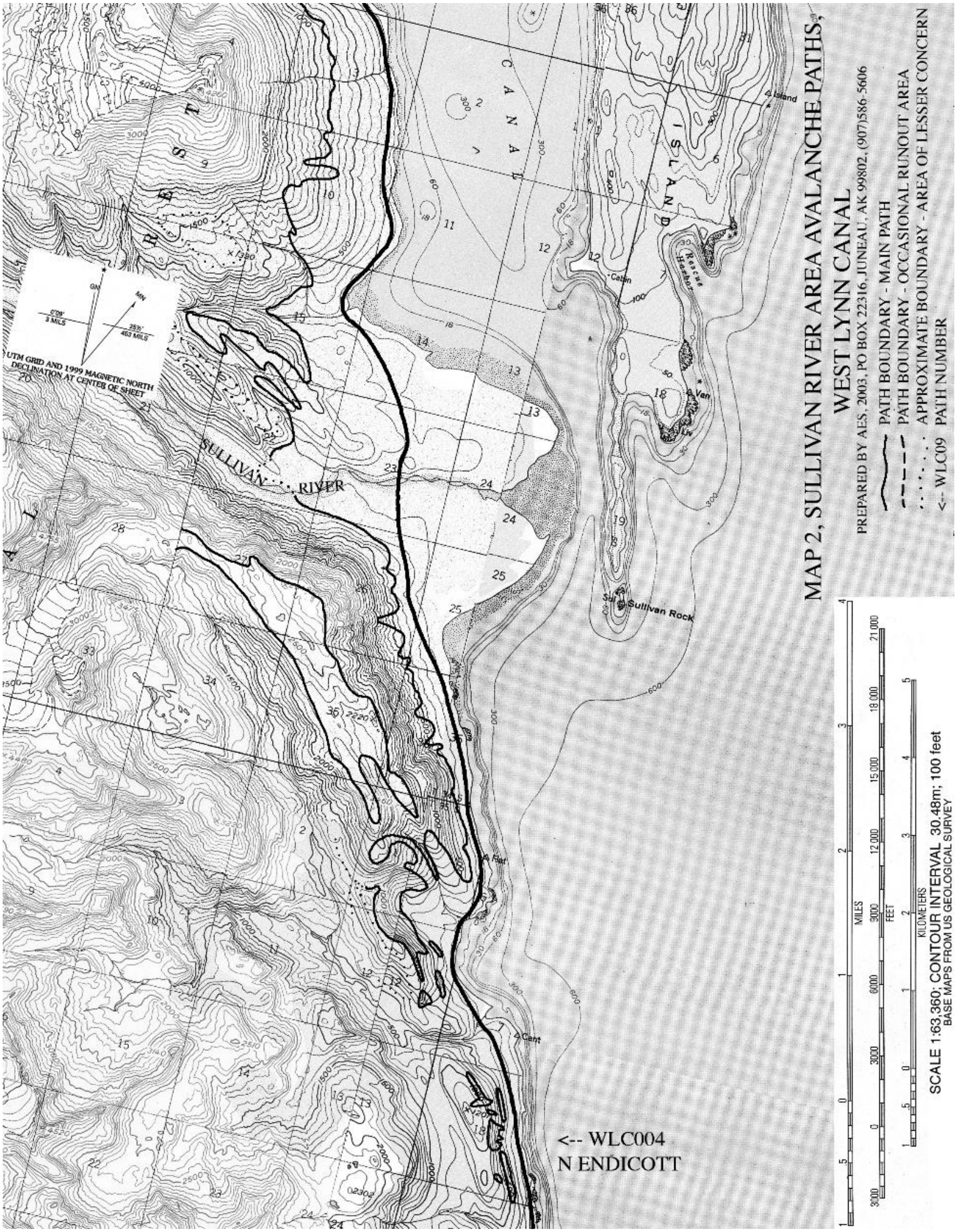

LC035
LC035
LC036

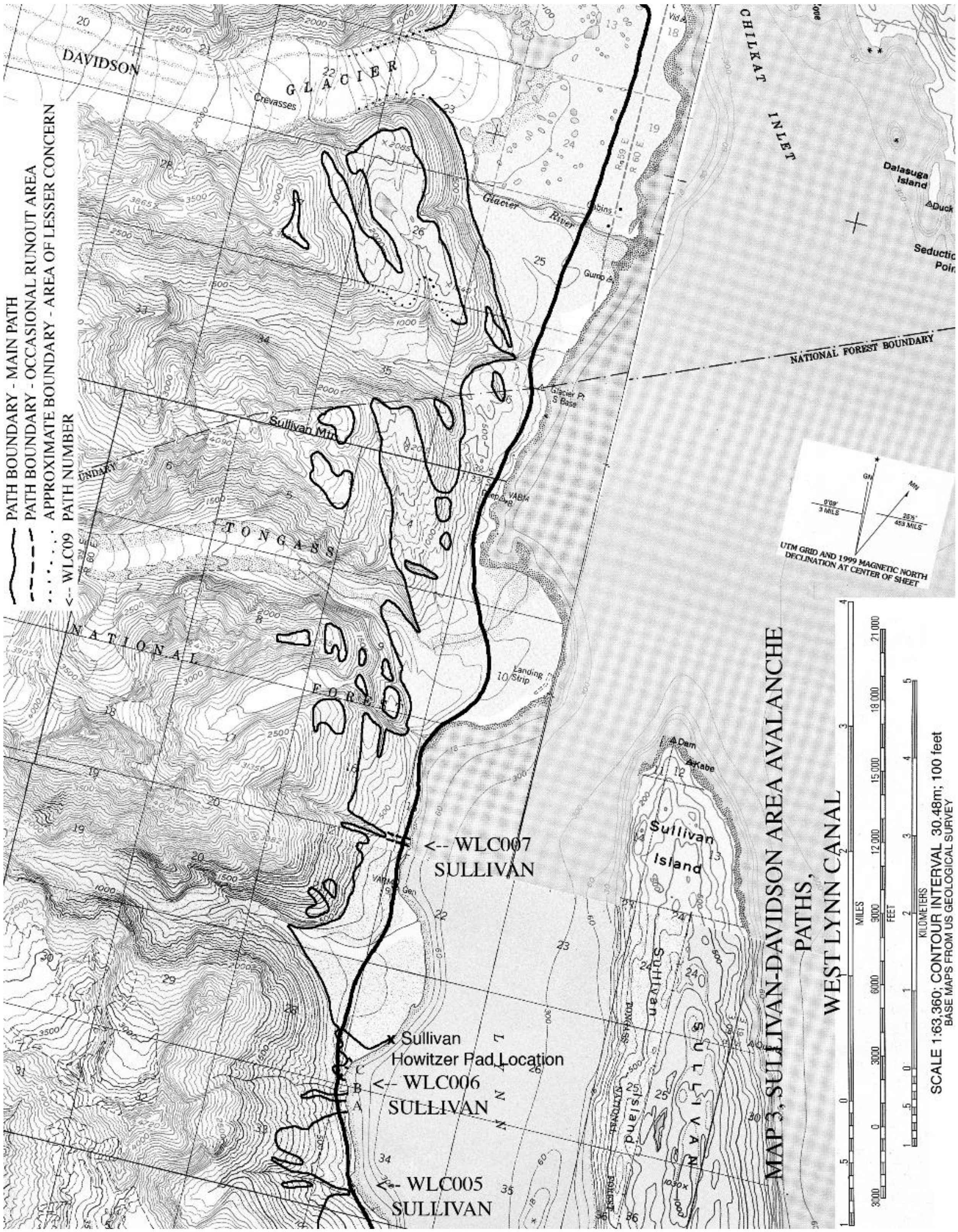
Path: LC035

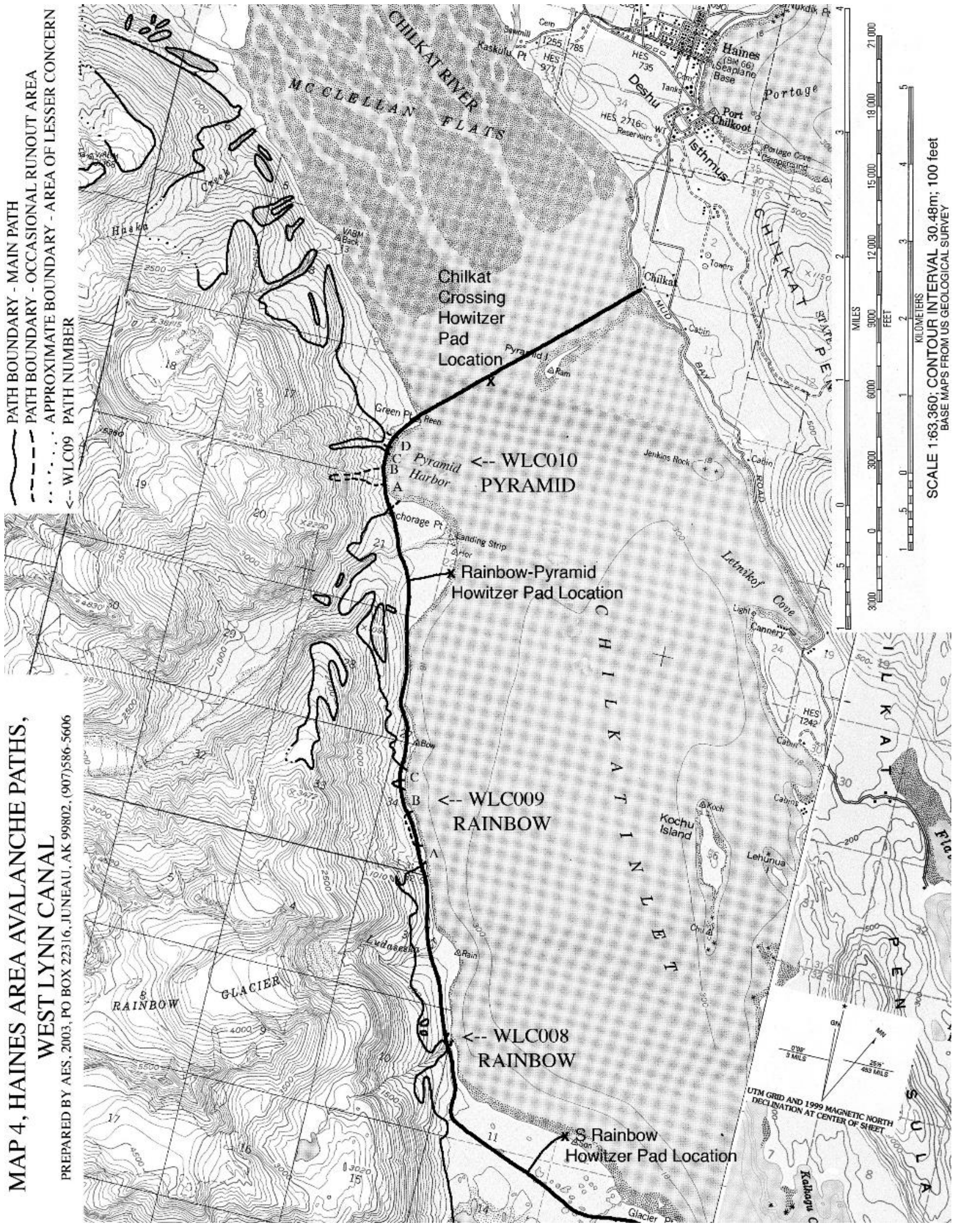
Path Group:	North Katzehin
Latitude-Longitude:	59.133721 -135.193685
Max Width:	260 feet / 79 meters
Typical Width:	110 feet / 34 meters
Starting Elevation:	3400 feet / 1036 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	multiple big bowls, faces and gullies
Start Aspect:	WSW
Path Type:	confined large diagonal gully
Runout Angle:	decreases markedly; affects ferry approach
Unmitigated avalanche hazard index (AHI):	0.23
Structural Mitigation:	Fill 0.2x
Structurally Mitigated AHI:	0.05
AHI with Forecasting and Exploders:	0.01

10. Atlas - West Lynn Canal Avalanche Maps

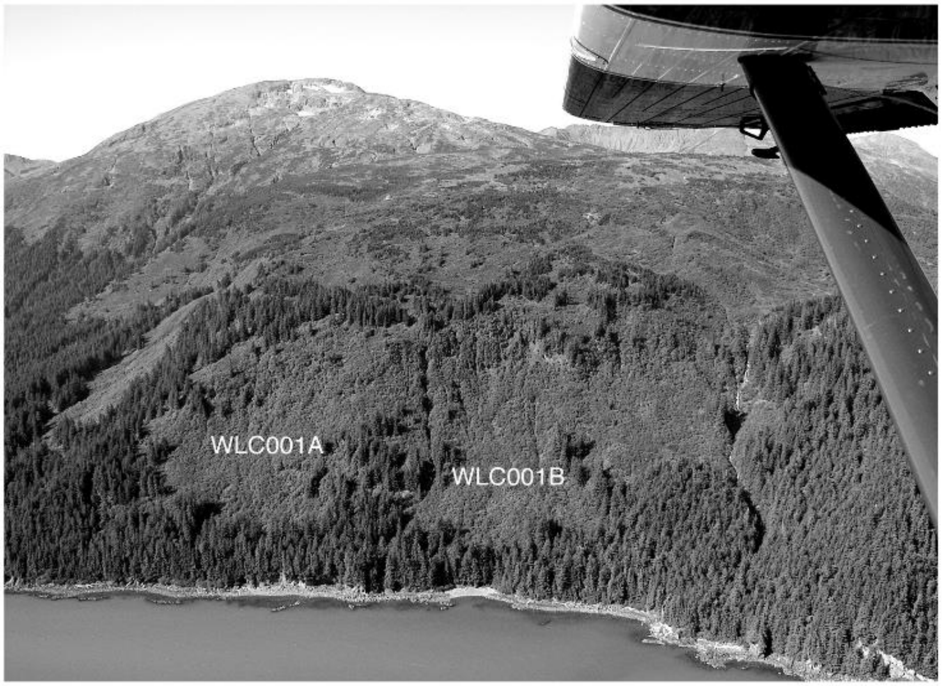



MAP 2, SULLIVAN RIVER AREA AVALANCHE PATHS, WEST LYNN CANAL
PREPARED BY AES, 2003, PO BOX 22316, JUNEAU, AK 99802, (907)586-5606
PATH BOUNDARY - MAIN PATH
PATH BOUNDARY - OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
<-- WLC09 PATH NUMBER
UTM GRID AND 1999 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SULLIVAN RIVER
Sullivan Rock
<-- WLC004
N ENDICOTT
MILES
FEET
KILOMETERS
SCALE 1:63,360; CONTOUR INTERVAL 30.48m; 100 feet
BASE MAPS FROM US GEOLOGICAL SURVEY


PATH BOUNDARY - MAIN PATH
PATH BOUNDARY - OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
<-- WLC09 PATH NUMBER
DAVIDSON GLACIER
CHILKAT INLET
Dalasuga Island
NATIONAL FOREST BOUNDARY
Sullivan Mtn
TONGASS NATIONAL FOREST
Landing Strip
<-- WLC007 SULLIVAN
Sullivan Island
x Sullivan Howitzer Pad Location
<-- WLC006 SULLIVAN
<-- WLC005 SULLIVAN
UTM GRID AND 1999 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
MAP 3, SULLIVAN-DAVIDSON AREA AVALANCHE PATHS, WEST LYNN CANAL
SCALE 1:63,360; CONTOUR INTERVAL 30.48m; 100 feet
BASE MAPS FROM US GEOLOGICAL SURVEY


MAP 4, HAINES AREA AVALANCHE PATHS, WEST LYNN CANAL
PREPARED BY AES, 2003, PO BOX 22316, JUNEAU, AK 99802, (907)586-5606
PATH BOUNDARY - MAIN PATH
PATH BOUNDARY - OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
<-- WLC09 PATH NUMBER
Chilkat Crossing Howitzer Pad Location
<-- WLC010 PYRAMID
Rainbow-Pyramid Howitzer Pad Location
<-- WLC009 RAINBOW
<-- WLC008 RAINBOW
S Rainbow Howitzer Pad Location
CHILKAT RIVER
MCCLELLAN FLATS
CHILKAT INLET
Haines
Port Chilkoot
Deshu Isthmus
Pyramid Harbor
Kochu Island
RAINBOW GLACIER
UTM GRID AND 1999 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
SCALE 1:63,360; CONTOUR INTERVAL 30.48m; 100 feet
BASE MAPS FROM US GEOLOGICAL SURVEY

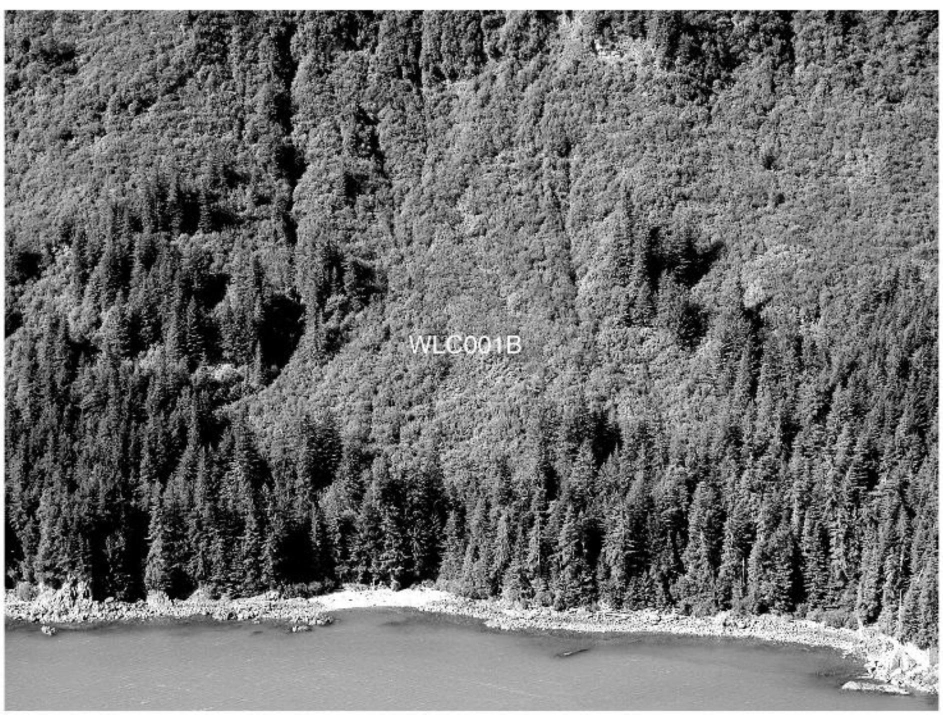
11. Atlas - West Lynn Canal Avalanche Paths



Path: WLC001A

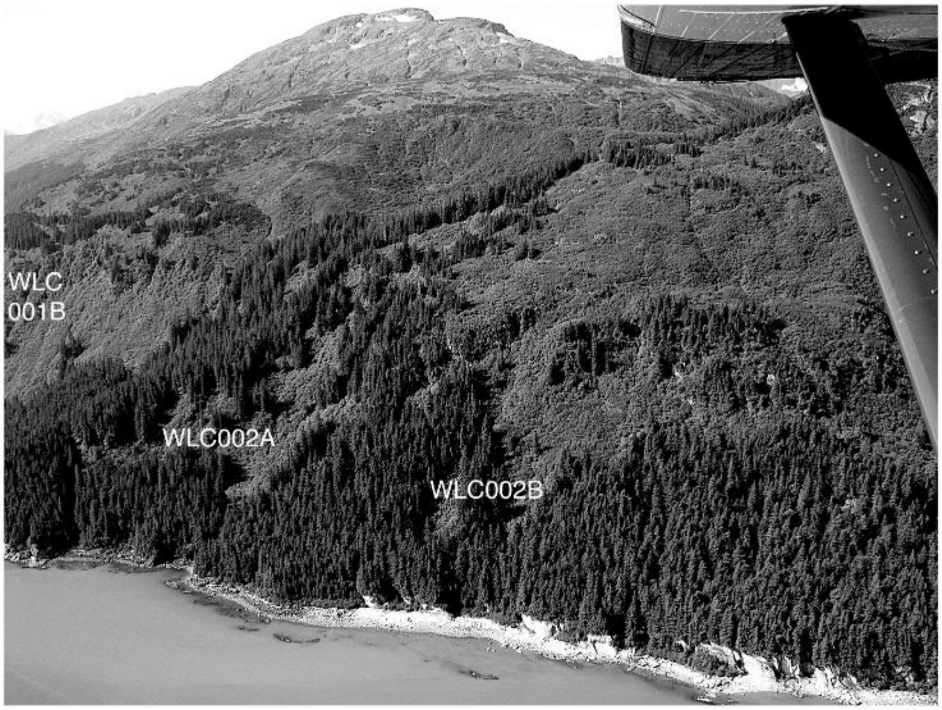
Path Group:	South Endicott
Latitude-Longitude:	59.084274 -135.281424
Max Width:	1000 feet / 305 meters
Typical Width:	175 feet / 53 meters
Starting Elevation:	1300 feet / 396 meters
Elevation Class:	medium low
Path Size:	medium
Starting Zone Characteristics:	open face
Start Aspect:	ENE
Path Type:	open face to thin forest
Runout Angle:	decreases abruptly
Unmitigated avalanche hazard index (AHI):	0.54
Structural Mitigation:	None
Structurally Mitigated AHI:	0.54
AHI with Forecasting and Exploders:	0.16

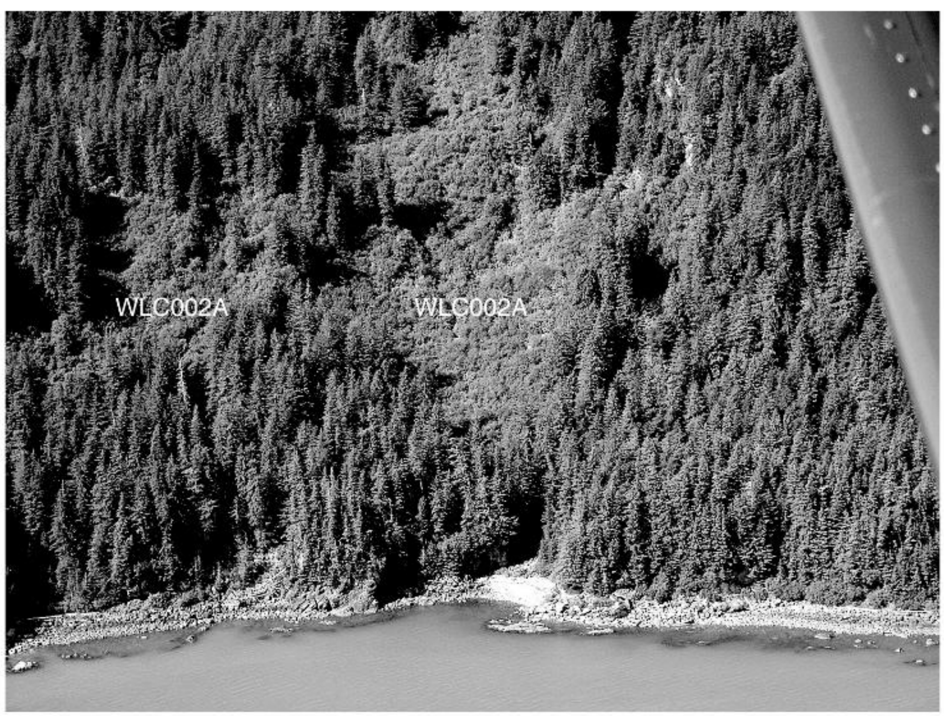

WLC001A
WLC001B


WLC001B

Path: WLC001B

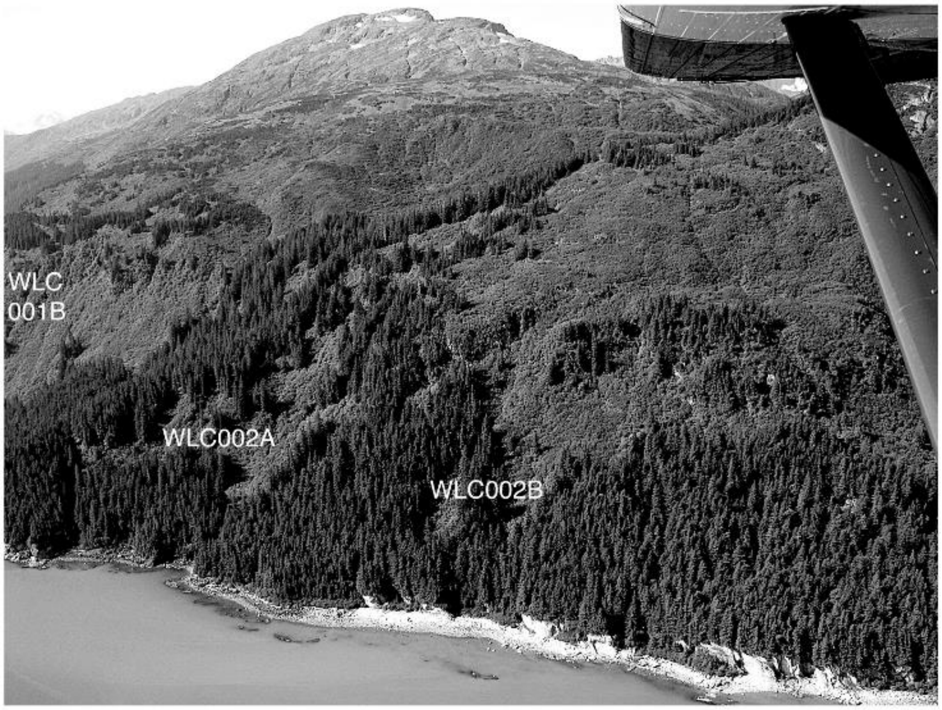
Path Group:	South Endicott
Latitude-Longitude:	59.084274 -135.281424
Max Width:	1000 feet / 305 meters
Typical Width:	125 feet / 38 meters
Starting Elevation:	1200 feet / 366 meters
Elevation Class:	medium low
Path Size:	medium
Starting Zone Characteristics:	open face
Start Aspect:	ENE
Path Type:	open face to thin forest
Runout Angle:	decreases abruptly
Unmitigated avalanche hazard index (AHI):	0.54
Structural Mitigation:	None
Structurally Mitigated AHI:	0.54
AHI with Forecasting and Exploders:	0.16


WLC
001B
WLC002A
WLC002B


WLC002A
WLC002A

Path: WLC002A

Path Group:	South Endicott
Latitude-Longitude:	58.453329 -135.142467
Max Width:	940 feet / 286 meters
Typical Width:	410 feet / 125 meters
Starting Elevation:	1000 feet / 305 meters
Elevation Class:	medium low
Path Size:	medium
Starting Zone Characteristics:	open face
Start Aspect:	ENE
Path Type:	open face to thin forest
Runout Angle:	decreases abruptly
Unmitigated avalanche hazard index (AHI):	0.51
Structural Mitigation:	None
Structurally Mitigated AHI:	0.51
AHI with Forecasting and Exploders:	0.15


WLC
001B
WLC002A
WLC002B


WLC002B

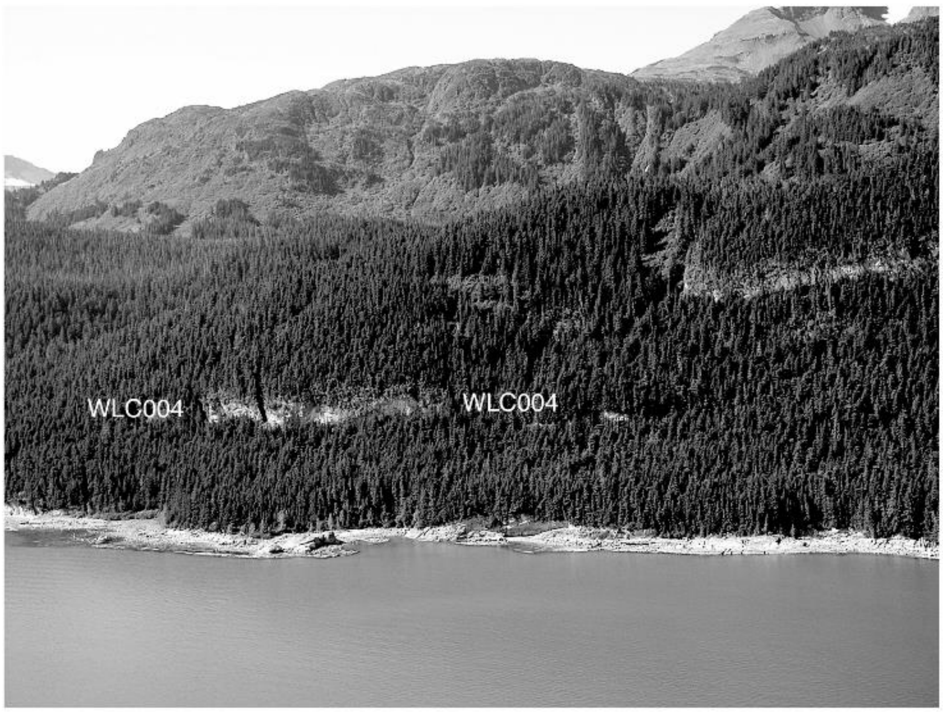
Path: WLC002B

Path Group:	South Endicott
Latitude-Longitude:	58.453329 -135.142467
Max Width:	590 feet / 180 meters
Typical Width:	350 feet / 107 meters
Starting Elevation:	1300 feet / 396 meters
Elevation Class:	medium low
Path Size:	medium
Starting Zone Characteristics:	open face
Start Aspect:	ENE
Path Type:	open face to thin forest
Runout Angle:	decreases abruptly
Unmitigated avalanche hazard index (AHI):	0.26
Structural Mitigation:	None
Structurally Mitigated AHI:	0.26
AHI with Forecasting and Exploders:	0.08


WLC003
WLC003

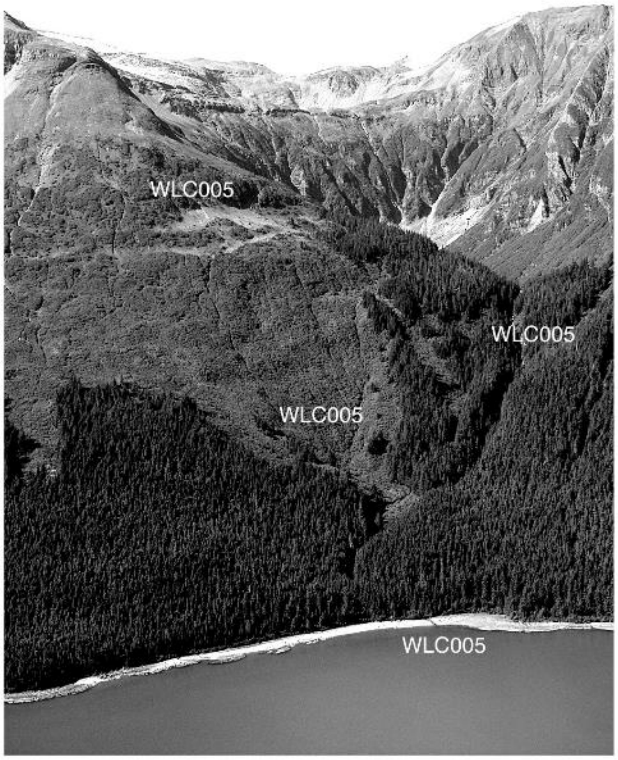
Path: WLC003

Path Group:	North Endicott
Latitude-Longitude:	58.46005 -135.143254
Max Width:	0.0 feet / 0.0 meters (stops above alignment)
Typical Width:	0.0 feet / 0.0 meters (stops above alignment)
Starting Elevation:	600 feet / 183 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	rock slabs and talus
Start Aspect:	ENE
Path Type:	rock slabs and talus
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.00
Structural Mitigation:	None
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00


WLC004
WLC004

Path: WLC004

Path Group:	North Endicott
Latitude-Longitude:	58.481183 -135.160027
Max Width:	0.0 feet / 0.0 meters (stops above alignment)
Typical Width:	0.0 feet / 0.0 meters (stops above alignment)
Starting Elevation (ft):	1200 feet / 366 meters
Elevation Class:	low
Path Size:	small
Starting Zone Characteristics:	rock slabs and talus
Start Aspect:	ENE
Path Type:	rock slabs and talus
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	0.00
Structural Mitigation:	None
Structurally Mitigated AHI:	0.00
AHI with Forecasting and Exploders:	0.00


WLC005
WLC005
WLC005
WLC005


WLC005
WLC005
WLC005

Path: WLC005

Path Group:	Sullivan
Latitude-Longitude:	58.500775 -135.175661
Max Width:	240 feet / 73 meters
Typical Width:	100 feet / 30 meters
Starting Elevation:	3300 feet / 1006 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	broad face and big bowl
Start Aspect:	NE
Path Type:	bowl and gullies
Runout Angle:	decreases abruptly
Unmitigated avalanche hazard index (AHI):	0.89
Structural Mitigation:	None
Structurally Mitigated AHI:	0.89
AHI with Forecasting and Exploders:	0.27


WLC006B
WLC006A
WLC006C
WLC006A
WLC006B
WLC006C


WLC006A
WLC
006B

Path: WLC006A

Path Group:	Sullivan
Latitude-Longitude:	58.573821-135.234129
Max Width:	960 feet / 293 meters
Typical Width:	580 feet / 177 meters
Starting Elevation:	4600 feet / 1402 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl and big face
Start Aspect:	ENE
Path Type:	broad face with gullies
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	17.96
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	8.98
AHI with Forecasting and Exploders:	2.69


WLC006B
WLC006A
WLC006C
WLC006A
WLC006B
WLC006C


WLC006A
WLC006C
WLC006B

Path: WLC006B

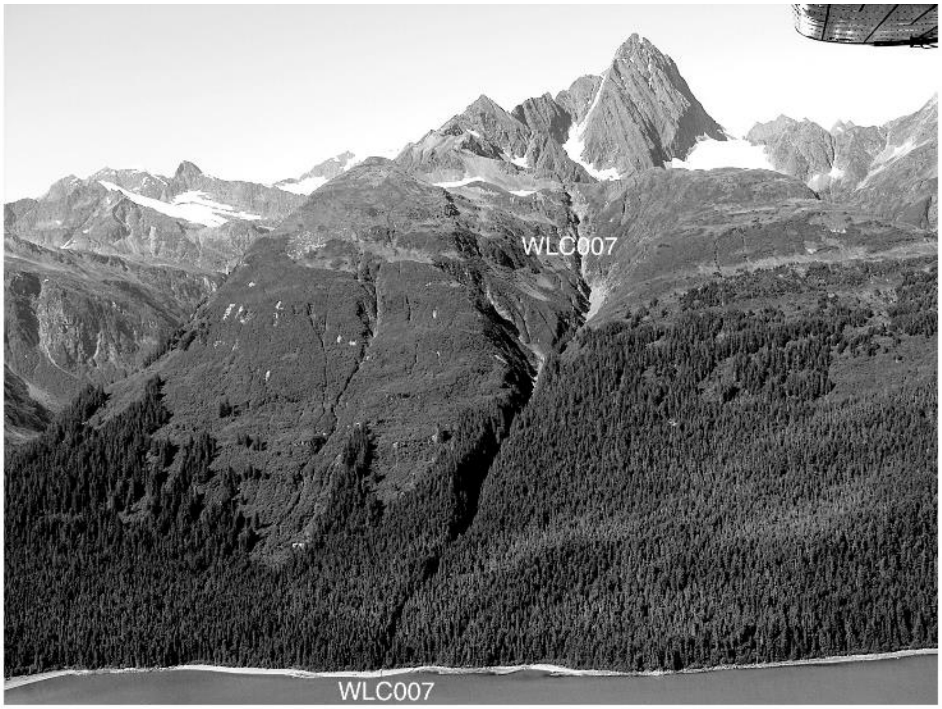
Path Group:	Sullivan
Latitude-Longitude:	58.573821-135.234129
Max Width:	960 feet / 293 meters
Typical Width:	650 feet / 198 meters
Starting Elevation:	4400 feet / 1341 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl and big face
Start Aspect:	ENE
Path Type:	broad bowl with gullies
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	17.97
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	8.98
AHI with Forecasting and Exploders:	2.69

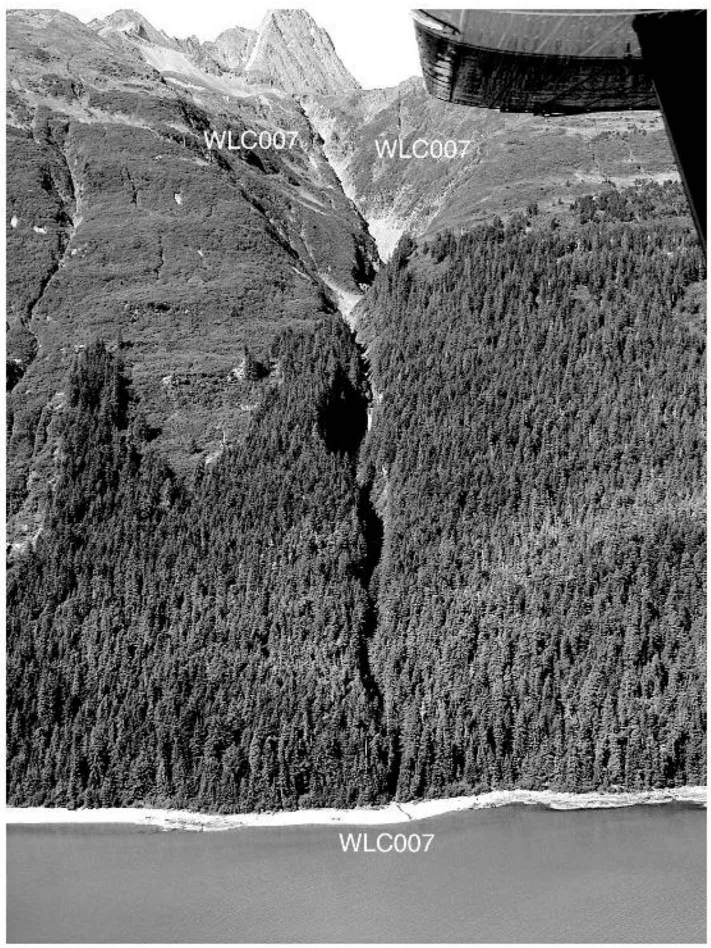

WLC006B
WLC006A
WLC006C
WLC006A
WLC006B
WLC006C


WLC006B
WLC006C

Path: WLC006C

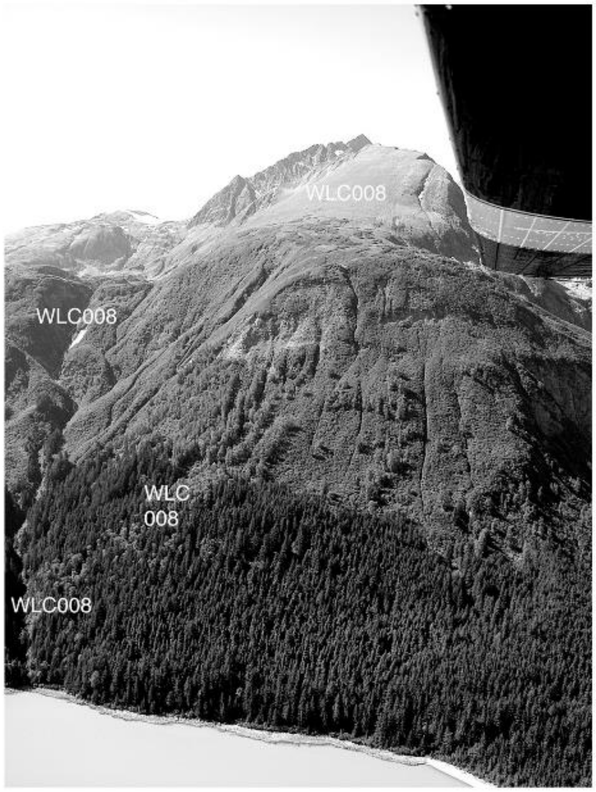
Path Group:	Sullivan
Latitude-Longitude:	58.573821-135.234129
Max Width:	960 feet / 293 meters
Typical Width:	510 feet / 155 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big face
Start Aspect:	E
Path Type:	broad bowl with gullies
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	17.96
Structural Mitigation:	None
Structurally Mitigated AHI:	17.96
AHI with Forecasting and Exploders:	5.39

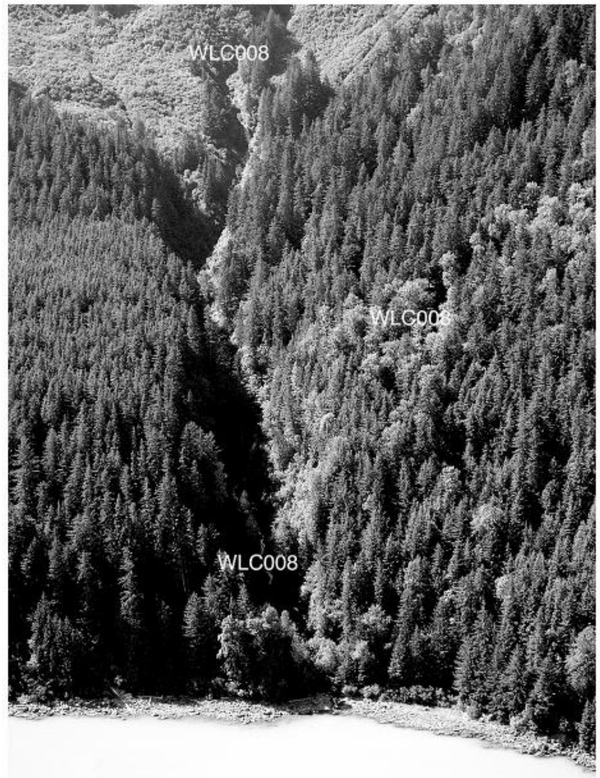

WLC007
WLC007

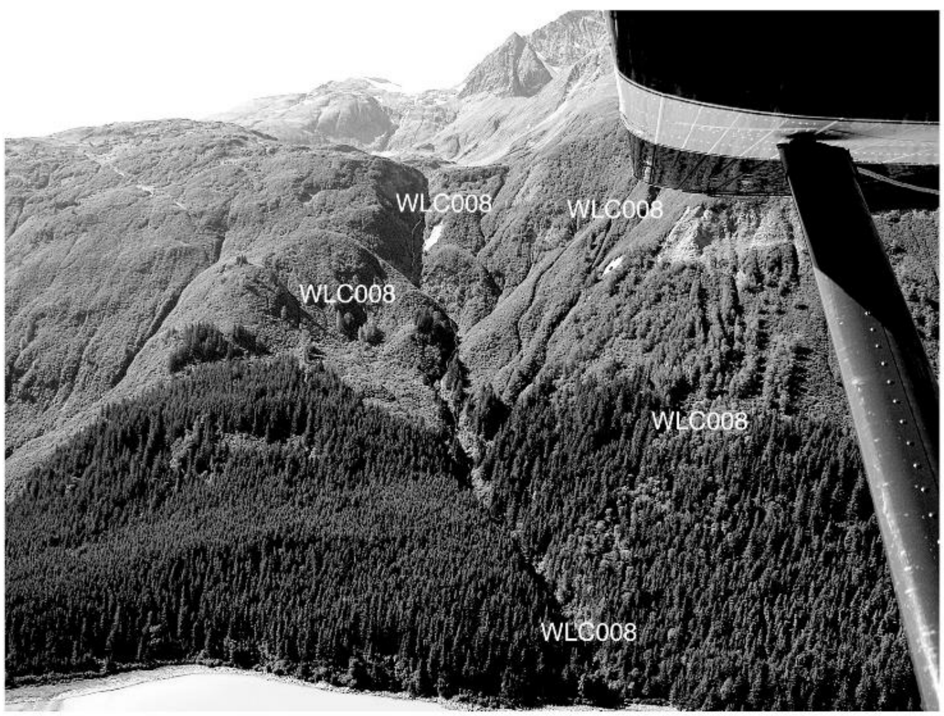

WLC007
WLC007
WLC007

Path: WLC007

Path Group:	Sullivan
Latitude-Longitude:	58.581881 -135.241298
Max Width:	120 feet / 37 meters
Typical Width:	70 feet / 21 meters
Starting Elevation:	3500 feet / 1067 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl with gullies
Start Aspect:	E
Path Type:	deeply incised big gully
Runout Angle:	moderate decrease; high bridge crossing
Unmitigated avalanche hazard index (AHI):	2.54
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.51
AHI with Forecasting and Exploders:	0.15


WLC008
WLC008
WLC
008
WLC008


WLC008
WLC008
WLC008


WLC008
WLC008
WLC008
WLC008
WLC008

Path: WLC008

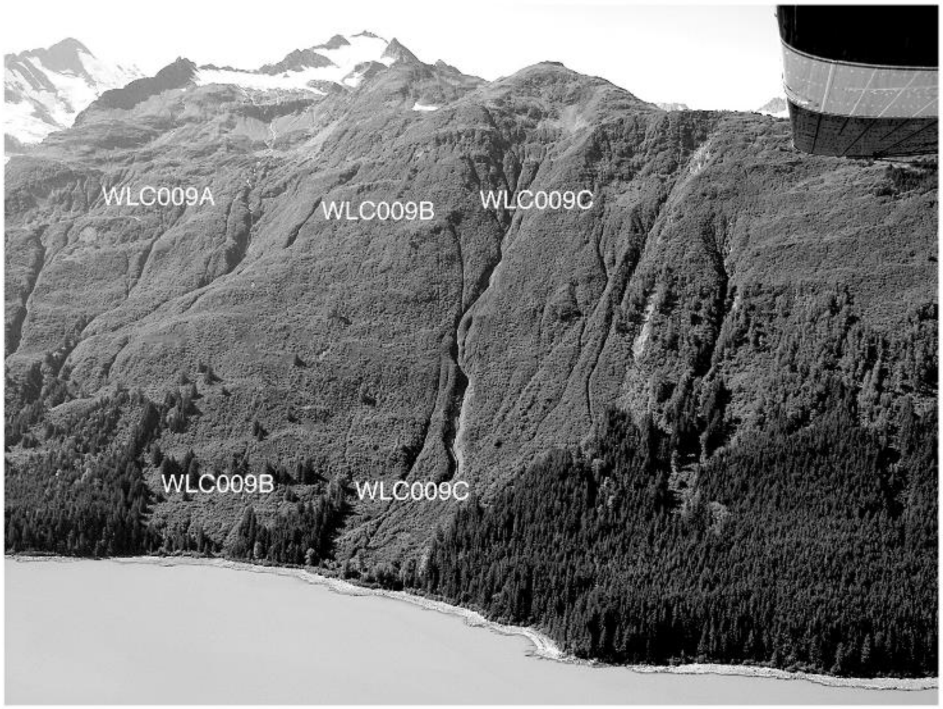
Path Group:	Rainbow
Latitude-Longitude:	59.070038 -135.264214
Max Width:	260 feet / 79 meters
Typical Width:	150 feet / 46 meters
Starting Elevation:	4000 feet / 1219 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big broad face and medium gullied bowl
Start Aspect:	ENE
Path Type:	gullied bowl into deeply incised big gully
Runout Angle:	decrease; high bridge crossing
Unmitigated avalanche hazard index (AHI):	2.11
Structural Mitigation:	Bridge 0.2x
Structurally Mitigated AHI:	0.42
AHI with Forecasting and Exploders:	0.13


WLC009A
WLC009A
WLC009B
WLC009C
WLC009A
WLC009B
WLC009C


WLC009A

Path: WLC009A

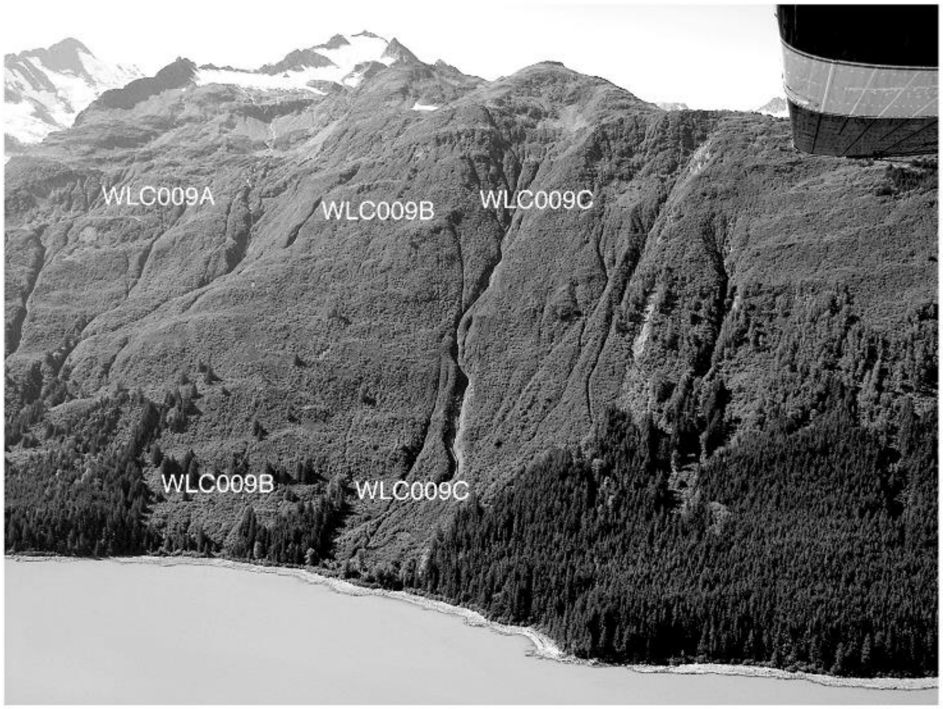
Path Group:	Rainbow
Latitude-Longitude:	59.000429-135.241143
Max Width:	1433 feet / 437 meters
Typical Width:	1420 feet / 433 meters
Starting Elevation:	5000 feet / 1524 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big bowl
Start Aspect:	ENE
Path Type:	gullied bowl into broad gullied unconfined
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	11.92
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	5.96
AHI with Forecasting and Exploders:	1.79


WLC009A
WLC009B
WLC009C
WLC009B
WLC009C


WLC009B
WLC009C

Path: WLC009B

Path Group:	Rainbow
Latitude-Longitude:	59.000429-135.241143
Max Width:	1433 feet / 437 meters
Typical Width:	1080 feet / 329 meters
Starting Elevation:	3400 feet / 1036 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	big broad face
Start Aspect:	ENE
Path Type:	big broad face into broad unconfined runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	11.92
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	5.96
AHI with Forecasting and Exploders:	1.9


WLC009A
WLC009B
WLC009C
WLC009B
WLC009C


WLC009B
WLC009C

Path: WLC009C

Path Group:	Rainbow
Latitude-Longitude:	59.000429-135.241143
Max Width:	1433 feet / 437 meters
Typical Width:	890 feet / 271 meters
Starting Elevation:	3400 feet / 1036 meters
Elevation Class:	high
Path Size:	very large
Starting Zone Characteristics:	medium bowls
Start Aspect:	ENE
Path Type:	broad unconfined track and runout with gullies
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	11.92
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	5.96
AHI with Forecasting and Exploders:	1.79


WLC
010C
WLC010D
WLC010D
WLC010B
WLC010A
WLC010A
WLC
010B
WLC
010C
WLC010D


WLC010A
WLC010B

Path: WLC010A

Path Group:	Pyramid
Latitude-Longitude:	59.105158-135.29264
Max Width:	630 feet . 192 meters
Typical Width:	100 feet / 30 meters
Starting Elevation:	3800 feet / 1158 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	big bowl and big broad face
Start Aspect:	ENE
Path Type:	broad bowl into broad unconfined with gullies
Runout Angle:	moderate decrease; alignment out on flats
Unmitigated avalanche hazard index (AHI):	1.21
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	0.61
AHI with Forecasting and Exploders:	0.18


WLC
010C
WLC010D
WLC010D
WLC010B
WLC010A
WLC010A
WLC
010B
WLC
010C
WLC010D


WLC010C
WLC010B
WLC010D

Path: WLC010B

Path Group:	Pyramid
Latitude-Longitude:	59.105158-135.29264
Max Width:	630 feet / 192 meters
Typical Width:	340 feet / 104 meters
Starting Elevation:	3100 feet / 945 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	small bowls and gullies
Start Aspect:	ENE
Path Type:	broad gully to unconfined gullied runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	1.21
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	0.61
AHI with Forecasting and Exploders:	0.18


WLC
010C
WLC010D
WLC010D
WLC010B
WLC010A
WLC010A
WLC
010B
WLC
010C
WLC010D


WLC010C
WLC010B
WLC010D

Path: WLC010C

Path Group:	Pyramid
Latitude-Longitude:	59.105158-135.29264
Max Width:	630 feet / 192 meters
Typical Width:	380 feet / 116 meters
Starting Elevation:	3700 feet / 1128 meters
Elevation Class:	high
Path Size:	medium
Starting Zone Characteristics:	big gully
Start Aspect:	ENE
Path Type:	broad gully to unconfined gullied runout
Runout Angle:	moderate decrease
Unmitigated avalanche hazard index (AHI):	1.21
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	0.61
AHI with Forecasting and Exploders:	0.18


WLC010D
WLC
010D
WLC010D


WLC010C
WLC010B
WLC010D

Path: WLC010D

Path Group:	Pyramid
Latitude-Longitude:	59.105158-135.29264
Max Width:	630 feet / 192 meters
Typical Width:	340 feet / 104 meters
Starting Elevation:	4200 feet / 1280 meters
Elevation Class:	high
Path Size:	large
Starting Zone Characteristics:	medium bowl, medium face, big gullied bowl
Start Aspect:	ENE
Path Type:	gullies and face to broad unconfined runout
Runout Angle:	decreases; usually stops above alignment
Unmitigated avalanche hazard index (AHI):	1.21
Structural Mitigation:	Elevated fill 0.5x
Structurally Mitigated AHI:	0.61
AHI with Forecasting and Exploders:	0.18

12.Technical Appendices

12.1. *APPENDIX 1: Avalanche Hazard Index (AHI) Calculation*

Introduction

The avalanche hazard index (AHI) is a dimensionless numerical expression representing damage and loss potential as the result of an interaction between snow avalanches and vehicles on a highway (Schaerer, 1989). The concept was first developed in Canada (Avalanche task force, 1974), and has been applied at various locations in North America and New Zealand (Fitzharris and Owens, 1980; Armstrong, 1981; Mears, 1993; Mears and Newcomb (unpublished); Fesler, Mears and Fredston, 1990; Mears, 1995.

Avalanche hazard on a highway contains two elements: (a) the frequency (or probability) of an encounter, and (b) the nature, magnitude, and severity of the resulting damage from the avalanche.

Damage Potential and Weighting the Consequences

The severity of the potential damage is used to define three idealized types of avalanches as follows:

1. Light snow avalanches. Flowing avalanches of light snow cross and block the highway, deposit snow approximately one to three feet (0.3 to 1.0m) deep, and could push a car off the highway but not bury it. **Light snow avalanches are assigned a weighting factor of 3.**

2. Deep snow avalanches. Flowing avalanches of deep snow deposit snow to a depth of more than 3 feet (1.0m) could bury or push vehicles off the highway and could severely damage a vehicle and injure or kill occupants. **Deep snow avalanches are assigned a weighting factor of 10.**

3. Plunging snow avalanches. Plunging snow avalanches fall onto a highway at high speeds after descending steep terrain *or* tumble vehicles off the highway down a steep slope or into the water. **Plunging snow avalanches are assigned a weighting factor of 12.** Many of the avalanche paths considered on East and West Lynn Canal and the Seward Highway produce avalanches that at times must be considered the plunging-snow type.

Avalanche Frequency and Width

Avalanche frequency and width (length of highway covered) must be estimated for each path for light snow, deep snow, and plunging snow avalanche types. Frequency, F, is expressed as the average number or occurrences of a given class of avalanche (light, deep, or plunging) in each path per year. F is computed as the reciprocal of the average return period, P, thus $F = 1/P$. For example, an avalanche (light, deep, or plunging type) with a return period of 10 years has an annual frequency of 0.10.

Calculating the AHI

The AHI is calculated by multiplying the damage-weighting factor (discussed above) by the frequencies of moving and stationary vehicles in avalanche paths. The encounter probability, P, is calculated

$P = P_M + P_W$,

where (1) P_M is the probability of a moving vehicles being hit by an avalanche and P_W is the probability of a waiting vehicle being hit by a second avalanche in the same path or by adjacent avalanches. When avalanches are closely spaced, as they are in the avalanche terrain of both the East and West Lynn Canal alignment alternatives, P increases because the P_W term is large. Even if traffic is light, a long queue of traffic can back up below avalanche paths.

The moving vehicle encounter probability, P_M is calculated $P_M = f(N,L,D,F,V)$, where (2) N = average daily winter traffic (495 vehicles per day on the East Lynn Canal route and 405 vehicles per day on the West Lynn Canal route, using the projected year 2050 traffic counts as updated in 2013), L = average highway length covered by avalanches of a given class, D = vehicle stopping distance (a function of speed and driver reaction time), F = frequency of avalanches of a given class, in years, and V = average vehicle speed (which also controls D). The calculation in (2) is repeated for each avalanche path and each class of avalanche in that path. The term P_M becomes an important factor only if traffic volume is very high (generally in excess of 10,000 vehicles per day) and is therefore not an important term on the Juneau access alternatives.

The waiting vehicle encounter probability P_W is calculated

$P_W = f(p_s,N,F) + 0.5\ f(p'_s, N,F)$,

where (3) p_s = probability of an avalanche in an adjacent path hitting traffic that is backed up until emergency response arrives. The length of a queue of vehicles stopped on the highway depends on traffic volume and response time. When avalanche paths are closely spaced and of relatively high frequency the probability p_s of vehicles in the queue being hit by an avalanche increases. Rather than the one or two-hour response time that is often used in these calculations, all paths with multiple starting zones, or in groups with other paths nearby, were assigned a varying increased probability of secondary avalanches, based on the proximity of other paths and how often they showed evidence of multiple releases. In equation (3), N is the number of vehicles exposed in avalanche terrain, F is the avalanche frequency in years, and p'_s is the probability of a second avalanche in the path that caused the traffic blockage.

The AHI is calculated for *each path, i,* as follows:

$AHI_i = \Sigma\ W_j\ (P_{mj} + P_{wj})$,

where (4) the subscript j refers to the three classes of avalanches (light, deep, and plunging).

Finally, a cumulative AHI_H was calculated for the entire East and West Lynn Canal routes, based on current proposed alignments as follows:

$AHI_H = \Sigma\ AHI_i$, where (5) $1 \leq i \leq n$ and n is the number of paths on each highway alignment considered.

As discussed by Schaerer (1989), each avalanche path (together with its neighboring paths) was assumed to be independent of other paths on the highway. Therefore, the same avalanche was assumed capable of hitting both moving and waiting traffic each time it occurred after another avalanche had blocked the highway. It could be argued that the AHI could be made more realistic by taking into account that traffic stops after one avalanche occurrence and that each avalanche can strike vehicles only once. However, this "more realistic" assumption would not allow a comparison between individual avalanche paths that is one of the primary objectives of this analysis. Therefore, the simpler approach was used to calculate the index. Furthermore, the AHI calculation assumes a uniform flow of traffic regardless of conditions. In fact, traffic would certainly be heavier on some days and would probably decrease during severe conditions. Both would change vehicle exposure to avalanches.

The standard, simple AHI calculating procedure, without shape factors, vehicle type, or societal cost, was applied because (a) it enables comparison between different paths, (b) it enables "problem areas" to be quantified, and (c) it enables the East and West Lynn Canal routes to be compared to each other and to the greatest number of other highways that have AHI values calculated.

For waiting and moving AHI figures, and calculation details, please refer to the raw data and calculation spreadsheets available online in pdf format at www.juneauaccess.alaska.gov. A traffic speed of 40 mph (64 km/hr) was used as a storm conditions traffic speed for AHI calculations.

12.2. *APPENDIX 2: AHI Data Collection and Reliability*

The results of the analysis are only as reliable as the data used. Where available, actual avalanche sizes and return intervals were used, with correction factors applied to normalize the figures to consistency with long-term climate and avalanche records.

Where there were no avalanche occurrences within the period of observation, the return period of the missing avalanche types was estimated to the nearest "half-order of magnitude" or approximately to within a factor of 3. The half-order of magnitude steps used have annual probabilities (and return periods) of 1.000 (1 year); 0.333 (3 years); 0.100 (10 years); 0.033 (30 years); 0.010 (100 years); 0.003 (300 years).

Avalanche types that did not occur during the six years of field observations were given a minimum return interval of 10 years, the next half-order of magnitude step up from six years.

The longer return interval estimates were determined in part by comparison with other paths in the region for which frequency data was available, and in part by path characteristics and vegetation patterns. Air photos and detailed laser-surveyed topographic maps allowed thorough study of vegetation patterns and terrain features that indicate path boundaries.

In northern Southeast Alaska, the limit of the most recent 30-year avalanche cycle on many paths is clearly visible as a sharp difference in the age of the trees where they have regrown since they were last destroyed in the early 1970s. This boundary yields good information for 30-year avalanche events on those paths.

Vegetation damage from the most recent 100-year to 300-year cycle is also visible on many paths. Some paths produced 200 year avalanches in the early 1970s cycle (Fesler, November 2003 note) and others show trimlines from earlier cycles in the 1920s or 1930s. Paths with no evidence of 100-year or more-frequent events fall into the 300-year return interval category, unless the characteristics of the path are such that the avalanche type in question does not occur at all.

The precision of these estimates is greatest for the shortest return interval events, which are the ones that have the greatest influence on the avalanche hazard index. Paths with longer than 30-year return intervals, which have the least reliable data, also have minimal impact on the AHI results.

Actual avalanche frequency data has been used wherever it is available. No observations are available for the West Lynn Canal alternative, but fixed-wing aerial observations were conducted along the East Lynn Canal route for six of the eight avalanche seasons since the original 1995 study. In four of these winters (1995-96, 1997-98, 2000-01, and 2001-02), flights were made on a regular basis throughout the winter, and frequencies can be reliably determined from the observations.

In 1996-97 and 1999-2000, flights were made only at the end of the season. Debris piles indicated which paths had produced large avalanches in those seasons, but the number of slides contributing to the piles could not be determined. Avalanche frequency was estimated for these two seasons by assuming that the paths that slid had as many avalanches as their average in the other years of observation.

While the observations data are very useful for EIS-level analysis, six years is a short period of record for climate-related phenomena, and more avalanche observations should be recorded for design-level studies. The sample has been evaluated to determine how representative it is, and corrected for bias with regard to known climate cycles. The route was re-flown in 2012 and the mapping was updated to reflect new and expanded paths. Aerial surveys show no new paths or expansion of existing paths through the winter of 2015-16. Activity has been consistent with the earlier analysis.

The key to this analysis is determining how the period of study fits into long-term climate patterns. While there is no guarantee that past climate patterns will continue into the future, climate history is the best tool available for predicting future trends.

Robert Kanan, a recently retired National Weather Service meteorologist and climatologist with long experience studying the climate of northern Southeast Alaska, analyzed long-term weather patterns and climate trends in the region for this study, and a correction factor was used to increase the frequencies to be consistent with the calculated long-term averages.

Raw Data and AHI Calculation Spreadsheets

The raw data and calculation spreadsheets are available in pdf format online at www.juneauaccess.alaska.gov.

12.3. *APPENDIX 3: AHI Input Data Analysis*

Long- term Climatology: Tropical Pacific Ocean El Niño-Southern Oscillation (ENSO), and Effects on Southeast Alaska Snowfall

Robert A. Kanan

Juneau, Alaska, August, 2003

1. Brief overview of ENSO.

El Niño-Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales. It has a strong influence on seasonal snowfall totals at Juneau and northern Southeast Alaska. ENSO is a 2- to 6-year cycle of warmer and colder sea surface temperatures, and tilting of the near-surface thermocline along the equator from 150 degrees west to the date line. More details are available on many Internet web sites, such as the NOAA/NWS Climate Diagnostic Center: and the Climate Prediction Center at:

2. How ENSO is measured.

The standard monitoring of ENSO is the Multivariate ENSO Index (MEI). The MEI uses the six main observed variables over the tropical Pacific: sea level pressure (Darwin to Tahiti), zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. Complete data are available from 1950 to present. Another, less complete measure of ENSO is the Southern Oscillation Index (SOI), the single-variable Darwin-to-Tahiti surface pressure difference. Except for a few missing years, data go back to 1882.

Other variables, such as precipitation and temperature climate, exhibit time-dependent behavior that is sensitive to some aspect of ENSO. Long-term records on the periphery of the Indian and Pacific Oceans have been constructed from historical sources, tree-ring reconstructions (summer temperature and winter rainfall), and annual record of oxygen isotope composition for a high-elevation glacier in Peru. ENSO estimates can be made back to the late 16th century, and at least a portion of the Medieval Warm Period (~A.D. 950-1250). In general, spectral power on time scales of about two to six years is statistically significant and persists throughout most of the time intervals sampled. Assuming that the ENSO phenomenon is the source of much of the variability at these time scales, this indicates that ENSO has been an important part of interannual climatic variations over broad areas of the circum-Pacific region throughout the last millennium. Significant correlations were found between El Niño and reconstructed Sierra Nevada winter precipitation at about two to four years throughout much of their common record (late 16th century to present), and between six and seven years from the mid-18th to early 20th century.

3. ENSO life cycle, and the longer decadal oscillations.

The ENSO cycle of two to four years also has a longer (~20 years) oscillation of prevailing warm and cold events. The prevailing very cold La Niña period from 1954-1976 had only three seasonal warm events greater than one standardized departure (1958,1966, and 1973). That cold period was followed by a very warm prevailing El Niño from 1977-1998 with only one cold departure (1988). Extending this longer decadal ENSO oscillation back farther in time becomes much less exact. The MEI data date back only to 1950, so the less useful SOI must be used to reconstruct earlier periods. There is at least some indication the decadal oscillation of about 20 years continues with an overall warm El Niño from about 1934-1954, prevailing cold La Niña from about 1915-1933, warm from 1894-1914, and perhaps a weak prevailing cold period prior to about 1893.

Besides the lack of MEI data, the difficulty in accurately extending the decadal ENSO oscillation to the first half of the last century and earlier is that the magnitude of the ENSO events was much weaker than those in modern time (since about 1950). There are other much longer period oscillations that may reinforce or reduce the magnitude, and/or alter the length of some of the shorter-period ENSO decadal oscillations.

4. ENSO effects on winter weather in Southeast Alaska

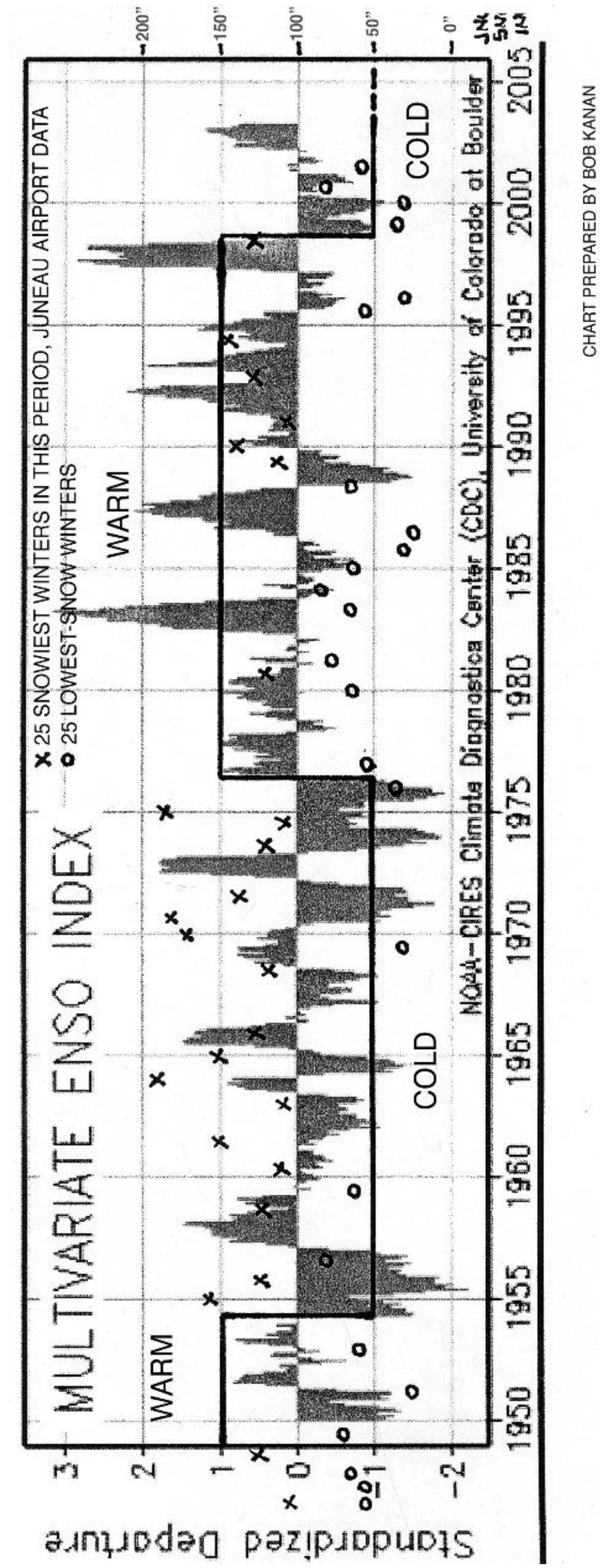
Juneau winter temperature and snowfall data show a strong correlation to ENSO. This is also the case for northern Southeast Alaska, especially north of the average position of the quasi-stationary Arctic front (a discontinuous line from Cape Spencer to Cape Fanshaw) after intense cold air outbreaks from Canada. The average position of the 500MB ridgeline is normally along the west coast of North America. But during warm El Niño events this average ridgeline position is displaced about 500 miles eastward into Canada. This allows a more frequent southwesterly flow aloft over Southeast Alaska, with the storm track across the north Pacific bringing warm, moist tropical source air onshore over the Southeast Alaska panhandle. Conditions are warmer and wetter, with less of the precipitation in the form of snow at sea level. Then, during cold La Niña conditions, the 500MB ridge line is displaced about 1000 miles westward to the eastern Aleutian Islands and the eastern Bering Sea. This pattern blocks storms from moving into the eastern Gulf of Alaska and allows Arctic high pressure to build over northwestern Canada. This is the prerequisite for outbreaks of cold air over northern Southeast Alaska so that the next southwesterly warm air overrunning flow produces both longer duration and larger amounts of snowfall before the snow changes to rain as the Arctic air is mixed with the warmer maritime-source air.

5. ENSO plot and Juneau snowfall

The longer-term shifts of the decadal oscillation are outlined on a plot of ENSO (using the MEI) from 1950 to the present. Then the seasonal (October 1 through –April 30) 25 years of highest and lowest snowfall at Juneau International Airport are plotted. The connection between snowfall and ENSO is very strong. La Niña (cold) events have the highest snowfall seasons, and El Niño (warm) has the lowest snowfall. The La Niña period from 1954 to 1977 had 16 of the 25 greatest seasonal snowfalls during the last 60 years in Juneau, and only four of the lowest snowfalls. The seasonal snowfall anomalies often are near the transition of brief ENSO shifts from the prevailing longer term decadal condition, or where shorter periods (one month or so) displacement of the 500MB ridge-line altered prevailing conditions.

Another way to look at the ENSO impact on the average (96.2 inches, or 2.44m) seasonal snowfall at Juneau airport during the last 60 years is to consider only the 20 greatest and 20 lowest snowfall totals. The following chart plots these differences, and the standard departure from normal temperatures. Seventeen of 40 years fell during cold La Niña conditions for an average of 126.2 inches, or 3.21m (or 131 percent of all seasons). Twenty-three seasons occurred during warm El Niño conditions with an average of 76.0 inches, or 1.93m (79 percent of all seasons). The average variability between El Niño and La Niña years is 50.2 inches, or 1.28m.

The chart shows standardized departure from normal winter temperatures.



6. Looking ahead from the present (2003)

The ENSO – PDO decadal oscillation most likely made a shift in 1998 from the strong prevailing warm (El Niño) conditions entered into during 1977 that lasted about 21 years. This shift to another long-term cold (La Niña) cycle in 1998 was confirmed in a 1999 conversation with Dr. Aants Leetmaa, director of the NWS Climate Prediction Center. If that is the case, the prevailing ENSO condition should be a series of cold La Niña events through the year 2018 or so. The major shift to colder La Niña conditions in 1998 initially lasted only through 2001, and then went to warm El Niño levels in 2002. That is not unlike how the cold 1954-1976 ENSO period started. The present 2003 status of ENSO is neutral, with no strong indications of warm or cold trends. The highest probability remains that the next 15 years will be mostly La Niña conditions. If the cold La Niña prevails, the average seasonal snowfall in northern Southeast Alaska will be significantly above average during the period.

Observations since the 2004 and 2005 reports indicate that the climate in the region has indeed shifted to the cold half of the PDO cycle.

Discussion of AHI Input Data

There has been no need to update the corrections based on Kanan's 2003 study:

Given Robert Kanan's long-term analysis, the question is where in the ENSO – PDO cycle the six years of study fall. It happens there were three years nominally in the warm half of the cycle (1995-96, 1996-97, and 1997-98) and three years nominally in the cold half (1999-00, 2000-01, and 2001-02). If they were representative years, it would be a simple matter to average them directly. Are they?

The warm-cycle winters appear to be representative of their warm cycle, which ran from 1976-77 through 1998-99. Comparison of winter (November through April) Juneau Airport National Weather Service Data available online for the winters of study with the 1976-99 warm period winters shows that the winters of study had sea-level snowfall 70 percent of the warm period average, precipitation 120 percent of the warm period average, and temperature 0.3°F (0.17°C) below the warm period average. This is a reasonable match, well within the standard deviation. In comparison with the long-term Juneau Airport averages, the sea-level snowfall was 60 percent of normal, the precipitation 80 percent of normal, and the temperature 1.6°F (0.89°C) above normal, about as expected for warm cycle years.

The cold-cycle winters are more problematic. They do not yet have the rest of their cycle for comparison, but Juneau Airport data shows sea-level snowfall at 50 percent of the long-term winter average, precipitation at 70 percent of average, and temperature 1.9°F (1.06°C) above normal. The temperature has obviously not dropped to what would be expected in a cold cycle. It appears that some correction for the last three years' data may be necessary.

What about avalanche activity?

A key to the analysis is the strong correlation Kanan demonstrated between weather in northern Southeast Alaska and the 20-year El Niño–Southern Oscillation (ENSO) and the related Pacific Decadal Oscillation (PDO) warm and cold cycles. Winters in northern Southeast Alaska show a bimodal pattern; they tend to be either cold and snowy, or warm and rainy, without much in-between.

Kanan extended the ENSO and Pacific Decadal Oscillation cycles back far enough to compare with the available recorded Juneau-area avalanche history, going back to 1890. The ENSO PDO cycle was extended using Kanan's analysis of pressure gradients in the South Pacific Ocean, not as accurate as the multivariate index (MEI) used in modern climatology, but the best available parameter for historical data.

The avalanche record was compiled by Bill Glude from the historical records available at the time of this study. Those included Doug Fesler and Jill Fredston's reports for the City & Borough of Juneau in 1992, for the A-J Mine in 1989, and for a DOT&PF Thane Road study in 1990. Fesler and Fredston's data came from historical newspaper articles, mining records, and highway records. Recent observations for the Lynn Canal and A-J Mine studies by Bill Glude were also incorporated.

This long-term avalanche history consists of slides big enough to have been recorded in the newspapers, by highway crews, or by other sources. Because the concern is slides large enough to reach a highway at low elevation, the bias of the data set is consistent with our interest. It is an incomplete record by people who were for the most part untrained in avalanche observation, but it is the most accurate long-term data set available.

Other data sets were considered, but rejected as unsuitable. The Juneau Icefield Research Project has records dating back to the 1940s, but they are primarily glacial mass balance and summertime climate records, and are not currently available in a usable format. There is avalanche data from the avalanche program on Bear Pass on the Stewart-Hyder highway northeast of Ketchikan, but that is 300 miles (480km) away, on a pass rather than along a fjord, in an area with roughly twice the precipitation on the coastal side of the mountains, in a much milder climate, and far from the influence of the arctic front which is key to northern Southeast Alaska winter weather patterns. There is avalanche data from the Seward Highway, but that is 700 miles (1130km) away, in a cooler area where the dynamics of the interplay between the arctic front and coastal storms from the Gulf of Alaska are much different.

The historical record below lists the total number of recorded slides by winter, broken into cold and warm ENSO – PDO periods. The avalanche rating is the highest rating assigned to a slide in that season. Because the cycles differ in length, the average number of slides per winter is calculated for each period. Finally a ratio, or multiplier, is calculated at the bottom of the spreadsheet comparing avalanche frequency between the warm and cold ENSO – PDO periods.

Juneau-Area Avalanche History Analysis

Avalanche season from...	to...	Number of avalanches	Largest size avalanche	Avg. annual # of avalanches for period	Average size avalanche for period	Period type
1889	1890	0.0				
1890	1891	3.0	5.0			
1891	1892	0.0				
1892	1893	1.0				
1893	1894	2.0	3.0	1.2	4.0	cold period
1894	1895	5.0	4.0			
1895	1896	0.0				
1896	1897	0.0				
1897	1898	0.0				
1898	1899	1.0				
1899	1900	0.0				
1900	1901	0.0				
1901	1902	0.0				
1902	1903	1.0	3.0			
1903	1904	0.0				
1904	1905	0.0				
1905	1906	0.0				
1906	1907	0.0				
1907	1908	0.0				
1908	1909	0.0				
1909	1910	1.0	4.0			
1910	1911	0.0				
1911	1912	0.0				
1912	1913	0.0				
1913	1914	0.0				
1914	1915	0.0		0.4	3.7	warm period
1915	1916	6.0	3.0			
1916	1917	4.0	5.0			
1917	1918	1.0	3.0			
1918	1919	1.0	3.0			
1919	1920	1.0	3.0			
1920	1921	2.0	4.0			
1921	1922	1.0	4.0			
1922	1923	3.0	4.0			
1923	1924	2.0	4.0			
1924	1925	0.0				
1925	1926	1.0	4.0			
1926	1927	0.0				
1927	1928	1.0	3.0			
1928	1929	1.0	5.0			
1929	1930	0.0				
1930	1931	0.0				
1931	1932	3.0	4.0	1.6	3.8	cold period
1932	1933	0.0				
1933	1934	2.0	3.0			
1934	1935	1.0	4.0			
1935	1936	1.0	3.0			
1936	1937	0.0				
1937	1938	0.0				
1938	1939	7.0	4.0			
1939	1940	0.0				
1940	1941	0.0				
1941	1942	0.0				
1942	1943	0.0				
1943	1944	0.0				
1944	1945	1.0	3.0			
1945	1946	1.0	3.0			
1946	1947	3.0	3.0			
1947	1948	1.0	3.0			
1948	1949	2.0	4.0			

Avalanche season from...	to...	Number of avalanches	Largest size avalanche	Avg. annual # of avalanches for period	Average size avalanche for period	Period type
1949	1950	0.0				
1950	1951	1.0	3.0			
1951	1952	1.0	4.0			
1952	1953	1.0	3.0	1.0	3.3	warm period
1953	1954	0.0				
1954	1955	7.0	3.0			
1955	1956	2.0	3.0			
1956	1957	0.0				
1957	1958	0.0				
1958	1959	1.0	3.0			
1959	1960	0.0				
1960	1961	0.0				
1961	1962	5.0	3.0			
1962	1963	0.0				
1963	1964	4.0	4.0			
1964	1965	1.0	3.0			
1965	1966	8.0	3.0			
1966	1967	1.0	3.0			
1967	1968	0.0				
1968	1969	0.0				
1969	1970	0.0				
1970	1971	9.0	3.0			
1971	1972	6.0	5.0			
1972	1973	1.0	3.0			
1973	1974	6.0	4.0			
1974	1975	3.0	4.0			
1975	1976	11.0	4.0	2.8	3.4	cold period
1976	1977	0.0				
1977	1978	0.0				
1978	1979	0.0				
1979	1980	1.0	3.0			
1980	1981	0.0				
1981	1982	1.0	3.0			
1982	1983	0.0				
1983	1984	0.0				
1984	1985	8.0	4.0			
1985	1986	0.0				
1986	1987	0.0				
1987	1988	0.0				
1988	1989	6.0	4.0			
1989	1990	0.0				
1990	1991	2.0	3.0			
1991	1992	0.0				
1992	1993	0.0				
1993	1994	0.0				
1994	1995	0.0				
1995	1996	1.0	3.0			
1996	1997	2.0	3.0			
1997	1998	1.0	3.0			
1998	1999	0.0		1.0	3.3	warm period
1999	2000	4.0	3.0			
2000	2001	0.0				
2001	2002	7.0	3.0			
2002	2003	0.0		2.8	3.0	cold period
		Cold period average		2.1	3.5	
		Warm period average		0.8	3.4	
		Warm to cold multiplier		2.6	1.0	

Avalanche frequency in the historical data set for the Juneau area shows a strong correlation with the 20-year El Niño – Southern Oscillation and Pacific Decadal Oscillation (ENSO – PDO) cycles, with 2.6 times as many slides recorded during cold cycles as in warm cycles.

Avalanche size does not show a correlation.

If the cold cycle years in the period of study were consistent with the long-term averages, there should be 2.6 times as many slides as in the warm cycle years. The records show 2.2 times as many observed hits to the alignment, a significant increase in avalanche frequency from the warm cycle winters, but lower than the long-term figure of 2.6.

The figures for cold cycle frequencies were corrected to eliminate the sample bias and normalize them to the long-term average multiplier of 2.6. The warm and cold cycle years' data were then averaged to calculate the frequencies for the avalanche hazard index.

For AHI calculation purposes, a standard relationship between total path width and the widths of plunging, deep, and light avalanches is often assumed. For these calculations, width ratios for each type of avalanche were derived based on field observations in the Lynn Canal terrain and snow climate, and applied those locally-derived ratios for greater accuracy.

There is one other correction to the data. The data set did not include any of the rare but very large avalanche cycles, and so an estimate was made to determine how significant that absence would be to the average frequencies used for the AHI calculations.

It has been demonstrated (Birkeland and Landry, 2002) that the size-frequency relationship of avalanches follows a power law, as do many other natural phenomena. That means that the number of events increases logarithmically as the size decreases, or that large events are much more rare than moderate or small events. A straight line with a characteristic slope can be fitted to the data for a given locality and used to characterize its avalanche behavior as a system.

This power-law relationship can be a useful tool, but no existing data sets for northern Southeast Alaska are complete enough to use it. The observation flight data is unsuitable because the observations are not daily, because the primary concern is large slides, and because the small slides are difficult to record accurately from the air. No daily records including the full range of sizes exist in the region.

A similar principle was used to determine the influence of very large but rare events on a frequency average. The theoretical spreadsheet of relative avalanche size (on a scale of one to 5, relative to path capability) in relation to return interval and frequency was constructed. Avalanche size as listed in the spreadsheet over the full 300-year return period was averaged and compared that to a three-year sample, the closest half-order of magnitude step to the six years of record. Relative size three and larger slides, which are the ones that will reach a low-elevation highway, were the focus. The difference in the averages was only 0.5 percent.

Although the difference is negligible, a factor of +0.005L was applied as a size-correction multiplier to the AHI factor L for avalanche width, expressed in the AHI calculations as length of the slide on the highway.

12.4. *APPENDIX 4: Highway Closures*

Closure periods were calculated using the weather logs and avalanche observations from the same six years of field studies as were used in the AHI calculations, with the same correction factors applied.

Each avalanche cycle was evaluated to determine how long the highway would have been closed, and what level of explosive work would have been conducted. Weather events that would have been forecast as avalanche cycles but turned out to be false alarms are also tallied, but given lower figures for closure time and explosive operations, as would have occurred once forecasters realized the expected activity was not materializing.

Highways with mitigated AHIs comparable to the East and West Lynn Canal route are left open at night at "low" through "considerable" hazard levels, unless natural avalanches are forecast to reach low elevations. If avalanches are likely to reach low elevations, and explosive work is not completed, the highway would be closed at night. Night closures were tallied for the major avalanche cycles.

Limitations of darkness and storm conditions were factored into the initial tallies for all options. Corrections are added as follows:

a. An additional 20 percent was taken from the explosive delivery mission tally for helicopter-based programs, because many days that appear suitable based only on the weather records would in fact be too windy, foggy, or stormy. The mission tally was simply reduced, as the window of opportunity would pass and the snowpack would either slide or stabilize on its own.

b. All blaster box figures were reduced 30 percent because the raw mission tally reflects only their capability for being fired in storm conditions. Operations using blaster boxes report that the high cost of ammunition and its delivery by helicopter necessitate using them conservatively.

c. Howitzer use figures for the West Lynn Canal WLC1 option were only reduced ten percent, as weather would not have much effect on transporting a trailered howitzer on the highway.

The tallies for missions and highway closure times under all options were further adjusted by 20 percent for crew limitations. It is often impossible to conduct explosive operations because the entire maintenance crew is tied up with other urgent work, or is working far enough away that they cannot get back in time, or because conditions develop too rapidly to respond, or because of budget and workforce limitations. Some other highway operations reported even greater limitations due to crew factors, but it is assumed here that safety and reliability of this highway would be a high enough priority to merit adequate funding. Short funding would increase closure time.

13. *APPENDIX 5: Transportation Avalanche Danger Scale*

LOW (green)

Natural and human-triggered avalanches unlikely.

Destructive avalanches unlikely to come near developed areas.

Normal caution.

MODERATE (yellow)

Natural avalanches unlikely; human-triggered avalanches possible.

Destructive avalanches possible but unlikely to come near developed areas.

Normal caution.

CONSIDERABLE (orange)

Natural avalanches possible; human-triggered avalanches likely.

Destructive avalanches may come near or reach developed areas.

Increasing caution in or under steeper terrain and in avalanche zones. Monitor forecasts.

HIGH (red)

Natural avalanches likely; human-triggered avalanches very likely.

Destructive avalanches likely to come near or reach developed areas.

Minimize exposure in avalanche zones. Monitor avalanche forecasts.

EXTREME (black)

Natural and human-triggered avalanches certain.

Destructive avalanches likely to reach developed areas.

Eliminate exposure to avalanche zones. Monitor avalanche forecasts.

13.1. *APPENDIX 6: Highway Closure and Operation Criteria*

These guidelines are a sample of the kind of material that is part of a project-specific operational avalanche plan and are not a substitute for such a detailed plan. A project-specific plan is required under Alaska case law for worker safety before construction or operation of an avalanche-exposed facility may proceed. Planning at that level is beyond the scope of this report.

LOW (green)

- Generally stable snowpack; avalanche activity unlikely.
- Highway open.
- Normal highway plowing operations are not required to call in their locations.
- Stationary snow removal operations, clearing avalanche debris or collection areas, must have approval of avalanche forecaster in charge, report to dispatch every 30 minutes, and have a spotter.

MODERATE (yellow)

- If natural avalanches are possible, but are not forecast to reach lower elevations, the highway is open. Areas of unstable snow exist, but are not widespread. Large avalanches are unlikely.
- Normal highway plowing operations call in their location every 30 minutes.
- Stationary snow removal operations must have approval of avalanche forecaster in charge, report to dispatch every 30 minutes, and have a spotter. No clearing of avalanche debris or collection areas.
- Workers must stay inside vehicles when working in avalanche areas.
- Crews should alert the avalanche forecaster in charge to any observations or changes in the weather that may affect avalanche activity.
- If status is Moderate without avalanches to lower elevations, but trend is toward increasing avalanche danger, crews prepare for possible sweep and closure. Preventive explosive work and spot closures initiated if danger level is increasing but instability is limited. Highway can open if explosive work is completed on all paths threatening highway, danger from ongoing conditions is minimal, and the danger level for the paths affecting the highway can be lowered to Moderate with no slides forecast to reach low elevations.
- If danger level is Moderate but natural avalanches may reach lower elevations, highway is swept and closed to all but DOT&PF and law enforcement use. Entry into closed area requires specific permission from the avalanche forecaster in charge. Crew precautions for Considerable danger level are in effect. Explosive work initiated if possible. Highway can reopen if explosive work is completed on all paths threatening highway, danger from ongoing conditions is minimal, and the danger level for the paths affecting the highway can be lowered to Moderate with no slides forecast to reach low elevations.

CONSIDERABLE (orange)

- Natural avalanches are possible. Instability more widespread.
- Highway closed to all but DOT&PF and law enforcement use. Entry into closed area requires specific permission from the avalanche forecaster in charge.

- Workers must stay inside vehicles when working in avalanche areas, and remain on the main highway and shoulders.
- Crews plowing or sweeping call in when entering and leaving every avalanche path, identifying their location to dispatch. No stationary equipment within avalanche areas.
- Crews should alert the avalanche forecaster in charge to any observations or changes in the weather that may affect avalanche activity, and should contact the forecaster immediately if there is any new avalanche activity.
- Explosive work initiated or continued if possible.
- Highway can be reopened with careful monitoring only after explosive work is completed on all paths threatening highway, danger from ongoing conditions is minimal, and the danger level for the paths affecting the highway can be lowered to Moderate with no slides forecast to reach low elevations.

HIGH (red)

- Generally unstable snowpack. Widespread avalanche activity has not yet begun, or is ending, but slides may reach the highway.
- Highway closed to all but DOT&PF and law enforcement use. Entry into closed area requires specific permission from the avalanche forecaster in charge.
- Explosive work initiated only if practical. Forecaster in charge may permit explosives work with strict precautions. Crews passing through avalanche zones must be spotted and must maintain constant communications.
- Plowing operations are allowed only in support of explosives missions, under the same rules. Workers must stay inside vehicles when working in avalanche areas, keep moving within avalanche areas, and remain on the main highway and shoulders.
- Highway can be reopened with careful monitoring only after explosive work is completed on all paths threatening highway, danger from ongoing conditions is minimal, and the danger level for the paths affecting the highway can be lowered to Moderate with no slides forecast to reach low elevations.
- These criteria would generally be difficult to meet during high danger level periods. The highway must remain closed if there is any doubt.

EXTREME (black)

- Widespread avalanche cycle reaching low elevations is imminent or in progress.
- Highway closed to all traffic. No exceptions.
- The forecaster in charge, as always, has the discretion to reduce the danger level when appropriate.

13.2. *APPENDIX 7: Explosive Calculations*

The explosives calculation worksheets have been updated to reflect the current alignment, delivery options, and recalculated AHI numbers, targeting mitigation measures to the paths where they are most needed.

The number of shots for each delivery method was calculated by studying each path from the air and on oblique and vertical airphotos, as well as on detailed topographic maps, to determine how many target areas are needed to ensure release.

The frequency weighting corrected for how often a particular path would be part of an explosive delivery mission. The greatest-threat, most-active paths are part of every mission, so their frequency weighting is one. Paths that would need explosive work on half the missions have a frequency weighting of 0.5, those that would need work on one third of the missions have a weighting of 0.3, and so on.

The “weighted average shots per mission” is the total number of shots multiplied by the frequency weighting, and the “weighted shots per year” is the weighted shots per mission multiplied by the number of missions per year, which is calculated separately based on the weather and highway closure analysis.

Charge sizes are calculated based on 25lb (12.5kg) ammonium nitrate – fuel oil (ANFO) bags for helicopter placement, 8-pound (3kg) high explosive for howitzer rounds, and 6-pound (3kg) mortar rounds for the blaster boxes.

For options with howitzers, the firing location is an open pad for sites the gun could be trailered to, or a secure garage at remote sites where the gun must be left between missions. Access to the firing location is a highway side turnout where the site is along the highway, a pad on a spur road (approximate spur road length given) if it is near the highway, or helicopter access if it is a remote site. For the howitzer option for the East Lynn alternative, three howitzers would be located at remote sites and one howitzer would be trailered to one of several locations for firing from an open pad.

The field of fire for a howitzer is the total side-to-side, or horizontal, angle between the farthest left and farthest right shot from that location. It is listed because howitzer capabilities vary, and repositioning may be required with some models to cover the full width of the field of fire.

The longest howitzer shot is listed because range is a concern. 105mm howitzers are routinely used up to 3 to 3.5 miles (4800-5600m) range for avalanche work. They can hit targets at over five miles (8000m), but accuracy for avalanche purposes suffers on those longer shots. All targets listed in the options not discarded are within howitzer range considered practical for avalanche purposes.

The elevation of the highest howitzer shot is listed because elevation and distance determine the necessary trajectory. All shot points could be hit with relatively flat trajectories that stay below 10,000’ (3050m). No shots have trajectories where overshooting would target inhabited areas.

Airspace must be closed in the vicinity of howitzer explosive delivery operations to avoid risk to aircraft. These closures are coordinated through the Federal Aviation Administration.

For options with blaster boxes, the width of the starting zone in meters is calculated as "start zone (m)", and is divided by the 300m range of a mast with two cabinets mounted on it to arrive at the number of masts. Determination of individual mast locations is a design-level choice that is beyond the scope of this study.

13.3. *APPENDIX 8: Explosive Calculation and Operations Worksheets*

ELC A & B Explosive Quantities and Locations

(East Lynn Canal Option A: Helicopter Only, Option B: Daisy Bell)

path	number of shots	frequency weighting	weighted average shots per mission	weighted average shots per year
LC001	5.0	0.5	2.5	6.3
LC002	8.0	1.0	8.0	20.2
LC003	3.0	0.2	0.6	1.5
LC003-1	2.0	0.1	0.1	0.3
LC004	1.0	0.1	0.1	0.1
LC005	15.0	0.5	7.5	18.9
LC005-1	2.0	0.5	1.0	2.5
LC006	15.0	1.0	15.0	37.8
LC007	2.0	0.5	1.0	2.5
LC008	4.0	0.8	3.0	7.6
LC009	4.0	1.0	4.0	10.1
LC010	2.0	1.0	2.0	5.0
LC011	3.0	1.0	3.0	7.6
LC012	15.0	0.7	10.5	26.5
LC013	15.0	0.8	12.0	30.3
LC014	10.0	1.0	10.0	25.2
LC015	1.0	0.1	0.1	0.3
LC016	5.0	0.1	0.3	0.6
LC017	4.0	0.3	1.2	3.0
LC018	6.0	1.0	6.0	15.1
LC019	0.0	0.0	0.0	0.0
LC019-1	2.0	0.3	0.6	1.5
LC020	0.0	0.0	0.0	0.0
LC021	0.0	0.0	0.0	0.0
LC022	1.0	0.2	0.2	0.5
LC023	1.0	0.8	0.8	1.9
LC024	10.0	1.0	10.0	25.2
LC025	4.0	1.0	4.0	10.1
LC026	6.0	1.0	6.0	15.1
LC026-1	1.0	1.0	1.0	2.5
LC027	1.0	0.5	0.5	1.3
LC028	2.0	0.8	1.6	4.0
LC028-1	1.0	0.1	0.1	0.1
LC028-2	2.0	0.1	0.1	0.3
LC029	2.0	0.5	1.0	2.5
LC030	1.0	0.1	0.1	0.1
LC031	1.0	0.1	0.1	0.1
ELC031-1	3.0	0.5	1.5	3.8
ELC031-2	3.0	0.5	1.5	3.8
LC032	1.0	0.1	0.1	0.1
LC033	1.0	0.1	0.1	0.1
LC034	1.0	0.1	0.1	0.1
LC035	5.0	0.5	2.5	6.3

ELC A & B Explosive Quantities and Locations

(East Lynn Canal Option A: Helicopter Only, Option B: Daisy Bell)

path	number of shots	frequency weighting	weighted average shots per mission	weighted average shots per year
TOTAL	171.0		119.4	301.0

ELC C Howitzer Operations

(Howitzer-helicopter-blaster box explosive delivery)

path	Howitzer firing location	explosive delivery?	field of fire	longest shot (m)	longest shot (mi)	highest shot (m)	highest shot (ft)
LC001	Berners	howitzer	25°	2600	1.6	1371.5	4500
LC002	none	blaster boxes		300	0.2	1798.2	5900
LC003	none	helicopter			0.0	0.0	
LC003-1	none	helicopter			0.0	0.0	
LC004	none	helicopter			0.0	0.0	
LC005	Eldred Rock	howitzer	80°	5600	3.5	1645.8	5400
LC005-1	Eldred Rock	howitzer	80°	4100	2.5	1280.1	4200
LC006	Eldred Rock	howitzer	80°	4500	2.8	1554.4	5100
LC007	Eldred Rock	howitzer	80°	3500	2.2	762.0	2500
LC008	Eldred Rock	howitzer	80°	4100	2.5	1219.1	4000
LC009	Eldred Rock	howitzer	80°	3100	1.9	396.2	1300
LC010	Eldred Rock	howitzer	80°	3300	2.0	457.2	1500
LC011	Eldred Rock	howitzer	80°	3400	2.1	487.7	1600
LC012	Eldred Rock	howitzer	80°	5600	3.5	1798.2	5900
LC013	Eldred Rock	howitzer	80°	5400	3.4	1615.4	5300
LC014	Eldred Rock	howitzer	80°	6500	4.0	1310.6	4300
LC015	none	helicopter			0.0	0.0	
LC016	none	helicopter			0.0	0.0	
LC017	Anyaka Isl.	howitzer	40°	6700	4.2	1615.4	5300
LC018	Anyaka Isl.	howitzer	40°	6900	4.3	1676.3	5500
LC019	Anyaka Isl.	snowshed	40°	7100	4.4	1798.2	5900
LC019-1	Anyaka Isl.	howitzer	40°	4400	2.7	1036.3	3400
LC020	Anyaka Isl.	snowshed	40°	5700	3.5	1219.1	4000
LC021	Anyaka Isl.	snowshed	40°	6300	3.9	1463.0	4800
LC022	Anyaka Isl.	howitzer	40°	4900	3.0	274.3	900
LC023	Anyaka Isl.	howitzer	40°	5700	3.5	1066.7	3500
LC024	Anyaka Isl.	howitzer	40°	5900	3.7	1097.2	3600
LC025	Chilkat Pen.	howitzer	30°	6500	4.0	1341.1	4400
LC026	Chilkat Pen.	howitzer	30°	6500	4.0	1341.1	4400
LC026-1	Chilkat Pen.	howitzer	30°	5300	3.3	335.3	1100
LC027	Chilkat Pen.	howitzer	30°	5600	3.5	640.0	2100
LC028	Chilkat Pen.	howitzer	30°	5700	3.5	670.5	2200
LC028-1	Chilkat Pen.	howitzer	30°	5600	3.5	548.6	1800
LC028-2	Chilkat Pen.	howitzer	30°	5600	3.5	518.1	1700
LC029	Chilkat Pen.	howitzer	30°	6300	3.9	914.4	3000

ELC C Howitzer Operations

(Howitzer-helicopter-blaster box explosive delivery)

path	Howitzer firing location	explosive delivery?	field of fire	longest shot (m)	longest shot (mi)	highest shot (m)	highest shot (ft)
LC030	Chilkat Pen.	howitzer	30°	5600	3.5	396.2	1300
LC031	none	helicopter			0.0	0.0	
ELC031-1	none	helicopter			0.0	0.0	
ELC031-2	none	helicopter			0.0	0.0	
LC032	none	helicopter			0.0	0.0	
LC033	none	helicopter			0.0	0.0	
LC034	none	helicopter			0.0	0.0	
LC035	none	helicopter			0.0	0.0	

ELC C Explosive Quantities and Locations

(East Lynn Canal Option C: Howitzer-blaster box-helicopter)

path	explosive delivery?	start zone (m)	# masts	# Howitzer shots	# blaster box shots	# heli shots	freq. weighting	weighted Howitzer shots/yr	weighted blaster shots/yr	weighted heli shots/yr
LC001	howitzer			12.0	0.0	0.0	0.5	57.6	0.0	0.0
LC002	blaster box	1600	5.3	0.0	15.0	0.0	1.0	0.0	148.5	0.0
LC003	helicopter		0.0	0.0	0.0	3.0	0.2	0.0	0.0	1.1
LC003-1	helicopter		0.0	0.0	0.0	2.0	0.1	0.0	0.0	0.2
LC004	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.1
LC005	howitzer		0.0	15.0	0.0	0.0	0.5	72.0	0.0	0.0
LC005-1	howitzer		0.0	2.0	0.0	0.0	0.5	9.6	0.0	0.0
LC006	howitzer		0.0	15.0	0.0	0.0	1.0	144.0	0.0	0.0
LC007	howitzer		0.0	2.0	0.0	0.0	0.8	14.4	0.0	0.0
LC008	howitzer		0.0	6.0	0.0	0.0	0.5	28.8	0.0	0.0
LC009	howitzer		0.0	5.0	0.0	0.0	1.0	48.0	0.0	0.0
LC010	howitzer		0.0	4.0	0.0	0.0	1.0	38.4	0.0	0.0
LC011	howitzer		0.0	3.0	0.0	0.0	1.0	28.8	0.0	0.0
LC012	howitzer		0.0	15.0	0.0	0.0	0.7	100.8	0.0	0.0
LC013	howitzer		0.0	20.0	0.0	0.0	0.8	153.6	0.0	0.0
LC014	howitzer		0.0	15.0	0.0	0.0	1.0	144.0	0.0	0.0
LC015	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.2
LC016	helicopter		0.0	0.0	0.0	5.0	0.1	0.0	0.0	0.5
LC017	howitzer		0.0	7.0	0.0	0.0	0.3	20.2	0.0	0.0
LC018	howitzer		0.0	10.0	0.0	0.0	1.0	96.0	0.0	0.0
LC019	snowshed		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC019-1	howitzer		0.0	3.0	0.0	0.0	0.3	8.6	0.0	0.0
LC020	snowshed		0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
LC021	snowshed		0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
LC022	howitzer		0.0	2.0	0.0	0.0	0.2	3.8	0.0	0.0
LC023	howitzer		0.0	3.0	0.0	0.0	0.8	21.6	0.0	0.0

ELC C Explosive Quantities and Locations

(East Lynn Canal Option C: Howitzer-blaster box-helicopter)

path	explosive delivery?	start zone (m)	# masts	# Howitzer shots	# blaster box shots	# heli shots	freq. weighting	weighted Howitzer shots/yr	weighted blaster shots/yr	weighted heli shots/yr
LC024	howitzer		0.0	12.0	0.0	0.0	1.0	115.2	0.0	0.0
LC025	howitzer		0.0	6.0	0.0	0.0	1.0	57.6	0.0	0.0
LC026	howitzer		0.0	7.0	0.0	0.0	1.0	67.2	0.0	0.0
LC026-1	howitzer		0.0	1.0	0.0	0.0	1.0	9.6	0.0	0.0
LC027	howitzer		0.0	2.0	0.0	0.0	0.5	9.6	0.0	0.0
LC028	howitzer		0.0	4.0	0.0	0.0	0.8	30.7	0.0	0.0
LC028-1	howitzer		0.0	1.0	0.0	0.0	0.1	0.5	0.0	0.0
LC028-2	howitzer		0.0	4.0	0.0	0.0	0.1	1.9	0.0	0.0
LC029	howitzer		0.0	4.0	0.0	0.0	0.5	19.2	0.0	0.0
LC030	howitzer		0.0	2.0	0.0	0.0	0.1	1.0	0.0	0.0
LC031	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.1
ELC031-1	helicopter		0.0	0.0	0.0	3.0	0.5	1.5	0.0	2.7
ELC031-2	helicopter		0.0	0.0	0.0	3.0	0.5	1.5	0.0	2.7
LC032	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.1
LC033	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.1
LC034	helicopter		0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.1
LC035	helicopter		0.0	0.0	0.0	5.0	0.5	0.0	0.0	4.6
			5.3	182.0	15.0	27.0		1305.6	148.5	12.4

ELC D Operations and Explosives

(East Lynn Canal option D: Blaster Boxes on Major Paths (Mitigated AHI > 1.75), Heli Backup)

path	explosive delivery	start zone (m)	# blast masts	# blast shots	# heli shots	freq. weighting	weighted avg. heli shots/ mission	weighted blaster shots/ mission	weighted blaster shots/yr	weighted heli shots/yr
LC001	helicopter			0.0	5.0	0.5	2.5	0.0	0.0	4.6
LC002	blaster box	1600	5.3	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC003	helicopter			0.0	3.0	0.2	0.6	0.0	0.0	1.1
LC003-1	helicopter			0.0	2.0	0.1	0.1	0.0	0.0	0.2
LC004	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC005	helicopter			0.0	10.0	0.5	5.0	0.0	0.0	9.1
LC005-1	helicopter			0.0	2.0	0.5	1.0	0.0	0.0	1.8
LC006	blaster box	1100	3.7	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC007	helicopter			0.0	2.0	0.5	1.0	0.0	0.0	1.8
LC008	helicopter			0.0	4.0	0.8	3.0	0.0	0.0	5.5
LC009	blaster box	100	1.0	5.0	0.0	1.0	0.0	5.0	49.5	0.0
LC010	blaster box	100	1.0	4.0	0.0	1.0	0.0	4.0	39.6	0.0
LC011	blaster box	100	1.0	4.0	0.0	1.0	0.0	4.0	39.6	0.0
LC012	helicopter			0.0	15.0	0.7	10.5	0.0	0.0	19.2

ELC D Operations and Explosives

(East Lynn Canal option D: Blaster Boxes on Major Paths (Mitigated AHI > 1.75), Heli Backup)

path	explosive delivery	start zone (m)	# blast masts	# blast shots	# heli shots	freq. weighting	weighted avg. heli shots/ mission	weighted blaster shots/ mission	weighted blaster shots/yr	weighted heli shots/yr
LC013	helicopter			0.0	15.0	0.8	12.0	0.0	0.0	21.9
LC014	blaster box	500	1.7	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC015	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.2
LC016	helicopter			0.0	5.0	0.1	0.3	0.0	0.0	0.5
LC017	helicopter			0.0	4.0	0.3	1.2	0.0	0.0	2.2
LC018	blaster box	900	3.0	10.0	0.0	1.0	0.0	10.0	99.0	0.0
LC019	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC019-1	helicopter			0.0	2.0	0.3	0.6	0.0	0.0	1.1
LC020	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC021	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC022	helicopter			0.0	1.0	0.2	0.2	0.0	0.0	0.4
LC023	blaster box	300	1.0	2.0	0.0	0.8	0.0	1.5	14.9	0.0
LC024	blaster box	800	2.7	12.0	0.0	1.0	0.0	12.0	118.8	0.0
LC025	blaster box	800	2.7	6.0	0.0	1.0	0.0	6.0	59.4	0.0
LC026	blaster box	1100	3.7	7.0	0.0	1.0	0.0	7.0	69.3	0.0
LC026-1	blaster box	100	1.0	1.0	0.0	1.0	0.0	1.0	9.9	0.0
LC027	blaster box	100	1.0	1.0	0.0	0.5	0.0	0.5	5.0	0.0
LC028	helicopter			0.0	2.0	0.8	1.6	0.0	0.0	2.9
LC028-1	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC028-2	helicopter			0.0	2.0	0.1	0.1	0.0	0.0	0.2
LC029	helicopter			0.0	2.0	0.5	1.0	0.0	0.0	1.8
LC030	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC031	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
ELC031-1	blaster box	300	1.0	3.0	0.0	0.5	0.0	1.5	14.9	0.0
ELC031-2	blaster box	200	0.7	3.0	0.0	0.5	0.0	1.5	14.9	0.0
LC032	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC033	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC034	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC035	helicopter			0.0	5.0	0.5	2.5	0.0	0.0	4.6
Totals		8100	27.0	103.0	89.0		43.6	99.0	980.4	79.7

ELC E Operations and Explosives

(East Lynn Canal Option E: Blaster Boxes Top Paths (Mitigated AHI > 4), Heli. Elsewhere)

path	explosive delivery	start zone (m)	# blast masts	# blast shots	# heli shots	freq. weighting	weighted avg. heli shots/ mission	weighted blast shots/ mission	weighted blast shots/yr	weighted heli shots/yr
LC001	helicopter			0.0	5.0	0.5	2.5	0.0	0.0	4.2
LC002	blaster box	1600	5.3	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC003	helicopter			0.0	3.0	0.2	0.6	0.0	0.0	1.0
LC003-1	helicopter			0.0	2.0	0.1	0.1	0.0	0.0	0.2
LC004	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC005	helicopter			0.0	15.0	0.5	7.5	0.0	0.0	12.6
LC005-1	helicopter			0.0	2.0	0.5	1.0	0.0	0.0	1.7
LC006	blaster box	1100	3.7	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC007	helicopter			0.0	2.0	0.5	1.0	0.0	0.0	1.7
LC008	helicopter			0.0	4.0	0.8	3.0	0.0	0.0	5.1
LC009	blaster box	100	1.0	0.0	4.0	1.0	4.0	0.0	0.0	6.7
LC010	helicopter			0.0	2.0	1.0	2.0	0.0	0.0	3.4
LC011	helicopter			0.0	3.0	1.0	3.0	0.0	0.0	5.1
LC012	helicopter			0.0	15.0	0.7	10.5	0.0	0.0	17.7
LC013	helicopter			0.0	15.0	0.8	12.0	0.0	0.0	20.2
LC014	blaster box	500	1.7	15.0	0.0	1.0	0.0	15.0	148.5	0.0
LC015	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.2
LC016	helicopter			0.0	5.0	0.1	0.3	0.0	0.0	0.4
LC017	helicopter			0.0	4.0	0.3	1.2	0.0	0.0	2.0
LC018	helicopter			0.0	6.0	1.0	6.0	0.0	0.0	10.1
LC019	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC019-1	helicopter			0.0	2.0	0.3	0.6	0.0	0.0	1.0
LC020	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC021	snowshed			0.0	0.0	0.0	0.0	0.0	0.0	0.0
LC022	helicopter			0.0	1.0	0.2	0.2	0.0	0.0	0.3
LC023	blaster box	300	1.0	2.0	0.0	0.8	0.0	1.5	14.9	0.0
LC024	blaster box	800	2.7	0.0	0.0	1.0	0.0	10.0	99.0	0.0
LC025	blaster box	800	2.7	6.0	0.0	1.0	0.0	6.0	59.4	0.0
LC026	helicopter			0.0	7.0	1.0	7.0	0.0	0.0	11.8
LC026-1	blaster box	100	1.0	1.0	0.0	1.0	0.0	1.0	9.9	0.0
LC027	helicopter			0.0	1.0	0.5	0.5	0.0	0.0	0.8
LC028	helicopter			0.0	2.0	0.8	1.6	0.0	0.0	2.7
LC028-1	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC028-2	helicopter			0.0	2.0	0.1	0.1	0.0	0.0	0.2
LC029	helicopter			0.0	8.0	0.5	4.0	0.0	0.0	6.7
LC030	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC031	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
ELC031-1	helicopter			0.0	3.0	0.5	1.5	0.0	0.0	2.5
ELC031-2	helicopter			0.0	3.0	0.5	1.5	0.0	0.0	2.5
LC032	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1

ELC E Operations and Explosives

(East Lynn Canal Option E: Blaster Boxes Top Paths (Mitigated AHI > 4), Heli. Elsewhere)

path	explosive delivery	start zone (m)	# blast masts	# blast shots	# heli shots	freq. weighting	weighted avg. heli shots/ mission	weighted blast shots/ mission	weighted blast shots/yr	weighted heli shots/yr
LC033	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC034	helicopter			0.0	1.0	0.1	0.1	0.0	0.0	0.1
LC035	helicopter			0.0	5.0	0.5	2.5	0.0	0.0	4.2
Totals		5 ,300	17.7	54.0	129.0		74.6	63.5	628.8	125.6

WLC F Howitzer Operations

(Howitzer explosive delivery)

path	firing location	type	access	spur road length (m)	spur road length (mi)	field of fire	longest shot (m)	longest shot (mi)	highest shot (m)	highest shot (ft)
WLC001 A & B	Endicott R.	open pad	spur road	800	0.5	30°	3000	1.9	396	1300
WLC002 A & B	Endicott R.	open pad	spur road	800	0.5	"	1900	1.2	488	1600
WLC003	*none*	*avoids path*								
WLC004	*none*	*avoids path*								
WLC005	Sullivan	open pad	spur road	500	0.3	70° (in 1st position)	3700	2.3	1311	4300
WLC006 A-C	Sullivan	open pad	spur road	500	0.3	"	3100	1.9	1402	4600
WLC007	Sullivan	open pad	spur road	500	0.3	10° (in 2nd position)	2900	1.8	1036	3400
WLC008	S. Rainbow	open pad	spur road	500	0.3	25° (in 1st position)	4000	2.5	1402	4600
WLC009 A-C	S. Rainbow	open pad	spur road	500	0.3	20° (in 2nd position)	4900	3.0	1219	4000
WLC009 A-C	Rainbow-Pyramid	open pad	spur road	400	0.2	25° (in 1st position)	4800	3.0	1219	4000
WLC010 A-D	Rainbow-Pyramid	open pad	spur road	400	0.2	40° (in 2nd position)	2900	1.8	1128	3700
WLC010 A-D	Chilkat Crossing	open pad	roadside turnout	0	0.0	depends on loc'n	depends on loc'n	depends on loc'n		3700
			Total spur road length (approx.)	4900	3.0					

WLC F Explosive Quantities and Locations

(West Lynn Canal option F: Howitzer Only)

path	# shots	frequency weighting	weighted average shots/ mission	weighted average shots/ year
WLC001 A & B	6.0	1.0	6.0	64.8
WLC00 2 A & B	6.0	1.0	6.0	64.8
WLC003	0.0	0.0	0.0	0.0
WLC004	0.0	0.0	0.0	0.0
WLC005	8.0	0.5	4.0	43.2
WLC006 A-C	20.0	1.0	20.0	216.0
WLC007	10.0	0.1	1.0	10.8
WLC008	20.0	0.3	6.0	64.8
WLC009 A-C	20.0	1.0	20.0	216.0
WLC010 A-D	15.0	1.0	15.0	162.0
Totals	105.0		78.0	842.3

WLC G Explosive Quantities and Locations

(West Lynn Canal Option G: Howitzer-Blaster Boxes)

path	explosive delivery	start zone (m)	# blaster box masts	# how. shots	# blaster box shots	freq. weighting	weighted avg. how. shots/ mission	weighted avg. how. shots/ yr	weighted average blaster shots/ mission	weighted average blaster shots/ yr
WLC001 A & B	blaster boxes	700	2.3	0	6	1.0	0.0	0.0	6.0	50.4
WLC002 A & B	blaster boxes	700	2.3	0	6	1.0	0.0	0.0	6.0	50.4
WLC003	*avoids path*									
WLC004	*avoids path*									
WLC005	howitzer			8	0	0.5	4.0	33.6	0.0	0.0
WLC006 A-C	blaster boxes	2200	7.3	0	20	1.0	0.0	0.0	20.0	168.0
WLC007	howitzer			10	0	0.1	1.0	8.4	0.0	0.0
WLC008	howitzer			20	0	0.3	6.0	50.4	0.0	0.0
WLC009 A-C	blaster boxes	2800	9.3	0	20	1.0	0.0	0.0	20.0	168.0
WLC010 A-D	blaster boxes	1600	5.3	0	15	1.0	0.0	0.0	15.0	126.0
Totals		8000	26.7	38	67		11.0	92.4	67.0	562.7

	WLC H Explosive Quantities and Locations									
	(West Lynn Canal option H: Howitzer; Blaster Boxes on WLC 009)									
path	explosive delivery	start zone (m)	# blaster box masts	# how. shots	# blaster box shots	freq. weighting	weighted avg. how. shots/ mission	weighted avg. how. shots/ yr	weighted average blaster shots/ mission	weighted average blaster shots/ yr
WLC001 A & B	howitzer	700	0.0	6.0	0	1.0	6.0	50.4	0.0	0.0
WLC002 A & B	howitzer	700	0.0	6.0	0	1.0	6.0	50.4	0.0	0.0
WLC003	*avoids path*			0.0						
WLC004	*avoids path*			0.0						
WLC005	howitzer		0.0	8.0	0	0.5	4.0	33.6	0.0	0.0
WLC006 A-C	howitzer	2200	0.0	20.0	0	1.0	20.0	168.0	0.0	0.0
WLC007	howitzer		0.0	10.0	0	0.1	1.0	8.4	0.0	0.0
WLC008	howitzer		0.0	20.0	0	0.3	6.0	50.4	0.0	0.0
WLC009 A-C	blaster boxes	2800	9.3	0	20	1.0	0.0	0.0	20.0	168.0
WLC010 A-D	howitzer	1600	0.0	15.0	0	1.0	15.0	126.0	0.0	0.0
Totals			9.3	85	20		58.0	487.1	20.0	168.0

13.4. *APPENDIX 9: Avalanche Program Budget Discussion*

The budget spreadsheets reflect efforts to catalog and price all components related to a viable avalanche program. They have been updated to 2015 costs to be consistent with other EIS updates. Whenever possible, cost estimates from DOT&PF or other state employees most knowledgeable about the particular item or service in question were used. The source of each estimate is given on the spreadsheets, and sources are listed in greater detail in the sources table in Section 13.8, Appendix 13.

Following are some of the assumptions used:

The basic program costs for such items as staffing, equipment, office space, and administrative overhead do not change from option to option, and some other costs, such as weather stations, vary only slightly. The major differences are in explosive delivery methods.

Helicopter ferry time from Juneau to the Lynn Canal area is estimated to be 1.2 hours round-trip for a typical mission, the average of 0.8 hours roundtrip from the helicopter bases to the southern end of either the East or West Lynn Canal highway, and flight time to the north end of 1.6 hours roundtrip. Since all destinations would be between these points, the ferry time used here is the average of 1.2 hours.

Standby time and additional flying time based on distance and typical rate of climb and travel were added to the ferry time in accordance with the type of mission; e.g., explosives work, weather station maintenance, blaster box reloading.

Monthly operating and replacement costs for DOT&PF heavy equipment are as supplied by DOT&PF staff.

Annual replacement costs for equipment are figured based on the following formula: new cost adjusted for inflation divided by useful life in years. This methodology is the same basic methodology DOT&PF uses to calculate monthly replacement costs for heavy equipment. Including replacement costs in the annual operating budget is meant to amortize the cost of recapitalization, so that there would not be a need for extra funds when equipment reaches the end of its useful life.

Labor costs were updated based on 2015 wages.

The time for temporary flaggers is estimated based on highway closure times during explosive delivery and snow removal time. While there would be gates to keep travelers out of avalanche zones during highway closures, highway flaggers would be needed in certain circumstances, such as when the highway is partially closed but one lane of traffic has been opened.

13.5. *APPENDIX 10: Avalanche Program Options Comparison*

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.					

13.6. *APPENDIX 11: Operating Budget Spreadsheets*

Operating Budget - East Lynn Canal Option A: Helicopter Only									
							Total annual cost	**Information source**	**Notes**
Explosives		Equipment		Cost per shot		Annual number of shots	Annual cost		
		Heli explosives		$99		301	$29,757	Austin Powder Ketchikan Alaska	updated to 2016 costs and current charge sizes; includes 12.5 kg ANFO, boosters, cap and fuse, igniters, sandbag, tape, shipping, and RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual cost		
	Explosive delivery	flight time		$1,889		17.0	$32,113	Coastal Helicopters	updated to 2016 rates
		standby		$945		4.0	$3,778	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	Item		Number	Unit cost	Total cost	Lifespan (years, averaged)	Annual replacement cost		replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract

	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs				$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.5	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.8	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,178,071**		

Operating Budget - East Lynn Canal Option B: Daisy Bell Only									
							Total annual cost	**Information source**	**Notes**
Explosives		Equipment		Cost per shot		Annual number of shots	Annual cost		
		Daisy Bell gas		$3.58		301	$1,078	AEL&P	Hydrogen & oxygen; updated by 19.4% increase from 2012 costs
		Daisy Bell maintenance					$2,388	AEL&P	Hydrogen & oxygen; updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual cost		
	Explosive delivery	flight time		$1,889		14.5	$32,113	Coastal Helicopters	updated to 2016 rates
		standby		$945		1.2	$3,778	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32.0	$60,448	Coastal Helicopters	updated to 2016 rates
		standby	4	$945	16	64.0	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20.0	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16.0	$15,112	Coastal Helicopters	updated to 2016 rates

Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Daisy Bell	annual maintenance		1	$2,388	$2,388		$2,388	Mike Janes, AEL&P	TAS; Daisy Bell exploder; updated by 19.4% increase from 2012 costs
Annual replacement costs	Item		Number	Unit cost	Total cost	Lifespan (years, averaged)	Annual replacement cost		replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$41.79	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$71.64		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz

		administrative overhead	15% of personnel costs		$383,816		$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	Cost per hour with multiplier	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,151,317**		

Operating budget - East Lynn Canal Option C: Howitzer-blaster box-helicopter									
							Total annual cost	**Information source**	**Notes**
Explosive delivery		Equipment	Number	Cost			**Annual cost**		
	Annual lease of 105mm Howitzer	available model	3	$100			$1,390	T. Onslow	2016 update from M. Murphy, AKDOT&PF
Explosives				Cost per round		Number of rounds	Annual cost		Annual number of rounds
	Howitzer			$183		1306	$238,720	G. Patz, DOT	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
	Blaster boxes			$230		149	$34,216	CIL Orion	2012 prices plus 15% for shipping; updated by 19.4% increase from 2012 costs. Cost per round includes RECCO reflectors
	Heli explosives			$99		12	$1,186	Austin Powder Ketchikan Alaska	updated to 2016 costs and current charge sizes; includes 12.5 kg ANFO, boosters, cap and fuse, igniters, sandbag, tape, shipping, and RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual cost		
	Explosive delivery	flight time		$1,889		10	$18,890	Coastal Helicopters	includes time to access Howitzer sites; updated to 2016 rates
		standby		$945		12	$11,334	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	includes two trips annually for blaster box loading/ unloading; updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal

Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	Item		Number	Unit cost	Total cost	Lifespan (years)	Annual replacement cost		Replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment			$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment			$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs			0.00	$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		

		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,418,160**		

Operating Budget - East Lynn Canal option D: Blaster Boxes on Major Paths, Heli Backup									
							Total annual cost	**Information source**	**Notes**
Explosives				Cost per round		Number of rounds	Annual cost		Annual number of rounds.
	Blaster boxes			$230		980	$225,047	CIL Orion	2012 prices plus 15% for shipping and expected cost increases. Cost per round includes $2.00 per round for RECCO reflectors
	Heli explosives			$99		80	$7,909	Austin Powder Ketchikan Alaska	updated to 2016 costs and current charge sizes; includes 12.5 kg ANFO, boosters, cap and fuse, igniters, sandbag, tape, shipping, and RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual Cost		
	Explosive delivery	flight time		$1,889		35	$66,115	Coastal Helicopters	updated to 2016 rates
		standby		$945		50.0	$47,225	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	includes two trips annually for blaster box loading and unloading; updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Monthly rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70

Annual replacement costs	Item		Number	Unit cost	Total cost	Lifespan (years)	Annual replacement cost		Replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment			$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment			$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs				$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,458,719**		

Operating Budget - East Lynn Canal Option E: Blaster Boxes Top 10 Paths, Heli. Elsewhere									
							Total annual cost	**Information source**	**Notes**
Explosive delivery	Equipment			**Cost per round**		Number of rounds	Annual cost		Annual number of rounds
	Blaster boxes			$230		629	$144,444	CIL Orion	2012 prices plus 15% for shipping; updated by 19.4% increase from 2012 costs. Cost per round includes RECCO reflectors
	Heli explosives			$99		126	$12,456	Austin Powder Ketchikan Alaska	updated to 2016 costs and current charge sizes; includes 12.5 kg ANFO, boosters, cap and fuse, igniters, sandbag, tape, shipping, and RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual Cost		
	Explosive delivery	flight time		$1,889		37	$69,893	Coastal Helicopters	updated to 2016 rates
		standby		$945		33	$31,169	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	includes two trips annually for blaster box loading and unloading; updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	Item		Number	Unit cost	Total cost	Lifespan (years)	Annual replacement cost		Replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment			$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment			$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs

	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs				$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$5,373	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,370,385**		

Operating Budget - West Lynn Canal option F: Howitzer Only

							Total annual cost	**Information source**	**Notes**
Explosive delivery		**Equipment**	**Number**	**Cost**			**Annual Cost**		
	Annual lease of 105mm Howitzer	available model	3	$100			$300	T. Onslow	2016 update from M. Murphy, AKDOT&PF
Explosives				**Cost per round**		**Annual number of shots**	**Annual cost**		
		Howitzer		$183		842	$153,907	G. Patz, DOT	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
Helicopter time		**(A-Star)**	**Hours per mission**	**Hourly rate**	**Number of missions**	**Total annual hours**	**Annual Cost**		
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates

		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			**Number of vehicles**	**Monthly cost per vehicle**	**Monthly cost**	**Number of months**	**Annual cost**		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	**Item**		**Number**	**Unit cost**	**Total cost**	**Lifespan (years)**	**Annual replacement cost**		Replacement figured with 3% inflation
	Chains for loaders		1	$12,537	$12,537	3	$4,304	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,745	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	32	$750	$24,000	8	$3,090	G. Patz, DOT	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	20	$125	$2,500	8	$322	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	Updated 12/24/15 based on current sign contract
Forecasting office operations			**Number**	**Unit cost**	**Monthly cost**	**Number of months**	**Annual cost**		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs

Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs				$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							$1,245,539		

Operating Budget - West Lynn Canal Option G: Howitzer-Blaster Box									
							Total annual cost	**Information source**	**Notes**
Explosive delivery		**Equipment**	**Number**	**Cost**	**Total monthly costs**	**Number of months**	**Annual cost**		
	Annual lease of 105mm Howitzer	available model	1	$1,390			$1,390	T. Onslow	2016 update from M. Murphy, AKDOT&PF
Explosives				**Cost per round**		**Number of rounds**	**Annual cost**		**Annual number of rounds.**
	Howitzer			$183		67	$10,212	G. Patz, DOT	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
	Blaster boxes			$230		563	$31,247	CIL Orion	2012 prices plus 15% for shipping; updated by 19.4% increase from 2012 costs. Cost per round includes RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		**(A-Star)**	**Hours per mission**	**Hourly rate**	**Number of missions**	**Total annual hours**	**Annual Cost**		
	Explosive delivery	flight time		$1,889		17	$22,308	Coastal Helicopters	updated to 2016 rates
		standby		$945		28	$11,240	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	includes two trips annually for blaster box loading and unloading; updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates

Vehicles/heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	**Item**		**Number**	**Unit cost**	**Total cost**	**Lifespan (years)**	**Annual replacement cost**		**Replacement figured with 3%inflation**
	Chains for loaders		1	$12,537	$12,537	3	$4,304	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,745	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	32	$750	$24,000	8	$3,090	G. Patz, DOT	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	20	$125	$2,500	8	$322	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	Replacement parts	4 stations				$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs

Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrative overhead	15% of personnel costs	0			$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	$383,816	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost per hour with multiplier	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			**Number of people**	**Cost per person**	**Cost**		**Annual cost**		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							$1,124,881		

Operating Budget - West Lynn Canal option H: Howitzer On Most Paths; Blaster Boxes on Path WLC009									
							Total annual cost	**Information source**	**Notes**
Explosive delivery		**Equipment**	**Number**	**Cost**			**Annual Cost**		
	Annual lease of 105mm Howitzer	available model	3	$1,390			$4,170	T. Onslow	2016 update from M. Murphy, AKDOT&PF
Explosives				**Cost per round**		**Annual number of shots**	**Annual cost**		
		Howitzer		$183		487	$89,017	G. Patz, DOT	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
		Blaster boxes		$230		168	$38,580	CIL Orion	updated to 2016 costs and current charge sizes; includes 12.5 kg ANFO, boosters, cap and fuse, igniters, sandbag, tape, shipping, and RECCO reflectors
		RECCO detector rental					$836	RECCO AB, Sweden	updated by 19.4% increase from 2012 costs
Helicopter time		**(A-Star)**	**Hours per mission**	**Hourly rate**	**Number of missions**	**Total annual hours**	**Annual Cost**		
	Explosive delivery	flight time		$1,889		5	$22,308	Coastal Helicopters	updated to 2016 rates
		standby		$945		8	$11,240	Coastal Helicopters	updated to 2016 rates
	Weather station maintenance	flight time	2	$1,889	16	32	$60,448	Coastal Helicopters	updated to 2016 rates
		standby	4	$945	16	64	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/heavy equipment			**Number of vehicles**	**Monthly cost per vehicle**	**Monthly cost**	**Number of months**	**Annual cost**		

Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replacement rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$332	$996	12	$11,952	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Annual replacement costs	**Item**		**Number**	**Unit cost**	**Total cost**	**Lifespan (years)**	**Annual replacemen t cost**		Replacement figured with 3% inflation
	Chains for loaders		1	$12,537	$12,537	3	$4,304	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,745	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	32	$750	$24,000	8	$3,090	G. Patz, DOT	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	20	$125	$2,500	8	$322	G. Patz, DOT	Updated 12/24/15 based on current sign contract
	Weather station maintenance	replacement parts					$72,707	Mark Moore, NWAC	Updated 12/24/15 based on current sign contract
Forecasting office operations			**Number**	**Unit cost**	**Monthly cost**	**Number of months**	**Annual cost**		
	Telephones		4	$42	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$72		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1.00	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1.00	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	0.50	$52,775	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrativ e overhead	15% of personnel costs	0.00	$37,539		$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	0.50	$211,099	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz

	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Total annual cost	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							$1,257,483		

Operating budget detail							
Forecasting office equipment	Item	Number	Unit cost	Total cost	Lifespan (years)	Annual replacement cost	Source
	desks/chairs	4	$500	$2,000	7	$303	AAS
	desktop computer	1	$3,000	$3,000	3	$1,034	B. Reiche, DOA
	laptop computers	3	$4,000	$12,000	3	$4,134	B. Reiche
	external hard drives	4	$300	$1,200	3	$413	B. Reiche
	fax	1	$200	$200	5	$42	B. Reiche
	phones	4	$425	$1,700	5	$357	B. Reiche
	scanner	1	$200	$200	5	$42	B. Reiche
	misc. supplies	1	$3,000	$3,000	1	$3,000	AAS
ELC Options	**Total**			$27,820	4	**$11,134**	updated by 19.4% increase from 2012 costs
Forecasting field equipment	Item	Number	Unit cost	Total cost	Lifespan (years)	Annual replacement cost	Source
	density kit	1	$200	$200	10	$21	Backcountry Access
	digital camera	1	$1,800	$1,800	3	$620	Canon
	binoculars	2	$200	$400	10	$43	Steiner
	snow kits	3	$85	$255	5	$54	UAF
	shovels	3	$74	$222	3	$76	G3
	snow saws	3	$50	$150	5	$31	LifeLink
	avalung packs	3	$300	$900	10	$96	Black Diamond
	helmets	3	$140	$420	10	$45	Smith
	skis or splitboards w/poles, bindings, skins	3	$1,710	$5,130	3	$1,767	average cost by AAS
	parkas	3	$570	$1,710	3	$589	Patagonia
	bibs	3	$620	$1,860	3	$641	Patagonia
	avalanche transceivers	3	$500	$1,500	3	$517	Pieps/ Barryvox
	probes	3	$85	$255	3	$88	G3
	EX600XLS VHF radios	2	$1,000	$2,000	5	$420	Motorola
	bivvy bags	4	$55	$220	5	$46	SOL Escape Bivvy
	First Aid kits	3	$50	$150	2	$77	Helenbac, plus heat packs
	Total			$27,887	5	**$6,127**	updated by 19.4% increase from 2012 costs
				Total cost	Lifespan (years)	Annual replacement cost	
Vehicle caches				$6,501	5	**$1,365**	updated by 19.4% increase from 2012 costs
				Total cost	Lifespan (years)	Annual replacement cost	
Avalanche caches				$22,380	5	**$4,476**	updated by 19.4% increase from 2012 costs

13.7. *APPENDIX 12: Capital Budget Spreadsheets*

Capital Budget - East Lynn Canal Option A: Helicopter Only						
Item	**Notes**	**Equipment type**	**Number**	**Cost**	**Total**	**Information source**
Magazines	2-Comet		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loaders		Cat 988G	2	$1,035,780	$2,071,560	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loaders		chains for Cat 988G	2	$12,537	$25,074	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozers		D9R	2	$1,126,743	$2,253,486	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent	2-maintenance, 1-forecasters	3/4 ton 4WD extended cab	3	$27,000	$81,000	G. Patz, updated 12/24/15 based on current SEF estimates
Snowmobiles	2-forecasters	RMK; Summit 800	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates		manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		15	$597	$8,955	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		10	$179	$1,791	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches			2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs

Vehicle caches			12	$6,501	$78,016	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	196	$750	$147,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	40	$125	$5,000	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$5,380,306**	

Operating Budget - East Lynn Canal Option B: Daisy Bell Only									
							Total annual cost	**Informa-tion source**	**Notes**
Explosives		Equipment		Cost per shot		Annual number of shots	Annual cost		
		Daisy Bell gas		$3.58		301	$1,078	AEL&P	Hydrogen & oxygen; updated by 19.4% increase from 2012 costs
		Daisy Bell mainten-ance					$2,388	AEL&P	Hydrogen & oxygen; updated by 19.4% increase from 2012 costs
Helicopter time		(A-Star)	Hours per mission	Hourly rate	Number of missions	Total annual hours	Annual cost		
	Explosive delivery	flight time		$1,889		14.5	$32,113	Coastal Helicopters	updated to 2016 rates
		standby		$945		1.2	$3,778	Coastal Helicopters	updated to 2016 rates
	Weather station mainten-ance	flight time	2	$1,889	16	32.0	$60,448	Coastal Helicopters	updated to 2016 rates
		standby	4	$945	16	64.0	$60,448	Coastal Helicopters	updated to 2016 rates
	Snow study	flight time	2.5	$1,889	8	20.0	$37,780	Coastal Helicopters	updated to 2016 rates
		standby	2	$945	8	16.0	$15,112	Coastal Helicopters	updated to 2016 rates
Vehicles/ heavy equipment			Number of vehicles	Monthly cost per vehicle	Monthly cost	Number of months	Annual cost		
Debris removal equipment	Operating rate	Cat 988G loader	2	$1,103	$2,206	12	$26,466	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replace-ment rate	Cat 988G loader	2	$3,755	$7,511	12	$90,131	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates

Debris removal equipment	Fuel	Cat 988G loader	2	$720	$1,440	12	$17,280	G. Patz, DOT	4 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Debris removal equipment	Operating rate	D9R dozer	2	$377	$754	12	$9,046	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Debris removal equipment	Replace-ment rate	D9R dozer	2	$4,085	$8,171	12	$98,046	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Debris removal equipment	Fuel	D9R dozer	2	$900	$1,800	12	$21,600	G. Patz, DOT	5 gal/hr burn rate; 6 hrs/day; 10 days/month; x $3/gal
Pickup trucks	Monthly operating rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes repair and maintenance; updated 12/24/15 with new SEF rates
Pickup trucks	Monthly replacement rate	3/4 ton 4WD, extended cab	3	$276	$828	12	$9,936	G. Patz, DOT	includes payments to credit bank to replace at end of service life; updated 12/24/15 with new SEF rates
Pickup trucks	Fuel costs	3/4 ton 4WD, extended cab	3	$193	$579	12	$6,948	G. Patz, DOT	1000 miles per mo. @14 mi/gal x $2.70
Daisy Bell	annual mainten-ance		1	$2,388	$2,388		$2,388	Mike Janes, AEL&P	TAS; Daisy Bell exploder; updated by 19.4% increase from 2012 costs
Annual replace-ment costs	Item		Number	Unit cost	Total cost	Lifespan (years, averaged)	Annual replace-ment cost		replacement figured with 3% inflation
	Chains for loaders		2	$12,537	$25,074	3	$8,609	G. Patz, DOT	updated by 19.4% increase from 2012 costs
	Avalanche caches		2	$22,380	$44,759	5	$9,220	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Vehicle caches		4	$6,501	$26,005	5	$5,357	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting office equipment		1	$27,820	$27,820	4	$7,164	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Forecasting field equipment		1	$27,887	$27,887	5	$5,537	AAS	see budget detail spreadsheet; updated by 19.4% increase from 2012 costs
	Signage	avalanche zone signs	196	$750	$147,000	8	$18,926	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		highway entry signs	2	$225	$450	8	$58	G. Patz, DOT	Updated 12/24/15 based on current sign contract
		trailhead warning signs	40	$125	$5,000	8	$644	G. Patz, DOT	Updated 12/24/15 based on current sign contract

	Weather station mainten-ance	Replace-ment parts					$72,707	Mark Moore, NWAC	15% of equipment cost annually; updated by 19.4% increase from 2012 costs
Forecasting office operations			Number	Unit cost	Monthly cost	Number of months	Annual cost		
	Telephones		4	$41.79	$167	12	$2,006	DOA	updated by 19.4% increase from 2012 costs
	Long distance				$170	12	$2,044	AAS	updated by 19.4% increase from 2012 costs
	Networking charge	monthly charge per employee		$71.64		30	$2,149	DOA	30 is the number of employee-months per year; updated by 19.4% increase from 2012 costs
Personnel		Position	Pay level		Annual cost with multiplier	FTE	Total annual cost		wages including overhead
	Forecasting staff	Equipment Operator	WG 52, Full Time	1	$101,533	1.00	$101,533	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Full Time	1	$95,954	1.00	$95,954	G Patz, DOT	updated to 2015 per G Patz
		Equipment Operator	WG 53, Seasonal	1	$95,954	0.50	$52,775	G Patz, DOT	updated to 2015 per G Patz
		administrati ve overhead	15% of personnel costs		$383,816		$37,539	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	seasonal operators for debris clearing	Wage group 53D	4	Cost per hour with multiplier	0.50	$211,099	G Patz, DOT	updated to 2015 per G Patz
	Avalanche-related operators	Seasonal operators for explosives makeup	Wage group 53D		$3,269		$3,269	G Patz, DOT	updated to 2015 per G Patz
				Number of flaggers	Cost	Number of hours	Total annual cost		
		temp. flagger	Wage group 56 (hourly)	2	$66.70	50.80	$3,388	G. Patz, DOT	updated to 2015 per G Patz
Training			Number of people	Cost per person	Cost		Annual cost		
		forecasters	3	$1,791	$6,415	annually	$6,415	G Patz, DOT	avalanche mitigation training; updated by 19.4% increase from 2012 costs
Total Annual Operating Budget							**$1,151,317**		

Capital Budget East Lynn Canal Option C: Howitzer-Blaster box-Helicopter						
Item	**Notes**	**Equipment type**	**Number**	**Cost**	**Total**	**Information source**
Blaster boxes	number of masts	Avalanche Guard	5.3	$286,560	$1,518,768	Installed ARR costs less 25% for quantity; plus 20% for increased cost since '04 and 19.4% increase since 2012
105mm Howitzer refurbishment			4	$24,000	$96,000	T. Onslow; confirmed 2016 M. Murphy
105mm Howitzer shipping	1 mobile, 3 stationary		4	$8,000	$32,000	T. Onslow; confirmed 2016 M. Murphy
concrete Howitzer enclosures w/magazine	Eldred Rock, Anyaka Island, Chilkat Peninsula		3	$6,865,500	$20,596,500	Liam Fitzgerald; Greens Creek Mine; updated by 19.4% increase from 2012 costs
Concrete pad with cutout for Howitzer	for mobile Howitzer		1	$41,790	$41,790	G. Patz; updated by 19.4% increase from 2012 costs
Ammunition for Howitzer targeting	First year only. Per round cost plus shipping		458	$183	$83,716	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
Magazines			2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Dud detection	includes equipment and software				$2,179	AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loaders		Cat 988G	2	$1,035,780	$2,071,560	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loaders		chains for Cat 988G	2	$12,537	$25,074	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozers		D9R	2	$1,126,743	$2,253,486	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent		3/4 ton 4WD extended cab	3	$27,000	$81,000	G. Patz, updated 12/24/15 based on current SEF estimates

Snowmobiles		RMK; Summit 800	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates		manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		15	$597	$8,955	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		10	$179	$1,791	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches			2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			12	$6,501	$78,016	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	196	$750	$147,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	40	$125	$5,000	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$27,751,259**	

Capital Budget - East Lynn Canal Option D: Blaster Boxes on Major Paths, Heli Backup

Item	Notes	Equipment type	Number	Cost	Total	Information source
Blaster boxes	number of masts	Avalanche Guard	27	$286,560	$5,802,840	Installed ARR costs less 25% for quantity; plus 20% for increased cost since '04 and 19.4% increase since 2012
Magazines	2-Comet		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Dud detection	includes equipment and software			$2,179	$2,179	AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loaders	1- Comet, 1-Katzehin	Cat 988G	2	$1,035,780	$2,071,560	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loaders		chains for Cat 988G	2	$12,537	$25,074	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozers	1- Comet, 1-Katzehin	D9R	2	$1,126,743	$2,253,486	G. Patz, updated 12/24/15 based on current SEF estimates

Pickup trucks or equivalent	2-maintenance, 1-forecasters	3/4 ton 4WD extended cab	3	$27,000	$81,000	G. Patz, updated 12/24/15 based on current SEF estimates
Snowmobiles	2-forecasters	RMK; Summit 800	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates	1-Comet, 1--Katzehin	manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		15	$597	$8,955	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		10	$179	$1,791	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches	1-Comet, 1-Katzehin		2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			12	$6,501	$78,016	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	196	$750	$147,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	40	$125	$5,000	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$11,185,325**	

Capital Budget - East Lynn Canal Option E: Blaster Box Top 10 Paths, Heli. Elsewhere						
Item	**Notes**	**Equipment type**	**Number**	**Cost**	**Total**	**Information source**
Blaster boxes	number of masts	Avalanche Guard	18	$286,560	$3,868,560	Installed ARR costs less 25% for quantity; plus 20% for increased cost since '04 and 19.4% increase since 2012
Magazines	2-Comet		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Dud detection	includes equipment and software			$2,179	$2,179	AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loaders	1- Comet, 1-Katzehin	Cat 988G	2	$1,035,780	$2,071,560	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loaders		chains for Cat 988G	2	$12,537	$25,074	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozers	1- Comet, 1-Katzehin	D9R	2	$1,126,743	$2,253,486	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent	2-maintenance, 1-forecasters	3/4 ton 4WD extended cab	3	$27,000	$81,000	G. Patz, updated 12/24/15 based on current SEF estimates
Snowmobiles	2-forecasters	RMK; Summit 800	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates	1-Comet, 1--Katzehin	manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs

Avalanche transceivers	gear for DOTPF crew		15	$597	$8,955	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		10	$179	$1,791	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches	1-Comet, 1-Katzehin		2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			12	$6,501	$78,016	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	196	$750	$147,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	40	$125	$5,000	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$9,251,045**	

Capital Budget - West Lynn Canal Option F: Howitzer Only

Item	Notes	Equipment type	Number	Cost	Total	Information source
105mm Howitzer refurbishment			1	$24,000		T. Onslow; confirmed 2016 M. Murphy
105mm Howitzer shipping			1	$8,000		T. Onslow; confirmed 2016 M. Murphy
Spur roads for Howitzer shots	number of road miles needed	2-lane gravel road with turnout	3.04	$298,500	$760,000	J. Beedle; updated by 19.4% increase over 2012 costs
Concrete pad with cutout for Howitzer			5	$41,790	$208,950	G. Patz; updated for 19.4% increase over 2012 costs
Magazines	2-Main Maintenance Station		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Ammunition for Howitzer targeting	First year only. Per round cost plus shipping		210	$183	$21,210	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
Dud detection	includes equipment and software			$2,179	$2,179	AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Repeaters (for weather station telemetry)			3	$13,134	$39,402	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loader	Cat 988G		1	$1,035,780	$1,035,780	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loader		chains for Cat 988G	1	$12,537	$12,537	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozer		D9R	1	$1,126,743	$1,126,743	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent	1-maintenance, 1-forecasters	3/4 ton 4WD extended cab	2	$27,000	$54,000	G. Patz, updated 12/24/15 based on current SEF estimates

Snowmobiles	2-forecasters	RMK 800 or equivalent	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates		manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		10	$597	$5,970	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		6	$179	$1,075	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches	1-Haines, 1-ferry landing		2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			10	$6,501	$65,013	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	32	$750	$24,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	20	$125	$2,500	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$4,028,381**	

Capital Budget - West Lynn Canal Option G: Howitzer-Blaster Box						
Item	**Notes**	**Equipment type**	**Number**	**Cost**	**Total**	**Information source**
Blaster boxes	Number of masts	Doppelmayr	27	$286,560	$5,802,840	Installed ARR costs less 25% for quantity; plus 20% for increased cost since ’04 and 19.4% increase since 2012
105mm Howitzer refurbishment			1	$24,000	$24,000	T. Onslow; confirmed 2016 M. Murphy
105mm Howitzer shipping			1	$8,000	$8,000	T. Onslow; confirmed 2016 M. Murphy
Spur roads for Howitzer shots	number of road miles needed	2-lane gravel road with turnout	3.04	$298,500	$907,440	J. Beedle; updated by 19.4% increase over 2012 costs
Concrete pad with cutout for Howitzer			5	$41,790	$208,950	G. Patz; updated by 19.4% increase from 2012 costs
Ammunition for Howitzer targeting	First year only. Per round cost plus shipping		76	$183	$13,892	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
Magazines	2-Main Maintenance Station		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Dud detection	includes equipment and software			$2,179	$2,179	AAS; updated by 19.4% increase from 2012 costs
Weather stations	ridge-top		2	$143,280	$286,560	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs;updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs

Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loader		Cat 988G	1	$1,035,780	$1,035,780	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loader	Cat 988G	chains for Cat 988G	1	$12,537	$12,537	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozer		D9R	1	$1,126,743	$1,126,743	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent	1-maintenance, 1-forecasters	3/4 ton 4WD extended cab	2	$27,000	$54,000	G. Patz, updated 12/24/15 based on current SEF estimates
Snowmobiles	2-forecasters	RMK 800 or equivalent	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates		manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		10	$597	$5,970	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		6	$179	$1,075	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches	1-Haines, 1-ferry landing		2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			10	$6,501	$65,013	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	32	$750	$24,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	20	$125	$2,500	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$10,289,903**	

Capital Budget - West Lynn Canal Option H: Howitzer On Most Paths; Blaster Boxes on Path WLC009						
Item	**Notes**	**Equipment type**	**Number**	**Cost**	**Total**	**Information source**
Blaster boxes	Number of masts	Doppelmayr	9.3	$286,560	$1,998,756	Installed ARR costs less 25% for quantity; plus 20% for increased cost since '04 and 19.4% increase since 2012
105mm Howitzer refurbishment			1	$24,000	$24,000	T. Onslow; confirmed 2016 M. Murphy
105mm Howitzer shipping			1	$8,000	$8,000	T. Onslow; confirmed 2016 M. Murphy
Spur roads for Howitzer shots	number of road miles needed	2-lane gravel road with turnout	3.04	$298,500	$907,440	Liam Fitzgerald; Greens Creek Mine; updated by 19.4% increase from 2012 costs
Concrete pad with cutout for Howitzer			5	$41,790	$208,950	G. Patz; updated by 19.4% increase from 2012 costs
Ammunition for Howitzer targeting	First year only. Per round cost plus shipping		76	$183	$13,892	per round updated 2016 cost from M. Murphy AKDOT&PF w/shipping plus 10 percent for emergency shipments
Magazines	2-Main Maintenance Station		2	$52,536	$105,072	G. Patz/AAS; updated by 19.4% increase from 2012 costs
Dud detection	includes equipment and software			$2,179	$2,179	AAS; updated by 19.4% increase from 2012 costs

Weather stations	ridge-top		2	$143,280	$286,560	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Weather stations	mid-elevation		1	$119,400	$119,400	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Repeaters	for weather station telemetry		3	$13,134	$39,402	ARR costs; updated by 19.4% increase from 2012 costs: current heli time;
Forecasting office		office equipment			$27,820	See capital budget detail; updated by 19.4% increase from 2012 costs
Forecasting office		field equipment			$27,887	See capital budget detail; updated by 19.4% increase from 2012 costs
Loader		Cat 988G	1	$1,035,780	$1,035,780	G. Patz, updated 12/24/15 based on current SEF estimates
Chains for loader	Cat 988G	chains for Cat 988G	1	$12,537	$12,537	G. Patz; updated by 19.4% increase from 2012 costs
Bulldozer		D9R	1	$1,126,743	$1,126,743	G. Patz, updated 12/24/15 based on current SEF estimates
Pickup trucks or equivalent	1-maintenance, 1-forecasters	3/4 ton 4WD extended cab	2	$27,000	$54,000	G. Patz, updated 12/24/15 based on current SEF estimates
Snowmobiles	2-forecasters	RMK 800 or equivalent	2	$15,522	$31,044	Polaris; SkiDoo; updated by 19.4% increase from 2012 costs
Snowmobile transportation equipment		double trailer	1	$2,149	$2,149	Mission Trailer; updated by 19.4% increase from 2012 costs
Road closure gates		manual swing gates	2	$11,940	$23,880	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche transceivers	gear for DOTPF crew		10	$597	$5,970	Pieps/ Barryvox; updated by 19.4% increase from 2012 costs
Headsets	gear for DOTPF crew		6	$179	$1,075	G. Patz; updated by 19.4% increase from 2012 costs
Avalanche caches	1-Haines, 1-ferry landing		2	$22,380	$44,759	See capital budget detail; updated by 19.4% increase from 2012 costs
Vehicle caches			10	$6,501	$65,013	See capital budget detail; updated by 19.4% increase from 2012 costs
Signage		avalanche zone signs	32	$750	$24,000	Updated 12/24/15 based on current sign contract
Signage		trailhead warning signs	20	$125	$2,500	Updated 12/24/15 based on current sign contract
Signage		highway entry signs	2	$225	$450	Updated 12/24/15 based on current sign contract
TOTAL					**$6,199,259**	

Capital budget detail					
Forecasting office equipment	**Item**	**Number**	**Price per item**	**Total Cost**	**Source**
	desks/chairs	4	$500	$2,000	average cost by AAS
	desktop computer	1	$3,000	$3,000	average cost by AAS
	laptop computers	3	$4,000	$12,000	average cost by AAS
	external hard drives	4	$300	$1,200	average cost by AAS
	fax	1	$200	$200	average cost by AAS
	phones	4	$425	$1,700	DOA

	scanner	1	$200	$200	average cost by AAS
	misc. supplies	1	$3,000	$3,000	average cost by AAS
	Total			**$27,820**	updated by 19.4% increase from 2012 costs
Forecasting field equipment	**Item**	**Number**	**Price per item**	**Total Cost**	**Source**
	density kit	1	$200	$200	Backcountry Access
	digital camera	1	$1,800	$1,800	Canon
	binoculars	2	$200	$400	Steiner
	snow kits	4	$85	$340	UAF
	shovels	4	$74	$296	G3
	snow saws	4	$50	$200	LifeLink
	Avalung Packs	4	$300	$1,200	Black Diamond
	helmets	4	$140	$560	Smith
	skis or splitboards w/poles, bindings, skins	4	$1,710	$6,840	average cost by AAS
	parkas	4	$570	$2,280	Patagonia
	bibs	4	$620	$2,480	Patagonia
	avalanche transceivers	4	$500	$2,000	Pieps/ Barryvox
	probes	4	$85	$340	G3
	EX600XLS VHF radios	4	$1,000	$4,000	Motorola
	bivvy bags	4	$55	$220	SOL Escape Bivvy
	First Aid kits	4	$50	$200	Helenbac, plus heat packs
	Total			**$27,887**	updated by 19.4% increase from 2012 costs
Vehicle Caches	**Contents**	**Amount**	**Price per item**	**Total cost per vehicle**	**Source**
	shovels	4	$75	$300	G3
	probes	4	$80	$320	G4
	avalanche transceivers	4	$500	$2,000	Pieps/Barryvox
	headlamps	4	$60	$240	Black Diamond
	batteries	1	$25	$25	packages of 12
	wand markers	10	$1	$10	AES
	dry bag	1	$150	$150	Seal Line
	field books and pencils	4	$20	$80	Rite in the Rain
	First Aid kits	4	$50	$200	Helenbac, plus heat packs
	AED	1	$1,800	$1,800	average cost by AAS
	bivvy bags	4	$55	$220	SOL Escape Bivvy
	winter trauma kit	1	$100	$100	average cost by AAS
	Total			**$6,501**	updated by 19.4% increase from 2012 costs
Avalanche caches	**Contents**	**Amount**	**Price per item**	**Total cost per cache**	**Notes**

	rucksacks or dry bag rucksacks	8	$100	$800	Seal Line
	avalanche transceivers	8	$500	$4,000	Pieps/Barryvox
	probes	8	$80	$640	G3
	shovels	8	$75	$600	G4
	headlamps	8	$60	$480	Black Diamond
	field books and pencils	8	$20	$160	Rite in the Rain
	rolls of flagging	5	$3	$15	hardware store
	glow sticks	20	$12	$240	REI
	road flares	20	$5	$100	auto supply
	duct tape (rolls)	5	$8	$40	hardware store
	electrical tape (rolls)	5	$5	$25	hardware store
	wand markers	25	$1	$13	flagged 1m(3'), bamboo or wire
	whistles	8	$5	$40	
	mountain snowshoes	8	$300	$2,400	MSR Lightning
	air horn	1	$15	$15	auto supply
	oxygen kit	3	$500	$1,500	with bag/valve/mask manual resuscitation
	probing guide cords	1	$20	$20	average cost by AAS
	batteries	3	$25	$75	packages of 12
	blankets	10	$20	$200	average cost by AAS
	sleeping bags	5	$200	$1,000	REI
	foam pads	5	$45	$225	Therm-a-Rest
	bivvy bags	5	$55	$275	SOL Escape Bivvy
	water bottles	8	$12	$96	Nalgene
	burner, stove & pot	1	$75	$75	average cost by AAS
	backboards	3	$130	$390	average cost by AAS
	litters	3	$900	$2,700	Cascade Rescue
	winter trauma kits	5	$100	$500	average cost by AAS
	AED	1	$1,800	$1,800	average cost by AAS
	First Aid kits	8	$40	$320	Helenbac
	Total			**$22,380**	updated by 19.4% increase from 2012 costs
				$84,588	

13.8. *APPENDIX 13: Information Sources*

Information Sources	
Alaska Avalanche Specialists	**Bill Glude, lead avalanche specialist**
Alaska Dept. of Administration	Becky Reiche, Southeast Region Contract Office, Division of General Services
	Tanci Mintz, State Facilities Manager, Division of General Services
	Shelly Saviers, Divison of Personnel
Alaska Dept. of Transportation and Public Facilities	**Greg Patz, SE Region Maintenance and Operations Director**
	Jack Beedle, Engineer/Architect IV, project manager
	Gene Darling, Statewide Equipment Manager
	Nancy Slagle, Anne Zenger, Mary Siroky; Administrative Services
	Terrence Onslow, Safety and Emergency Support Specialist, retired
	Kerby Wright, Equipment Operator
	Doug Lewis, Equipment Operator
	Reid Bahnson, Equipment Operator
	Brad Bylsma, Equipment Operations Analyst
	Frank Richards, Engineer/Architect IV
Alaska Electric Light & Power (AEL&P)	**Mike Janes, Avalanche Forecaster**
Alaska Railroad Corporation	**Dave Hamre**
Austin Powder Alaska	**Tony Barajas and Melody McAllister**
BC Ministry of Transportation and Highways (MOTH)	Mike Boissonneault, avalanche specialist
Capitol Information Group, Alaska Budget Report	budget spreadsheets by staffers Judy Erickson, Rebecca Braun
Coastal Helicopters	**John JAG Garrard**, Jim Wilson, Mike WIlson
Colorado Avalanche Information Center (CAIC)	Knox Williams, director
	Nick Logan, associate director
	Andy Gleason and Jerry Roberts, Silverton forecasters
	Mark Mueller, Wolf Creek Pass forecaster
	Lee Metzger and Stu Schafer, Loveland/Berthoud forecasters
Colorado Dept. of Transportation	Greg Roth
Northern Communications Company	**radio pricing; updates by online research**
Northwest Avalanche Center (NWAC)	Mark Moore, forecaster
Parks Canada (British Columbia)	Dave Skjonsberg and Bruce McMahon, avalanche specialists
Snowbird Ski Area, Utah	Dean Cardinel, avalanche control
Southeast Alaska Avalanche Center	Bill Glude, former director and lead avalanche specialist
U.S. Army	Sue Back
Utah Dept. of Transportation	Liam Fitzgerald

Sources in bold were used for the 2013 and 2016 updates.

13.9. *APPENDIX 14: Avalanche Dynamics and Impact Loads on Exposed Bridges*

Purpose of the Dynamics Analysis

The East Lynn Canal Highway alignment includes at least three bridges that cross avalanche paths (at Paths LC028, LC029, and LC041), and at least two bridges on the West Lynn Canal alignment (at Paths WLC007 and WLC008) that are exposed to avalanches. Because bridges are expensive structures that are necessary for the operation of either highway, the "design-magnitude" avalanche at bridge locations was calculated to determine their exposure to flowing and powder avalanches and the magnitude of the impact and/or stagnation pressures.

The following avalanche-dynamics parameters are necessary to determine pressures (and ultimately the forces) on bridges. Bridges can be designed or structurally protected.

- The avalanche starting zone[1] size and location and the design-magnitude avalanche stopping position along the path profile;
- The avalanche speed at the bridge site, which is computed by an avalanche-dynamics modeling procedure after the stopping position is determined;
- The avalanche flow depth at the bridge site (which determines if the proposed bridge is reached by the flowing or powder design avalanche);
- The avalanche flowing bulk density;
- The avalanche impact pressure and/or stagnation pressure[2] at the bridge site.

Procedures Used to Compute these Dynamics Parameters

Determining the Starting and Stopping Positions: The stopping positions for the design-magnitude events were determined by creating an avalanche path profile from the starting zone to sea level. These profiles were constructed from the detailed topography (25-foot contour intervals) provided by DOT&PF. Because all East Lynn Canal paths of concern stop in the water, the actual runout position could not be computed. Therefore, "synthetic" profiles that extended from the edge of the water on slopes of 10% (5.7°) were constructed to calibrate the parameters used in the dynamics model. This slope corresponded to typical runout-zone slopes of a large number of major avalanche events documented in coastal regions of Alaska. The stopping positions along these synthetic profiles (the α-angle or average path slope) was then computed based on the steepness of the avalanches above the 10° point (the β-angle) using a statistical regression equation, derived from the databases of Alaska coastal and Southeast region avalanches.

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[1] *Steep terrain at the top of the avalanche path where avalanche begin, accelerate and increase in mass; these areas are usually in excess of 30° inclination and discharge snow into the avalanche tracks and runout zones lower in the path.*

[2] *Impact and stagnation pressures are reference pressures rather than design pressures; final design pressures require details about bridge shape and the derived coefficients of drag and lift which are ultimately used to compute drag, lift, and thrust forces.*

Avalanche Speeds at the Bridge Sites: Avalanche speeds were computed through use of a 3-component, stochastic, avalanche-dynamics model (Perla, et. al. 1984 [with 2001 revisions, unpublished]). This model simulated avalanches along the centerline profile, starting at the top of the path (the starting zone) and stopping at the point determined in the previous step.

Avalanche Flow Depth at the Bridge Site: The cross sectional area (for the denser flowing snow portion of the avalanche) was computed by dividing the computed discharge (in m^3/sec) by the speed (in m/sec). The shape of the cross sectional areas below the bridges, determined from the detailed topographic maps, was then converted to flow depth. This flow depth does not include the impact of the powder-avalanche portion of the flow, which was considered separately.

Avalanche Bulk Density: A density of 200 kg/m^3 was used for the density of the flowing lower core of the avalanche, assuming the design avalanche would consist of dry snow, even at sea level in the coastal climate of Southeast Alaska. Wet-snow avalanches could have densities two to three times greater than those assumed, but speed (which is the most important parameter in computing pressures) would be substantially less than those of the dry-snow avalanches. The powder-avalanche portion, which may extend as much as 100-130 feet (30-40m) above the flowing snow, was assumed to have a density of 10 kg/m^3.

Impact and Stagnation Pressures: Impact pressure from flowing snow and stagnation pressures from the powder avalanche were both computed as follows: $P = \frac{1}{2} \rho V^2$, where ρ = density (200 kg/m^3 flowing, 10 kg/m^3 powder) and V is the computed speed (in meters/sec) at the bridge site. It should be noted that the impact and stagnation pressures are not design pressures. Final design pressures would depend on structure shape, which is currently not known. The impact and stagnation pressures can be used to assess the feasibility of construction.

Additional Factors: Multiple events during a single avalanche season can raise the effective avalanche-running surface and create possible impact with structures at a higher level than snow-free topographic mapping will indicate. The possibility of deep snow deposits from previous avalanches was considered in the analysis.

Results of the Analysis

Figure 12-1 illustrates the various dimensions and parameters at each bridge site. These are:

- H: Clearance range of the bottom of the bridge above the gully
- Hp: Flow height of the powder avalanche (ft & m)
- Hf: Flow height of the flowing avalanche (ft & m)
- Ps: Powder-avalanche stagnation pressure (lbs/ft2 & kPa)
- Pf: Flowing avalanche impact pressure (lbs/ft2 & kPa)

The vertical clearance, C, of the bridge *above the avalanche*, if any, is the difference between the height range, H and the flowing or powder-avalanche height (i.e., C = H – Hf or C = H – Hp respectively), for clearances of the flowing and powder avalanche portions.

The following additional comments refer to the analysis and data presented in Table 12-1:

The pressures given here should not be used for deriving final-design forces. Bridge locations have been and continued to be adjusted as design work proceeds. The locations of the crossings analyzed here have already changed. Until the final location, bridge shape, and clearance above the terrain is determined; calculated loads will change.

Design pressures (Ps or Pf) may also require adjustment by an impact factor, Fi; the final unit loads would therefore be Fi*Ps when exposed to powder avalanches and Fi*Pf when exposed to flowing avalanches; the magnitude of Fi usually is between 1.0 and 2.0 but depends critically on the free period of the bridge and the rise time of the avalanche impact, factors that must be considered in final design.

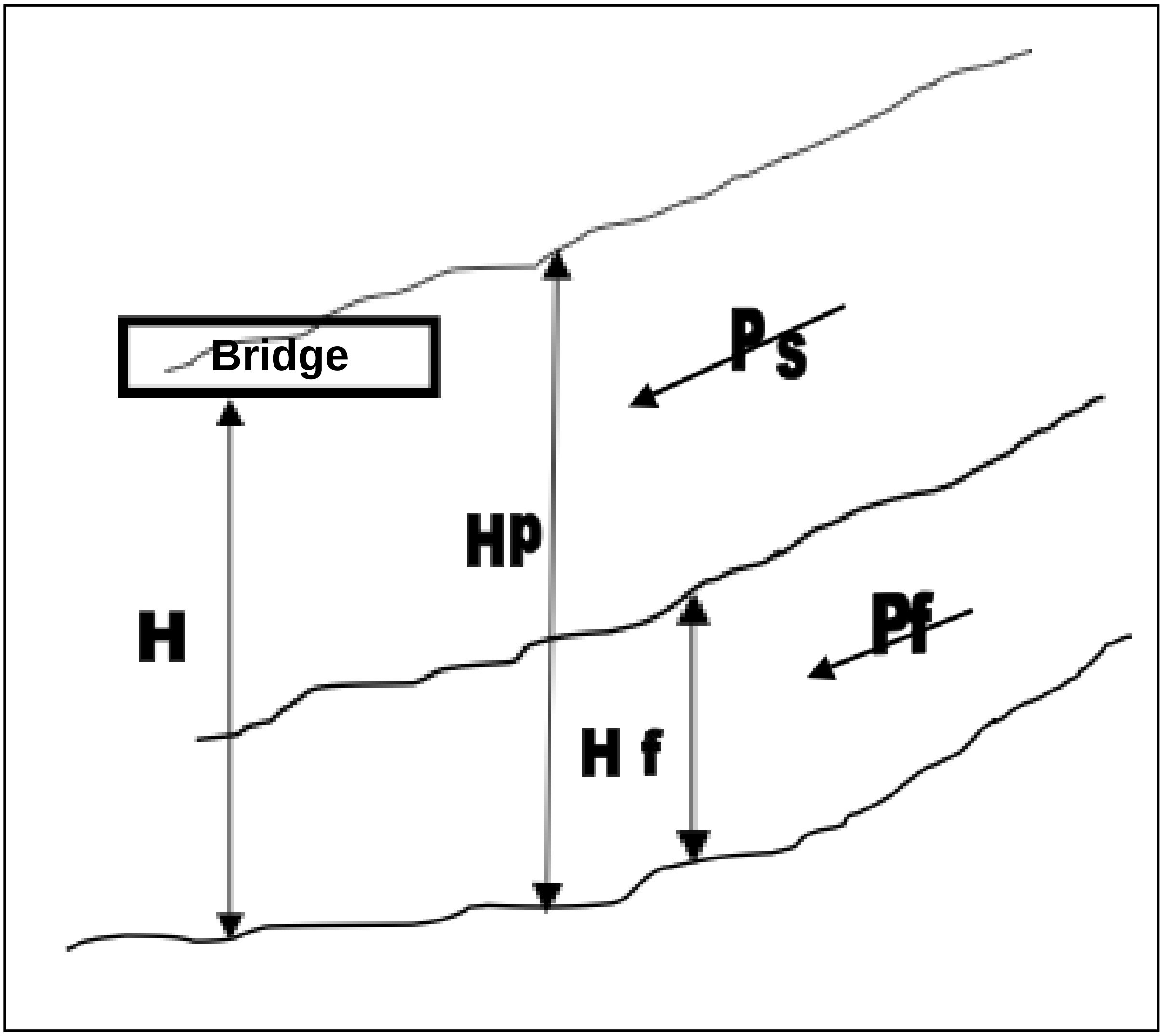
Bridges exposed to powder avalanches will also have vehicles exposed to powder avalanches; when Ps is > or = 80 psf (hurricane-force winds are usually less than 50 psf) they may be capable of pushing (or lifting and pushing) a vehicle off the bridge even if the vehicle is not exposed to the larger flowing- avalanche pressures.

Avalanche Heights and Pressures at Bridge Locations

Path	H	Hp	Hf	Ps	Pf	Comments
ELC 028	55 ft, 17m	98 ft, 30m	44ft, 13m	119 psf, 581 kg/m^2	2,382 psf, 11,629 kg/m^2	A
ELC 029	20 ft, 6 m	131 ft, 40m	57 ft, 17m	101 psf, 493 kg/m^2	2,015 psf, 9,837 kg/m^2	B
WLC 007	75 ft, 23 m	98 ft, 30m	4 ft, 1.2 m	22 psf 107 kg/m^2	440 psf, 2,148 kg/m^2	A
WLC 008	75 ft, 23 m	131 ft, 40 m	31 ft, 9 m	97 psf, 474 kg/m^2	1,943 psf, 9,486 kg/m^2	B

A: Stagnation pressure (Ps) only at driving surface; flowing avalanche pressure (Pf) at exposed piers.
B: Both stagnation pressure and flowing-avalanche pressures (Ps & Pf) affect driving surface and exposed piers.

Schematic Drawing of Bridge Impact Analysis



Schematic drawing showing dimensions and avalanche pressures on bridges that span gullies. H = deck above gully; Hp = powder-avalanche height; Hf = flowing-avalanche height. Refer to table for magnitudes of lengths and pressures at various avalanche paths.

13.10. *APPENDIX 15: References*

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13.11. *APPENDIX 16: Peer Review*

The 2004 study was peer reviewed at the draft stage by three nationally prominent avalanche specialists: Dr. Edward LaChappelle of McCarthy, Alaska, Doug Fesler of Anchorage, Alaska, and Dr. Chris Landry of Silverton, Colorado. Their recommendations were incorporated to the extent possible into the original study.

The 2013 updated AHI and mitigation calculations were reviewed by Arthur I Mears, PE, and Chris Wilbur, PE, of Mears and Wilbur; and they did all the structural mitigation calculations, design, and cost estimates.

Program specifics such as staffing and howitzer range for this 2016 revision were reviewed by Matt Murphy of the Alaska DOT&PF avalanche program.

13.12. *APPENDIX 17: Resumes*

Resumes and background information are listed here for the principal author and major reviewers.

13.12.1. **Bill Glude, principal author**

Bill Glude
Avalanche Specialist

OVERVIEW

Bill Glude is the owner of and lead forecaster/instructor for Alaska Avalanche Specialists in Juneau, AK. He is a Professional Member and certified instructor with the American Avalanche Association, and has served on its Board of Directors. He has over 35 years of professional avalanche experience.

RECENT PROJECT HIGHLIGHTS

Alaska Avalanche Specialists, LLC. 1990-present. AAS is the largest avalanche consulting business in Alaska. AAS professional staff has experience in all aspects of avalanche work, including consulting, planning, training, artificial release, helicopter and hand blasting, structural mitigation, research, risk analysis, mapping, and project management. Lead forecasters all have at least ten years' experience in the field; assistants go through a rigorous apprenticeship that trains them to the highest standards in the industry. AAS regularly draws on and works closely with Art Mears, Chris Wilbur, and Dave McClung, North America's top avalanche dynamics engineers. Recent project highlights include:

- **White Pass and Yukon Railroad avalanche program**, annual spring project, Skagway, AK, 2007-present. Program has developed from an evaluation into a full daily avalanche program every spring. This operational transportation program involves explosive use, crew training, daily forecasting and fieldwork, and plan development.

- **Tsugaike Kogen Ski Area Off-Piste Avalanche Program**, with Evergreen Outdoor Center and Japan Avalanche Specialists, first modern ski area avalanche program in Japan; planning, oversight, and operations, 2014-preeent.

- **Takatz Lake Hydroelectric Project,** field reconnaissance avalanche evaluation and route analysis for east-west power line across Baranof Island to Sitka, study with Commonwealth Associates, Inc. for City of Sitka Electric Department, 2011-12.

- **Constantine Metal Resources Palmer VMS Project**, reconnaissance-level avalanche study for hard rock prospect near Haines, AK, operational hazard evaluation, 2010-present.

- **Alaska Electric Light & Power Snettisham Power Line Avalanche Reconstruction, Redesign, and Prevention Programs,** comprehensive avalanche program for reconstruction; development and operation of long-term mitigation program including mapping, risk assessment, structural mitigation, forecasting, crew training, and avalanche blasting program, 2008-2010; review, support, and emergency response, 2010-11.

- **Swan Lake - Tyee Lake Intertie Avalanche Evaluation,** field study, dynamics, and recommendations for mitigation for avalanche-affected structures, spring 2008.

- **WSL-Institut für Schnee- und Lawinenforschung SLF, Study at Swiss Avalanche Research Center**. One-week study of Swiss avalanche operations, including participation as a member of the daily forecasting team and presentations at colloquium**,** March 2008

- **International Avalanche Mitigation Conference, Egilsstadir, Iceland**. Four-day conference on avalanche mitigation for industry, transportation, and communities; followed by four-day field trip to study rescue and mitigation measures in Reykjavik and Westfjords areas**,** March 2008.

- **Chignik Connectors Highway Avalanche Study**, for HDR Inc. and Alaska DOT&PF, Alaska Peninsula, 2007-08.

- **All Juneau Access Environmental Impact Statement (EIS)** highway avalanche studies for Alaska DOT&PF, from preliminary studies to 2012 SEIS, including field studies and observations, Avalanche Hazard Index calculation, risk analysis, mapping and zoning, development of mitigation alternatives and recommendations, avalanche program design, budgets, public hearings, workshops, report writing, graphics, and layout, Juneau, AK 1995-present.

- **Coeur Alaska Kensington Mine avalanche program** including program development, mapping, plan, weather instrumentation, observations, crew training and curriculum, forecasting, management, dynamics, hand and helicopter blasting, staff recruitment, Juneau, AK, 2006-07.

- **Seward Highway Avalanche Hazard Index evaluation for Alaska DOT&PF, 2005.**

- **Alaska DOT&PF highway avalanche forecasting, Thane Road,** 2003-2006.

- **City and Borough of Juneau Avalanche Response Plan,** wrote first version and participated in community meetings to develop final draft, Juneau, AK 2003-04.

- **Numerous US Forest Service Special Use Permit and private tour operator avalanche hazard studies,** Juneau area, AK, 1998-present.

- **Alaska Mountain and Wilderness Hut Association,** hut sites avalanche study, Kenai Peninsula, AK, 2006.

- **State of Alaska Department of Public Safety, rescue response and avalanche evaluation**, False Troy, one skier, Juneau, AK, 1995; McGinnis Mtn., two snowboarders, Juneau, AK, 1999; Haney Range, one snowmachiner, Cordova, AK, 2001; Devil's Thumb, two climbers, Petersburg, AK, 2003.

- **Chugach Electric jobsite avalanche forecasting**, Southcentral AK, Seward Highway area, repair job for avalanche damage, for Alaska Mountain Safety Center (AMSC), 2000.

- **State of Alaska Division of Emergency Services hazard evaluation and forecasting,** Southcentral Alaska, for AMSC, Cordova and Valdez, 2000.

- **State of Alaska DOT&PF hazard evaluation and highway corridor helicopter explosive work,** Southcentral AK, Richardson Highway, 2000.

- **Cordova Electric Cooperative Power Creek Hydroelectric Project,** avalanche mapping, program development, risk management plan, crew training, and operational forecasting program, Cordova, AK, 2001-02.
- **University of Alaska Southeast (UAS)**, teaching Level 1 and 2 avalanche and related field courses for the Outdoor Studies and guest lecturer for Environmental Science Programs, 1999-2013.
- **Evergreen Outdoor Center, Hakuba, Nagano, Japan**, senior backcountry guide, guide trainer, forecaster; consulting with local ski areas; teaching Canadian Avalanche Association AST1 and 2 courses; winters 2009-present.
- **Red Mountain and Coal Bank/Molas Passes Avalanche Program Study, CO**, April 2003. One week study of operational avalanche program on high-hazard highway, including fieldwork and forecasting with the CDOT team.
- **Founder and Director, Southeast Alaska Avalanche Center (SAAC)**, Nonprofit providing avalanche education and advisories, 2007 pilot urban forecasting program for CBJ, spurred CBJ to create urban avalanche program that replaced SAAC, 1996-2007.
- **Senior avalanche specialist, Echo Bay A-J Mine, Juneau, Alaska**, operational forecasting, crew training, observations, helicopter blasting, for AMSC, Juneau, AK, 1993-95.

EDUCATION

- Bachelor of Science in Geology, University of Washington, Seattle, WA 1973. Specialty in glaciology and glacial geology, including avalanche studies.
- Started formal Avalanche training in 1970 under glaciologist Dr. Ed LaChappelle, pioneer avalanche researcher, University of Washington; continued under his guidance and review until death in 2007. Attended American Avalanche Institute Level 1 in 1976; mentored for next 12 years under most top avalanche specialists from US, Canada, and Europe while teaching full-time for Alaska Avalanche School. Annual continuing education at all conferences possible, including all International Snow Science Workshops since 1998. Work regularly with top avalanche specialists worldwide.

PROFESSIONAL CERTIFICATION

- **American Avalanche Association (AAA) Professional Member since 1998.**
- **AAA Certified Avalanche Instructor.** Master certification that requires 10 years' teaching experience; strong scientific background. Other franchise-style instructor-training programs award "certification" in the US, but AAA certification is the only recognition by all peers.
- **US Bureau of Alcohol, Tobacco, and Firearms (ATF) Explosives License, Responsible Person and permit holder**. AAS field staffers have at least ATF Employee Possessor status.
- **Medical: Wilderness First Responder (WFR) and CPR - current;** Emergency Trauma Technician (ETT), Emergency Trauma Technician (EMT), National Ski Patrol Outdoor Emergency Care (OEC), and Wilderness First Aid and Survival - all lapsed.

- **National Ski Patrol (NSP) Avalanche Instructor training**, Levels 1 and 2, 2006. Taught NSP courses 2007. Eaglecrest Pro Patrol trainings and joint rescue exercises, 1996-present. Invited to review new NSP avalanche curriculum, 2007-08.

- **Languages:** Functional but inelegant German, Spanish, and Japanese.

RESEARCH AND PUBLICATIONS

- **AK Block snow test**, 2003-present. Papers presented and published at International Snow Science Workshops, 2004, 2006, and 2008; Swiss SLF Federal Institute for Snow and Avalanche Research colloquium, 2008. See AAS website's research page.

- **Faceted melt forms weak layer studies**, 1995-present, paper presented and published at International Snow Science Workshop, Davos, 2009. See AAS website's research page.

- **Arctic snow studies**, US Geological Survey, published two Open File Reports, 1976-79.

- Published **numerous *Avalanche Review* articles and photos** on topics ranging from meeting reports to education and research.

13.12.2. Arthur I. Mears, principal engineer

Art Mears is well known in the avalanche business and has not used a résumé for many years. Here is a short summary of recent projects, and a publications list, both from the Mears and Wilbur (http://mearsandwilbur.com/) website.

"Art Mears, P.E. was raised in upstate New York, but has spent most of his life in Colorado, and much of his time in mountains of the Western United States. He has a B.S. in Civil Engineering and an M.S. in Geology from the University of Colorado, Boulder. Based in Gunnison, he formed Arthur I. Mears, P.E., Inc. in 1981. Mr. Mears has been an avalanche consultant on over 1000 projects in 9 states and 8 countries. He has published over 35 technical and research papers and works with international colleagues from Canada, Switzerland, Norway and Austria."

Projects

I-90 Snoqualmie Pass East Avalanche Mitigation

In partnership with URS Corporation and the Washington State Department of Transportation (WSDOT), provided avalanche design criteria for a six-lane clear span snowshed to replace the existing two-lane snowshed. Due to its length, the proposed snowshed would function similarly to a tunnel, requiring lighting, ventilation, fire protection and monitoring. Guy F. Atkinson, the general contractor, designed an avalanche bridge to replace the snowshed. The bridge will cross over the avalanche paths with clearances up to 70 feet and allow snow to pass underneath. Bridge piers will be designed to withstand avalanche impacts. We provided technical review of the contractor's plans, including a quantitative risk assessment for the snowshed to allow comparison of risks between the snowshed and avalanche bridge options.

Provided design layout and specifications for avalanche starting zone structures (snow nets). These steel cable meshes are anchored into the ground to hold the snowpack in place and prevent initation of large avalanches that can reach I-90 travel lanes.
WSDOT will install real-time instrumentation to monitor stresses and deflections in the snow nets and corresponding snow heights and densities. This information will be used for day-to-day avalanche forecasting and control work, and to provide a better understanding of snow net performance for maintenance, repairs and future designs in this deep maritime snowpack. For more information, go to WSDOT Project Site

Snettisham Transmission Tower, Juneau, Alaska

The Snettisham 138kV transmission line connects Alaska's capital to a source of abundant hydroelectric power. This line traverses rugged terrain with significant avalanche exposure. Worked with Alaska Electric Light and Power, and Dryden & LaRue to provide recommendations and avalanche design parameters for protecting one of the most exposed transmission line towers.

A massive, reinforced concrete splitting wedge was considered but eliminated due to difficulties and expenses in transporting heavy materials to this remote location by helicopter. The solution became a porous steel structure consisting of tubular steel and steel sections designed to function similarly to a concrete wedge. The wedge is approximately 40 feet high. Unlike concrete, the steel wedge is designed to flex during impact, thereby reducing peak impact pressures. Construction was completed in October, 2009.

In March 2012, the structure survived its first full scale field test when an estimated 30-year return period avalanche impacted the splitting wedge. KTOO News Story ISSW 2012 Paper Two similar splitting wedges were constructed to protect nearby towers. AEL & P Press Release

Rockfall Hazard Study - Telluride, Colorado

Provided services to assess and quantify rockfall hazard to areas within the Town limits and along the Town-maintained Highway 145 Spur. Historic rockfall events dating to the 1950s were documented based on newspaper records and interviews with long-time residents. Evaluated rockfall source areas in the field and modeled rockfall energies with the Colorado Rockfall Simulation Program (CRSP) Final work product was a risk-based rockfall hazard map for the town delineating High, Moderate and Low rockfall hazard zones and a rating of rockfall hazard along to Highway 145 Spurs. Download Report (10MB)

Residential Avalanche Hazard Mapping and Mitigation
Provided avalanche hazard mapping, and mitigation design parameters for residential developments and structures in:

- Pitkin, San Juan, Summit Counties, and Ophir, Colorado
- Ketchum, Sun Valley, and Blaine and Camas Counties, Idaho
- Taos Ski Valley, New Mexico
- Summit and Salt Lake counties, and Sundance, Utah
- Chelan County, Washington"

Art Mears Publications

1 Florian Rudolf-Miklau, Siegfried Sauermoser, Arthur I. Mears (Eds.), in press, 2014, The Technical Avalanche Protection Handbook 1st Edition, Ernst & Sohn
2 Wilbur, Chris, Art Mears, Stefan Margreth & Sue Burak, 2014 Avalanche Dynamics Model RAMMS Applied in two North American Climates, Proc. International Snow Science Workshop, Banff, Alberta, Canada
3 Wilbur, Chris, Mike Janes & Art Mears, 2012, Avalanche Impact Performance of a Light-weight Diversion Structrue, Snettisham Transmission Line, Southeast Alaska , Proc. International Snow Science Workshop, Anchorage, AK.
4 Wilbur, C., A.I. Mears, D. LaRue, and Bill Glude, 2010, A Light-weight Splitting Wedge to Protect Tower 4/6 Snettisham Transmission Line, Southeast Alaska , Proc. International Snow Science Workshop, Squaw Valley, California, pp. 258-262.
5 Mears, A.I. and C. Wilbur, 2008, A Case Study in Avalanche Risk Tolerance in Two Transmission Lines: 1) Colorado, USA and 2) Eastern Iceland, Proc. International Snow Science Workshop, Whistler, British Columbia, pp. 209-214.
6 Mears, A.I., 2006, Avalanche size increase resulting from forest removal and wind loading - a case study from central Colorado using AVAL-1D, Proc. International Snow Science Workshop, Telluride, Colorado, pp. 775-777.
7 Mears, A.I., 1998, Tensile strength and strength changes in new snow layers, Proc. International Snow Science Workshop, SunRiver, Oregon, pp. 574-576.
8 Mears, A.I., 1996, Dry slab thickness and density during major storms: Proc, International Snow Science Workshop, Banff, BC, Canada, pp. 91-93.
9 Mears, A.I., 1996, Avalanche structural protection - an overview, Proc. Snowsymp 94, Manili, India, pp. 10-19.
10 Mears, A.I., 1996, Regional variations in extreme avalanche runout distance, Proc, Snowsymp 94, Manali, India, pp. 252-255.
11 Mears, A.I. 1993, Snow avalanche hazard analysis and mitigation on highways, Proc. of the conference on transportation routes through difficult terrain, pp. 487-494, A.A. Balkema/Rotterdam/Brookfield.
12 Mears, A.I., 1992, The East Riverside Avalanche Accident of 1992 - Engineering and Snow-safety Considerations, International Snow Science Workshop, Breckenridge, CO.
13 Mears, A.I., 1992, Snow-Avalanche Hazard Analysis for Land-use Planning and Engineering, Colorado Geological Survey Bulletin 49.
14 McClung, D.M. and Mears, A.I., 1991, Extreme Value Prediction of Snow Avalanche Runout, Cold Regions Science and Technology, Vol. 19.
15 Mears, A.I., 1990, Measurements of Avalanche Loads, East Riverside Avalanche Shed, Colorado, International Snow Science Workshop, Bigfork, MT.
16 Mears, A.I., 1989, Regional Comparisons of Avalanche Profile and Runout Data, Arctic and Alpine Research, Vol. 21, No. 3.
17 Mears, A.I., 1988, Comparisons of Colorado, Eastern Sierra, Coastal Alaska, and Western Norway Avalanche Runout Data, International Snow Science Workshop, Whistler, B.C.
18 McClung, D.M. and Mears, A.I., 1988, Extreme Avalanche runout: Data from Four Mountain Ranges, Annals of Glaciology, Vol. 13.

19 Mears, A.I., 1986, Instrumentation of Avalanche Loads, East Riverside Avalanche Path, Colorado, International Snow Science Workshop, Squaw Valley, CA.
20 Mears, A.I., 1984, Climate Effects on Snow Avalanche Travel Distances, International Snow Science Workshop, Aspen, CO.
21 Mears, A.I., 1982, Release and Motion of Arctic Slushflows (abstract), International Snow Science Workshop, Bozeman, MT
22 Mears, A.I., 1981, Design Criteria for Avalanche Control Structures in the Runout Zone, USDA Forest Service, General Technical Report RM-84
23 Martinelli, M.T., Lang, T., and Mears, A.I., 1980, Calculations of Avalanche Friction Coefficients from Field Data, Journal of Glaciology, Vol. 26, No. 94.
24 Mears, A.I., 1980, Municipal Avalanche Zoning: Contrasting Policies of Four Western U.S. communities, Journal of Glaciology, Vol. 26, No. 94.
25 Mears, A.I., 1980, A Fragment-flow Model of Dry-snow Avalanches, Journal of Glaciology, Vol. 26, No. 94.
26 Bradley, W.C., and Mears, A.I., 1980, Calculations of Flows Needed to Transport Coarse Fraction of Boulder Creek alluvium at Boulder, Colorado, Geological Society of America Bulletin, Vol. 91.
27 Mears, A.I., 1979, Flow Dynamics of the Frank Slide (abstract), Presented at the Annual Meeting of the Rocky Mountain Section, Geological Society of America.
28 Mears, A.I., 1979, abstract, Flooding and Sediment Transport in a Small Alpine Drainage Basin in Colorado: Geology, v. 7.
29 Mears, A.I., 1979, Colorado Snow Avalanche Area Studies and guidelines for Avalanche-Hazard Planning, Geology; Colorado Geological Survey Special Publ. No. 7.
30 Mears, A.I., 1977, Snow Avalanche Hazard Identification and Delineation, in Shelton, D.C. (ed.), Proc. Governor's Third Conference on Environmental Geology; Colorado Geological Survey Special Publ. No. 8.
31 Mears, A.I., 1977, Debris-flow Hazard Analysis and Mitigation - an Example from Glenwood Springs, Colorado, Colorado Geological Survey Information Series 8.
32 Mears, A.I., 1976, Guidelines and Methods for Detailed Snow Avalanche Hazard Investigations in Colorado, Colorado Geological Survey Bulletin 38.
33 Ives, J.E., Mears, A.I., Carrara, P.E., and Bovis, M.J., 1976, Natural Hazards in Mountain Colorado, Annals of the Association of American Geographers, Vol. 66.
34 Bovis, M.J. and Mears, A.I., 1976, Statistical Prediction of Snow Avalanche Runout from Terrain Variables in Colorado, Arctic and Alpine Research, Vol. 8.
35 Mears, A.I., 1975, Dynamics of Dense Snow Avalanches Interpreted from Broken Treesabstract, Geology, Vol. 3.
36 Andrews, J.T., Mears, A.I., Miller, G.H., Pheasant, D.R., 1972, Holocene Late Glacial Maximum and Marine Transgression in the Eastern Canadian Arctic, Nature Physical Sciences, Vol. 239.”

13.12.3. **Chris Wilbur, second engineer**

B. CHRISTOPHER WILBUR, P.E.

Education: B.S. Geological Engineering, Colorado School of Mines, 1984
M.S. Civil (Geotechnical) Engineering, University of Colorado, 1990

Registration: Professional Engineer(Civil), Colorado, Utah, Washington and New Mexico
Applying for Alaska P.E. in 2016.

Experience Summary:

Mr. Wilbur is an engineer with over 25 years of experience in earth science and engineering. Prior to opening an independent practice in 1994, he worked as a geotechnical engineer for Stone & Webster Engineering Corporation in Denver, Dames & Moore in San Francisco and Fox & Associates in Denver. Mr. Wilbur specializes in geologic hazard processes, including snow avalanches, debris flows and rockfall.

Representative Project Work:

WSDOT I-90 Snoqualmie Pass Avalanche Mitigation Subconsultant to URS Corp., Seattle, 2007-2016. Provided recommendations and preliminary loads and layout for avalanche prevention structures (snow nets) in a starting zone. Provided technical support and review for a new 6-lane snow shed. Completed a Quantitative Risk Assessment (QRA) to evaluate probabilities and consequences for life-safety and economic losses related to a proposed six lane snowshed.

Avalanche Hazard Mapping, Risk Assessment and Load Design Criteria, 2006-2015 Over 50 projects completed with or reviewed by Arthur I. Mears, P.E., Inc., including Snettisham Transmission Line (3 avalanche diversion structures), Trans Alaska Pipeline RGV-118 Diversion Structure, Golden Meadows Mine, Stibnite, Idaho, Henderson Molybdenum Mine, Colo., Tri-State Electric Transmission Line, Colo., and residences in Aspen, Silverton, Ophir, and Pitkin County, Colo., Park City, Utah, Taos Ski Valley, NM and Sun Valley, Ketchum and Blaine County, Idaho.

Post-fire Geologic Hazards Assessment and Hazard Reduction Program, Mesa Verde National Park, 2000. Provided emergency assessment of post-fire geologic hazards for the Burned Area Emergency Rehabilitation (BAER) Team at Mesa Verde National Park following the Bircher Fire in 2000. Prepared report with quantitative risk assessments of geologic hazards including landslides, mudflows, and rockfall hazards.

Geologic Hazard Mapping, Town of Rico, Colorado, 1996. Prepared geologic hazards and constraints maps as part of the town's planning efforts. Compiling existing information, and prepared maps and a report showing potentially unstable slopes, slopes failure complexes, active landslides, rockfall hazard areas, avalanche paths, and debris fans.

Publications: http://mearsandwilbur.com/pubs.html

Affiliations:

Affiliate Member, American Avalanche Association

Member, American Society of Civil Engineers Geoinstitute

Winter Response Team Leader, La Plata County Search and Rescue

13.12.4. Doug Fesler, reviewer

DOUG FESLER, AVALANCHE HAZARD CONSULTANT

Alaska Mountain Safety Center, Inc, Anchorage, Alaska.

PROFESSIONAL EXPERIENCE STATEMENT March 2007

Doug Fesler is a recognized avalanche hazard consultant with over 30 years of avalanche forecasting and hazard management experience in Alaska. He is Co-Director of the Alaska Mountain Safety Center, Inc. (AMSC), a non-profit organization specializing in avalanche hazard management and mitigation solutions for residential development, construction, mining, transportation, utilities, film and recreational industries. Mr. Fesler's expertise in avalanche hazard evaluation and mountain rescue includes:

AVALANCHE HAZARD EVALUATION/LAND USE PLANNING

- Avalanche hazard mapping and zonation;
- Terrain, snow climate and avalanche occurrence analysis;
- Computer modeling of avalanche runout limits, velocities, and impact forces;
- Research and analysis of historical avalanche data.

AVALANCHE HAZARD MITIGATION

- Analysis of structural mitigation alternatives and operational risk reduction measures;
- Avalanche safety planning and implementation;
- Determination of design criteria for engineering solutions.

AVALANCHE HAZARD MANAGEMENT

- Field snow stability assessments and terrain analysis;
- Site surveys and assessments of avalanche exposure;
- Avalanche forecasting and hazard management;

- Helicopter bombing and other hazard reduction operations;
- Avalanche rescue contingency planning and implementation;

AVALANCHE AND MOUNTAIN SAFETY

- Accident investigation and analysis;
- Accident site management and mountain rescue response;
- Film crew safety and stunt coordination in hazardous terrain;
- Avalanche and mountain safety/rescue training for personnel;
- Technical writing and editing.

RECENT CONSULTING PROJECTS:
Avalanche Hazard Evaluation, Mapping, and Mitigation Studies:

- Municipality of Anchorage, Heritage Land Bank, Review of avalanche hazard affecting the proposed Glacier-Winner Creek Project, Girdwood, AK (2007).
- Four Dam Pool Power Administration: Avalanche hazard evaluation and mitigation analysis of the Solomon Gulch 138 kV transmission line, Thompson Pass section (2006).
- Municipality of Anchorage, Heritage Land Bank, Avalanche hazard evaluation and mapping of two proposed subdivisions and three other large parcels in Bear Valley and Indian, AK (2005, 2006).
- City of Valdez, Avalanche hazard evaluation and mapping of the proposed Valdez Visitor Information Center (2005).
- URS Corp., Avalanche hazard evaluation, mapping, and mitigation study of the proposed alternative sites for a Cordova Oil Spill Response Facility EIS (2005).
- City of Valdez: Avalanche hazard mapping of the proposed Valdez Middle School (2004).
- AES for ADOT/PF: Technical peer review of the Juneau Access Project, Snow Avalanche Technical Studies, Draft Final Snow Avalanche Report, EIS (2003).
- Alascom, Inc.: Mitigation design for Tern Lake repeater site, Kenai Penn (2003).
- Kean & Associates: Avalanche assessment of Univ. of Alaska, Poe Bay Subdivision (2002).
- Chugach Electric Association: Comprehensive avalanche atlas covering Anchorage-Portage-Hope-Moose Pass grid (Rev. 2003, 1991); numerous mapping and mitigation studies in Chugach and Kenai Mountains (2000, 1991, 1990, 1989, and 1988).
- HDR Engineering, Inc.: Avalanche mapping and mitigation studies: Sterling Hwy Alternatives Project (2001); Whittier Access Project (1996); Whittier Alternative Access EIS (1993).
- Private landowners and real estate developers: Avalanche hazard assessments and mitigation studies in numerous communities including Anchorage, Cordova, Juneau,

Valdez, Eagle River, Chugiak, Indian, Girdwood, Moose Pass, Chignik, Seward, and Unalaska (present-mid-1980s).

- City of Cordova and the Federal Emergency Management Agency: Mapping and mitigation study, MP 5.5 Subdivision, Cordova (2000).
- City of Valdez and the Federal Emergency Management Agency: Mapping and mitigation studies, Phase 1 & 2, Town Mountain avalanche area and Mineral Creek Subdivision (2000).
- Dryden and LaRue, Inc.: Avalanche mitigation studies: Seward/Davies Creek transmission line (2000), 1993; Eklutna Power Project (2000); Lawing to Seward (1991); Summit Lake (1989); Thompson Pass (1989).
- Peratrovich, Nottingham, & Drage, Inc.: Mapping of Whittier Access Project (1998).
- Kodiak Electric Association: Mitigation of Elbow Pass, Terror Lake transmission line (1998).
- Echo Bay Exploration, Inc.: Kensington Mine EIS, avalanche hazard mapping and mitigation studies (1993, 1992, and 1990).
- Municipality of Anchorage: Upper Glacier Creek avalanche hazard mapping study (1993).
- AK Dept of Natural Resources: MP 16 Trailhead evaluation and mapping, Hatcher Pass (1993).
- Bonneville Power Administration and Burlington Northern Railroad: Evaluation and mapping of all microwave repeater sites and access routes in Washington, Idaho, and Montana (1993).
- City and Borough of Juneau: Avalanche and mass wasting analysis and hazard mapping of Behrends Subdivision and White Subdivisions, Juneau, AK (1992)
- Yukon Pacific Corp.: Feasibility study for the proposed Anderson Bay LNG Plant Site, Valdez, AK (1991).
- Alaska Department of Transportation & Public Facilities: Thane Road comprehensive avalanche hazard mapping and mitigation analysis, Phase 1 & 2 studies (1990, 1991).
- Alaska Electric Light & Power Co.: Avalanche & snow creep analysis, Annex Ck. line (1989).
- Alaska Power Administration (Eklutna Project transmission line mitigation, Pioneer Peak (1989).
- Echo Bay Exploration.: A-J Mine EIS evaluation, mapping, and mitigation, Juneau (1989-95).
- U.S. Army: Whittier Tank Farm Facility, avalanche hazard evaluation & mapping (1988).

Operational Avalanche Hazard Management (i.e., avalanche forecasting, snow safety and rescue contingency planning, snow stability evaluation, and/or avalanche control with explosives):

- Full Metal Minerals Ltd., Avalanche hazard assessment for the Lucky Shot Mine Project, Talkeetna Mts., (2006).
- Iditarod Trail Committee, Avalanche hazard assessment and explosive control of Rainy Pass/Dalzell Gorge area (2006).
- City of Seward, Electrical Department, Snow safety plan development, site-assessment, and avalanche forecasting an exposed job site along Kenai Lake where a power line was previously destroyed (2006).
- Anglo-American Summit Project: On-site evaluation of potential avalanche hazard affecting proposed mineral survey operations and training (2005, 2006).
- Chugach Electric Association: On-call avalanche hazard assessments, forecasting, control, training, & technical advice for numerous projects in Chugach and Kenai Mountains (present -1988, yearly).
- Copper Valley Electric Association: Avalanche hazard management, forecasting and explosive control for Solomon Gulch 138 kV T-line Avalanche Repair Projects (2006, 2003, 2000, 1988).
- City of Valdez: Avalanche forecasting for Mineral Creek Subdivision, Valdez (2000).
- Alaska Department of Labor, Labor Standards and Safety Division: Operational avalanche evaluation of Power Creek Hydroelectric Project, Cordova (2001, 2000).
- IT Corporation: Hazard evaluation of job site, Whittier Tank Farm Facility (2000).
- Wilder Construction: Avalanche forecasting for Bird Hill Landslide Stabilization Project (2000).
- Norcon, Inc.: Avalanche hazard management for major repair projects: Bird Hill, Kern Creek, Hope Road, Lower Summit Lake, and Whittier, AK (2000, 1999).
- City Electric, Inc.: Hazard management for Bird Hill Transmission Line Project (1998).
- Echo Bay Alaska, Inc.: Managed A-J Mine Avalanche Safety Program (daily avalanche forecasting and control), 1995-1989; developed A-J Mine Avalanche Safety Plan (1995, 1989).
- Herndon and Thompson, Inc.: Avalanche safety plan and rescue contingency training for Seward Highway Reconstruction Project (1995).
- Kiewit Pacific Company: Avalanche forecasting for the Seward Highway Reconstruction Project (1993- 94), developed Avalanche Safety Plan (1993).
- World Extreme Skiing Championships: Preliminary site evaluation and rescue contingency planning, Thompson Pass (1991).
- Rockford Corporation: Avalanche hazard management for Bird Hill Pipeline Project (1991).
- TAB Electric: Avalanche forecasting for Peterson Creek Powerline Reconstruction (1990).
- Alaska Power Administration: Avalanche forecasting and control for Pioneer Peak Powerline Reconstruction Project (1988).

Other Technical Expertise:

- Murdock & Assoc., Technical advice in civil litigation due to negligence resulting in an avalanche death within a ski area, Hutchison vs. Powdr Corp. (2005-2007)
- Alaska Mountain Rescue Group, Site commander and team leader for numerous search, rescue, and recovery missions. Training coordinator, 16 years. (1974-2000).
- Alaska State Troopers: On-call rescue response hazard assessment (present--1970s).
- AK Dept. of Law, Attorney General: Technical advice, civil litigation: Brookman vs. State of Alaska, 2002.
- Alaska Dept. of Law, Office of Special Prosecutions and Appeals: Expert witness and technical consultant, for the first conviction in US history of a company charged with criminally negligent homicide in the avalanche death of an employee, State of Alaska vs. Whitewater Engineering, (2001).
- Alaska Dept of Labor, Occupational Safety and Health: Consultant and expert witness: job safety violations and negligence, State Dep. of Labor vs. Whitewater Engineering (2001-1999).
- Alaska Dept. of Natural Resources: Technical input & review of educational interpretive signs (2001).
- Alaska Division of Emergency Services: On-call hazard evaluations for southcentral Alaska and technical advice during the Millennium Avalanche Cycle (2000).
- Dillon and Findley: Technical advice, civil litigation: Stone vs. Whitewater Engineering, (1999).
- Mestes LLD: Expert witness, civil litigation: Rizer vs. Sebu & Alyeska Resort, (1993-4).

Documentary Projects/Feature Films (safety coordination, technical stunt set-up, avalanche detonation, pyrotechnics, and/or logistics coordination):

- Wild Survival with Corben Bernsen, Warren Miller Films, Colorado (*Episode 150: Avalanche Rescue*, 2002).
- Kroschel Films, Minnesota (*Into the White*, 2001; Avalanche, 1997; *Seven Years in Tibet*, 1997; *Black Feather*, 1995, *Running Free* 1993).
- IMAX, AH Productions, Colorado (*Avalanche Hunter*, 2001)
- Discovery Channel, Pioneer Productions, UK (*White Out*, 2001; *Storm Watch*: *Avalanche*, 1999).
- Dateline NBC (Segment on avalanches, 1999).
- National Geographic Television (*Avalanche: The White Death*, 1999).
- NOVA, WGBH/Boston (*Preview Avalanche* and *Avalanche*, 1997).
- IMAX film on Alaska, Hollywood Productions, California, (1996).
- National Geographic Society Explorer Series, Okapi Productions, NJ (*Avalanche*, 1995).

- PBS, New Media, Inc., Connecticut, (Trailside: Make your own Adventure (*Kayaking in Glacier Country*, 1993).
- Good Morning America, segment on avalanches, (circa 1990).

Avalanche Hazard Management Training (i.e., avalanche hazard recognition, assessment, management, rescue response, avoidance., decision making, and safety)
Principal instructor in over 450 major avalanche workshops held throughout Alaska, the western U.S., and Canada. Custom training has been provided to the following and to numerous other organizations:

AK. Dept of Transportation & Public Facilities Alyeska Pipeline Service Co.
Alaska Mountain Rescue Group
Alaska State Troopers Alpine Meadows Ski Area
American Avalanche Institute
Anchorage, Sitka, & Valdez, AK Fire Depts. Aspen Mountain Rescue
Aspen Highlands Ski Area
Chugach Electric Association, Inc.
ICE-SAR (Icelandic Search and Rescue Org.) Juneau Mountain Rescue

***PROFESSIONAL EXPERIENCE*:**

Portland Mountain Rescue
National Avalanche School
National Outdoor Leadership School
National Park Service
North Slope Borough Search & Rescue Team Sitka Volunteer Search & Rescue Team
U.S. Army, Northern Warfare Training Center
U.S. Forest Service
U.S. Natural Resources Conservation Service U.S. Navy Seals
210th Air Nat. Guard Para-Rescue Squadron

Present-1986, Avalanche Hazard Consultant and Co-Director, **Alaska Mountain Safety Center**, Inc. (AMSC). Co-founded by Doug Fesler and Jill Fredston in 1986, the AMSC was established as a non-profit organization “to promote public safety in the mountain environment through education, consulting, research, and publishing.” Much of the work involves providing avalanche hazard consulting services to industry, government, and the private sector within Alaska and the western U.S. As a public service to the recreational public, the AMSC also operates the highly respected and popular Alaska Avalanche School, the Reach and Teach and Training the Trainers Programs,, and provide custom avalanche safety training to pro-patrolman, rescue squads, construction crews, law enforcement, park rangers, linemen, operational supervisors, land managers, and others. Additionally, the AMSC publishes and distributes *Snow Sense, A Guide to Evaluating Snow Avalanche Hazard*, rev. 1999, 1984, and *The Avalanche Inclinometer, 2002, 1996*. It also maintains the *Alaska Avalanche Database,* a compilation of more than 4500 historical avalanche events affecting people and facilities in Alaska. Founding member American Association of Avalanche Professionals, former board member and chairman of the education committee, 1986-1988.

1986-1979, Director, Alaska Snow Avalanche Safety Program, Alaska Department of Natural Resources: Developed, implemented, and coordinated a statewide avalanche information program responsible for: a) providing assistance to government agencies in identifying and mitigating avalanche hazards, b) investigating avalanche accidents, c) compiling a statewide data base of avalanche occurrences, and d) coordinating a comprehensive statewide avalanche safety education program under the Alaska Avalanche School.

1979-1975, Chief Ranger, Chugach State Park, AK Dept. of Natural Resources. Responsible for all field operations, including avalanche forecasting, search and rescue, law enforcement, interpretation, and maintenance programs within Chugach State Park, a nearly half million acre park adjoining Anchorage. During this period, Fesler co-founded the Alaska Avalanche Forecast Center, the Southcentral Alaska Avalanche Committee, the Anchorage Search and Rescue Council, and founded the Alaska Avalanche School, and the Chugach State Park Fast Action Response Team. Additionally, from 1971 to 1975, Fesler was heavily involved in search and rescue, law enforcement, and public education as a park ranger in Chugach State Park.

EDUCATION:

Bachelor of Science: Sociology and Education, North Dakota State University, 1969. Additional studies: University of Alaska, Anchorage, 1970, and University of Maine, 1968. Additional training includes: Alaska Public Safety Academy, 580 hrs law enforcement training, certified Special Officer of the Dept. of Public Safety (1971-1979); EMT I training, 88 hrs (1976) and 120 hrs (1979); Managing the Search and Rescue Function course (1978) and Managing the Lost Person Incident (1998), Alaska Blasters Course, Certified Avalanche Blaster, 1978.

***PUBLICATIONS*:**

Fredston and Fesler, revised 1999, 1984, *Snow Sense: A Guide to Evaluating Snow Avalanche Hazard*, AMSC, Anchorage, AK, 116 pages (recognized for more than a decade as the leading, small authoritative reference on the subject). In addition, Fesler has published, or been the subject of, numerous articles, stories, papers, and films relating to public awareness of avalanche hazard. Recent publications include:

- *Is It Safe?: Evaluating Avalanche Hazard*, Ski Patrol Magazine, Vol. 19, No. 2, pp 48-51, National Ski Patrol, (March 2003).
- *Avalanche Safety* (avalanche brochure for snowmobilers), co-authored with Jill Fredston, AMSC), Snowmobile Trail Grants Program, Alaska Department of Natural Resources, (2003).
- *Avalanche Awareness* (avalanche brochure for backcountry travelers), co-authored with Jill Fredston, AMSC), Alaska State Troopers, (2003).
- *The Avalanche Evaluator Guidebook*, (a avalanche slope measuring tool with avalanche hazard evaluation checklist and a detailed instruction booklet for evaluating potential avalanche hazard) AMSC, (2002).
- *A Look at Terrain Analysis*, National Avalanche School, (May 1999).

HONORS:

- 2004, Alaska Department of Public Safety, *Certificate of Recognition*
- 2002, American Avalanche Association, *Honorary Lifetime Member Award*, (highest honor)
- 2002, Mountain Rescue Association of USA, *Distinguished Lifetime Service Award*
- 2000, Alaska Mountain Rescue Group, *Honorary Recognition (for courageous & dedicated service from 1974-2000.)*
- 1995, Anchorage Fire Department, *Lifesaver Award*
- 1994, American Association of Avalanche Professionals, *Special Service Award*
- 1990, United States Army, Northern Warfare Training Center, *Certificate of Achievement*
- 1989, Mountaineering Club of Alaska, *Honorary Lifetime Membership Award*

13.12.5. **Edward LaChapelle, reviewer**

Edward LaChapelle died in 2007, after his review of the 2006 Final EIS, Juneau Access Appendix J, Snow Avalanche Report. He was a pioneer in the avalanche field who was known to all by reputation, and no resumé is available among his papers, or online.

His accomplishments include the development, with Monty Atwater, of the use of explosives for avalanche mitigation for both highways and ski areas; and the development of the original propane-oxygen exploders that led to today’s widely used GazEx exploders. The research center at Alta, Utah worked closely with Utah DOT as well as the ski areas, and the INSTAAR project in the San Juan Mountains researched avalanche mitigation on Colorado Highway 550’s Coal Bank/Molas and Red Mountain Passes.

Wikipedia Entry States

“Edward Randle "Ed" LaChapelle (May 31, 1926 – February 1, 2007) was an American avalanche researcher, glaciologist, mountaineer, skier, author, and professor. He was a pioneer in the field of avalanche research and forecasting in North America.”

Education and Research Experience, from Wikipedia

“Following high school at Stadium High School, he served in the Navy from 1944 to 1946, and then attended the University of Puget Sound, graduating in 1949 with degrees in physics and math.

He then studied at the Swiss Federal Institute for Snow and Avalanche Research in Davos, Switzerland from 1950 to 1951, and returned to the US to work as a snow ranger for the Forest Service in Alta, Utah starting in 1952.

Montgomery Atwater, who had established the first avalanche research center in the Western Hemisphere at Alta over the preceding 7 years, said of his hew hire: "To describe Ed LaChapelle is to write the specifications for an avalanche researcher: graduate physicist, glaciologist with a year's study at the Avalanche Institute, skilled craftsman in the shop, expert ski mountaineer. He even looked like a scientist, tall and slender with a slight stoop and that remote look in his eye which means peering into one's own mind." LaChapelle worked at Alta for the next two decades, eventually becoming head of the avalanche center."

From 1967 to 1982, LaChapelle was professor of atmospheric sciences and geophysics at the University of Washington, and then professor emeritus following his retirement until his death.

From 1973 to 1977, he was involved in avalanche studies at the Institute for Arctic and Alpine Research (INSTAAR) of the University of Colorado at Boulder.

In 1968, he was involved in the development of the avalanche transceiver, which has since become a standard piece of safety equipment for backcountry skiing.

He also travelled extensively to do research on snowfall and glaciers in Greenland, Alaska, and notably the Blue Glacier on Mount Olympus in Washington.

Wikipedia lists these books by Edward LaChapelle

- LaChapelle, Edward R. (1985). The ABC Of Avalanche Safety. The Mountaineers. ISBN 0-89886-103-9.
- Ferguson, Sue A.; LaChapelle, Edward R. (2003). The ABCs Of Avalanche Safety. Mountaineers Books. ISBN 0-89886-885-8.
- LaChapelle, Edward R. (2001). Field Guide to Snow Crystals. International Glaciological Society. ISBN 0-295-98151-2.
- LaChapelle, Edward R. (2001). Secrets of the Snow : Visual Clues to Avalanche and Ski Conditions. University of Washington Press. ISBN 0-295-98151-2.
- Post, Austin; LaChapelle, Edward R. (2000). Glacier Ice. University of Washington Press. ISBN 0-295-97910-0.

Notes[edit]

1 Jump up

^ Atwater (1968), p. 114.

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- Berwyn, Bob (2007-02-02). "Skiing community loses a pillar". Summit Daily News. Retrieved 2007-02-19.

• Stettler, Jeremiah (2007-02-04). "Renowned avalanche researcher dies". The Salt Lake Tribune. Retrieved 2007-02-19.
• Young, Bob (2007-02-11). "Avalanche researcher "a giant in his field"". NewWest. Retrieved 2007-02-19.
• Goodwin, Stephen (2007-02-15). "Ed LaChapelle: Snow scientist and author of 'The ABC of Avalanche Safety'". The Independent. Retrieved 2007-02-25.
• Skoog, Lowell (2001-12-05). "Alpenglow Ski History - Edward R. LaChapelle". taped phone interview. Retrieved 2007-02-19.
• Atwater, Montgomery M. (1968). The Avalanche Hunters. Macrae Smith Company. ISBN 0-8255-1345-6.
• LaChapelle, Dolores (1993). Deep Powder Snow: Forty Years of Ecstatic Skiing, Avalanches, and Earth Wisdom. Kivakí Press. ISBN 1-882308-21-2.

13.12.6. **Chris Landry, reviewer**

Christopher C. Landry – Former Executive Director

Center for Snow and Avalanche Studies
Silverton, CO

Chris Landry served as the Executive Director for the Center for Snow and Avalanche Studies since its founding in 2002, in Silverton, CO until his succession by Jeff Derry in the fall of 2015. As founder of CSAS, Landry identified and then developed the CSAS's Senator Beck Basin Study Area on Red Mountain Pass in the San Juan Mountains, at Red Mountain Pass. CSAS and its Senator Beck Basin have become a venue for long-term mountain system monitoring, interdisciplinary American and international snow system research, field education, international dust-on-snow workshops, and the home base for the Colorado Dust-On-Snow program (CODOS), a state-wide dust-on-snow and mountain snowmelt monitoring program providing operational monitoring and analysis services to the Colorado water management community.

EDUCATION
2002: Master of Science – Earth Sciences, Montana State University, Bozeman.

1984: Bachelor of Arts - Loretto Heights College, Denver, Colorado

EMPLOYMENT
2002-2015: Exec. Director, Center for Snow and Avalanche Studies, Silverton, Colorado.

2001-2002: Research Assistant, Dept. of Earth Sciences, Montana State University – Bozeman

1992-1999: President, lead forecaster, Yule Creek Avalanche Services, Inc.

AFFILIATIONS
Professional Member – American Avalanche Association (1995 through present)
Affiliate Member – Canadian Avalanche Association (1997 through present)
Member – American Geophysical Union (2001 through present)

Refereed Publications

2016: Axson, J. L., H. Shen, A. L. Bondy, C. C. Landry, J. Welz, J. M. Creamean, A. P. Ault (2016), Transported Mineral Dust Deposition Case Study at a Hydrologically Sensitive Mountain Site: Size and Composition Shifts in Ambient Aerosol and Snowpack, *Aerosol and Air Quality Res.*, 16: 555-567, doi:10.4209/aaqr.2015.05.0346

2015: Lapo, K. E., L. M. Hinkelman, C. C. Landry, A. K. Massmann, and J. D. Lundquist (2015), A simple algorithm for identifying periods of snow accumulation on a radiometer, *Water Resour. Res.*, 51, doi:10.1002/2015WR017590.

2014: Chen, Y., C. M. Naud, I. Rangwala, C. C. Landry, and J. R. Miller, Comparison of the sensitivity of surface downward longwave radiation to changes in water vapor at two high elevation sites, *Environ. Res. Lett.* 9 (2014) doi:10.1088/1748-9326/9/11/114015

2014: Landry, C. C., K. A. Buck, M. S. Raleigh, and M. P. Clark (2014), Mountain system monitoring at Senator Beck Basin, San Juan Mountains, Colorado: A new integrative data source to develop and evaluate models of snow and hydrologic processes, *Water Resour. Res.*, 50, doi:10.1002/2013WR013711.

2013: Raleigh, M. S., C. C. Landry, M. Hayashi, W. L. Quinton, and J. D. Lundquist (2013), Approximating snow surface temperature from standard temperature and humidity data: New possibilities for snow model and remote sensing evaluation, *Water Resour. Res.*, 49, 8053–8069, doi:10.1002/2013WR013958.

2012: Painter, T. H., S. M. Skiles, J. S. Deems, A. C. Bryant, and C. Landry. Dust radiative forcing in snow of the Upper Colorado River Basin: Part I. A 6 year record of energy balance, radiation, and dust concentrations, *Water Resour. Res.*, doi:10.1029/2012WR011985.

2012: Skiles, S. M., T. H. Painter, J. S. Deems, A. C. Bryant, and C. Landry. Dust radiative forcing in snow of the Upper Colorado River Basin: Part II. Interannual variability in radiative forcing and snowmelt rates, *Water Resour. Res.*, doi:10.1029/2012WR011986.

2012: Naud, C. M., J. R. Miller, and C. Landry. Using satellites to investigate the sensitivity of longwave downward radiation to water vapor at high elevations, *J. Geophys. Res.*, 117, D05101, doi:10.1029/2011JD016917.

2010: Painter, T.H., J.S. Deems, J. Belnap, A. Hamlet, C. Landry, B. Udall. Response of Colorado River runoff to dust radiative forcing in snow. *Proc. National Academy of Sciences* Sept. 2010 (in press).

2010: Simonson, S.E., E. Greene, S. Fasnacht, T. Stohlgren and C. Landry. Practical Methods for Using Vegetation Patterns to Estimate Avalanche Frequency Magnitude. *Proceedings of the 2010 International Snow Science Workshop*, Squaw Valley, California.

2010: Lawrence, C. R., T. H. Painter, C. C. Landry, and J. C. Neff. Contemporary geochemical composition and flux of aeolian dust to the San Juan Mountains, Colorado, United States, J. Geophys. Res., 115, G03007, doi:10.1029/2009JG001077.

2009: Steltzer, H., C. Landry, T.H. Painter, J. Anderson, E. Ayres. Biological consequences of earlier snowmelt from desert dust deposition in alpine landscapes, *Proc. National Academy*

of Sciences 2009 106:11629-11634; published online before print June 29, 2009, doi:10.1073/pnas.0900758106

2008: Neff, J.C., A.P. Ballantine, G.L. Farmer, N.M. Mahowald, J.L. Conroy, C.C. Landry, J.T. Overpeck, T.H. Painter, C.R. Lawrence, R.L. Reynolds. Increasing eolian deposition in the western United Sates linked to human activity. *Nature Geoscience*, doi:10.1038/ngeo133

2007: Painter, T. H., A. P. Barrett, C. C. Landry, J. C. Neff, M. P. Cassidy, C. R. Lawrence, K. E. McBride, G. L. Farmer. Impact of disturbed desert soils on duration of mountain snow cover. *Geophys. Res. Lett*., 34, L12502, doi:10.1029/2007GL030284.

2006: Marshall, H.P., G. Koh, M. Sturm, J. Johnson, M. Demuth, C. Landry, J. Deems, A. Gleason. Spatial variability of the snowpack: experiences with measurements at a wide range of length scales with several different high precision methods. Proceedings International Snow Science Workshop 2006, p. 359-364.

2004: Landry, C., K. Birkeland, K. Hansen, J. Borkowski, R. Brown and R. Aspinall. Snow stability on uniform slopes: implications for extrapolation. *Cold Regions Science and Technology*, Vol. 39, Nos. 2-3, p. 205-218.

2002: Birkeland, K.W. and C.C. Landry. Power-laws and snow avalanches. *Geophysical Research Letters,* Vol. 29, No. 11, 10.1029/2001GL014623, p. 49 1-3.

2001: Landry, C.C., J. Borkowski, and R.L. Brown. Quantified loaded column stability test: mechanics, procedure, sample-size selection, and trials. *Cold Regions Science and Technology*, Vol. 33, p. 103-121.

PRESENTATIONS:

Sept 29, 2014: Chris Landry presented a poster and paper on “Desert Dust and Snow Stability” at the International Snow Science Workshop in Banff, Alberta.

Nov 8, 2012: Chris Landry presented "Snow system interannual variability case study - WY 2011 and WY 2012" at the Upper Colorado River Basin Conference, Grand Junction, CO.

July 16-20, 2012: Presented Senator Beck Basin Mountain System Observatory poster at the CUHASI meeting in Boulder, CO.

April 19, 2012: Mountain System Processes and Change Presentation to the Seven Basin States Technical Committee in Las Vegas, NV.

April 18, 2012: Guest Lecture on dust-on-snow and Senator Beck Basin for Bureau of Reclamation Lower Basin Offices, Las Vegas, NV.

Feb 24, 2011: Upper Rio Grande Watershed Snowmelt Impacts of Dust-on-Snow presented to the Annual Meeting of the Engineer Advisors to the Rio Grande Compact Commission in Albuquerque, NM.

Jan 31, 2012: Dust-on-Snow is Affecting Colorado Snowmelt Water Supplies presented to the CSU Agricultural Advisory Committee, Southwestern Colorado Research Center.

Nov 3, 2011: Dust-on-Snow in Colorado and its Hydrological Effects presented at the Public Lands Partnership meeting in Montrose, CO.

Oct 31, 2011: Proposed Alpine to Arid Hydrologic & Ecological Observatory presented at Mesa University in Grand Junction, CO.

Oct 8, 2010: Dust-on-Snow and Colorado Avalanche Processes at CAIC's Colorado Snow and Avalanche Workshop in Leadville, CO.

Oct 7, 2010: Presentation about the Colorado Dust-on-Snow Program at the Mountain Studies Institute Climate Conference in Silverton, CO.

Oct 1, 2011: Mountain System and Plant Community Monitoring presented at the Colorado Native Plant Society meeting in Carbondale, CO.

Aug 19, 2010: Dust-on-Snow in Colorado presented to Denver Water, Denver, CO.

Feb 11, 2010: How Dust-on-Snow is Complicating Ditch and Reservoir Operations presented to the Ditch and Reservoir Company Alliance (DARCA) Annual Convention, Durango, CO

Nov 19, 2009: The Martian Winter of 2008-2009 presented to the Colorado Cattlemen's Association, Colorado Springs, CO.

Nov 18, 2009: USFS Climate and Water Presentation, Boulder, CO.

August 20, 2009: The Martian Winter of 2008-2009 presented to the Colorado Water Congress, Steamboat Springs, CO.

June 9-12, 2008: Mountain System Monitoring and Research Synergies talk at the MTNCLIM 2008 Conference, Silverton, CO.

March 2008: Colorado State 2008 Hydrology Days presentation: Integrated mountain system monitoring and snow system research at Senator Beck Basin, San Juan Mountains, Southwest Colorado

July 2007: CSAS Presents Dust-on-Snow Talk at Colorado Water Workshop, Gunnison, CO.

April 2007: Talk Presented to the Spring Runoff Conference at Utah State University, Logan, UT.

Oct 2005: Landry co-hosts, with the University of Colorado 's Cooperative Institute for Research in Environmental Sciences, a Snow System Science Workshop, Boulder, CO.

March 2005: Presented poster at MTNCLIM2005, a conference, Pray, MT

December 2004: Presented poster titled, "Mountain Snow System Interactions" and featuring our dust on snow pilot study and a discussion of avalanche formation processes interactions at the Fall Meeting of the American Geophysical Union held in San Francisco, CA.

Sept 2004: Presented poster introducing the CSAS to the avalanche scientists in attendance at the 2004 International Snow Science Workshop Conference held September 19-24, 2004 in Jackson Hole, WY.

April 2003: Center for Snow and Avalanche Studies introduced our Senator Beck Basin Study Area to the Western Snow Conference in Vancouver, BC

Additionally, dozens of routine fall presentations regarding dust-on-snow to CODOS program funding agencies, 2006-2015.

POPULAR PRESS

During the 2002-2015 period Landry was interviewed and/or quoted in popular press articles by the New York Times, Wall Street Journal, Los Angeles Times, Denver Post, Arizona Republic, National Public Radio, National Science Foundation Discovery, Le Monde, GEO, Backcountry Magazine, Skiing Magazine, Colorado Springs Gazette, Aspen Times, Grand Junction Daily Sentinel, Crested Butte News, Gunnison Country Times, Pueblo Chieftan, Durango Herald, and Silverton Standard, as well as other minor publications.

AFFILIATIONS:

American Geophysical Union

American Avalanche Association – Professional Member

Canadian Avalanche Association – Affiliate Member