Juneau Access Improvements Project
Draft Supplemental Environmental Impact Statement

2013 Update to Appendix J
Snow Avalanche Report

Prepared for:

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

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Prepared by:

Alaska Avalanche Specialists
P.O. Box 22316
Juneau, AK 99802

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Table of Contents

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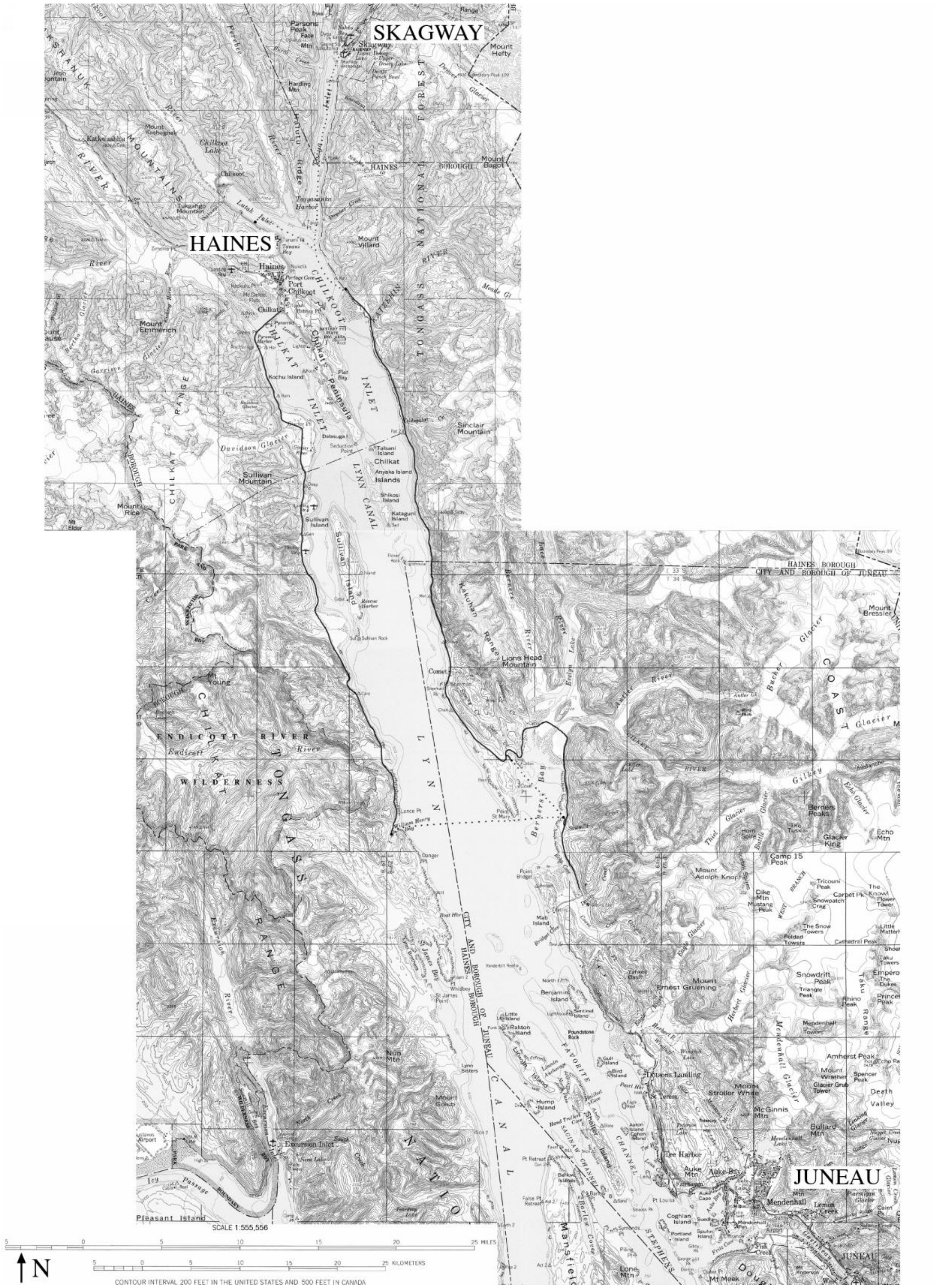
1. Lynn Canal Vicinity Map



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 2013 East Lynn Canal alignment is affected by 43 avalanche paths, and the West Lynn Canal alignment is affected by 19 paths.

2.2. ***2013 Update***

This report updates the 2004 SDEIS Appendix J, Snow Avalanche Technical Report, and the 2005 FEIS Addendum to Appendix J. Except for the updates, the information in the 2004 and 2005 documents is still valid. New information in this report includes revised traffic projections, new alignments, new costs, and new mitigation technologies and 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.

In this study, the AHI calculations have been updated to reflect the results of additional geotechnical and environmental studies. Mitigation alternatives and cost figures are also updated. The unmitigated AHI figure for the current East Lynn Canal alignment is now 288, and for the West Lynn Canal alignment it is 101.

The unmitigated AHI figures for both alignments fall in the high or very high category, but are in the middle of 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 options studied 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 forecasting, warnings, highway closures, and explosives, 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 options evaluated 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, 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	$8,603,893	$1,665,746	12.1	9.9	0.8-2.2	27.7
G W Lynn, DOTPF, Howitzer plus Blaster Boxes	$8,025,234	$1,384,025	5.5	8.4	0.4-1.0	17.9

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 the 2013 SDEIS update process, this report updates the 2005 SDEIS Appendix J, Snow Avalanche Technical Report, and the 2006 FEIS Addendum to Appendix J. Except for the updates, the information in the 2004 and 2005 documents is still valid. New and updated information includes revised traffic projections, new alignments, changes in costs, and new mitigation technologies.

Two alternative highway alignments are being considered. 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 17 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 460 vehicles per day on the East Lynn Canal route and 365 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 2013 Lynn Canal alternatives are 288 for East Lynn Canal and 101 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 the lowest-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 some slide paths. Elevated fills that raise the highway above the avalanche flow level 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.

The remaining avalanche hazard is managed through an industry-standard program of risk management using a combination of forecasting, explosives, and preventive highway closures. 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, makeup and standby helicopter time, time spent waiting for charges to go off, 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 five 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. Blaster boxes are one of several special explosive delivery methods using a fixed, remotely-operated installation. They are evaluated here as a representative sample of the fixed installation methods currently available. Like many of these methods, they are relatively new technology that may prove to be limited by such coastal climate factors as rime ice buildup. They 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.

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.

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, and avalanche program operating costs approximately equal to the Daisy Bell option, but total highway closure time is greatest under this option.

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 avalanche program capital cost is $150,000 more than for Option A, the avalanche program operating costs are a little over $28,000 lower, and the closure times are 13 percent lower.

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 by 39 percent over Option A, but the avalanche program capital costs are roughly $18.7 million higher because it requires expensive howitzer and blaster box installations, and the avalanche program operating costs are over $140,000 higher because it requires substantial helicopter time and expensive howitzer ammunition as well.

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.

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

This option uses blaster boxes on all the paths with a mitigated AHI greater than 1.75, 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, with avalanche program capital costs roughly $4.86 million higher than those for Option A; and servicing them and loading their charges requires substantial helicopter time with avalanche program operating costs a little under $240,000 higher than those for Option A; but these options have the lowest highway closures 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 options ELC 3A and ELC 3B. Avalanche program capital costs are roughly $3.24 million higher than those for Option A, avalanche program operating costs are roughly $165,000 higher, and closures are reduced by 14 percent.

3.8. *West Lynn Canal Mitigation Options*

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

A howitzer could 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.

This option 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.

Avalanche program capital costs are roughly $590,000 lower than those for East Lynn Canal Option A, avalanche program operating costs are a little over $19,000 higher, and closures are 75 percent lower. This option has lower capital costs and lower total closure time than any of the East Lynn Canal options, but has more closure time than option WLC 2.

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 the lowest closure time of any option studied, 79 percent lower than West Lynn Canal Option F, but has high initial capital cost and high helicopter time cost for reloading the blaster boxes. Avalanche program capital costs are roughly $4.28 million higher than those for East Lynn Canal Option A and roughly $4.87 million higher than for West Lynn Canal Option F. Avalanche program operating costs are just under $43,000 lower than those for East Lynn Canal Option A and just over $62,000 higher than for West Lynn Canal Option F.

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,	$3,742,743	$1,426,952	25.9	12.4	0.8-8.0	27.7
B E Lynn, DOTPF, Daisy Bell only	$3,892,743	$1,398,947	22.4	12.4	0.8-8.0	27.7
C E Lynn, DOTPF, Howitzer, plus Blaster Boxes & Helicopter	$22,480,784	$1,570,028	15.8	11.6	0.6-4.1	27.7
D E Lynn, DOTPF, Blaster Boxes, plus Helicopter	$8,603,893	$1,665,746	12.1	9.9	0.8-2.2	27.7
E E Lynn , DOTPF, Limited Blaster Boxes, plus Helicopter	$6,983,893	$1,591,346	22.4	12.4	0.8-6.1	27.7
F W Lynn, DOTPF, Howitzer Only	$3,152,833	$1,446,176	6.4	10.8	0.4-0.9	17.9
G W Lynn, DOTPF, Howitzer plus Blaster Boxes	$8,025,234	$1,384,025	5.5	8.4	0.4-1.0	17.9

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. 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. It is important to avoid the human tendency to regard these short-term variations as trends, and budgetary planning should always consider the more severe winters that will follow. Poor budgeting would result in increased closure time and risk.

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. 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 number 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 formulae 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 460 for the East Lynn Canal highway route and 365 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, stopping distances and chances 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, only limited occurrence data are available from recent reconnaissance observations, and the return periods must be obtained indirectly. This is done by extrapolation from the available reconnaissance data and from avalanche path data in areas around Juneau where a longer record exists.

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.

4.3. *AHI Changes from 2004 and 2005 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 have resulted in a new 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 460 for the East Lynn Canal route and 365 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 as part of 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.

Alignment alternative	Average annual debris
East Lynn Canal,	47,752 cubic yards (36,509 cubic meters)
West Lynn Canal	29,775 cubic yards (22,764 cubic meters)

5. Regional Snowfall

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.

Juneau Airport	96" (2.4 m)
Lena Point	79" (2.0 m)
Tee-Harbor area	145" (3.7 m)
Haines downtown	79" (2.0 m)
Haines Airport	171" (4.3 m)
Haines Highway, Pleasant Camp	250" (6.4 m)
Skagway Airport	52" (1.3 m)
Skagway (harbor)	37" (0.9 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.

Average snowfall at the Haines Highway Pleasant Camp Customs Station, at the base of the pass at 900 feet (274 m) elevation is 316 percent of the Haines downtown figure. That is the same 3x magnitude increase as the summer precipitation from downtown Juneau, compared 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 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, specifically Skagway, is often under the influence of strong downslope conditions that reduce precipitation in snow events, resulting in much less snow near sea level.

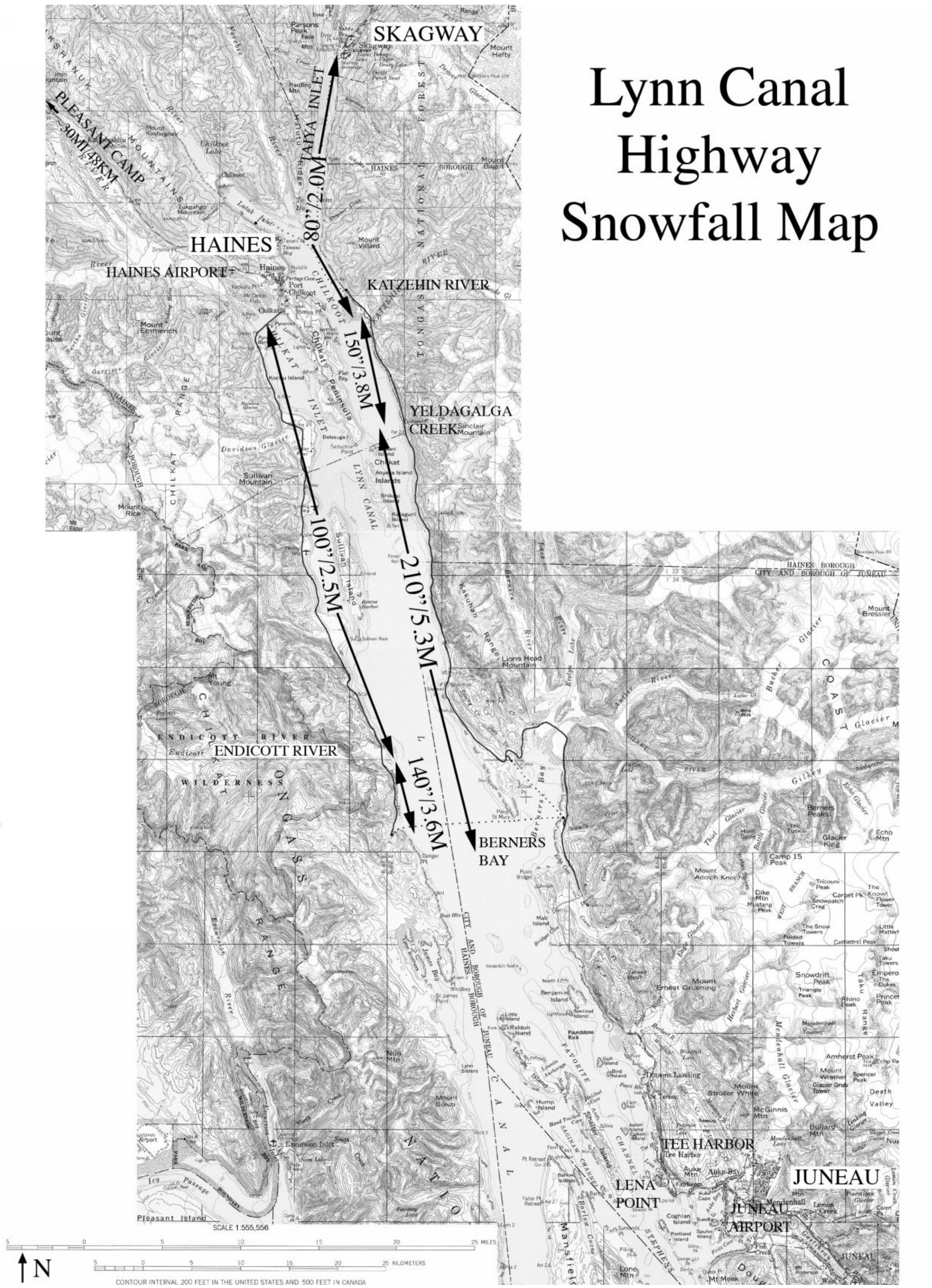
For example, Skagway had 455 consecutive days with no measurable snowfall from November 29, 1937 to December 29, 1938. The Haines area snowfall gradient increases up the Chilkat River because it also becomes closer to steep terrain. Haines can get very large snowfalls; for example, on February 1, 1991 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 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. That 150 percent correction yields snowfall figures of 210 inches (5.3m) from the Berners Bay area to Yeldagalga Creek, 150 inches (3.8 m) from Yeldagalga Creek to the Katzehin River, and 80 inches (2.0 m) from the Katzehin up Taiya Inlet to Skagway, including the Katzehin ferry terminal area. The average of these three figures is 147 inches (3.7 m) for the East Lynn alignment as a whole.

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 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).

Figure 3: Snowfall Map



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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 but not always 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 0.15 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	Little Cottonwood, UT	1045	40
	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	
	Average, Very High AHI highways	**502**	**52**
High AHI highways	Berthoud Pass, CO	93	20
		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	**285**	**31**
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	**234**	**26**
Lynn Canal	**East Lynn, AK (very high)**	**288**	**28**
	West Lynn, AK (very high)	**101**	**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 52, 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	Mitigated AHI	Avalanche Zone, Miles	Residual AHI/ Mile	Avalanche Zone, Km	Residual AHI/ Km
Very High AHI highways	Little Cottonwood, UT	1045	40	7.0	5.7	11.3	3.6
	Rogers Pass, BC	1004	40	24.8	1.6	40.0	1.0
	Red Mtn. Pass, CO	335	70	17.4	4.1	28.0	2.5
	* Seward Highway, AK (Anchorage-Seward, old alignment)	331	70	88.9	0.8	143.1	0.5
	* Seward Highway, AK (Anchorage-Girdwood, old alignment)	188	39	16.5	2.4	26.6	1.5
	Coal Bank/Molas, CO	108	23	34.0	0.7	54.7	0.4
	Average, Very High AHI highways	**502**	**47**	**31.4**	**2.5**	**50.6**	**1.6**
High AHI highways	Berthoud Pass, CO	93	20	16.0	1.2	25.7	0.8
	Coquihalla, BC	90	19	12.4	1.5	20.0	0.9
	Loveland Pass, CO	80	17	8.0	2.1	12.9	1.3
	Wolf Creek Pass, CO	54	11	18.4	0.6	29.6	0.4
	Silverton-Gladstone, CO	49	10	6.5	1.6	10.5	1.0
	Teton Pass, WY	47	10	13.8	0.7	22.2	0.4
	Average, High & Very High AHI highways	**285**	**31**	**22.0**	**1.9**	**35.4**	**1.2**
Moderate AHI highways	Lizard Head Pass, CO	39	8	21.0	0.4	33.8	0.2
	I-70 Tunnel Approaches, (	27	6	15.0	0.4	24.1	0.2
	Thane Road, AK	21	4	2.9	1.5	4.6	1.0
	Average, all highways	**234**	**26**	**20.2**	**1.7**	**32.5**	**1.0**
Lynn Canal	**East Lynn (very high)**	**288**	**28**	**23.0**	**1.2**	**37.0**	**0.8**
	West Lynn, AK (very high)	**101**	**18**	**31.3**	**0.6**	**50.4**	**0.4**

• 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 evaluating 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 available from which to determine absolute probabilities.

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 since 1981, 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.

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

Category	Deaths per Year
Alaska, Motor Vehicle Accidents	100.55
Alaska, Poisoning	81.45
Alaska, Other Accidental Death	44.27
Alaska, Drowning & Submersion	24.64
Alaska, Falls	18.64
Alaska, Suffocation/Choking	16.36
Alaska, Air Transport Accidents	14.64
Alaska, Snow Machine Related Accidents	14.36
Alaska, Water Transport Accidents	13.27
Alaska, Exposure to Smoke, Fire, and Flame	11.55
Alaska, ATV Related Accidents	7.36
Alaska, Other Transport	2.55
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 1999-2009. 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 Parks Highway, 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 traffic death rate for Alaska over the most recent ten-year period for which figures are available is 95 deaths per year, over 1600 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 101 deaths per year. The rate for poisonings is 81 deaths per year, for other transport accidents including air, water, snowmachine, and ATV, it is 52 deaths per year, for drowning and submersion it is 25 per year, for falls it is 19 per year, and for exposure to smoke, fire, and flame it is 12 per year For other accidental deaths, it is 44 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 above the normal avalanche flow level and 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

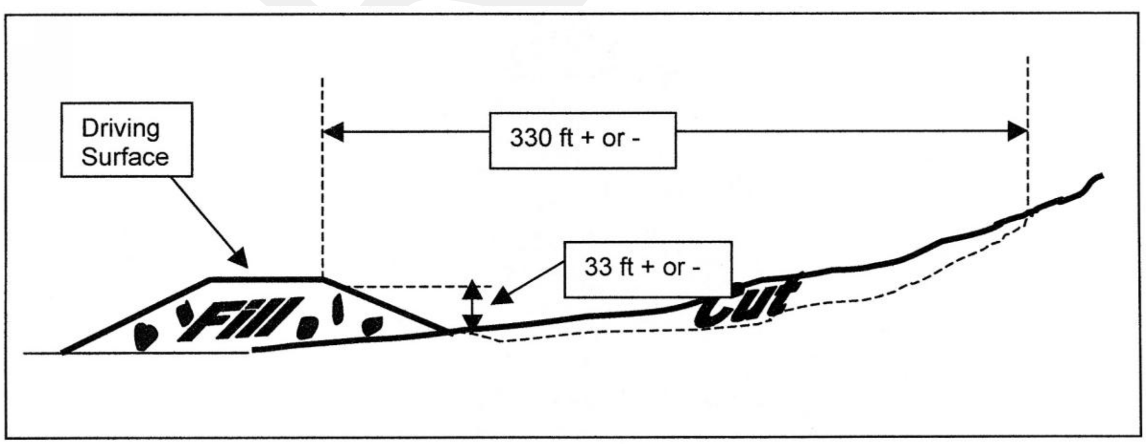


Figure 9: Elevated Fills

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 without applying the additional blanket reduction factor for avalanche forecasting and use of remote exploders and other explosive techniques. The final figures include 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	58.18	0.00	800'/244m snowshed
ELC021	S Yeldagalga	46.99	0.00	400'/122m snowshed
ELC006	Eldred Rock	42.67	8.53	bridge 0.2x
ELC025	N Yeldagalga	19.12	11.47	bridge 0.2x for half
ELC002	N Kensington	17.65	8.82	33'/10m elevated fill 0.5 x
ELC020	S Yeldagalga	16.15	0.00	300'/91m snowshed
ELC026-1	N Yeldagalga	11.30	11.30	
ELC014	Eldred Rock	8.79	4.40	33'/10m elevated fill 0.5 x
ELC026	N Yeldagalga	8.71	1.74	bridge 0.2x
ELC024	S Yeldagalga	8.44	8.44	
ELC023	S Yeldagalga	4.68	4.68	
ELC009	Eldred Rock	4.49	4.49	
ELC008	Eldred Rock	3.99	0.80	bridge 0.2x
ELC031-1	Wild Bird	3.88	3.88	new path
ELC031-2	Wild Bird	3.88	3.88	new path
ELC018	S Yeldagalga	3.82	3.82	
ELC012	Eldred Rock	3.34	0.67	bridge 0.2x
ELC010	Eldred Rock	2.99	2.99	
ELC029	N Yeldagalga	2.93	0.59	bridge 0.2x
ELC011	Eldred Rock	2.68	2.68	
ELC028	N Yeldagalga	2.21	0.44	bridge 0.2x
ELC005	Eldred Rock	2.17	0.43	bridge 0.2x
ELC027	N Yeldagalga	1.90	1.90	
ELC028-1	N Yeldagalga	1.44	1.44	
ELC013	Eldred Rock	1.34	1.34	
ELC028-2	N Yeldagalga	0.97	0.97	
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	0.41	0.00	tunnels
ELC035	N Katzehin	0.22	0.04	fill 0.2x
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**	288.27	92.39	
Total	**With Exploders & Forecasting**	86.48	27.72	

Figure 11: West Lynn Canal Avalanche Paths by AHI

Path #	Path Group	Unmitigated AHI	Structurally Mitigated AHI	notes
WLC006A	Sullivan	17.88	8.94	elevated fill 0.5x
WLC006B	Sullivan	17.88	8.94	elevated fill 0.5x
WLC006C	Sullivan	17.88	17.88	
WLC009A	Rainbow	11.84	5.92	elevated fill 0.5x
WLC009B	Rainbow	11.84	5.92	elevated fill 0.5x
WLC009C	Rainbow	11.84	5.92	elevated fill 0.5x
WLC007	Sullivan	2.50	0.50	bridge 0.2x
WLC008	Rainbow	2.09	0.42	bridge 0.2x
WLC010A	Pyramid	1.20	0.60	elevated fill 0.5x
WLC010B	Pyramid	1.20	0.60	elevated fill 0.5x
WLC010C	Pyramid	1.20	0.60	elevated fill 0.5x
WLC010D	Pyramid	1.20	0.60	elevated fill 0.5x
WLC005	Sullivan	0.88	0.88	
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**	101.29	59.58	
Total	**With Exploders & Forecasting**	30.39	17.87	

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 East Lynn Canal options. They have the disadvantages of high cost, light/shadow vision problems, ice formation, 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.

Colorado avalanche and natural hazards consulting engineers Mears and Wilbur developed preliminary estimated 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.
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.

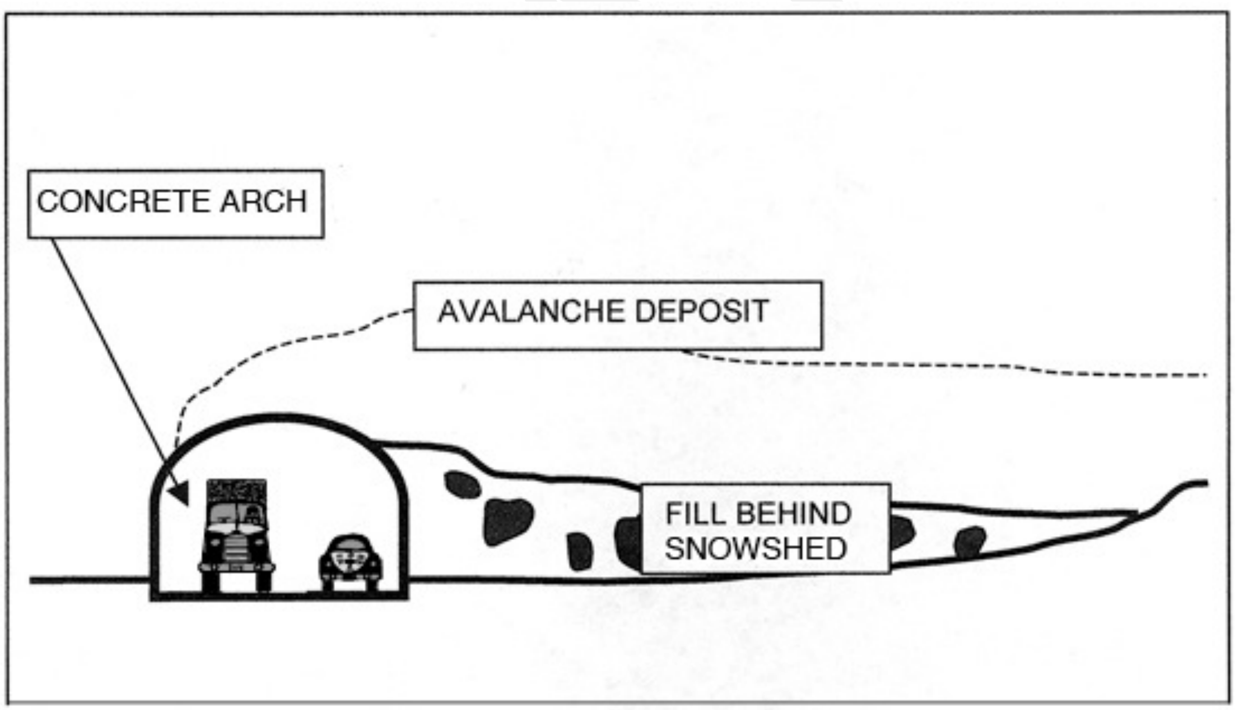
Based on the data and adjustments for inflation, design factors and location, and designing for the 50 to 100 year return period design-magnitude avalanche, they estimated total loads and preliminary costs as shown below.

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 will be budgeted 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, 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 US 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 avalanche specialists and an intern are the core staff of the avalanche program. The East Lynn Canal alternative would require an additional full-time six-month technician position (research analyst I) to provide support. The lead avalanche specialist would be a year-round position, and the assistant forecaster and intern would work a six-month 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 forecasters to alternate working as the forecaster in charge for three days weekly, with the intern 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. At least one specialist would back up the intern during times of potential avalanche activity.

6.4.3. **Staff Qualifications**

The lead avalanche specialist should have minimum qualifications of 10 winters working fulltime as an avalanche specialist, at least four years of professional-level avalanche forecasting experience in a lead position, US Level I and II avalanche training, US professional-level avalanche operations training, and familiarity with local weather patterns and snow conditions. The lead avalanche specialist should also have avalanche explosives experience and experience in developing and operating a major highway 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, US Level I and II avalanche training, US professional-level avalanche operations training, demonstrate a commitment to continuing education, and maintain membership in relevant professional associations.

Field assistants should have US Level I and II avalanche training, and be in a training program leading to a career in the field.

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

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

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.

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 to Haines, where the data could be uploaded to a website.

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 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.

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 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 best develop from thorough training and drilling.

Avalanche explosives historically have dud (unexploded charge) rates of less than one percent. 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, should 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.

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, the potential presence of duds, highway closures, and avalanche areas. 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

There would be a ferry terminal on each highway and a DOT&PF maintenance station near Kensington Mine on the East side route. These structures could serve as emergency refuges.

There is currently only cellular phone coverage in 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.

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, so the downslope side of the cut is opened 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 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. Recommended highway operations and closure guidelines for specific avalanche danger levels 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 are 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 US 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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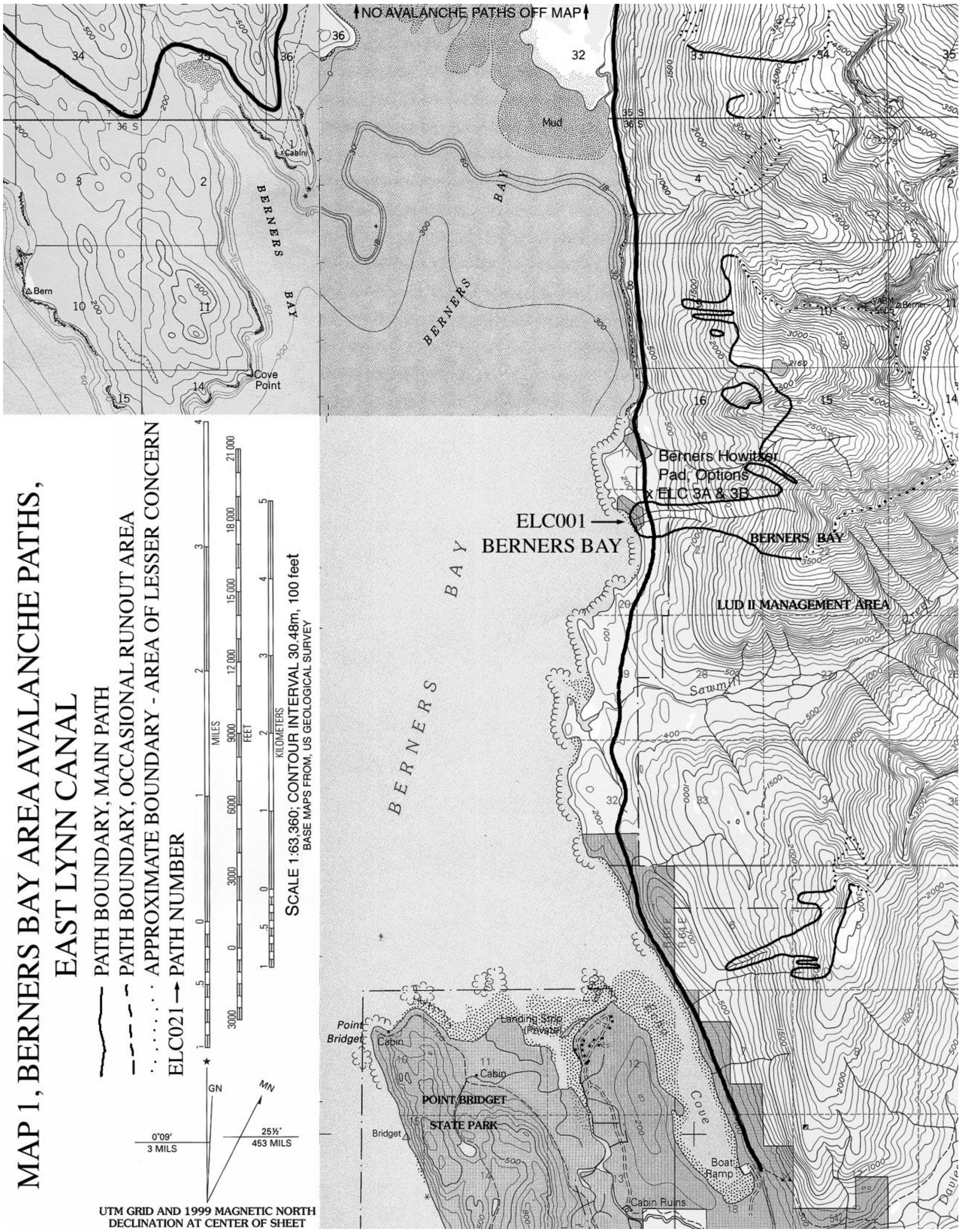
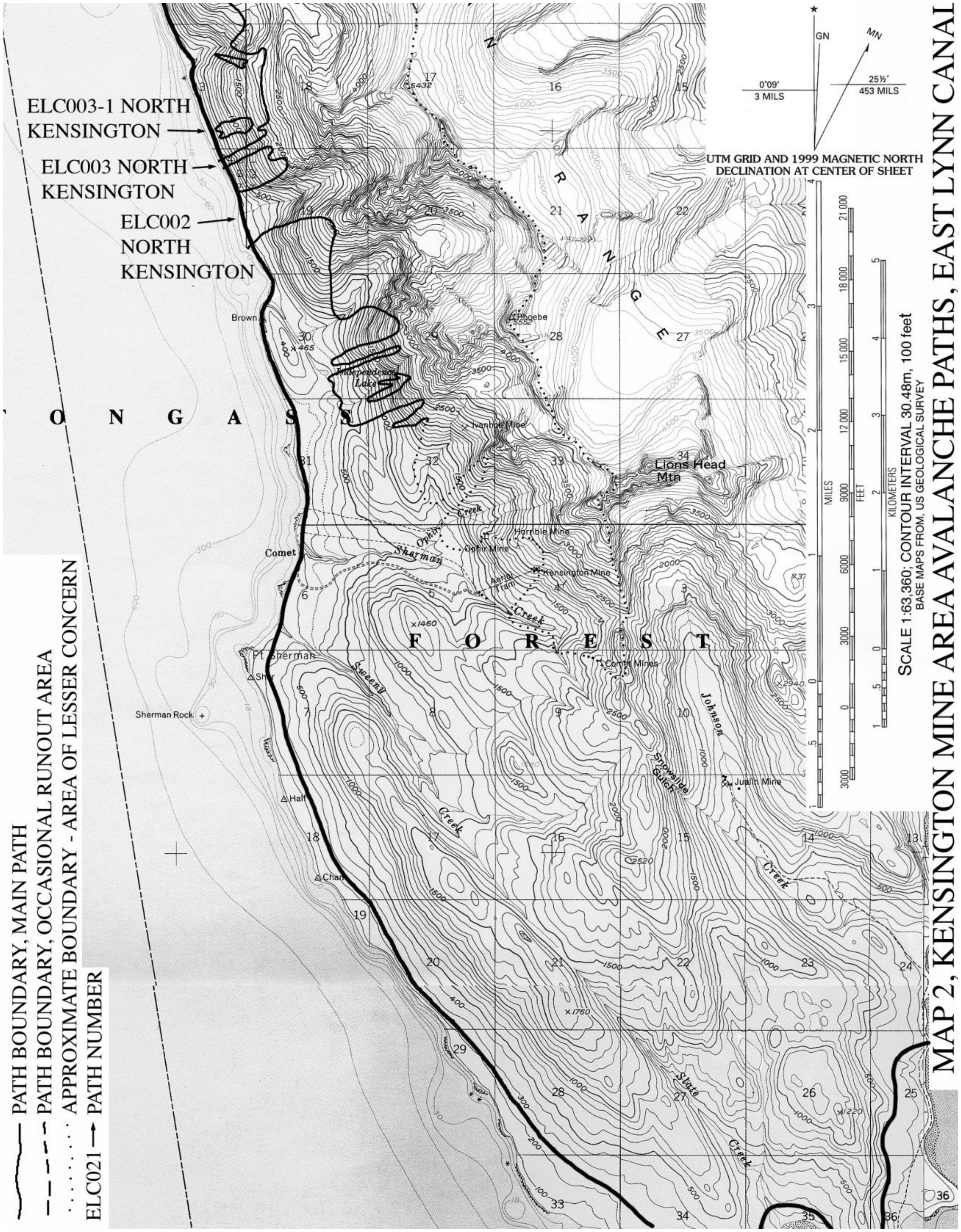
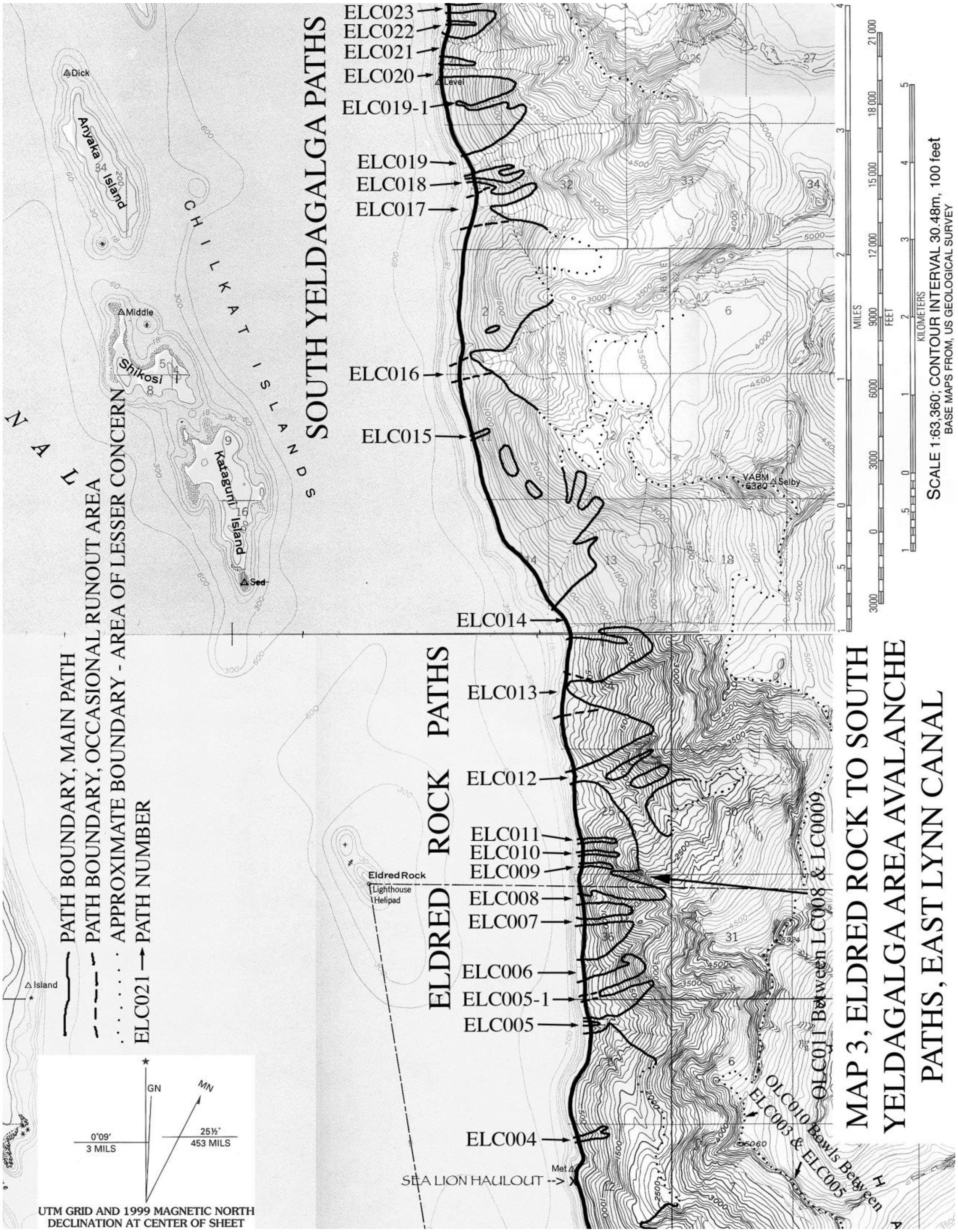

MAP 1, BERNERS BAY AREA AVALANCHE PATHS, EAST LYNN CANAL
PATH BOUNDARY, MAIN PATH
PATH BOUNDARY, OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
ELC021 → PATH NUMBER
MILES
FEET
KILOMETERS
SCALE 1:63,360; CONTOUR INTERVAL 30.48m, 100 feet
BASE MAPS FROM, US GEOLOGICAL SURVEY
GN
MN
0°09′
3 MILS
25½°
453 MILS
UTM GRID AND 1999 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET
NO AVALANCHE PATHS OFF MAP
Mud
BERNERS BAY
Cove Point
Bern
Cabin
Berners Howitzer Pad, Options ELC 3A & 3B
ELC001
BERNERS BAY
BERNERS BAY
LUD II MANAGEMENT AREA
Sawmill
Point Bridget
Landing Strip (Private)
POINT BRIDGET STATE PARK
Bridget
Cove
Boat Ramp
Cabin Ruins


MAP 2, KENSINGTON MINE AREA AVALANCHE PATHS, EAST LYNN CANAL
PATH BOUNDARY, MAIN PATH
PATH BOUNDARY, OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
ELC021 → PATH NUMBER
ELC003-1 NORTH KENSINGTON
ELC003 NORTH KENSINGTON
ELC002 NORTH KENSINGTON
UTM GRID AND 1999 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
GN
MN
0°09′
3 MILS
25½°
453 MILS
SCALE 1:63,360; CONTOUR INTERVAL 30.48m, 100 feet
BASE MAPS FROM US GEOLOGICAL SURVEY
MILES
FEET
KILOMETERS
TONGASS
FOREST
RANGE
Lions Head Mtn
Phoebe
Independence Lake
Ivanhoe Mine
Horrible Mine
Ophir Mine
Kensington Mine
Comet Mines
Jualin Mine
Ophir Creek
Sherman Creek
Sweeny Creek
Johnson Creek
Snowslide Gulch
State Creek
Aerial Tram
Brown
Comet
Pt Sherman
Sherman Rock
Half
Chan


MAP 3, ELDRED ROCK TO SOUTH YELDAGALGA AREA AVALANCHE PATHS, EAST LYNN CANAL
SOUTH YELDAGALGA PATHS
ELDRED ROCK PATHS
PATH BOUNDARY, MAIN PATH
PATH BOUNDARY, OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
ELC021 → PATH NUMBER
ELC023
ELC022
ELC021
ELC020
ELC019-1
ELC019
ELC018
ELC017
ELC016
ELC015
ELC014
ELC013
ELC012
ELC011
ELC010
ELC009
ELC008
ELC007
ELC006
ELC005-1
ELC005
ELC004
OLC011 Between LC008 & LC0009
OLC010 Bowls Between ELC003 & ELC005
SEA LION HAULOUT -->
CHILKAT ISLANDS
Anyaka Island
Shikosi
Katagunl Island
Eldred Rock
Lighthouse
Helipad
SCALE 1:63,360; CONTOUR INTERVAL 30.48m, 100 feet
BASE MAPS FROM, US GEOLOGICAL SURVEY
MILES
FEET
KILOMETERS
UTM GRID AND 1999 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET
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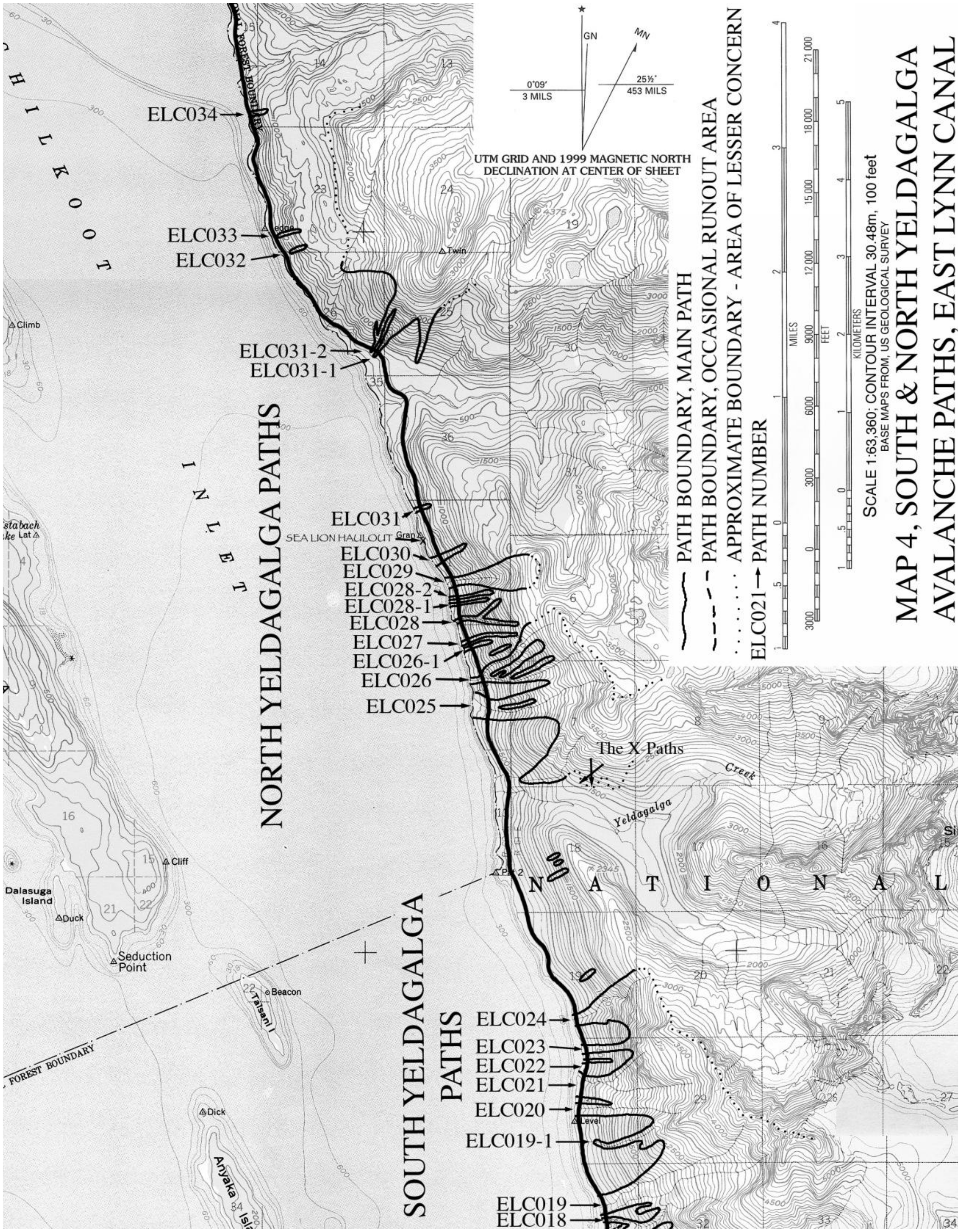
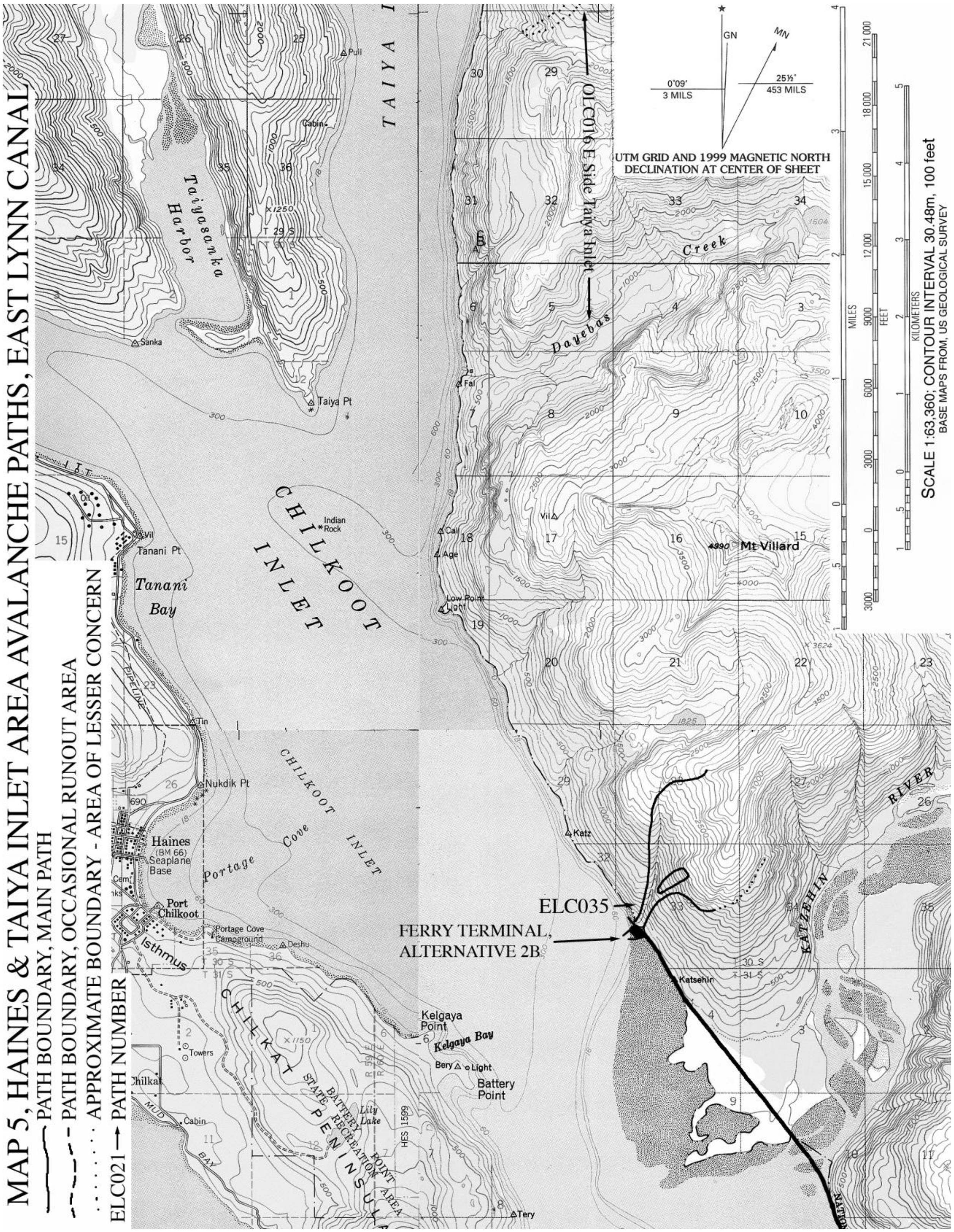

MAP 4, SOUTH & NORTH YELDAGALGA
AVALANCHE PATHS, EAST LYNN CANAL
SCALE 1:63,360; CONTOUR INTERVAL 30.48m, 100 feet
BASE MAPS FROM, US GEOLOGICAL SURVEY
PATH BOUNDARY, MAIN PATH
PATH BOUNDARY, OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
ELC021 PATH NUMBER
UTM GRID AND 1999 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET
GN
MN
0°09′
3 MILS
25½°
453 MILS
MILES
FEET
KILOMETERS
NORTH YELDAGALGA PATHS
SOUTH YELDAGALGA
PATHS
CHILKOOT INLET
NATIONAL
FOREST BOUNDARY
ELC034
ELC033
ELC032
ELC031-2
ELC031-1
ELC031
SEA LION HAULOUT
ELC030
ELC029
ELC028-2
ELC028-1
ELC028
ELC027
ELC026-1
ELC026
ELC025
The X-Paths
Yeldagalga
Creek
ELC024
ELC023
ELC022
ELC021
ELC020
ELC019-1
ELC019
ELC018
Climb
Twin
Ledge
Cliff
Dalasuga
Island
Duck
Seduction
Point
Beacon
Talsani
Dick
Anyaka
Level


MAP 5, HAINES & TAIYA INLET AREA AVALANCHE PATHS, EAST LYNN CANAL
PATH BOUNDARY, MAIN PATH
PATH BOUNDARY, OCCASIONAL RUNOUT AREA
APPROXIMATE BOUNDARY - AREA OF LESSER CONCERN
ELC021 → PATH NUMBER
OLC016 E Side Taiya Inlet
ELC035
FERRY TERMINAL, ALTERNATIVE 2B
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
CHILKOOT INLET
TAIYA
Taiyasanka Harbor
Tanani Bay
Haines
Port Chilkoot
Portage Cove
Mt Villard
Dayebas Creek
KATZEHIN RIVER
Kelgaya Bay
Battery Point
CHILKAT PENINSULA

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